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Observer-based survey of the prawn trawl sectors (inshore & offshore prawn) of the New South Wales ocean trawl fishery

Retained and discarded catch characteristics

Daniel D. Johnson & Thomas C. Barnes

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More information

Daniel D. Johnson, Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay, NSW 2315, Australia

www.dpi.nsw.gov.au

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Cover image: NSW DPI Observer program

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Non-technical summary

Observer-based survey of the prawn trawl sectors (inshore and offshore prawn) of the New South Wales Ocean Trawl Fishery

Principal investigators

Daniel D. Johnson and Thomas C. Barnes

Address

NSW Department of Primary Industries

Port Stephens Fisheries Institute

Locked Bag 1

Nelson Bay, NSW 2230

Tel: 02 4982 1232. Fax: 02 4982 1107

Objectives

The broad objectives initially outlined for the project were:

1. Document bycatch in the prawn trawl sector (inshore and offshore prawn) of the NSW ocean trawl fishery (OTF);
2. Identify extent of regulatory induced discarding;
3. Describe interactions with threatened, endangered and protected species.

These broad objectives were refined into more specific objectives to inform each component of the analysis of the data generated throughout the survey:

1. Estimate total annual retained and discarded catches of quota, commercial and non-commercial species;
2. Identify extent of regulatory induced discarding of otherwise marketable fish, including:
   - any species caught and discarded south of Smoky Cape because of existing regulations,
   - Eastern Rock Lobster (*Sagmariasus verreauxi*) taken in any trawl net;
3. Explore environmental and vessel operational factors that drive discarding;
4. Where possible measure the benefits associated with the introduction of bycatch-mitigation measures via a direct before-after comparison between the current and previous observer-based surveys of the ocean prawn trawl sector;
5. Quantify and describe the nature of interactions (including life status at time of interaction) with threatened, endangered and protected fish, sharks, marine mammals, reptiles, and seabirds; and
6. Identify future research priorities.

Key words

Commercial fishing;, prawn trawl, observer research, bycatch, discarding, protected species

Summary

Quantification of bycatch, and particularly discarded bycatch is challenging for many types of fishing. Penaeid (prawn) trawling is no exception as the discard community is often diverse but inconsistent in composition and biomass. Further, quantification is also complicated by limited resources to implement monitoring programs and vessel space is limited to house observers and monitoring equipment. The data collected by the present survey was a timely detailed investigation of bycatch from a fishery that has been previously shown to catch substantial amounts of non-target organisms.

The inshore and offshore prawn sectors (hereafter ocean prawn trawl sector, OPTS) of the New South Wales ocean trawl fishery (OTF) managed by NSW Department of Primary Industries (NSW DPI) is the most valuable sector of the OTF with total annual catches (target and byproduct species) estimated to be worth approximately $A30 million. Reported total landings from the OPTS between 2016–2017 and 2018–2019 averaged almost 1,000 tonnes per annum. In 2018/19 landings were reported from more than 165 species, however 78% of the catch comprised just four species: Eastern King Prawn (*Melicertus plebejus*) contributed 42% (634 t), Eastern School Whiting (*Sillago flindersi*) contributed 23% (350 t), and Trawl Octopus (Octopodidae - undifferentiated) and Stout Whiting (*Sillago robusta*) contributed 9% (140 t) and 5% (70 t) of landings, respectively.

Management arrangements in the OPTS include restrictions on number of endorsements; regulations pertaining to permitted gear, boat capacity restrictions, minimum legal length limits (MLL) and targeted spatial management, including an extensive network of inshore closures that are primarily targeted at protecting juvenile Eastern King Prawns. In 2019, the NSW Government's Commercial Fisheries Business Adjustment Program introduced linkages between shares and catch and effort in the OPTF. Revised management arrangements included a total allowable effort quota (TAE) and individual transferrable quotas (ITQs) for Tiger Flathead (*Platycephalus richardsoni*), Sand/Bluespotted Flathead (*Platycephalus caeruleopunctatus*) and Silver Trevally (*Pseudocaranx dentex*), as well as a combined catch quota for Eastern School Whiting and Stout Whiting.

Discarding of unwanted organisms captured by commercial fishing gears is a major issue in the management of trawl fisheries worldwide. Because of the nature of the gear, subtropical climate and inshore location of trawl grounds, demersal penaeid trawl fisheries, including the OTPF have been characterised by a relatively high level of discarding. Following the initial assessment of fleet-wide discarding in the OPTS several bycatch reduction devices (BRDs) were developed and implemented. However, no assessment of fishery-level discarding has occurred since 1994. Quantifying magnitude and composition of discarded catches in the OPTS is fundamental to examining the impact of management regulations designed to limit fishing mortality and is necessary to facilitate the assessment of the impact of bycatch on both target and non-target species, and the broader marine ecosystem.

The primary objectives of this study were to estimate the total catch (retained and discarded) and quantify the total number and circumstances of interactions (including the life status at the time of the interaction) between the OPTS and threatened and protected species (TEPS).

To address the objectives, NSW DPI designed and implemented an observer-based survey with appropriately high levels of replication with respect to the number of fishing days observed within seasons. In the absence of sampling designs that provide statistically robust coverage for estimating the total number of discards in the OPTS for a desired precision and level of confidence, the current study used a relatively simple survey design similar to that applied in the initial assessment of fleet-wide discarding in the OPTS. However, given large declines in reported effort (~80%), the sampling fraction within the current study was approximately four times greater than the previous survey.

Prior to the commencement of the field-sampling phase of the current program, to measure the effect of subsampling on the information generated from trawl surveys and provide relationships to assist the interpretation of data derived from such surveys, various proportional subsamples (by weight) were sorted from ocean prawn trawl catches taken during normal fishing operations. Based on these findings, program objectives and on-board logistical constraints, the decision was made to sample >30% of the total discards from each shot monitored for catch composition. In contrast to the previous observer-based survey of the OTPS that restricted catch sampling to target and byproduct species, the current study collected information on all components of the discarded catch (i.e., number and weight by species). Therefore, the present study is the first to accurately quantify and estimate the magnitude of catches of most non-target bycatch species in the OTPS. This includes bycatches of elasmobranchs which have received increasing attention over the last decade.

To reduce the likelihood of recruitment overfishing occurring (low egg production) and to maximise value of the catch, gear specifications are often introduced to limit the capture of non-desirable size classes in penaeid trawls. Our results indicate that ~80 to 90% of the total observed catch of Eastern King Prawns from the OPTS exceeded the optimal length at first capture to maximise yield-per-recruit. Similarly, ~30% of the observed catch of Eastern King Prawns from the combined fleets of the North and Central zones exceeded the estimated mean size at sexual maturity. The observed size-structure of catches and low discard rates (~98% retained) suggest that fishers predominately target trawl grounds known to support populations of the larger more valuable Eastern King Prawns.

Mean discarded catch per trip (kg ± SE) by the combined fleets of the North, Central and South zones during year-1 and year-2 was 384.7 ± 17.7 kg and 489.6 ± 19.0 kg, respectively. Observed discarded catches in the OPTS comprised a combination of: 1) unmarketable species with limited or no commercial value that are a bycatch of the fishery and are discarded 100% of the time; 2) target species discarded because of current size limits and possession limits (e.g., Bluespotted Flathead and Tiger Flathead); and 3) several species, including the quota-managed whiting species that were observed to be retained and discarded at the discretion of the fisher with behaviour influenced by market price and processing capability (e.g., on-board freezing capacity). In the present study, the discarded portion of observed catches comprised 382 species, with Butterfly Gurnards (*Lepidotrigla modesta, L. mulhalli*), Longspine Flathead (*Platycephalus longispinis*), Spotted Bigeye (*Priacanthus macracanthus*) and Yellowtail Scad (*Trachurus novaezelandiae*) accounting for approximately 45% of total discards (by weight, all trips combined).

Discarded catches of commercial species were dominated by Eastern School Whiting and Stout Whiting. Approximately 35% of the total catch of both species were estimated to be discarded from the combined fleets of the North and Central zones. The size-structure of observed catches of both Eastern School Whiting and Stout Whiting indicate a large proportion of discarded catches of both species are greater than the estimated mean size at sexual maturity. The impact of the implementation of ITQs on rates of discarding in the OPTS has not been quantified. Discarded catches of commercially valuable species need to be accounted for in future stock assessments with ongoing development of bycatch reduction in management solutions.

Environmental and operational drivers caused significant variation in discarding in the OTPS. However, the combination of drivers (e.g., location, season, year, trawl speed, engine capacity) and the types of relationships varied among the five species groups analysed. A positive relationship between the retained and discarded catch was identified but was relatively weak and may not represent a simple function of these variables. This result suggests that discard count estimates based solely on the retained catch weight (such as that reported in fisher's logbooks) would be inaccurate for the OPTS.

To improve the precision of fleet-wide estimates of catches, analyses within the current study compared two alternative estimators of total discards. The comprehensive method of accounting for all major sources of variation and developing an efficient estimator of fishery-wide discard number during our study was only possible because of the detailed observations made, which included estimating the sample fraction of the shot weight and counting, as well as weighing, all observed discards and retains by species. To allow temporal comparisons of estimates of discards, future observer-based surveys of the OPTS should employ a similar catch-sampling strategy and use the comprehensive estimator of fishery-wide discards developed within the current study.

The observed discard rate in the OPTS was generally lower than historical estimates and is equivalent to national and international penaeid trawl fisheries. Regular monitoring and research would continue the development of mitigation methods in the OPTS and combined with management tools would achieve the sustainability objectives outlined in the Ocean Trawl Fishery Management Strategy. Data collected during the current study should be incorporated in a quantitative ecological risk assessment of the OTF to ensure risks associated with the fishery are assessed and managed at both a whole-of-fishery and species-specific level with high emphasis placed on managing the impact of fishing activities on target and non-target, protected species, and the broader marine ecosystem.

Observed rates of interactions between the OPTS and species listed as threatened, endangered, and protected under the *Fisheries Management Act* 1994 or the *Biodiversity Conservation Act* 1999 were generally low. No marine mammals (e.g., dolphins and seals) or marine reptiles (e.g., sea turtles or sea snakes) were observed to be caught or negatively interact with vessels in the current study. A variety of seabirds, including threatened species were attracted close to vessels during trawl operations. Despite more than 41,000 seabirds being counted or estimated from extrapolated counts during 1,048 observations, no negative interactions (defined by interaction with gear, injury or death) were recorded. Seabirds were attracted to forage near the vessels with the ecological impact of such behaviour unknown.

During the study, 133 syngnathids (Seahorses, Pipefishes, and Seadragons) were observed to be caught from 31 trawl shots (~2.2% of total shots) on 19 fishing trips (~4.4% of total trips). Observed catches did not include any species listed as being critically endangered. The total number of syngnathids estimated to be caught by the OPTS over the two-year duration of the survey was ~4,750 individuals. The fate of discarded syngnathids is unknown.

A total of one Grey Nurse Shark (*Carcharias taurus*) and one Sandtiger Shark (*Odontaspis ferox*) were caught during observed fishing trips. Both individuals were highly active upon gear retrieval, had no external wounds, skin damage or bruising, were not bleeding, and were observed to vigorously swim away from the vessel when immediately released following capture. Other elasmobranchs were caught during the survey, while none were listed as threatened in NSW, catches included species of conservation concern in other jurisdictions.

In conclusion, this study is the first to estimate the total number of discards for bycatch species in the OPTS and to estimate the precision of discard estimates for the main species groups as a function of the number of trips observed. The differences in effective sample sizes among species groups should be considered for a rational allocation of observation effort in future observer-based surveys of the OPTS. To evaluate the effectiveness of management measures designed to limit fishing mortality and better assess the health of the interacting ecosystem the collection of time-series data on discarding in the OTF should be prioritised. Despite participating vessels reporting approximately 50% of the total catch from the fishery during the current study, the level of co-operation of OPTS fishers likely compromises the representativeness of components of the derived total catch estimates from the survey. To ensure all future observer-based surveys are representative and cost effective, regulation amendments to support Division 4B (Part 9) of the *Fisheries Management Act 1994* (scientific observer program) that requires fishing business/endorsement holders to allow authorised scientific observers on board vessels and facilitate observers in the course of their scientific observer duties while on board should be further developed and implemented with industry consultation to ensure consideration of vessel capacity issues. Because of vessel capacity constraints and other operational issues there is also a need to consider the costs, logistics and deliverables of the alternative data sources and sampling strategies for future monitoring of the OTF (e.g., vessel cameras).

Introduction

Background

Discarding of unwanted organisms retained by commercial fishing gears, collectively termed 'bycatch' (sensu Saila, 1983), is a key issue in the management of trawl fisheries worldwide (Hall et al., 2000, Machias et al., 2001). Demersal penaeid trawl has been reported to be a large discarder due to the nature of the gear, the high species diversity associated with the subtropical climate and inshore location of trawl grounds (Kelleher, 2005, Saila, 1983, Ye et al., 2000). The inshore and offshore prawn sectors of the New South Wales Ocean Trawl Fishery (OTF) is characterised by a relatively high level of discarding (Kennelly et al., 1998). Discarded catches consist of non-marketable organisms, individuals discarded because of quota allocations, market forces (e.g., lease prices, value), fisher behaviour (e.g., high grading) and undersized or undesirable (e.g., damaged crustaceans) target and byproduct organisms (Hall, 1999, Saila, 1983). In subtropical, tropical and temperate areas of the world, the bycatch of penaeid trawls is often characterised by a large diversity of species (Dell et al., 2009, Kennelly et al., 1998), which makes monitoring and mitigation difficult (Stobutzki et al., 2001). Further, the composition of bycatch and abundance of individual species is often influenced by factors including depth, seabed characteristics, commercial effort and prawn catch (Dell et al., 2009, Stobutzki et al., 2003, Tonks et al., 2008, Watson et al., 1990). Variations in discarding have also been shown to be a result of environmental fluctuations and vessel operational differences (e.g., Barnes et al., 2022, Feekings et al., 2012).

Research has shown that trawl fisheries have significant deleterious effects on populations of target and non-target species and their habitats (Hall, 1996). Demersal trawl fisheries are under increasing pressure to demonstrate their ecological sustainability but the problem of bycatch remains an obstacle in achieving this goal (Hall and Mainprize, 2004). Not surprisingly, the necessity to reduce discarding, has been recognised at the international level such as the United Nations Food and Agriculture Organization's (FAO) International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2011). Quantifying the volume, structure and composition of discarded catches is a key requirement of ecosystem-based fisheries management and is essential to evaluating the effectiveness of management measures designed to limit total fishing mortality on target and byproduct species and understanding the potential effects of discarding on the broader ecosystem (Branch, 2006, Brewer et al., 2007, Broadhurst, 2000). A key issue with discarding in trawl fisheries is the lack of survivorship of many organisms (Hill and Wassenberg, 2000, Saila, 1983). Despite progress in the development of more selective fishing gears, undetected bycatch mortality for fish that escape from fishing gear, or are discarded after landing is a critical problem in the management of fisheries worldwide (Davis and Olla, 2002). To protect and conserve the marine environment, monitoring the impacts of trawling on bycatch and developing appropriate management strategies is essential (Heales et al., 2007, Stobutzki et al., 2001). Despite this, some fisheries with high discarding by volume, often have only occasional monitoring and characterisation (Barnes et al., 2022, Kennelly, 2020).

A combination of technical measures (e.g., physical gear modifications), spatial controls (e.g., short and long-term closures), impact quotas (e.g., output controls), effort controls (e.g., total allowable effort caps) and voluntary industry actions (e.g., move on provisions) are commonly used to reduce and limit fishery-wide discarding and minimise impacts on seabed habitats and biota. Physical modifications, commonly referred to as bycatch reduction devices (BRD's) that exploit behavioural or morphometric differences between species are installed in fishing gears to allow the escape of non-target or non-desirable size classes of target species (Broadhurst, 2000, Broadhurst et al., 2012). Spatial closures prohibit trawling in designated areas that span a wide range of geographic and environmental conditions with much broader objectives than just preventing local trawling impacts (Gell and Roberts, 2003). Real-time spatial management tools provide a flexible alternative to static spatial management (McConnaughey et al., 2020). This approach has recently been reported to have reduced discarding in multiple fisheries by creating a variety of incentives to avoid unwanted catch (Little et al., 2015). However, temporary closures may result in effort being displaced to less productive fishing grounds potentially increasing trawl effort because of lower catch rates (Kenchington, 2011) and can expand the trawling footprint, subsequently, increasing the overall impacts to fish assemblages and habitats. Bycatch quotas are implemented to reduce and manage trawl bycatch of vulnerable species to achieve conservation objectives without displacing fishing effort or reducing catches or catch rates (Wallace et al., 2015). A combination of vessel capacity and effort restrictions are often implemented to reduce total fishing effort as well as the capacity of the fleet (McConnaughey et al., 2020). The utility of individual measures is dependent on the characteristics of the management system in place, capacity to develop and monitor new measures, and the extent to which the fishery is already achieving defined management objectives for target and byproduct species (McConnaughey et al., 2020). Despite the development and implementation of management measures in trawl fisheries worldwide, the FAO's most recent estimation of global discarding was ~55 % of the total catch (FAO, 2011). Reductions appear slow or stalled partially due to a lack of understanding of the complexities of discard drivers (Barnes et al., 2022, Catchpole et al., 2005).

As the volume of discarding is costly to monitor, it is often estimated from reported catches using a discard-to-retained catch ratio derived from a representative monitoring program under the assumption that the relationship between retained catch and discarding is linear. But, this is often shown to be not the case or concerningly, not even assessed (Kelleher, 2005, Kennelly, 2020). Fishing mortality for target species is often controlled through total allowable catches (TACs) determined via established single-species approaches that are not adapted to the management of multi-species fisheries catching a range of target and byproduct species in unselective fishing gear (Briton et al., 2020, Fulton et al., 2019, Ulrich et al., 2011). Setting restrictive quotas for individual species is likely to lead to over-quota discards placing pressure on stocks of concern and adding uncertainty to stock assessments. As a result, estimation of total fishing mortality becomes more difficult when a combination of individual quota allocations, market forces and changes in fisher behaviour impact discarding. The relationship between discarding and retained catch needs to be better understood to determine if estimations of discarding are reasonable, and hence, if the impact of discarding is accurately assessed in the OPTS (Barnes et al., 2022).

The estimation of discards from observer-based monitoring programs requires appropriate stratification and replication and can be challenging to execute in a robust manner (Bergh et al., 2009, Borges et al., 2004). Estimates of fleet-wide catches and bycatches may be biased by the selection of non-representative sampling units, fisher participation rates and changes in fishing practices when observers are present (Faunce, 2011, Liggins et al., 1997). Applying a systematic sampling design across fisheries and methods at regular intervals enables bycatch on observed fishing trips to be extrapolated to fishery-wide estimates with a higher degree of precision (Bergh et al., 2009). However, the costs of such programs are prohibitive to many small-scale fisheries, including the OTF. Despite the challenges associated with implementing short-term "opportunistic" observer-based surveys, sampling of catches by scientific observers on board commercial fishing vessels is still considered the most reliable method to obtain fishery-dependent data on retained and discarded catches (Alverson et al., 1994, Kennelly, 1995). However, estimated catches, reported size-structure of catches and information collected on operational aspects of fisheries (e.g., locations fished, gear used, etc.) from short-term surveys only represent a snapshot. Therefore, estimates may not reflect longer-term aspects of catches taken within the fisheries. The inclusion of inaccurate data on discarding in both stock assessments and ecological risk assessments may have the equivalent effect of ignoring the discard component of fishing mortality. Consequently, there is a need to examine the accuracy and precision of estimates of catch derived from all observer-based surveys (Bergh et al., 2009, Liggins et al., 1997).

Interactions between fishing vessels and threatened, endangered, and protected species (TEPS) may be positive through the additional food source provided; however, for critically endangered species, even rare negative interactions can have deleterious effects on population viability (Lewison et al., 2004). Incidental catches of Sea Turtles (Cheloniidae), Sea Snakes (Elapidae: Hydrophiinae), Eared Seals (Otariidae), Dolphins (Delphinidae), Pipefishes (Syngnathidae) and multiple species of elasmobranchs (e.g., sharks, rays, skates and sawfishes) all listed as protected under the *Environmental Protection and Biodiversity Conservation* (EPBC) *Act* 1999 have been documented in Australian trawl fisheries (Brewer et al., 2006, Jaiteh et al., 2014, Stephenson et al., 2008, Stobutzki et al., 2001). The use of BRDs has been mandated in national and international penaeid trawl fisheries, primarily to mitigate against the bycatch of Sea Turtles, as well as large sharks and rays (Brewer et al., 2006, Robins et al., 1999, Stephenson et al., 2008,). Previously reported interactions between the OPTS and TEPS include a small number of Pipefishes and a single interaction with a Sandtiger Shark (*Odontaspis ferox*), known locally as Herbst Nurse Shark (Macbeth et al., 2008). No marine reptiles, marine mammals or seabirds have been reported from observed catches or through mandatory TEPs reporting legislated under the *Fisheries Management Act* 1994. However, a number of commercial and non-commercial species of elasmobranchs have been recorded in catches from the OPTS (Kennelly et al., 1998, Macbeth et al., 2008). The life history characteristics of many species of elasmobranchs limit their ability to recover from anthropogenic mortality, such as that resulting from capture and discarding in trawl fisheries (Campbell et al., 2020). Long-term comparisons of mean catch rates of sharks and rays from fishery-independent surveys completed on trawling grounds (200 – 650 m depth) off New South Wales during the early years of exploitation, and replicated after 20 years of commercial fishing, suggest that the biomass of most species of sharks and rays declined rapidly (Graham et al., 2001). The first step to redress historic population declines of endemic sharks and rays is to quantify species-specific fishery impacts and find practical and affordable solutions to minimise bycatch and maximise the survival of discarded individuals.

Following the initial assessment of fleet-wide discarding in the OPTS a number of BRDs were implemented, however, no assessment of fishery-level discarding has occurred since 1994 (see Kennelly et al., 1998). To estimate the total catch (retained and discarded), investigate the effectiveness of management measures designed to limit discarding, and quantify the total number and circumstances of interactions (including the life status at the time of the interaction) between the OPTS and TEPS, observer-based surveys with appropriately high levels of replication with respect to the number of fishing days observed within a given spatiotemporal category are required.

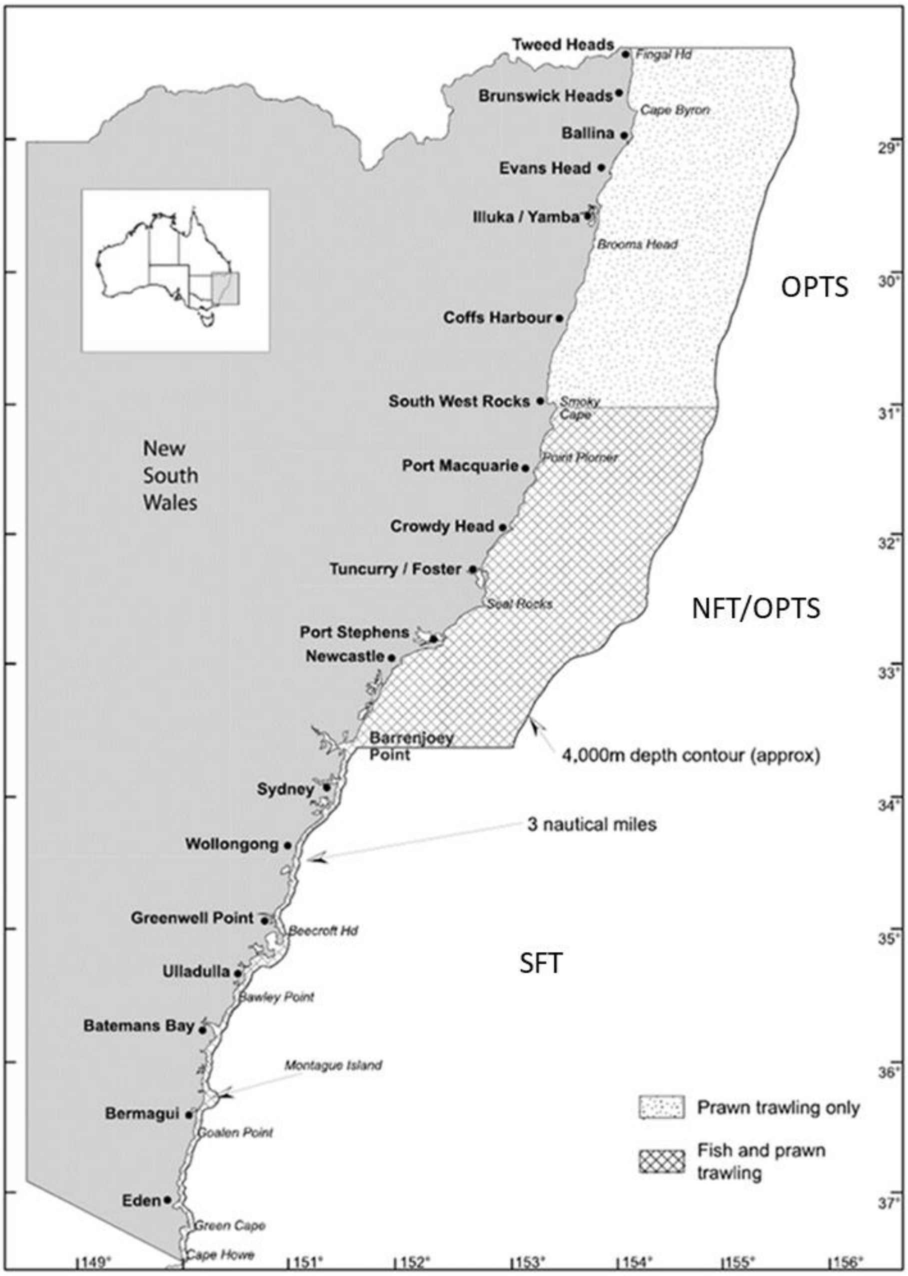
NSW ocean trawl fishery

The OTF managed by New South Wales Department of Primary Industries (NSW DPI) is a restricted fishery. As at September 2018, 120 fishing businesses held entitlements to operate in the prawn-trawl sector of the OTF (NSW DPI, 2007), with some holding multiple endorsements within other fisheries operating in or near waters off NSW, primarily the NSW Ocean trawl: fish northern zone (NFT) and the Queensland east coast otter trawl fishery (ECOTF). The vessels used in the OPTS range in size between 9–21 m in length and are fitted with engines ranging from 51 – 317 kW.

The boundaries of the OTF extend from the NSW coastal baseline seaward to the 4,000 m isobath (approx. 60 to 80 nautical miles (nm) offshore) between Barrenjoey Point (33°35′ S) and the Queensland border (28°00′ S). In ocean waters south from Barrenjoey Point to the Victorian border (37°36′ S), trawling is currently managed by NSW from the coastal baseline seaward to 3 nm offshore only (Figure 1), and the Commonwealth retains jurisdiction for trawling outside 3 nm to the edge of the Australian Fishing Zone (NSW DPI, 2007).

The OPTS of the OTF is currently managed via restrictions on number of endorsements; total allowable effort quota (TAE), permitted gear, boat capacity, minimum legal size (MLS), possession limits and, individual transferrable quotas (ITQs) for Tiger Flathead (TFH, *Platycephalus richardsoni*), Sand/Bluespotted Flathead (BSFH, *Platycephalus caeruleopunctatus*) and Silver Trevally (*Pseudocaranx dentex*), as well as a joint "mixed bag" catch quota for Eastern School Whiting (ESW, *Sillago flindersi*) and Stout Whiting (SW, *Sillago robusta*). There is one spatially different output restriction, south of Smoky Cape (31° S) all fish taxa with a MLL must be discarded. Targeted spatial management is employed within the fishery, including an extensive network of inshore closures that are primarily targeted at protecting small juvenile Eastern King Prawns (EKP, *Melicertus plebejus*) from fishing mortality (Taylor and Johnson, 2021). The designated fishing area of the OTF is impacted by Broader Marine Estate management arrangements, including Habitat Protection Zones (HPZs) and Sanctuary Zones (SZs) within Marine Protected Areas (MPAs).

Figure 1 NSW ocean trawl fishery areas. Sectors include inshore and offshore prawn (OPTS), fish northern zone (NFT) and southern fish trawl (SFT) sectors (Source NSW DPI, 2007).



The OPTS is the most valuable sector of the NSW OTF fishery with total annual catches (target and byproduct species) estimated to be worth approximately $A30 million. Reported total landings from the OPTS between 2016–2017 and 2018–2019 averaged almost 1,000 tonnes per annum, with the highest total landing of 1,525 tonne in 2018/19 (NSW DPI Catch records). In 2018/19, landings were reported from more than 165 species, however, 78% of the catch comprised just four species: EKP contributed 42% (634 t), ESW contributed 23% (350 t), Trawl Octopus (Octopodidae - undifferentiated) and SW contributed 9% (140 t) and 5% (70 t) of landings, respectively (Table 1).

Annually, 75 –81 of the 120 OPTS endorsement holders reported from 5,233 (2017/18) to 5,957 (2016/17) days effort from the fishery (mean = 5,606 days). Total days effort, mean number of days effort reported by an active fishing business (>1 day reported, ± SE) and, the maximum number of days reported from an endorsement holder is shown in Table 1. Approximately 90% of the total annual effort in the fishery was reported from 50 of the 120 endorsements.

Table 1 Reported landings (tonnes) of total landings and effort (total days), mean and maximum days per fishing business (FB) and number of FB's reported from the OPTS from 2016/17 to 2018/19.

Species	2016/2017	2017/18	2018/19
Species			
Eastern King Prawn (*Melicertus plebejus*)	813.4	605.4	634.0
Eastern School Whiting (*Sillago flindersi*)	394.6	389.9	350.3
Trawl Octopus (Octopodidae - undifferentiated)	150.6	79.2	139.9
Stout Whiting (*Sillago robusta*)	45.4	60.7	69.8
Balmain Bug (*Ibacus peronii*)	33.1	38.0	57.2
Cuttlefishes (Sepiidae – undifferentiated)	50.4	41.0	48.1
Bluespotted Flathead (*Platycephalus caeruleopunctatus*)	28.4	30.1	27.7
Yellowtail Scad (*Trachurus novaezelandiae*)	11.3	22.3	26.5
Eastern School Prawn (*Metapenaeus macleaya*)	35.9	5.3	19.3
Flatheads (Platycephalidae – undifferentiated)	21.5	17.3	6.6
Eastern Shovelnose Ray (*Aptychotrema rostrata*)	10.3	11.7	11.1
Giant Cuttlefish (*Sepia apama*)	18.9	9.4	8.3
Pencil Squid (*Uroteuthis chinensis* complex)	6.4	5.5	6.6
Gloomy Octopus (*Octopus tetricus*)	13.7	10.7	5.1
Goatfishes (Mullidae – undifferentiated)	9.3	4.7	10.3
Total landings	1782.2	1464.2	1525.4
Effort			
Total days	5957	5233	5629
Mean days per FB (± SE)	73.5 (5.2)	70.8 (5.2)	75.5 (5.3)
Max. days reported by FB	191	213	188
Number of FB reported	81	75	75

OPTS management arrangements

The OPTS is categorised into two endorsements that determine the areas of operation. The ocean prawn trawl inshore (OTISP) endorsement authorises the holder to use an otter trawl net (prawns) to take fish (other than deep-water prawns) for sale from inshore waters not more than 3 nm from the natural coastline. While the ocean prawn trawl offshore (OTOSP) endorsement authorises the holder to use an otter trawl net (prawns) to take fish (other than deep-water prawns) from offshore waters more than 3 nm from the natural coastline and north of a line due east from Barrenjoey Point (Figure 1).

Permitted gear

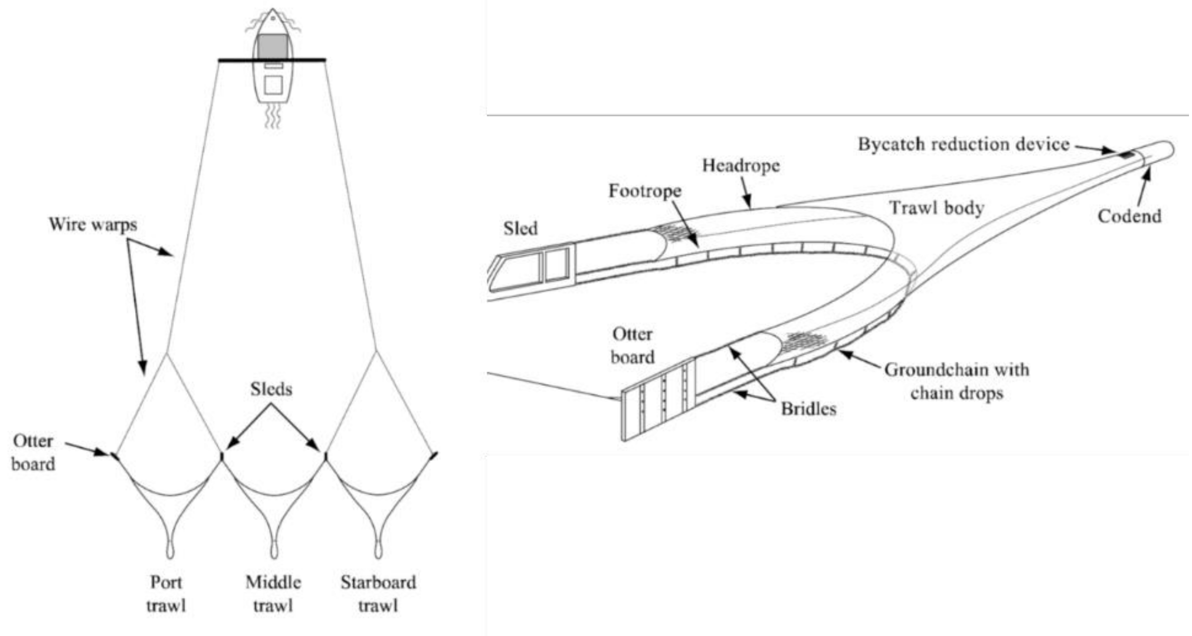
General waters

Under the Fisheries Management (Ocean Trawl Share Management Plan) Regulation 2006 an otter trawl net (prawns) is described as having: mesh not less than less than 40 mm or more than 75 mm, total length of net (length of head line between the first and last hanging) or, where multiple nets are used, the total combined length of the head line of each net between the first and last hanging not exceeding 55 m; the codend of the net (or part of the net capable of being used as a codend) is not less than 40 mm nor more than 50 mm, codend circumference greater than 2.5 m but not more than 150 meshes if diamond mesh or not less than 35 mm nor more than 45 mm, constructed of single twine knotless polyamide or polyethylene material not more than 3 mm in diameter and hung on the bar so that the meshes are square shaped; no more than one line of ground chain with links of not more than 12 mm in diameter; droppers with a minimum length of 100 mm and fitted to separate the foot rope of the net from the ground line or ground chain and sweeps secured to the head line and otter board so that the distance between the point of attachment to the otter boards and the first hanging of the net does not exceed 5 m or the distance from the trawl gallows to the stern of the boat (whichever is the greater). It is a requirement that all trawl nets are fitted with an approved bycatch reduction device (BRD) of dimensions specified in legislation (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/639977/bycatch-closure.pdf). Shown diagrammatically is a standard trawl gear configuration).

School Prawns

Fishers targeting School Prawns within 2 nm from the natural coastline are permitted a range of net and codend modifications outlined in legislation (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/1217288/Fisheries-Management-Inshore-and-Offshore-Prawn-Trawl-Nets-Order-2020.pdf).

Figure 2 Standard trawl gear configuration used by ocean penaeid-trawl fishers in NSW (left) and zoomed port net (right, Adapted from Macbeth et al. 2004; Broadhurst et al 2004).



Methods

Sampling scope and design

One of the main objectives of this survey was to quantify the extent of regulatory induced discarding of otherwise marketable fish of any species taken in the OPTS, whether because of size limits, or management arrangements that limit the species that can be taken south of Smoky Cape. Statistical approaches based on the variances from the mean of biological metrics from species, or species groups, can inform observer sampling designs to effectively streamline surveys to ensure sufficient data is collected. These statistical approaches can produce a range of observer sampling fractions and associated precision, meaning program designers and managers can readily assess any given observer sampling intensity. An example of this is the Integrated Scientific Monitoring program (ISMP) program for the SESSF which considers various coefficients of variation (CVs) for discard rates and size/age composition of the total catch (retained and discarded) for quota species, major non-quota species, other non-quota species and any other species/groups identified by the ISMP review committee (Bergh et al., 2009). Based on the time elapsed between the current and most recent observer-based survey of the OPTS (~27 years; Kennelly et al., 1998), changes in management arrangements, areas of operation and characteristics of the fleet, the historical observer data was considered to be redundant and unlikely to inform appropriate sampling fractions.

Ideally, a dedicated pilot study would have been done to determine appropriate sample sizes required for each spatial/temporal category to estimate quantities of fish discarded for a desired precision and level of confidence. However, given the time and resources required for a study, it was decided to implement a relatively simple survey design. The proposed level of observer coverage within the current study (227 nights per year) is similar to that previously applied by Kennelly et al. (1998), 192 nights per year. However, as reported effort in the fishery has declined from ~25,000 nights per year in the early 1990's to ~5,600 nights in recent years (~80% decrease), the proposed sampling fraction within the current study is approximately four times greater than that of the previous survey.

Spatial and temporal sampling

Coastal waters from Dudley (~33.0°S) to Tweed Heads (~28.0°S) west of the 100-fathom depth contour were initially stratified into five distinct 'zones' aligned with the ocean zones (OZ1–5) that fishers can select from when filling out the spatial information in mandatory logbooks. However, during the early stages of implementation, multiple trips were observed to fish across the boundary of OZ1 and OZ2. To facilitate the implementation of the program, OZ1 and OZ2 were merged to form a North zone. Similarly, given the low effort in OZ4, the decision was made to combine OZ4 and OZ5 to form a South zone. The duration of the two-year field-sampling program (2017/18–2018/19) was divided into eight distinct temporal periods coinciding with the four seasons in each year (Table 2): spring (September to November), summer (December to February), autumn (March to May) and winter (June to August). A hypothetical two-factor matrix used to assign available observer sampling effort (~227 days) across the three zones and four seasons sampled annually. Sampling effort was proportional to spatiotemporal fishing effort recorded in mandatory industry logbooks for 2015/16 and 2016/17.

Table 2 Description of sampling periods.

Period	Months (Inclusive)
P1	September 2017 – November 2017
P2	December 2017 – February 2018
P3	March 2018 – May 2018
P4	June 2018 – August 2018
P5	September 2018 – November 2018
P6	December 2019 – February 2019
P7	March 2019 – May 2019
P8	June 2019 – August 2019

Obtaining observer sampling trips

The *Fisheries Management Act* 1994 currently does not have regulations that allow scientific observers compulsory access to fishing trips completed in any of NSW share managed or restricted fisheries. Therefore, this study was restricted to voluntary hosting of observers by fishers. Prior to the commencement of the survey, project managers from NSW DPI attempted to contact OTF business owners and nominated fishers to further inform them about the project and to determine their interest in participating. For fishers willing to participate, arrangements were made to organise and complete observed fishing days at regular intervals. Where the fisher initially refused, actively fished, and avoided participation or increased participating in the fishery, regular attempts were made to contact them throughout the duration of the project.

On-board data collection

Data collected on observed fishing trips included: 1) operational, 2) vessel and gear, 3) catch composition, and 4) wildlife abundance and interaction data.

Operational data

For each observed fishing trip, a general vessel voyage summary was completed. Voyage summary data comprised the name of the observer, vessel, port of departure and return, voyage start and finish date, activity summary (i.e., total number of hauls observed/ samples retained) and a description of any wildlife mitigation measures deployed throughout the trip. The duration of observed fishing trips ranged between one and three calendar days, with each day considered a separate fishing day to conform to existing NSW DPI catch reporting regulations. During each fishing trip, operational data collected for each trawl shot included: date, time and location (latitude/longitude to nearest minute), depth of trawl deployment/retrieval, vessel speed, number of turns and sea-surface temperature.

Vessel and gear data

For each observed fishing trip, information on fishing vessels, crews and electronic fishing equipment installed and/or used on the vessel was recorded. Specific information collected related to the fishing gear used including net design, headrope length, mesh size, codend configuration, ground gear configuration and details of otter boards used.

Catch composition

To measure the effect of subsampling on the information generated from trawl surveys and provide relationships to assist the interpretation of data derived from such surveys, prior to the commencement of the field-sampling phase of the current program, various proportional subsamples (by weight) were sorted from catches taken during normal fishing operations (see Silburn et al., 2020 for full details). Results suggest that 50% of total species diversity in a sample would be detected if only 10% of the total sample mass was sorted; however, abundance estimates of individual species under different subsampling scenarios varied depending on their rarity. For common species, the abundance in a sample was estimated with reasonable accuracy from sorting only 10% of the biomass, whereas sorting >60% of the biomass was required to obtain an accurate estimate of abundance for rarer species (Silburn et al., 2020). Based on these findings, program objectives and logistical constraints while on board the vessel, the decision was made to sample >30% of the total discards from each shot for catch composition.

After each trawl, the contents of the codends were spilled onto a sorting tray and representative samples collected to describe catch composition. Samples were sorted into commercial (retained) and non-commercial (discarded) components; commercial species were further divided into retained and discarded categories. The total weights and numbers of all finfishes, crustaceans, cephalopods and elasmobranchs were estimated by scaling subsamples to total retained and discarded catch weights. The sizes of economically important prawns (rostral length – RL), finfish (fork length – FL or total length – TL), crabs (carapace length – CL), cephalopods (dorsal mantle length – DM) and elasmobranchs (TL) were recorded.

Wildlife abundance/interaction data

The abundance of seabirds, cetaceans and marine mammals was recorded within an area defined by a 180-degree arc centred on the selected observation position and extending 250 m astern and 250 m to each side of the vessel. Abundance was estimated by species or species groups where identification to species level was not possible during 5-minute observation periods (while setting and hauling the net). For each observation period the information collected included start and finish time, shot number, observer position, estimated count and the accuracy of the count defined as, either accurate , estimated or extrapolated . Wildlife behaviour was recorded as the percentage of each species engaged in each of four activity categories: 1) intensively searching (INT), 2) irregularly searching (IRR), 3) totally disinterested (TOT), and 4) roaming widely (ROM).

The major contact points monitored for interaction included trawl warps, stabiliser arms and stabiliser paravanes. For each observed interaction, data collected included time, vessel activity, fate, age class (unknown, adult, juvenile and sub-adult), contact codes and, contact points (warp wire, trawl doors, vessel, net, backstop, bridles, sweep and paravanes). Life status following interaction was described according to seven categories: 1) dead and damaged, 2) dead, in rigour, 3) dead and flexible, 4) alive, just, 5) alive, sluggish, 6) alive and vigorous, and (7) unknown.

Data analysis and presentation

Industry logbook and observer coverage

Total reported fishing effort from the OPTS over the two-year duration of the study was extracted from NSW DPI commercial fisheries catch and effort reporting system (FishOnline, NSW DPI unpublished). Endorsed OTF fishers are required to submit a logsheet for each fishing day, for each location or combination of locations, fishing methods and/or endorsements fished. For individual fishing days, OTF endorsement holders are required to report the grid and site location where "most" fish were caught, the cumulative time in hours of all trawl shots for the days catch and catch information including, species code, weight (kg) and the processing code for fish that have been processed (i.e., headed and gutted). The estimated fraction (%) of total reported fishing effort observed in each spatial and temporal stratum was calculated.

Spatial distribution of observed trawl shots

For each trawl deployment observed, the mid-point, calculated from the latitude and longitude data collected for the start and finish points of each trawl deployment was plotted onto maps of the NSW coast and adjacent waters.

Estimates of mean catch rates (± SE) for retained, discarded and total catches of commercial and dominant bycatch species

Estimates of mean retained, discarded and total (retained + discarded) catches per trip were calculated annually and for each spatial/temporal sampling stratum. For all primary and key secondary commercial species (NSW DPI, 2007) and bycatch species that represented >2% of total fishery bycatch (number or weight). Catch rates are presented as the mean weight and number caught per trip across all replicate observed trips within a sampling stratum. The above catch rates were based on the sampling period predictor; the same analysis was done on a categorical depth predictor but with the response catch rate weighted to the shot level. This was done as occasionally trips trawled a range of depths. Standard error (SE) of the sample mean was calculated conventionally for each variable examined.

Size-structure of catches

Size-frequency distributions were plotted for all primary and key secondary commercial species where greater than 100 individuals were measured in each zone. The weighted size-structure of retained and discarded catches (weighting factor reflecting biomass for each trip and subsample amount) was calculated for BSFH, EKP, ESW, SW and TFH. Proportional size distributions exceeding the MLL , length-at-maturity (L_{50}) or optimal size at first capture (L_{YPR}) were estimated. For ESW and SW, male and female L_{50} estimates reported in Gray et al. (2014) were averaged for each species, and the proportion of individuals exceeding this threshold was visually compared among zones (pooled across years). The optimal size at first capture for EKP was calculated based on the methodology outlined in Taylor and Johnson (2021). Male and female L_{YPR} estimates were averaged, and the proportion of individuals exceeding this threshold was visually compared among zones and years.

Discard drivers

General

Analysis was performed to determine variation in discarding from environmental and operational variables which has been published in the primary literature (see Barnes et al., 2022); however, a summary is provided in this and other sections. All data were summarised to the trip level to remove autocorrelation potential. Species were grouped into major taxa (herein species groups) for analysis: 1) all elasmobranchs (sharks and rays) combined, 2) crustaceans, 3) fish, 4) commercial crustaceans, and 5) commercial fish. Commercial crustaceans and fish were any species that were retained for sale by OPTS fishers during the present study. In all models, the response variable (discarded catch) was based on counts (i.e., numbers) of individual organisms.

Environmental and operational drivers

To test the null hypothesis of no relationship between environmental and operational factors (the potential discard drivers) and discarding response variables (hypothesis 1) Generalised Additive Mixed Models (GAMMs) were used via the 'mgcv' R package. The full model took the following form:

Discarding per trip (separately on species groups) = β + s(track complexity) + s(longitude,latitude) + s(depth,season) + s(vessel velocity) + s(engine capacity) + s(weight of catch retained) + season + year + random effect(vessel) + offset(log(swept area)) + ε

β is an overall intercept, s represents smooths (either cubic regression or Gaussian process for spatial kriging) as exploratory analysis suggested nonlinear relationships and ε is an error term. Where appropriate, continuous factors were weighted means (trip level, e.g., depth). The swept area was modelled as an offset to standardise the response variable (Afzali et al., 2021, Wang et al., 2020). The swept area was calculated by linear distance trawled multiplied by 80% of the combined net headline length (functional net opening) (Sterling, 2005). The model was run on the species groups separately as the survivorship and contribution to discarding is separate for these groups (Hill and Wassenberg, 1990, Hill and Wassenberg, 2000). Track complexity is reported in the Results (see Barnes et al. (2022) for more details on track complexity and all drivers).

Exploratory analysis of total retained catch weight and number of discards

To test the null hypothesis of no correlation between discarded and retained catch (hypothesis 2), fish and all species groups combined discarding were modelled against mean retained catch weight per trawl trip as an indicator of the robustness of extrapolating the volume of discarding from fisher reported catches. Vessel name was included as a random effect. Teleost fish were done separately in this exploratory model as they were the most abundant, are important (i.e., exploited by other fisheries) and data exploration suggested a positive linear relationship may exist. The modelling process was like hypothesis 1 except the models only included the variables mentioned above and the offset was applied by dividing the response variable by the log swept area to facilitate using a negative binomial GLM that doesn't have the offset function. The weight of catch retained was fitted as a linear factor. The model took the following form:

Discarding per trip (separately on fish and combined species groups) = β + weight of catch retained + random effect(vessel) + ε

β is an overall intercept and ε is an error term.

Estimation of total, retained and discarded catches

The statistical rationale for the specific statistical methods applied is described next in general terms with the full details on the theory and statistical calculations given in the Appendix 1.

The first requirement is that discard rate and total discards estimates for the fishery be made in terms of counts of animals and not in terms of weights. Numbers rather than weights are required for studies of stock status, stock assessments to provide allowable catch limits, for both target and bycatch species and for studies of population dynamics with regard to threatened and endangered species. Therefore, in order to take advantage of the census provided by the commercial catch data, the total weight landed by species in this data needed to be converted to numbers.

Given an estimate of the discard proportion by species, $\hat{p}_j^{(d)}$ for species j, and over all species (using sums of number of discards and retains ignoring species) of $\hat{p}'$ as obtained from the observer data, a "direct" estimate of the fishery total (2017–2019) number of discards is estimated as $\hat{M}' = \sum_j \frac{W_j}{\overline{w}_j^{(r)}} \hat{p}_j^{(d)} \left(1 - \hat{p}_j^{(d)}\right)^{-1} I_j + \frac{H}{h} \sum_j s_j^{(d)} \left(1 - I_j\right)$

where W_j is the total weight landed (only retains recorded) from the commercial data for species j, $\overline{w}_j^{(r)}$ is the average weight of individuals retained, I_j is an indicator variable that takes the value of 1 if the species is commercial (and is represented in the commercial dataset) and there was more than a single shot in the CFOP for which the species had a retained catch (i.e., so that the variance of $\overline{w}_j^{(r)}$ could be estimated) otherwise it takes the value zero, $s_j^{(d)}$ is the total number discarded for species j (after scaling up shot-level numbers observed by the inverse of the shot-level sample fraction) , H is the total hours trawled by the fishery in 2017–2019, and h is the total hours of trawl observed in the CFOP.

It can be seen that the term $\frac{H}{h}\sum_{j} s_j^{(d)}\left(1-I_j\right)$ is effectively a scaled-up CPUE estimate of fishery total discards across species for which $I_j = 0$. Because of differences in regulations related to permitted species north and south of 30° 54′ S (southern boundary of Central zone), analyses were preformed separately for the two regions, hereafter, termed Region 1 (North + Central zones) and Region 2 (South zone). A small number of trips targeting School Prawns (*n* = 7) and trips targeting EKP with low sample fractions or incomplete datasets (*n* = 3) were excluded from analyses.

Estimates of interactions with threatened, endangered and protected species

Estimates of the fishery-wide (Region 1) number of syngnathids caught along with %CVs across a range of values for the number of trips observed were calculated. The method used to estimate number of syngnathids uses observed syngnathid numbers as a proportion of the combined discarded number across all fish species plus syngnathid numbers given by $\hat{p}_{TEPS}\hat{M}'$. The statistical estimation method is described in full in Appendix 1.5.

Results

Observer coverage and fisher participation

Effort and adherence to sampling design

Of the 227 observer days planned in the two-factor sampling matrix, 190 (84%) and 245 (108%) were successfully observed in year-1 and year-2 of the survey, respectively (Table 3). Adherence to the sampling design varied both spatially and temporally; deviance from the original design was due primarily to variable rates of voluntary operator participation. The number of days observed within individual spatiotemporal groupings ranged from 1 (P5; Central) to 55 (P7; North). A total of 604 and 853 shots were observed for catch composition in year-1 and year-2 of the survey, respectively.

More than 90% of the planned observer trips were carried out in the North zone in both year-1 and year-2 of the survey (90 and 127%, respectively, Table 3), however a smaller proportion of planned trips in the Central (54 and 80%) and South zones (87 and 80%) were observed. In both year-1 and year-2 of the survey, the number of trips observed in autumn and winter were equal to, or in excess, of those originally planned. However, in year-1, only 68 and 89% of planned trips were observed in spring (P1) and summer (P2), respectively (Table 3).

Table 3 Completed and proposed (in parentheses) number of replicate/observed fisher days (Obs.), reported effort (Rep.) and percentage (%, in parentheses) of trips observed for the two years and eight sampling periods for North, Central, South and combined zones.

Temporal	North		Central		South		Combined	
group	Obs.	Rep.	Obs.	Rep.	Obs.	Rep.	Obs.	Rep.
P1	15 (21)	708 (2.1)	3 (8)	171 (1.8)	7 (8)	272 (2.6)	25 (37)	1151 (2.2)
P2	19 (24)	668 (2.8)	5 (12)	337 (1.5)	7 (10)	180 (3.9)	31 (46)	1185 (2.6)
P3	43 (40)	740 (5.8)	16 (17)	301 (5.3)	13 (15)	426 (3.1)	72 (72)	1467 (4.9)
P4	46 (45)	813 (5.7)	4 (15)	340 (1.2)	12 (12)	277 (4.3)	62 (62)	1430 (4.3)
year-1	123 (130)	2929 (4.2)	28 (52)	1149 (2.4)	39 (45)	1155 (3.4)	190 (227)	5233 (3.6)
P5	35 (21)	866 (4.0)	1 (8)	180 (0.6)	8 (8)	194 (4.1)	44 (37)	1240 (3.5)
P6	31 (24)	883 (3.5)	8 (12)	301 (2.7)	4 (10)	226 (1.8)	43 (46)	1410 (3.0)
P7	55 (40)	922 (6.0)	18 (17)	325 (5.5)	14 (15)	390 (3.6)	87 (72)	1637 (5.3)
P8	45 (45)	800 (5.6)	16 (15)	327 (4.9)	10 (12)	215 (4.7)	71 (62)	1342 (5.3)
year-2	166 (130)	3471 (4.8)	43 (52)	1133 (3.8)	36 (45)	1025 (3.5)	245 (227)	5629 (4.4)
Total	289 (260)	6400 (4.5)	71 (104)	2282 (3.1)	75 (90)	2180 (3.4)	435 (454)	10862 (4.0)

Of the 77 endorsement holders that submitted catch and effort logsheets for the OPTS over the 24-months field survey, 30 endorsement holders hosted an observer. During the observed period, participating vessels reported between 49% (year-1) and 45% (year-2) of the total catch from the fishery. Fishers' response and willingness to participate and/or stated reasons for not participating could be grouped into several categories summarised in Table 4.

Reported logbook fishing effort and observed trips

NSW DPI Catch and Effort reporting system for the two-year duration of the study of the study (September 2017 – August 2019) recorded a total of 5,233 and 5,629 fisher days from year-1 (P1-P4) and year-2 (P5-P8) of the survey, respectively. Overall, observed trips accounted for 3.6 and 4.4% of the total number of trips reported to have been undertaken in year-1 and year-2 of the survey, respectively (Table 3). The proportion of total reported trips observed compared to the total trips for individual temporal strata ranged from 2.1 – 6.0% (North), 0.6 – 5.0% (Central) and 1.8 – 4.7% in the South zone. Observer coverage was lowest in spring/summer (2.2 – 3.5% of trips) and highest in autumn/winter (4.3 – 5.3% of trips) in both year-1 and year-2 of the survey.

Table 4 Response of fishers when requested to host an observer during OPTS fishing events.

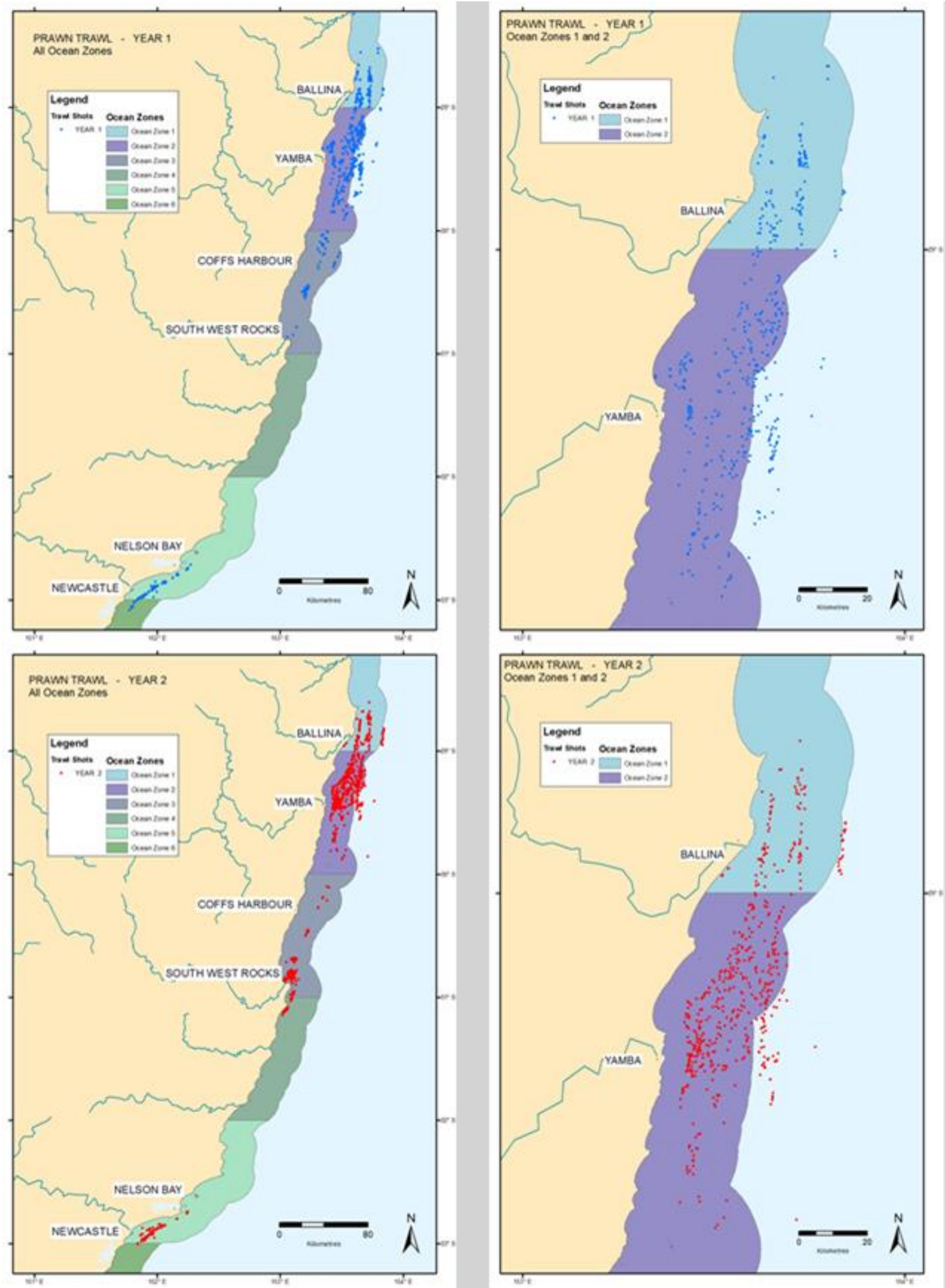
Response to request to host observer	year-1%	year-2%
Hosted an observer on multiple trips; participated when requested to do so	32	19
Hosted an observer on multiple trips, but during the sampling became difficult to contact	12	25
Hosted an observer on a single trip, but decided not to participate further	3	3
Agreed to participate, however sporadic nature of fishing activity did not facilitate routine observer coverage	3	3
Declined to participate for reasons including current fisheries management regulations	28	28
Declined, citing lack of planned trawling as reason	12	12
Unable to be contacted	12	12

Spatial distribution of observed trawl shots

In the North zone (OZ1–OZ2), the location of observed trawl shots was generally similar among years, heavily concentrated around the ports of Yamba/Iluka and Ballina (Figure **3**). In contrast, observed fishing locations in the Central zone in year-1 and year-2 of the survey were different, with observed trawl shots concentrated around the northern and southern areas of OZ3 during year-1 and year-2 of the survey, respectively.

In the South zone (OZ4 – OZ6) observed trawl shots were concentrated around the ports of Newcastle and Nelson Bay (
Figure **3**). During year-2 of the survey, a small number of observed trawl shots from the port of South West Rocks were observed to occur in OZ4 (South zone).

Figure 3 Spatial distribution of observed shots during year-1 and year-2. Left panels all zones; right panels North zone.



Observed catch characteristics

Catch retention and discard rates

Mean total catch per trip (kg ± SE) by the combined fleets of the North, Central and South zones during year-1 and year-2 was 567.2± 24.6 kg and 712.6 ± 24.5 kg, respectively. This total comprised:

Year-1:
Total catch: 567.2 ± 24.6 kg
Retained catch: 182.5 ± 10.9 kg
Discarded catch: 384.7 ± 17.7 kg
Commercial species*: 115.8 ± 10.0 kg
Non-commercial (bycatch) species: 268.9 ± 13.4 kg

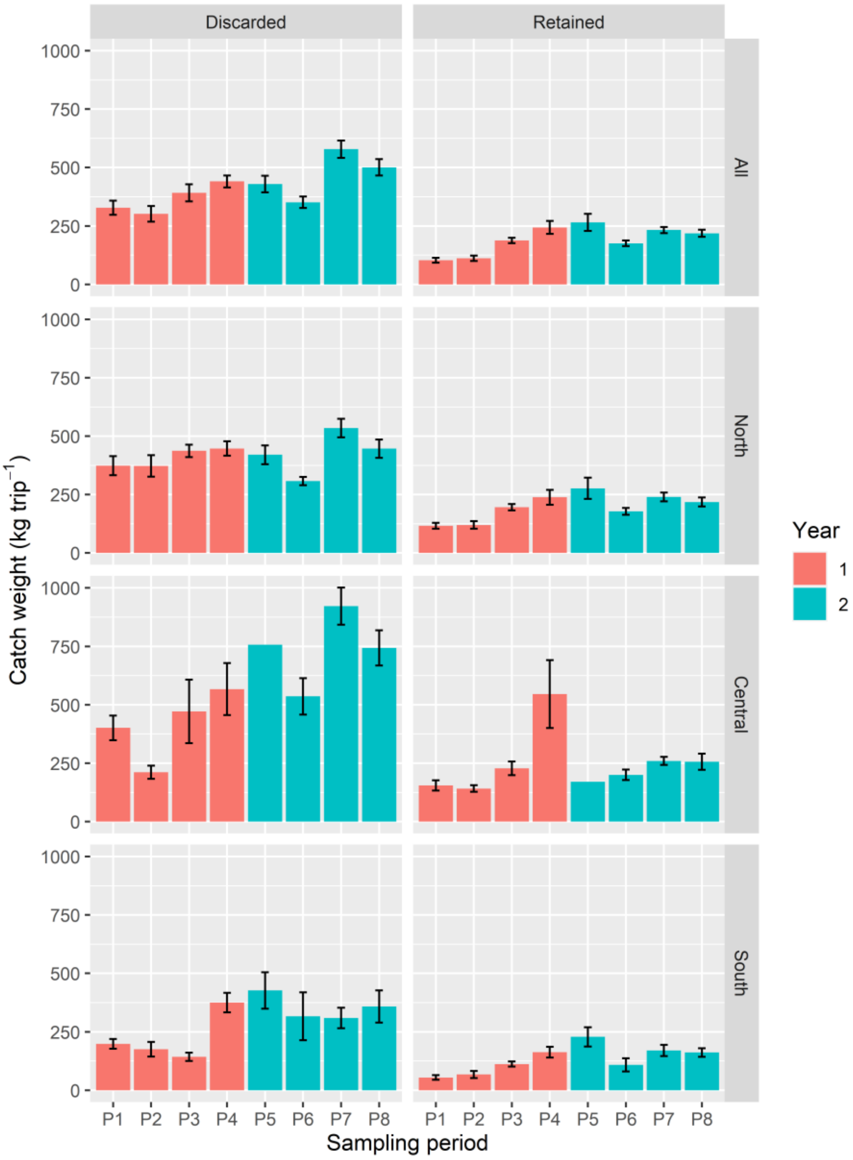
Year-2:
Total catch: 712.6 ± 24.5 kg
Retained catch: 223.0 ± 9.5 kg
Discarded catch: 489.6 ± 19.0 kg
Commercial species*: 191.6 ± 10.8 kg
Non-commercial (bycatch) species: 298.0 ± 13.9 kg

*Commercial species include all species observed to be retained from more than two trips per year (Appendix 2).

Retained catches (mean kg per-trip^{-1} ± SE) in year-2 (223.0 ± 9.5 kg) were approximately 20% greater than those observed in year-1 (182.5 ± 10.9 kg). However, in both the North and Central zones, retained catches in year-1 (North; 212.3 ± 13.8 kg, Central; 250.2 ± 13.1 kg) and year-2 (North; 213.3 ± 13.1 kg, Central; 243.1 ± 15.8 kg) of the survey were similar across years. In contrast, mean retained catches in the South zone in year-1 (109.2 ± 10.9 kg) were generally less than year-2 (173.7 ± 13.2 kg) for all sample periods. The species comprising the greatest proportions of the overall retained catch during observed trips (by weight) were consistent between years (Appendix 3). Observed catches of EKP, ESW, SW and Octopuses accounted for approximately 75% of the retained catch in both years.

Discarded catches in year-2 (489.6 ± 19.0 kg) were approximately 30% greater than those observed in year-1 (384.7 ± 17.7 kg). Overall, the discarded portion of observed catches comprised 380 species (Appendices 4, 5), with Butterfly Gurnards (*Lepidotrigla modesta, L. mulhalli)*, Longspine Flathead (*Platycephalus longispinis*), Spotted Bigeye (*Priacanthus macracanthus*) and Yellowtail Scad (*Trachurus novaezelandiae)*, accounting for approximately 45% of total discards (by weight, all trips combined) in year-1 and year-2 of the survey (Appendix 4). While there was evidence of possible seasonal differences in catch rates, the differences were not consistent across zones or years (Figure 4). Observed discard rates in the North and Central zones in both year-1 and year-2 of the survey were generally greatest in autumn (P3, P7) and winter (P4, P8). Mean discarded catches in the Central zone from P7 (920.5 ± 86.9 kg) and P8 (743.2 ± 77.8 kg) estimated from a combination of trips targeting EKP and School Prawns (SP) were greater than all other zone/period groupings (Figure 4). Observed discard rates in the South zone were generally less than the North and Central zones, particularly in year-1, where mean discarded catches ranged from 142.6 ± 19.4 (P3) to 374.8 ± 43.7 kg (P4).

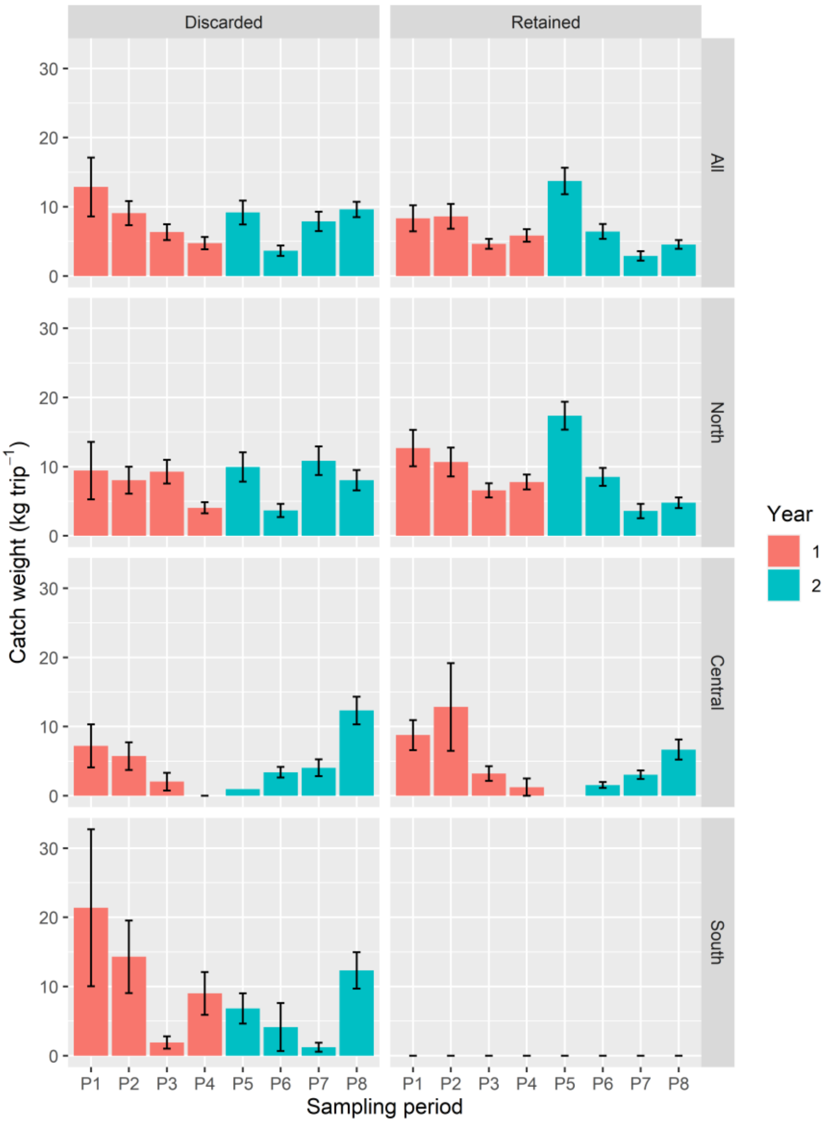
Figure 4 Mean catch rates (kg per-trip^{-1} ± SE) of retained and discarded catches from all, North, Central, and South zones.



Commercial species accounted for approximately 30 and 40% of the total discards in year-1 and year-2 of the survey, respectively. Several species were observed to make a consistently high contribution to discarded catches of commercial species recorded across all zones (Appendix 5). Approximately 75% of the discarded catch of commercial species was comprised of finfish, with the most abundant species relatively consistent across years. Spotted Bigeye was the most abundant species observed in catches contributing 15.1% (year-1) and 24.4% (year-2) of total finfish discards. Other species which made a consistently high contribution to discarded catches included ESW (12.3 – 14.1%), SW (2.9 – 12.8%) and BSFH (5.2 – 8.0%). Crustaceans were observed to account for approximately 15% of total discards of commercial species (12.6 – 16.4%), with Common Trawl Crab (Portunidae; 34.0 – 49.4%) and Smooth Bug (*Ibacus chacei*; 31.3 – 39.7%) the most abundant species. Discarded catches of commercially important sharks and rays were dominated by Eastern Shovelnose Ray (*Aptychotrema rostrata*; 34.4 – 46.1%) and Eastern Fiddler Ray (*Trygonorrhina fasciata*; 17.3 – 36.4%).

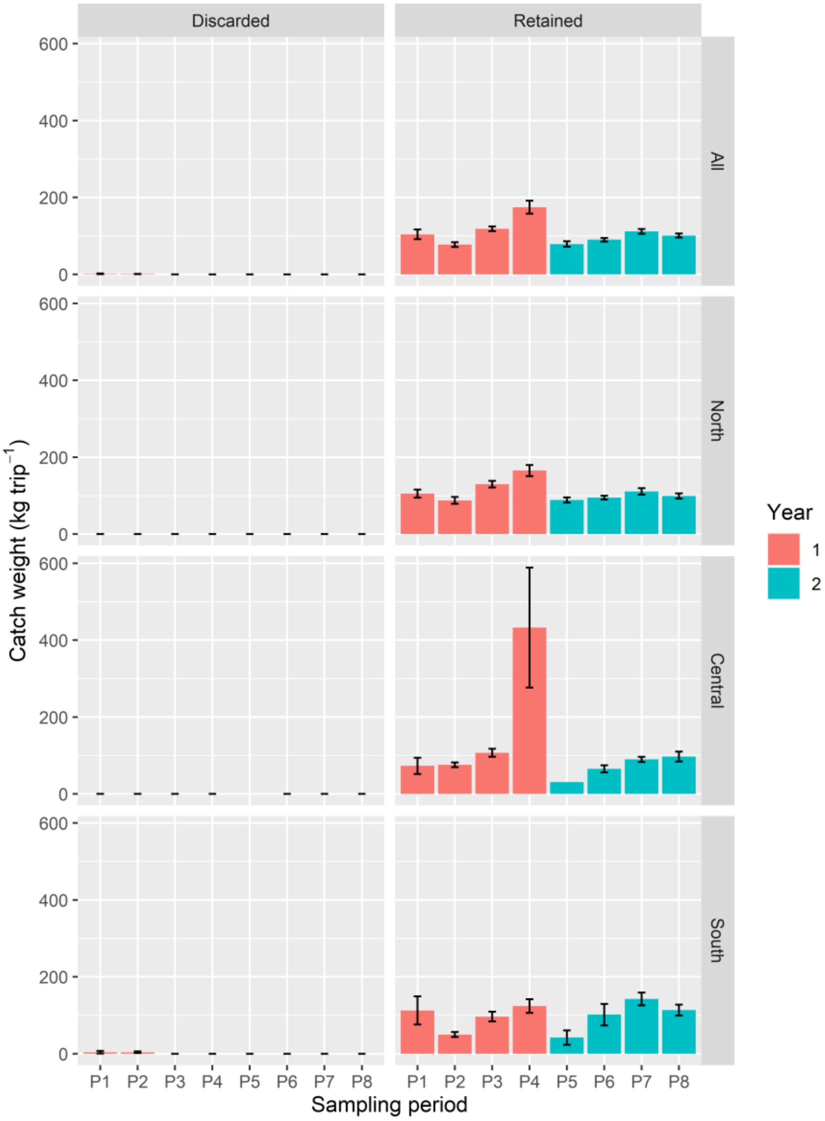
Mean retained and discarded catches (kg per-trip^{-1} ± SE) of BSFH in the North zone were generally greater than the Central zone for most sampling periods (Figure 5). Seasonal differences in observed catch rates were not consistent across zones or years. Differences between zones and sample periods may reflect sampling intensity with only a small number of trips and trawl shots observed from P4 – P6 in the Central zone. Differences in the depth distribution of observed trawl shots between sample periods may have also impacted catch rates (See section Catch rates by depth). Observed discard rates of BSFH were similar to mean retention rates in all zone/period combinations. In the south, discarded catches of BSFH were highly variable among sample periods despite most observed shots catching BSFH (Figure 5). For combined analyses (i.e., pooled across zones), observed mean retained catches from year-1 (6.2 ± 0.6 kg) and year-2 (5.9 ± 0.5 kg) and discarded catches in both year-1 (6.7 ± 0.7 kg) and year-2 (7.8 ± 0.7 kg) were similar (Figure 5). Mean retained and discarded catches (no per-trip^{-1} ± SE) are shown in Appendix 6.

Figure 5 Mean catch rates (kg per-trip^{-1} ± SE) of retained and discarded catches of Bluespotted Flathead from all, North, Central, and South zones.



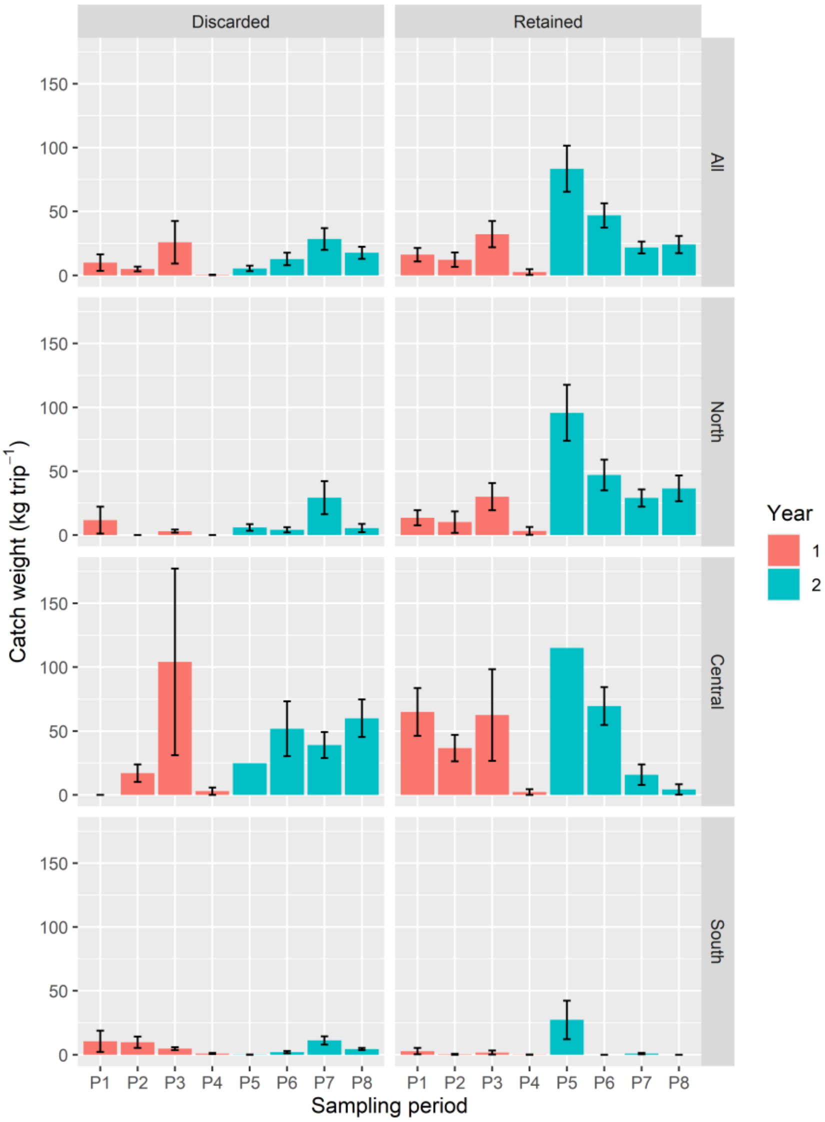
Mean retained catch rates (kg per-trip^{-1} ± SE) for EKP in the North zone were generally greater than the Central and South zones (Figure 6). However, catches in the Central zone during P4 (432.6 ± 180.3 kg), which included a small number of trips (n = 4) and shots (n = 15) were greater than all other sampling periods. Seasonal differences were observed in catch rates across zones in both years sampled. Mean retained catches in autumn (P3, P7) and winter (P4, P8) were generally greater than spring (P1, P5) and summer (P2, P5). Catches in the South zone were impacted by season, with mean retained catches from spring (P1; 78.8 ± 17.5 kg) and summer (P2; 49.8 ± 7.1 kg) lower than both autumn (P3; 96.6 ± 13.2 kg) and winter (P4; 124.2 ± 18.6 kg) during year-1 of the survey. Similarly, in the Central zone during year-2 of the survey, mean retained catches from spring (P5; 31.0 ± 0.0 kg) and summer (P6; 65.2 ± 9.6 kg) were lower than both autumn (P7; 89.7 ± 7.0 kg) and winter (P8; 97.3 ± 13.3 kg). Observed discard rates of EKP were consistently lower than mean retention rates in all zone/period combinations (Figure 6). For combined analyses (i.e., pooled across zones), observed mean retained catches from year-1 (126.9 ± 6.7 kg) were greater than year-2 (98.9 ± 3.15 kg). Similarly, for analyses that excluded the small number of extremely high catches observed during P4 in the Central zone, mean catch rates from year-1 of the survey (120.4 ± 5.2 kg) were greater than year-2 (Figure 6).

Figure 6 Mean catch rates (kg per-trip ± SE) of retained and discarded catches of Eastern King Prawn from all, North, Central, and South zones.



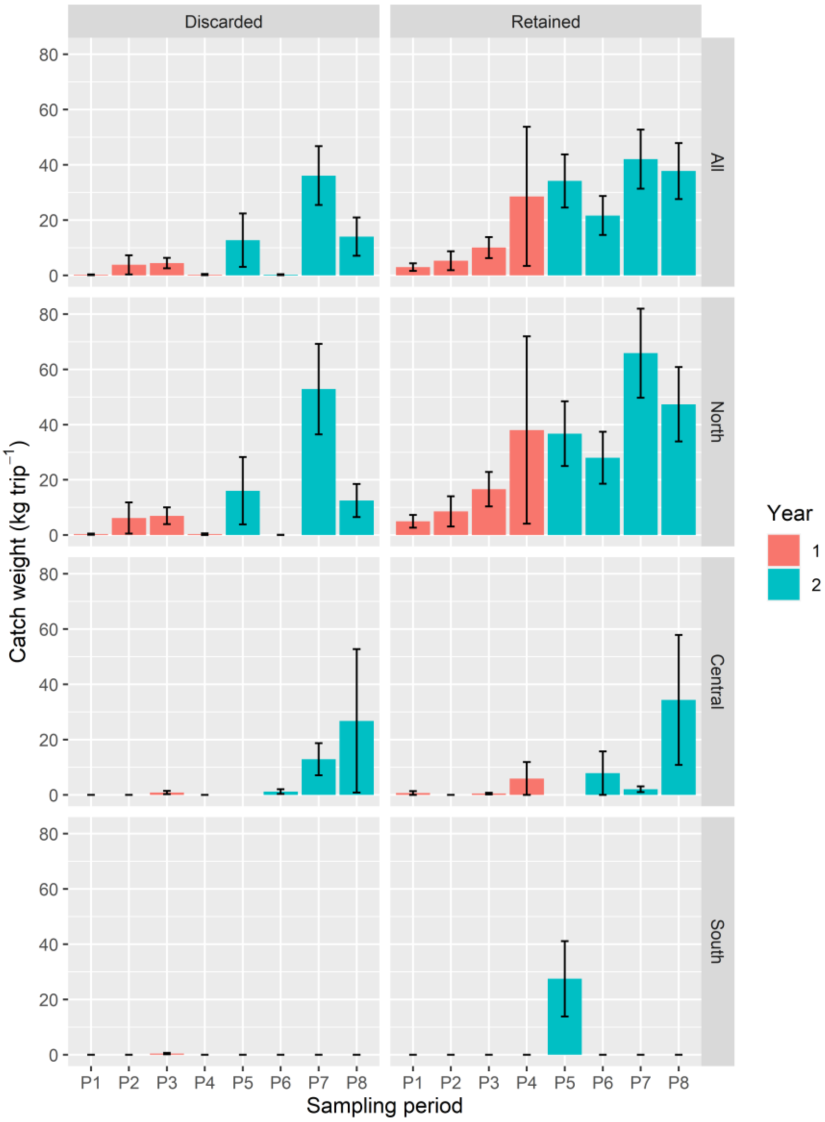
Observed discard rates of ESW were highly variable among zone/period groupings (Figure 7). In contrast to the North zone, where discarded catches were ≤ to retained catches, mean discarded catches from the Central zone were ≥ to retained catches for several sample periods (Figure 7). Mean retained and discarded catches of ESW in the South zone were consistently lower than the North and Central zones. The proportion of the total ESW catch discarded was variable between zone/period groupings. For example, in the North zone during P7, mean retained (29.1 ± 15.8 kg) and discarded catches (29.3 ± 13.1 kg) were similar, while, during P6 and P8 mean retained catches (P6: 47.1 ±12.3 kg, P8; 36.5 kg ± 10.2 kg) were greater than observed discarded catches of 4.2 ± 2.0 kg and 5.5 ± 3.3 kg, respectively. High discard rates in the Central zone were often the direct result of observing a small number of trips discarding large quantities of ESW (Max. 1057.2 kg). For combined analyses (i.e., pooled across zones), observed mean retained (37.6 ± 4.6 kg) and discarded catches (18.5 ± 3.5 kg) from year-2 were greater than both retained (17.2 ± 7.2 kg) and discarded (11.7 ± 6.4 kg) catches from year-1 (Figure 7).

Figure 7 Mean catch rates (kg per-trip^{-1} ± SE) of retained and discarded catches of Eastern School Whiting from all, North, Central, and South zones.



Mean retained catches (kg per-trip^{-1} ± SE) of SW in the North zone, were greater than Central and South zones in all sample periods (Figure 8). Observed discard rates of SW in the North zone were consistently lower than mean retention rates (Figure 8). However, the proportion of the total SW catch discarded was variable between sample periods. For example, in P7, mean retained (65.8 ± 16.2 kg) and discard catches (52.8 ± 16.5 kg) were similar, while in P6 and P8, retained catches of 28.0 ± 9.5 kg and 47.3 ± 13.6 kg, respectively, were greater than mean observed discarded catches during both sample periods (P6; 0.1 ± 0.1 kg, P8; 12.5 ± 6.1 kg). Observed seasonal differences in catch rates were not consistent across zones or years. In the North zone, both mean retained (47.7 ± 7.2 kg) and discarded catches (24.3 ± 6.4 kg) during year-2 of the survey were greater than both retained (22.0 ± 12.9 kg) and discarded (3.6 ± 1.4 kg) observed during year-1. Similarly, for combined analyses (i.e., pooled across zones), observed mean retained (35.8 ± 5.2 kg) and discarded catches (19.2 ± 4.7 kg) from year-2 of the survey were greater than both retained (14.4 ± 8.3 kg) and discarded (2.4 ± 0.9 kg) catches in year-1 (Figure 8).

Figure 8 Mean catch rates (kg per-trip^{-1} ± SE) of retained and discarded catches of Stout Whiting from all, North, Central, and South zones.

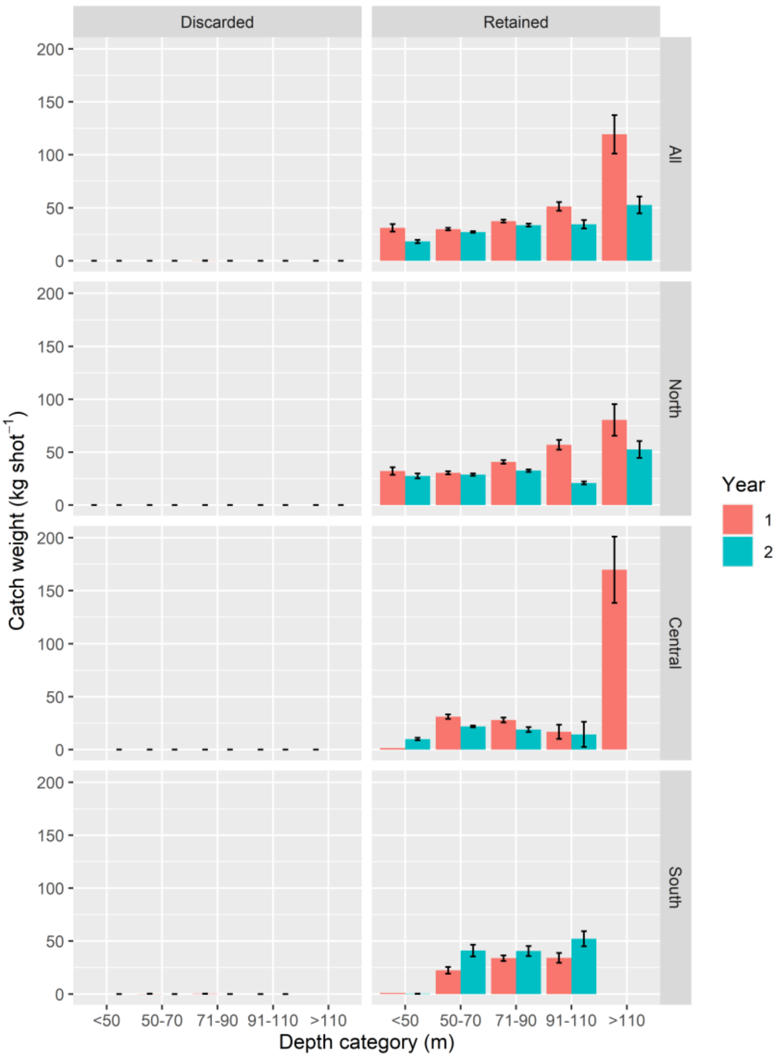


The high standard error estimates associated with mean 'non-directed' catch rates, often limit comparisons of spatial and temporal differences in catch rates. In the case of each of the species presented above and commercial byproduct species (Appendix 7) and non-commercial bycatch species (Appendix 8), patterns in catch rates among zones and period groupings may reflect sampling intensity, depth distribution of observed trawl shots, gear configuration (i.e., BRD used) and the fishing power of vessels observed within individual zone/period groupings.

Catch rates by depth

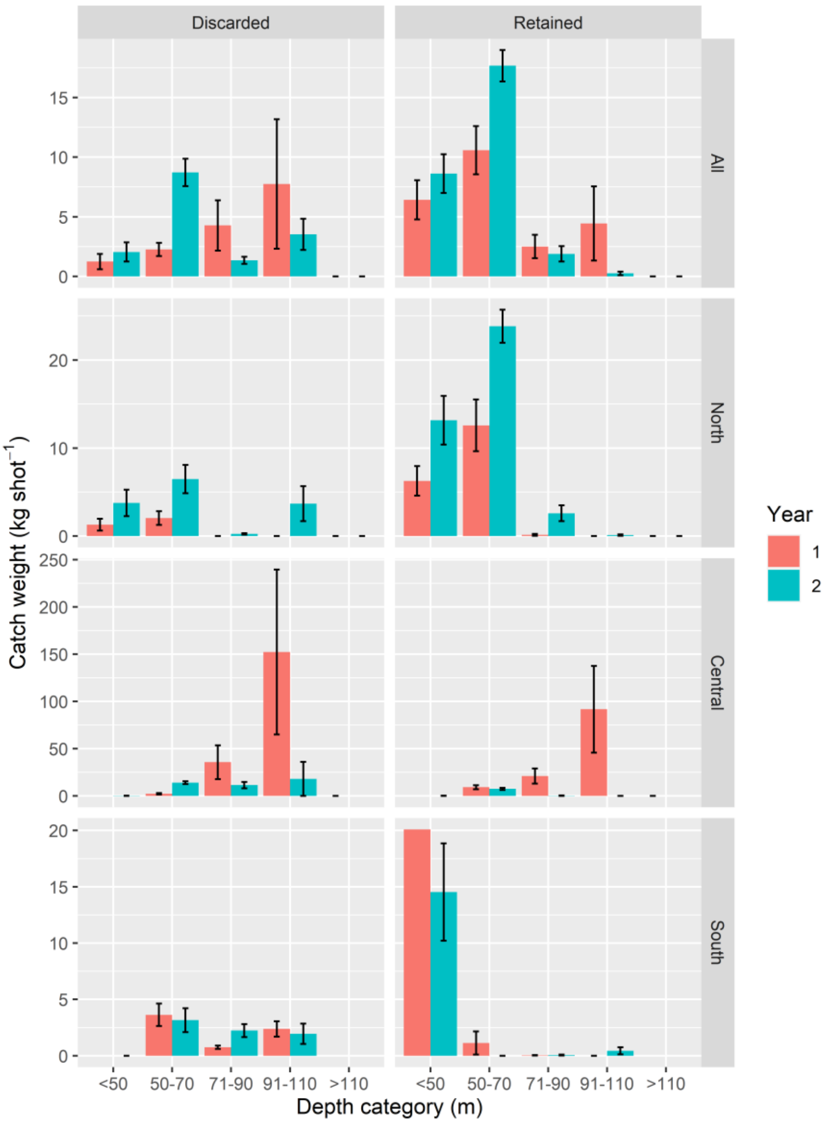
Mean retained catch rates (kg per-shot^{-1} ± SE) for EKP were highest in depths >110 m with means (± SE) ranging between 64.7 ± 8.3 and 169.8 ± 33.0 kg per shot in the North and Central zones, respectively (Figure 9). However, only a small proportion of the total observed catch in the North (6%) and Central (21%) zones was caught in depths >110 m.

Figure 9 Mean catch rates (kg per-shot^{-1} ± SE) of retained, discarded and total catches of Eastern King Prawn from all, North, Central and South zones per depth grouping. Data are pooled across sample periods.



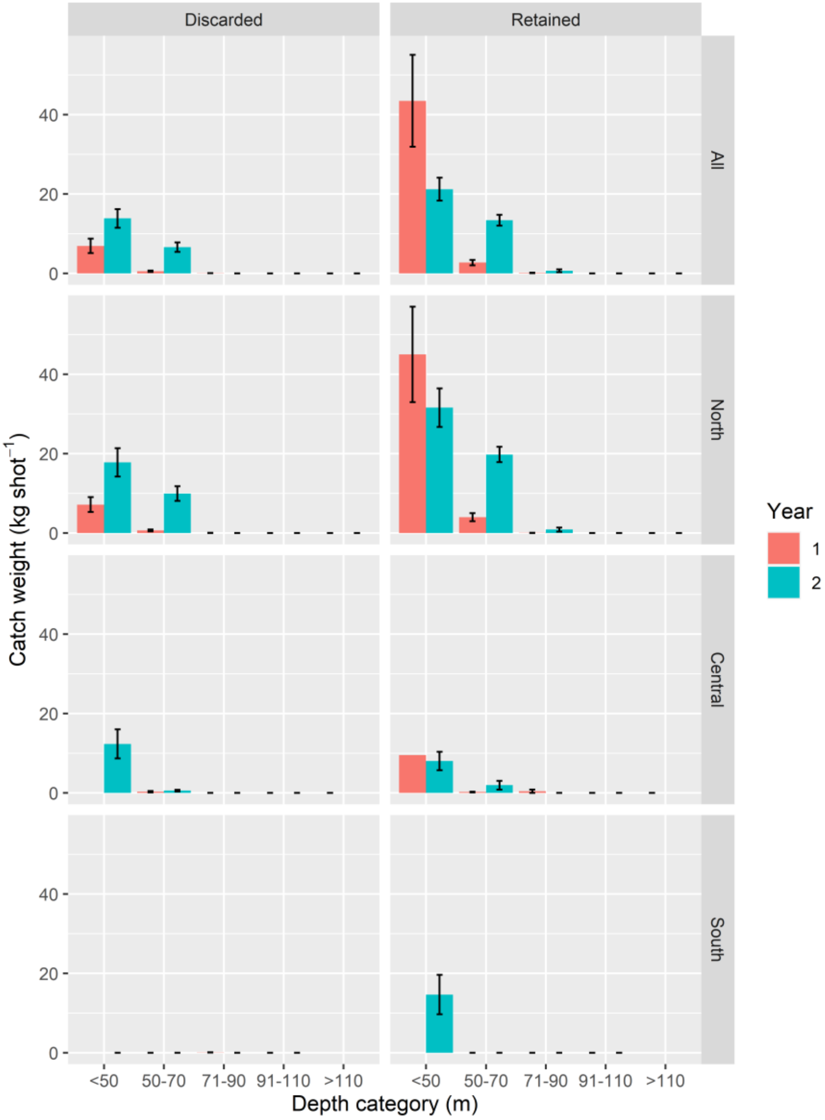
Spatial differences were observed in mean retained and discarded catch rates (kg per-shot^{-1} ±SE) of ESW among depth groupings (Figure 10). For example, in the North, the proportion of the total retained (83%) and discarded catch (82%) and, catch rates of both retained (20.4 ± 1.6 kg) and discarded catches (5.1 ± 1.2 kg) from the 50–70 m depth grouping were greater than all other depths. In contrast, in the Central zone, mean retained (55.0 ± 37.7 kg) and discarded catches (98.6 ± 6.1 kg) from the 91-110 m depth grouping were greater than all other depths. However, the proportion of the total retained (11%) and discarded (13%) catch observed from 91–110 m group was lower than the 50-70 m depth group (52–58%). In the South, mean retained (14.9 ± 4.2 kg) and discarded catches (3.4 ± 0.7 kg) were greatest in the <50 m and 50–70 m depth groupings, respectively.

Figure 10 Mean catch rates (kg per-shot^{-1} ± SE) of retained, discarded and total catches of Eastern School Whiting from all, North, Central and South zones per depth grouping. Data are pooled across sample periods.



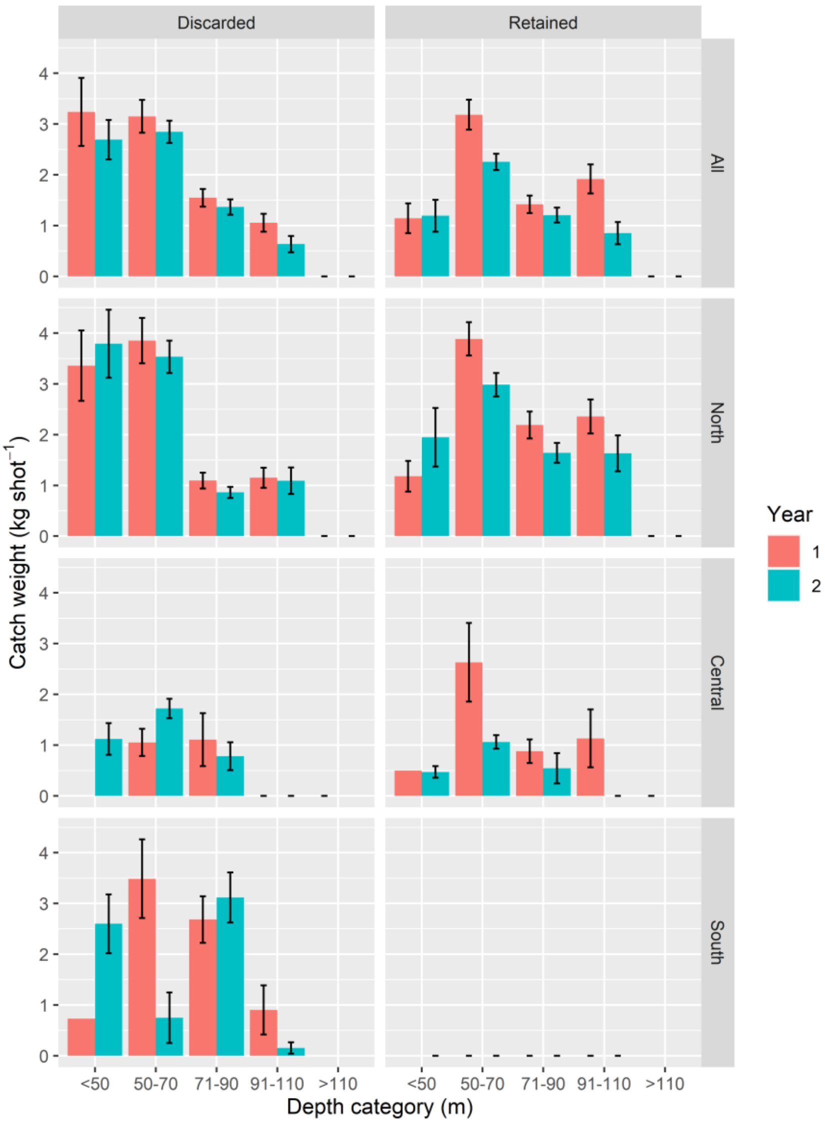
Mean retained catch rates (kg per-shot^{-1} ± SE) of SW observed from <50 m was greater than all other depths, with means (± SE) ranging between 8.1 ± 2.3 kg and 37.1 ± 5.7 kg per shot in the Central and North zones, respectively (Figure 11). However, in the North, the proportion of total retained (57%) and discarded (64%) catch observed from 50–70 m was greater than <50 m strata (36–42%). Similarly, for discarded catches, mean catch rate from <50 m in the North (13.4 ± 2.3 kg) and Central (12.1 ± 3.6 kg) zones were greater than catches rates from 50–70 m with means of 0.5 ± 0.2 kg and 7.2 ± 1.3 kg per shot from the Central and North zones, respectively (Fig. 11).

Figure 11 Mean catch rates (kg per-shot^{-1} ± SE) of retained, discarded and total catches of Stout Whiting from all, North, Central, and South zones per depth grouping. Data are pooled across sample periods.



Mean discarded catch rates (kg per-shot^{-1} ± SE) of BSFH in the North and Central zones were highest in depths 50–70 m with means (± SE) ranging between 1.6 ± 0.2 and 3.6 ± 0.3 kg per shot in the North and Central zones, respectively (Figure 12). Similarly, for retained catches, mean catch rate from 50–70 m in the North (1.4 ± 0.2 kg) and Central (3.3 ± 0.2 kg) zones were greater than catches rates from trawl shots observed in <50 m and > 70 m. Despite the observed decline in retained and discarded catch rates at depths > 70 m, the proportion of the total catch retained from 71–90 m and 91–110 m depth groupings in the Central zone increased to >65%. In the South, where regulations prohibit the taking of all Flathead spp., catch rates from the <50 m (2.5 ± 0.6 kg), 50–70 m (2.2 ± 0.5 kg) and 71–90 m (2.8 ± 0.3 kg) depth groupings were similar. Catch rates of trawl shots observed in depths >90 m (21 shots) declined to 0.4 ± 0.2 kg per shot (Figure 12).

Figure 12 Mean catch rates (kg per-shot^{-1} ± SE) of retained, discarded and total catches of Bluespotted Flathead from all, North, Central, and South zones per depth grouping. Data are pooled across sample periods.



In the case of each of the species presented above, patterns in catch rates among depths may follow patterns in fishing effort (i.e., number of trawl shots per depth) and frequency of targeting, with levels of targeting varying among depths. Furthermore, short-term temporal variations in the distribution of species among depth zones, gear configuration (i.e., headline length) and operational variables, including shot duration and tow speed, may have impacted catch rates.

Discard drivers

Environmental and operational drivers

Environmental and operational factors were significant drivers of discarding in all species-group response models (Table 5). Therefore, the null hypothesis of no effect of environmental and operational drivers was rejected. Environmental drivers, latitude, and season (either as a main effect or interactive with depth or both), were drivers of discarding for all species groups. One operational driver (the retained catch) featured in the discarding models of all species groups except elasmobranchs (Table 5). The model deviance explained was low for fish (~42%) and elasmobranchs (~47%), and high for commercial fish, crustaceans, and commercial crustaceans (all ~70%) (Table 5).

Table 5 Final reduced GAMM results for species groups relationships with environmental and operational factors (the discard drivers) utilising only statistically significant factors.

Response	Factors	Deviance explained
Elasmobranchs	Track, longitude:latitude, season, year	46.6%
Crustaceans	longitude:latitude, depth:summer, autumn, retained catch, season	76.5%
Fish	Latitude, depth:summer, autumn, winter, spring, retained catch, season	42.2%
Commercial crustaceans	longitude:latitude, depth:summer, autumn, spring, kW, retained catch, year	68.5%
Commercial fish	Track, longitude:latitude, depth:winter, spring, speed, retained catch, season	64.2%

Environmental driver effects

Spatial – latitude and longitude

The spatial effect on discarding varied among species groups (Figure 13 to Figure 17). Elasmobranch discarding was consistent along the entire north to south extent of the OPTS with discarding greatest inshore at 30 °S (± 1 °S) (Figure 13). Crustacean discarding was also along the north to south extent but not in an area from ~29.5 to 30.0 °S (Figure 14, ~North zone). Again, discarding was generally greatest inshore but lacked the spatial consistency of elasmobranch discarding. Fish discarding was slightly higher in the north (29 to 30 °S) of the OPTS (Figure 15). There was no effect of longitude on fish discarding. Commercial crustaceans were discarded in three small areas (Figure 16). This was strongest in the southernmost part of the fishery and offshore of ~30.5 °S (Central zone). Commercial fish were also discarded in multiple areas including offshore of 29.5 °S with a narrow ridge extending southward on the offshore extremity of trawling to ~31.5 °S. In the far south of the OPTS (the South zone), commercial fish discarding was very strong between observed shots from 32.5 °S and the southernmost extent, except for a relatively small area at ~33.0 °S and between 151.75 and 152.0 °E where there was no discarding (Figure 17).

Figure 13 Significant effects plots from the discarded elasmobranchs response GAMMs; shaded area (left) and error bars (right) represent 95% confidence limits while the surfaces (middle) represent the effect of 2-d smoothing on spatial coordinates (for complete figures see Barnes et al. (2022)).

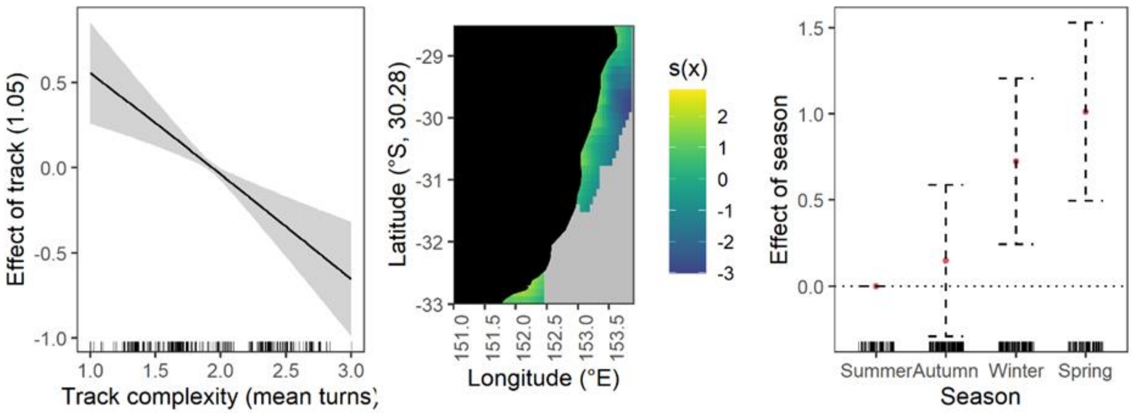


Figure 14 Significant effects plots from the discarded crustacean response GAMMs; shaded area (top and lower left) and error bars (lower middle) represent 95% confidence limits while the surfaces (lower right) represent the effect of 2-d smoothing on spatial coordinates (see Barnes et al., 2022).

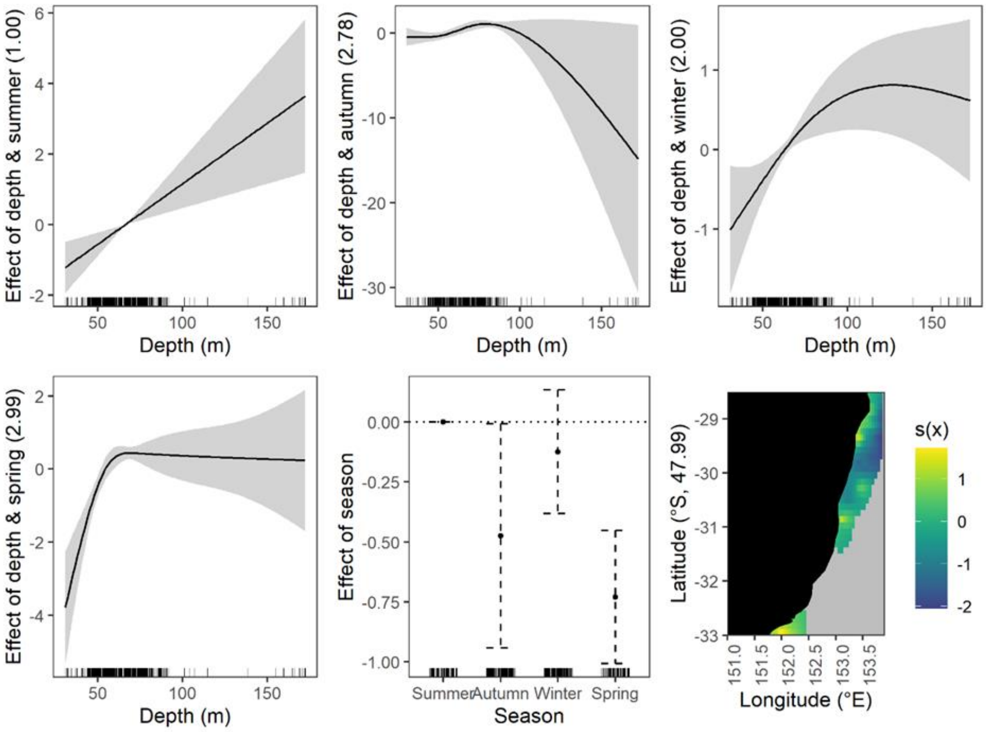


Figure 15 Significant effects plots from the discarded fish response GAMMs; shaded area (top and lower left, middle) and error bars (lower right) represent 95% confidence limits (see Barnes et al., 2022).

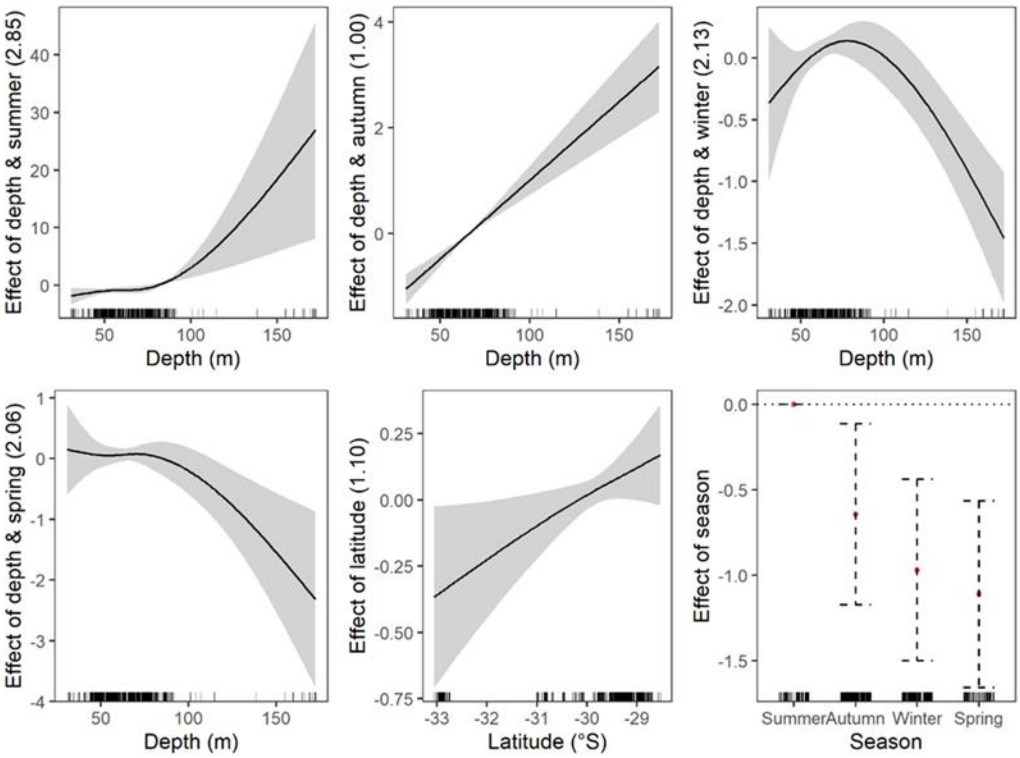


Figure 16 Significant effects plots from the discarded commercial crustacean response GAMMs; shaded area (top and lower left, middle) represents 95% confidence limits while the surfaces (lower right) represent the effect of 2-d smoothing on spatial coordinates (see Barnes et al., 2022).

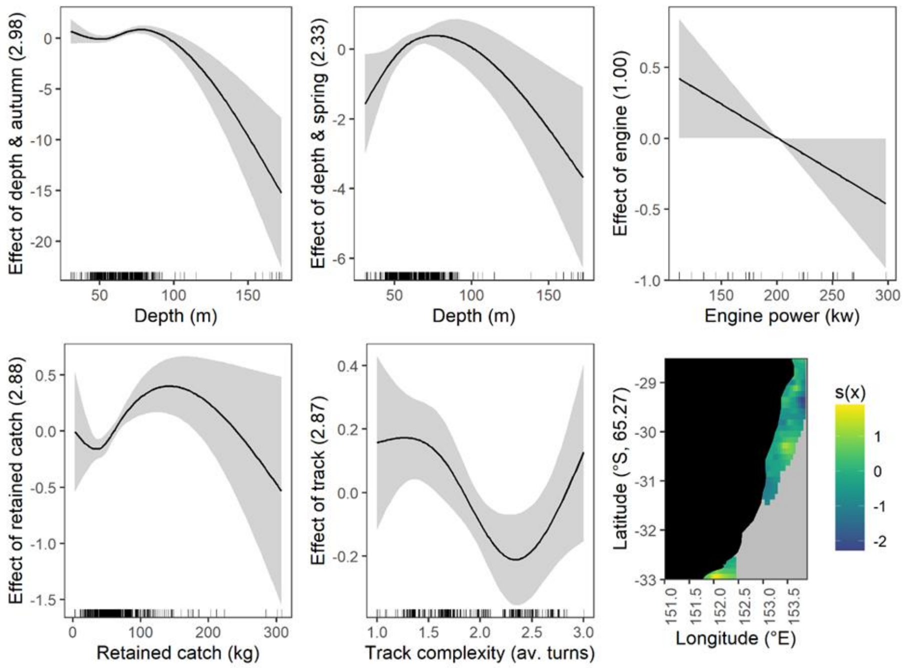
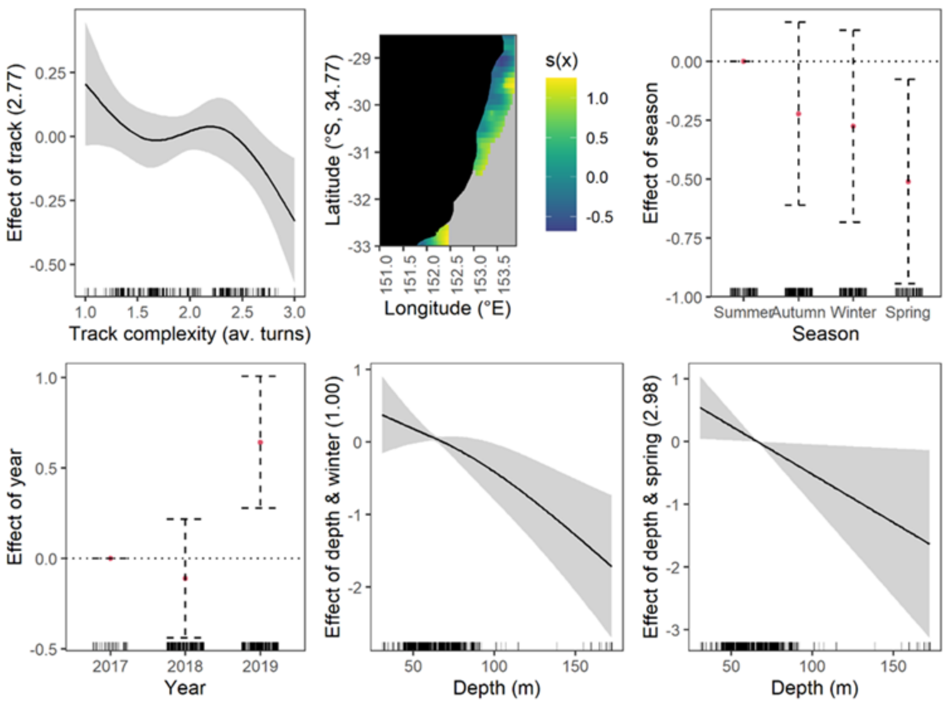


Figure 17 Significant effects plots from the discarded commercial fish response GAMMs; shaded area (top left; lower middle, right) and error bars (top right; lower left) represent 95% confidence limits while the surfaces (top middle) represent the effect of 2-d smoothing on spatial coordinates (see Barnes et al., 2022).



Temporal – year, season and season and depth interaction

The temporal effect on discarding varied, and occasionally season interacted with depth (Figure 13 to Figure 17). More elasmobranchs were discarded in 2018 and 2019 compared to 2017 (Figure 13). Also, more were discarded in winter and spring compared to summer. Fewer crustaceans were discarded in autumn and spring compared to summer (Figure 14). There was a positive relationship between crustacean discarding and increasing depth during summer across the depth range, autumn between ~50 to 100 m, winter at depths below 100 m, and spring at depths below 70 m. There was greatest uncertainty in crustacean discarding at the deeper extremities evidenced by the wider confidence intervals (Figure 14).

Fewer fish were discarded in all seasons compared to summer (Figure 16). A positive relationship between discarding and depth occurred in summer and autumn with the relationship linear in autumn and with a sharp increase in slope at ~100 m deep in summer. The discarding and depth relationship was reversed in winter and spring where a negative linear relationship was evident at depths >70 m (Figure 16). There was no clear relationship at depths <70 m for winter and spring.

Commercial crustaceans were discarded more in 2018 and 2019 compared to 2017 (Figure 16). There was a negative discarding and depth relationship in autumn and spring. Fewer commercial fish were discarded in spring compared to summer (Figure 17). There was a negative discarding and depth relationship during winter and spring, however, again there was no clear relationship at <70 m in winter. The greatest uncertainty was again at deeper depths (Figure 16, Figure 17).

Operational driver effects

Track complexity

Increasing track complexity generally had a negative relationship with discarding of elasmobranchs and commercial taxa (crustacean and fish) (Figure 13, Figure 16 and Figure 17). A near linear relationship was found for elasmobranchs and commercial fish, however, the spline shows a brief plateau between 1.5 and 2.5 for commercial fish (Figure 17). Discarding of commercial crustaceans had a negative relationship with increasing track complexity but at 2.5 mean turns the relationship changes to positive (Figure 16).

Vessel engine capacity and trawl speed

The only effect of engine capacity on discarding was for commercial crustaceans (Figure 16). Increasing capacity had a negative linear relationship with discarding. Trawl speed only affected commercial fish discarding (Figure 17). The effect was non-linear with an initial negative relationship to mid-speed ranges and then positive.

Retained catch weight

Discarding of all species groups except elasmobranchs generally had a positive relationship with increasing mean retained catch weight (Figure 14, , Figure 16 and Figure

17). Crustaceans had a near linear relationship except at higher retained catches (Figure 14). Fish also had a near linear relationship (Figure 15). Commercial crustaceans had a near linear positive relationship with discarding to 50 to 150 kg; thereon the relationship changed to negative but with increasing uncertainty (e.g., widening of confidence intervals) (Figure 16). Discarding of commercial fish had a near linear positive relationship with retained catch but plateaued after ~200 kg (Figure 18, Figure 19).

Exploratory analysis of discarding and retained catch for fish and all species groups combined

Discarding fish and combined species groups had a significant positive linear relationship with the mean weight of the retained catch (Figure 18 and Figure 19). Therefore, the null hypothesis of no correlation is rejected. However, the relationship was relatively weak for both fish and all species groups combined (r^2 = 28 and 35% respectively).

Figure 18 Relationship between log standardised count of discarded fish and net haul level weighted mean of retained catch.

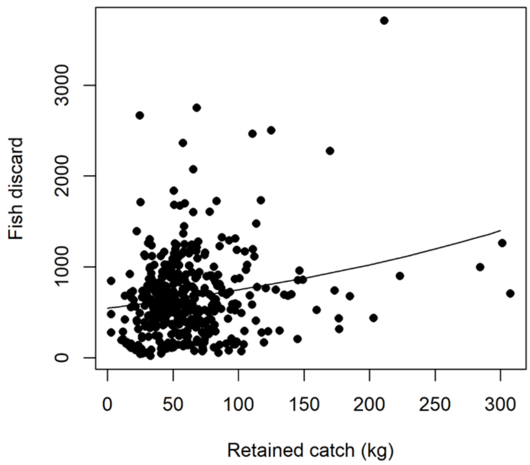
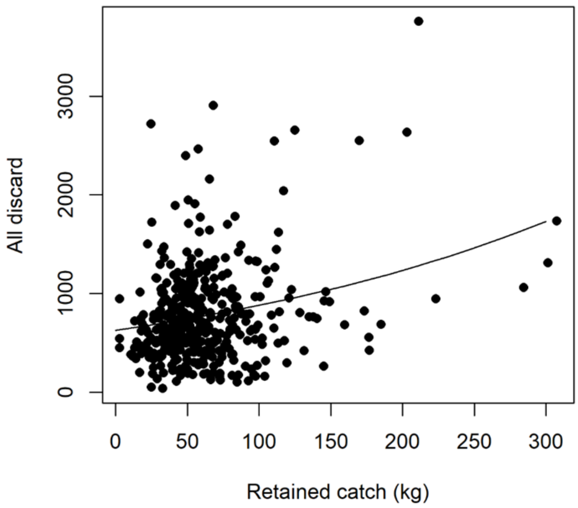


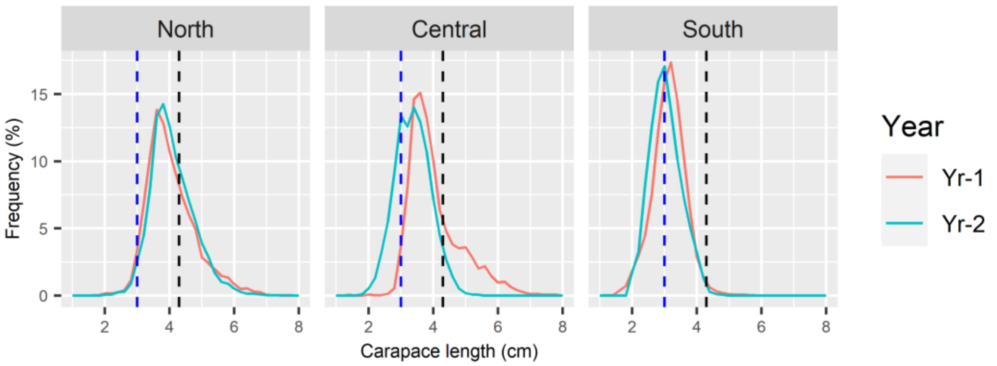
Figure 19 Relationship between log standardised count of all discarded functional groups (fish, crustaceans and elasmobranchs) and net haul level weighted mean of retained catch.



Size-structure of retained and discarded catches

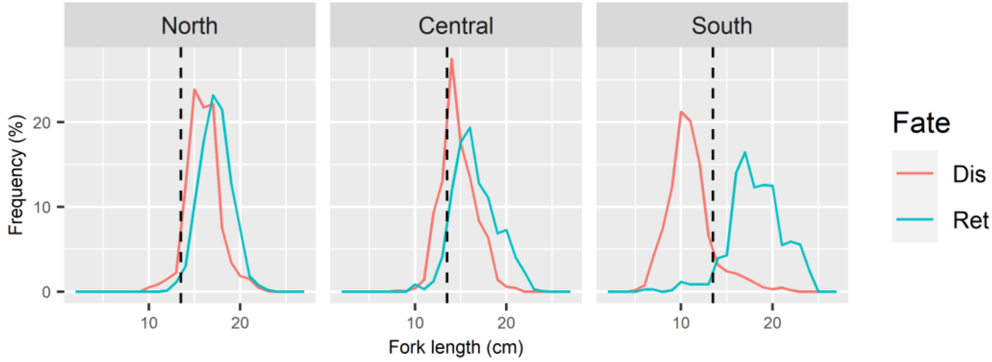
Relative size structures of EKP for the three zones showed divergent trends in terms of size modes and alignment between years (Figure 20). For example, the mean and modal size class of observed catches by carapace length (CL) in the Central zone from year-1 (mean 4.09 ± 0.01 cm CL, mode 3.7 cm CL) were greater than year-2 (mean 3.42 ± 0.01 cm, CL, mode 3.0 cm CL, Figure 20). The mean size of EKP declined with increasing latitude in both years, with the mean size of EKP in the North zone in both year-1 (4.10 + 0.01 cm CL) and year-2 (4.14 ± 0.01cm CL) of the survey, greater than estimates of 3.18 ± 0.01 cm CL and 3.07 ± 0.01 cm CL from the South zone in year-1 and year-2, respectively (Figure 20). The proportion of EKP exceeding L_{YPR} during year-1 of the survey in the North (96.5%) and Central zones (97.5%) was higher than the South zone (62.0%). Similarly, in year-2 of the survey, the proportion of EKP exceeding this threshold in the south (48.8 %) was lower than both the Central (72.7 %) and North zones (97.5%). There were negligible prawns captured within the South zone that exceeded the estimated L_{50} for EKP (< 2%). The proportion of EKP exceeding L_{50} in the Central zone was variable between years, declining from 30.6 % during year-1 to 6.8% during year-2. In contrast, in the North zone, the proportion of EKP exceeding L_{50} in both year-1 (35.2%) and year-2 (37.8%) of the survey were similar (Figure 20). The size-structure of observed catches of EKP in the North, Central and South zones during each sampling period are shown in Appendix 9.

Figure 20 Relative size-structure of Eastern King Prawn within the North, Central and South zones in year-1 (Yr-1) and year-2 (Yr-2). Also indicated is the optimal length at first capture (LYPR, vertical blue dashed line; Taylor et al. (2021) and an estimate of length-at-maturity (L_{50}, vertical black dashed line; Montgomery et al. (2007)).



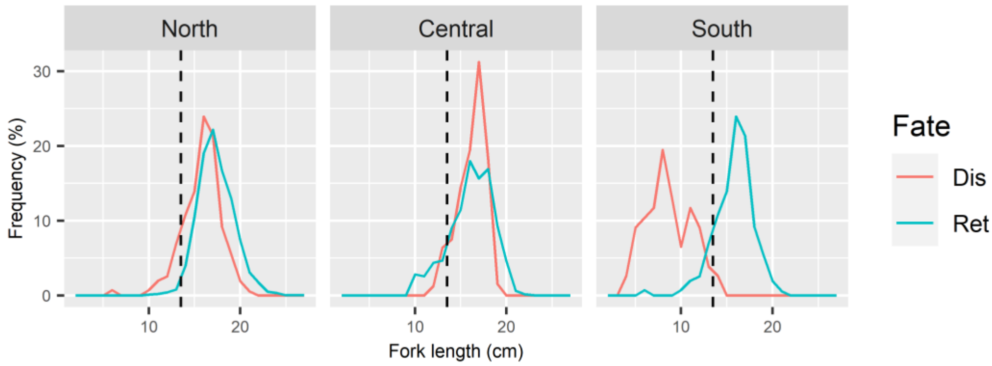
Relative size structures of observed catches (retains + discards) by fork length (FL) of ESW differed among spatial groupings, with the mean and modal size class of catches from the North zone (mean 17.38 ± 0.01 cm TL, mode 17 cm FL) greater than the Central (mean 15.78 ± 0.02 cm, TL, mode 14 cm FL) and South zones (mean 12.92 ± 0.11 cm, FL, mode 11 cm TL). When size composition data was expressed relative to the length-at-maturity (L_{50}), the proportion of discarded ESW less than this threshold in the South zone (88.2 %) was greater than the Central (24.3%) and North (5.1%) zones (Figure 21). In contrast, the proportion of retained ESW exceeding this threshold was relatively consistent across zones, ranging from 93.5% in the Central zone to 95.6% and 98.8% in the South and North zones, respectively.

Figure 21 Relative size-structure of retained (Ret) and discarded (Dis) catches of Eastern School Whiting within the North, Central and South zones. Also indicated is an estimate of length-at-maturity (L_{50}, vertical dashed line; Gray et al. (2014)).



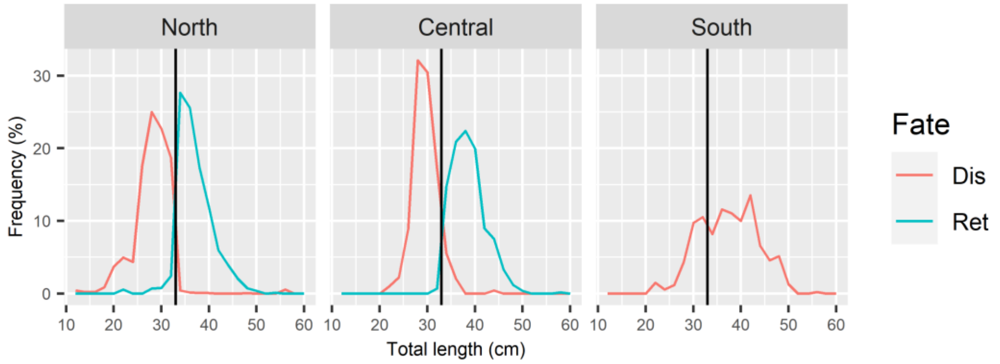
Relative size structures of observed catches by total length (TL) of SW (retains + discards) were similar among spatial groupings, with the mean and modal size class of catches from the North (mean 17.04 ± 0.02 cm TL, mode 17 cm TL), Central (mean 16.35 ± 0.06 cm TL, mode 18 cm TL) and South zones (mean 16.46 ± 0.21 cm TL, mode 17 cm TL) relatively consistent (Figure 22). When size composition data was expressed relative to the length-at-maturity (L_{50}), the proportion of retained SW exceeding this threshold was relatively consistent across zones, ranging from 85.6% in the Central zone to 97.3% and 98.5% in the South and North zones, respectively. Like ESW, the proportion of discarded SW less than this threshold in the South zone (97.4%) was greater than the North (12.9%) and Central (7.7%) zones (Figure 22).

Figure 22 Relative size-structure of retained (Ret) and discarded (Dis) catches of Stout Whiting within the North, Central and South zones. Also indicated is an estimate of length-at-maturity (L_{50}, vertical dashed line; Gray et al. (2014)).



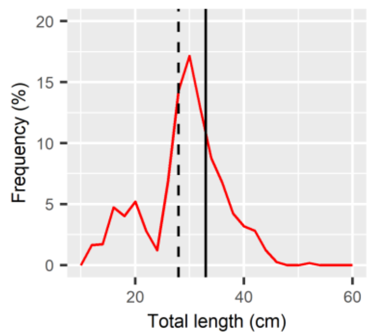
Relative size structures of observed catches by total length (TL) of BSFH (retains + discards) differed among spatial groupings, with the mean and modal size class of catches from the South zone (mean 36.91 ± 0.20 cm TL, mode 32 cm TL) greater than the Central (mean 33.57 ± 0.16 cm, TL, mode 29 cm TL) and North zones (mean 30.07 ± 0.06 cm, TL, mode 28 cm TL). When size composition data was expressed relative to the MLL, the proportion of BSFH exceeding this threshold declined from 72.18% in the South zone to 53.9 % and 27.3 % in the Central and North zones, respectively (Figure 23).

Figure 23 Relative size-structure of retained (Ret) and discarded (Dis) catches of Bluespotted Flathead within the North, Central and South zones. Also indicated is the current minimum legal length (MLL, vertical line).



Observed catches by total length (TL) of TFH in the South zone were dominated by sublegal sized individuals with the mean (28.67 ± 0.05 cm TL) and modal size class (29 cm TL) of observed catches lower than the current MLL (33 cm TL). When size composition data was expressed relative to the NSW MLL, 72.6% of the catch was below this threshold (Figure 24). However, ~65% of the observed catch exceeded the size-limit applied to Commonwealth managed fisheries (28 cm TL).

Figure 24 Relative size-structure of discarded catches of Tiger Flathead within the South zone. Also indicated is the current minimum legal length (MLL) in NSW (vertical solid line) and Commonwealth jurisdictions (vertical dashed line).



Estimates of total annual retained and discarded catches

Table 6 gives biannual estimates of fishery total landed numbers (i.e., including discards and retains), percent discards, and average weight of retains and discards per animal from the observer survey and by quota species for Region 1 (North + Central) and Region 2 (South). Discarded catches of ESW in Region 1 (4,427,883 individuals (IND) ~254.4 t) and Region 2 (2,558,678 IND ~61.4 t) were greater than all other quota species. However, the proportion of the total catch discarded in Region 1 (34.1%) was lower than Region 2 (69.1%) with the average weight of both retains (0.048 kg) and discards (0.024 kg) in Region 2 being less than discards in Region 1 (0.057 kg). Estimated discards (989,068 IND ~44.5 t) and the proportion of the total catch of SW discarded in Region 1 (36.3%) were greater than both estimated discards (12,698 IND ~0.2 t) and the proportion of the total catch discarded in Region 2 (6.3%). Similar to ESW, the mean weight of both retained

(0.048 kg) and discarded (0.024 kg) SW in the Region 2 was less than Region 1 (Table 6). Despite regulations preventing fishers from retaining BSFH and TFH in Region 2, estimated discards of BSFH (63,500 IND ~20.0 t) were lower than Region 1 (329,216 IND ~62.2 t). In contrast, estimated discards of TFH in Region 2 (216,037 IND ~54.7 t) were higher than Region 1 (6,679 IND ~1.0 t).

Table 6 Biannual estimates of fishery total landed numbers (i.e., including discards and retains), percent discards, and average weight of retains and discards per species.

Common name	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Region 1				
Eastern School Whiting	12874369	34.4	0.072	0.057
Stout Whiting	2724704	36.3	0.067	0.045
Bluespotted Flathead	483430	68.1	0.370	0.189
Tiger Flathead	8066	82.8	0.373	0.148
Region 2				
Eastern School Whiting	3702862	69.1	0.048	0.024
Stout Whiting	201559	6.3	0.047	0.015
Bluespotted Flathead	63500	100.0*	0.000	0.315
Tiger Flathead	216037	100.0*	0.000	0.253

*100% discarded because of regulation prohibiting the harvest of BSFH and TFH.

Biannual estimates of fishery total landed numbers (i.e., including discards and retains), percent discards, and average weight of retains and discards per animal for commercial; finfish, crustaceans, molluscs, elasmobranchs and combined non-commercial species for each group for Regions 1 and 2 are shown in Tables 10–17 of Appendix 1. Species of both commercial and recreational importance including Ocean Jacket (*Nelusetta ayraudi*), Yellowtail Scad, Blue Mackerel (*Scomber australasicus*) and Redfish (*Centroberyx affinis*) were estimated to be caught in greater numbers than less frequently observed species such as John Dory (*Zeus faber*), Largehead Hairtail (*Trichiurus lepturus*), Mulloway (*Argyrosomus japonicus*), Snapper (*Chrysophrys auratus*), Tailor (*Pomatomus saltatrix*) and Teraglin (*Atractoscion aequidens*). Mean catch rates (no per-trip^{-1}) for Blue Mackerel, John Dory, Mulloway, Largehead Hairtail, Snapper, Tailor and Teraglin are shown in Appendix 10.

Catches of Eastern Rock Lobster

Low numbers of Eastern Rock Lobsters were observed to be caught during this study. A total of 112 Eastern Rock Lobsters were caught from 23 trips (i.e., 5.3% occurrence) ranging in depth from 48–132 m. The catch varied between the zones, with 60, 48 and 4 Eastern Rock Lobsters caught from the South, Central and North zones, respectively. The numbers of trips observed to catch Eastern Rock Lobsters varied between zones, ranging from 19 in the South to 1 in the North. Observed catches in the Central zone included a single large catch of 40 Eastern Rock Lobsters.

On-board handling practices and fishing gear used

Catch sorting techniques

No vessels observed during the study were fitted with mechanical catch-sorting hoppers. All but one vessel, spilled the entire catch onto a sorting table and manually sorted the catch into retained and discarded components and, either immediately released discards, or batched discards and offal for release when steaming to reduce potential wildlife interactions. A single vessel was observed to spill the catch into a 400 l tank filled with sea water and use sieved scoops to remove and sort prawns from bycatch. The number of crew (range: 1–3) and time spent sorting individual catches (range: 0.5–1.5 h) was variable and influenced by many factors including, but not limited to: volume of catch, target species, dominant bycatch species, vessel capacity, crew competency and sea state. Crews were regularly observed to release sharks and rays as quickly as possible using non-destructive means to maximise post-release survival.

Description of vessels

Specifications of observed vessels are presented in Appendix 11. The relationship between trawl vessel length (m), engine capacity (kW) and total headline length (m) were generally consistent for observed and non-observed OTF vessels (Appendix 11).

Wildlife mitigation, abundance, and interaction

Wildlife mitigation measures

During the study, vessels were routinely observed to store offal and discarded “trash fish” while setting, towing and retrieving fishing gear and dump while steaming to avoid and, or lessen, the risk of wildlife interactions.

Wildlife abundance

Over the duration of the study, 12 taxa of seabirds and 5 marine mammal species were identified within the observation area around the fishing vessels, with a total of 45,658 seabirds and marine mammals counted or estimated from extrapolated counts during 1048 observations (Table 7, Appendix 12). At least one individual of three seabird species/ family groups including; Shearwaters (*Puffinus carneipes*, *P. pacificus*, *P. tenuirostris*), Silver Gull (*Chroicocephalus novaehollandiae*) and Crested Tern (*Thalasseus bergi*) were regularly observed (>50% occurrence) around trawlers (Figure 25). The most abundant species group was Shearwaters (Table 7), representing 47.3% and 45.0% of all seabirds observed in year-1 and year-2, respectively. However, the composition of observed wildlife and abundance of individual species varied among zones and years. For example, in the North zone, 88% of total seabirds observed were Silver Gulls or Crested Terns, while in the Central and South zones, 53–86% of the seabirds observed were Shearwaters. Low numbers of Albatrosses (Aves; Diomedeidae) were observed for all zone/period groupings (Table 7, Appendix 12).

The mean number and the frequency of occurrence of the most abundant group overall, Shearwaters, were generally highest in the South zone in the first year of the study, with means (± SE) ranging between 100.3 ± 88.2 and 116.9 ± 54.9 per observation during P1 and P2, respectively (Figure 25). Strong temporal disparities were apparent within the Shearwater group with the mean number of individuals observed during spring (P1 and P5) and winter (P4 and P8) lower than summer (P2 and P6) and autumn (P3 and P7) for all zones during both year-1 and year-2 of the survey.

Strong spatial disparities were apparent for Crested Tern, with mean numbers (± SE) observed in the North zone (7.2 ± 1.9 (P5) to 19.8 ± 3.6 (P2)) higher that the Central and South zones for all sample periods during year-1, and P5 – P7 during year-2 of the survey (Figure 25). There were no clear seasonal patterns in abundance in the North, with the mean number of birds counted per observation similar across all sample periods.

Silver Gulls were frequently observed during wildlife observation periods in the North and Central zones (Figure 25). Strong temporal disparities were apparent, with mean numbers (± SE) observed during autumn and winter in the North (31.3 ± 3.0 (P4) – 63.5 ± 5.8 (P8)), Central (20.0 ± 2.5 (P4) – 70.8 ± 8.1 (P8)) and South zones (20.9 ± 2.0 (P4) – 47.4 ± 5.9 (P7)) generally higher than spring and summer during both year-1 and year-2 of the survey (Figure 25).

Mean total number (± SE) of the most abundant mammals observed around trawlers, Common Dolphin (*Delphinus delphis*) were highest in the North zone during year-1 (3.5 ± 0.5 (P1) to 13.9 ± 1.3 (P4)) and year-2 (7.4 ± 0.7 (P6) to 11.9 ± 0.6 (P5)) of the survey. Extremely lower numbers of Common Dolphins were observed around trawlers in the South zone, with 56 and 19 individuals counted from 108 and 124 wildlife observation periods during year-1 and year-2 of the survey, respectively. Eared Seals (Otariidae – undifferentiated) were infrequently observed in all zones, with a total of 9 individuals counted within the observation area around fishing vessels during 5 observations (~0.5% occurrence).

The behaviour of seabirds attending trawlers varied between species, zones and for observations made while setting and hauling gear (Figure 26). For example, in the Central and South zones, Shearwaters were regularly observed roaming widely or being totally disinterested in fishing operations while setting gear, and intensively or irregularly searching for food while hauling gear. In contrast, in the North, the observed behaviour of Shearwaters was generally similar for observation periods made while setting and hauling gear. Similarly, the observed behaviour of Silver Gulls and Crested Terns varied between zones and observed activities. Silver Gulls were most frequently observed intensively or irregularly searching for food in the North and South zones, respectively. Similarly, the proportion of Silver Gulls, roaming widely or observed to be total disinterested in fishing operations while setting gear was greater in the Central and South zones (Figure 26). For observation periods made while hauling gear, Crested Terns were most frequently observed irregularly searching for food in the Central and South zones, and intensively searching for food in the North.

Figure 25 Mean number (± SE) of Shearwaters, Silver Gulls and Crested Terns per observation period while setting and hauling gear in the North, Central, and South zones for each sample period.

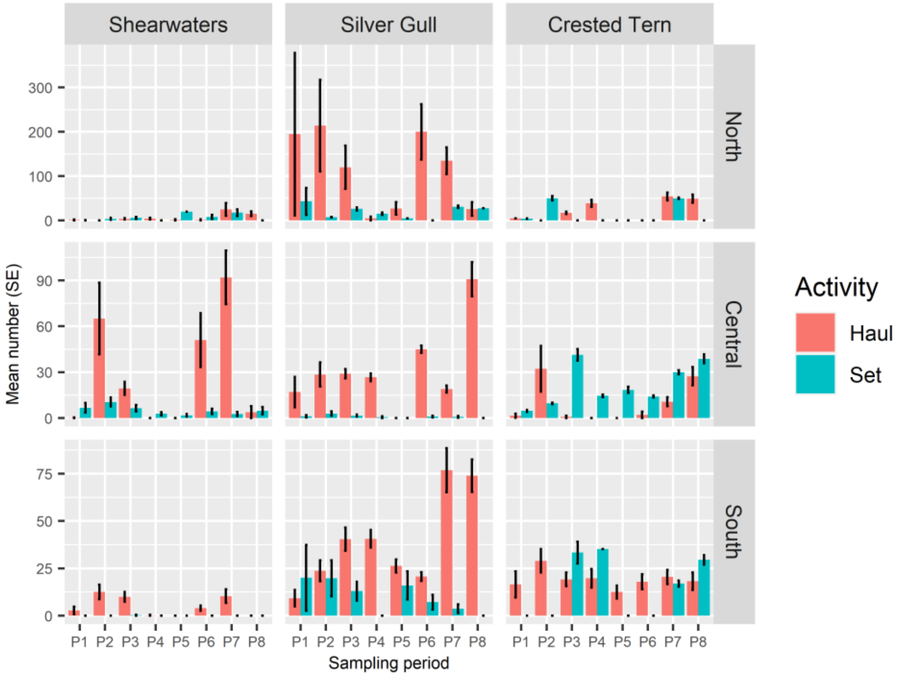
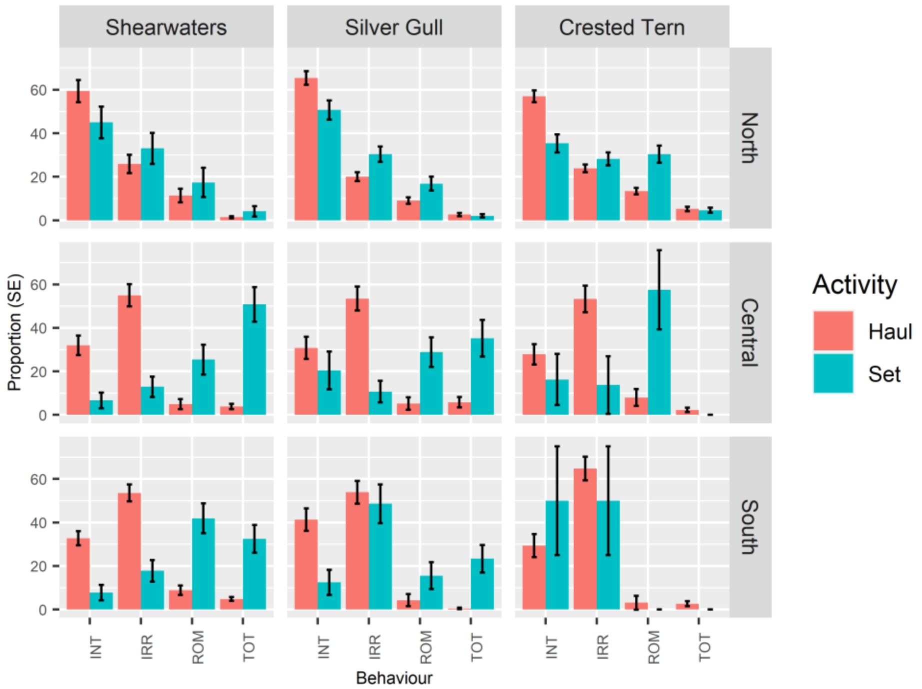


Figure 26 Mean proportion (± SE) of behaviour engaged in each of four activity categories; intensively searching (INT), irregularly searching (IRR), roaming widely (ROM) and totally disinterested (TOT) for Shearwaters, Silver Gulls and Crested Terns. Data are pooled across spatial and temporal groupings.



In the case of each of the species presented above, patterns in abundance and observed behaviour may be impacted by the timing of observation (i.e., sun set, sun rise), discarding practices, and the order that fishing activities were observed. For wildlife abundance, counts made while setting gear immediately after hauling gear, may have influenced the behaviour of birds because of scavenging opportunities created while hauling gear.

Interactions with threatened, protected, and endangered species

During the study, 133 syngnathids were observed to be caught from 31 trawl shots (~2.2% of total shots) on 19 fishing trips (~4.4% of total trips, Appendix 12). Observed catches in the Central zone were greater than the North zone with totals of 103 and 30 individuals caught, respectively. No syngnathids were observed to be caught in the South zone. Catches of sygnathids included 93 Bentstick Pipefish (*Trachyrhamphus bicoarctatus*), 10 Common Seadragon (*Phyllopteryx taeniolatus*) and 30 undifferentiated seahorses and Pipefishes (Syngnathidae – undifferentiated). The total number of syngnathids estimated to be caught by the OPTS fleet over the two-year duration of the survey was ~4,750 individuals (see Appendix 1.5 for full details). The fate of discarded syngnathids is unknown.

A total of one Grey Nurse Shark (*Carcharias taurus*) and one Sandtiger Shark (*Odontaspis ferox*) were caught during observed fishing days, each recorded during separate fisher days within the Central zone. Both individuals were highly active upon gear retrieval, had no external wounds, skin damage or bruising, were not bleeding, and were observed to vigorously swim away from the vessel when immediately released following capture.

Table 7 Number of wildlife observation events (Obs.), total number of individuals (n) and frequency of occurrence (%) of total seabirds, Albatrosses, Shearwaters, Silver Gulls, Crested Terns and Dolphins observed during wildlife abundance counts in year-1 and year-2 of the survey.

Zone	Obs.	Total Sea birds		Albatrosses		Shearwaters		Silver Gulls		Crested Terns		Dolphins	
	n	n	%	n	%	n	%	n	%	n	%	n	%
North	263	8396	65.0	2	0.4	1029	19.0	3742	45.2	3558	50.6	276	14.1
Central	96	2586	63.5	6	1.0	1369	39.6	808	34.4	403	17.7	59	19.8
South	108	7309	63.9	8	4.6	6261	48.1	867	27.8	173	12.0	56	14.8
year-1	467	18291	64.5	16	1.5	8659	30.0	5417	39.0	4134	34.9	391	15.5
North	336	8587	50.3	87	3.3	770	7.7	4040	28.3	3540	31.3	1009	39.8
Central	121	6610	54.5	0	0.0	3960	32.2	1685	27.3	965	22.3	37	9.1
South	124	7797	50.8	1	0.8	5607	33.9	1336	24.2	853	16.1	19	11.3
year-2	581	22994	51.3	88	2.1	10337	18.4	7061	27.2	5358	26.2	1065	26.9

Discussion

Description of retained and discarded catches

Estimates of catches

Quantifying the magnitude and composition of discarded catches in the OPTS of the OTF is fundamental to examining the impact of management regulations designed to limit fishing mortality and is necessary to facilitate the assessment of the impact of bycatch on both target and non-target species, and the broader marine ecosystem. On average, 32% of the total catch taken by trawlers in the OPTS was observed to be retained (retained: discard ratio of 1:2.1 kg). When compared to the 1990–92 survey, the observed discard rate in North zone (2.0:1 kg) was lower than both Ballina (5.1:1 kg) and Yamba/Iluka (3.2:1 kg) fleets sampled within the North zone (Kennelly and Borges, 2018, Kennelly et al., 1998). Observed mean discarded catch (kg/boat day^{-1}) from the North zone (435.3 kg) is similar to estimates for the shallow (462.7 kg) and deep-water (392.8 kg) sectors of the Qld ECOTF (Wang, et al., 2020), but is lower than mean discarded catches from Ballina (795.0 kg) and Yamba/Iluka (581.1 kg) fleets in the 1990–92 survey (Kennelly and Borges, 2018, Kennelly et al., 1998). Under the assumption that the actual reduction in discards following the implementation of BRDs is equivalent to that estimated from experimental work, Kennelly (2018) estimated a ~30% reduction in discards from the OPTS. Observed reductions in the North zone appear to be equivalent to those predicted by Kennelly (2018). However, observed discard rate (2.6:1) and mean discarded catch (637.8 kg) from the Central zone were greater than both the discard rate (1.6:1) and mean discarded catch (383.5 kg) previously reported for OPTS vessels departing from Coffs Harbour (Kennelly et al., 1998, Kennelly, 2018). For the South zone, estimates of both discard rate (1.9:1) and mean discarded catches (245.8 kg) from the 1990–92 survey (Kennelly and Borges, 2018, Kennelly et al., 1998) were similar to both discard rate (2.0:1) and mean discarded catch (287.4 kg) from the current study. The latter results indicate that some of the predicted reductions in discards following the implementation of BRDs may have been offset by a number of factors, including, but not limited to increases in the fishing capacity of OTF vessels. Therefore, the observed reductions in bycatch in the North zone may be the direct results of long-term changes in the structure of populations being fished, and reductions in abundance of major bycatch species on trawl grounds. However, the results of a trawl survey examining the diversity and abundance of non-target species across a network of areas closed to trawling relative to adjacent areas that were open to trawling in the OTF identified inconsistent impacts for different non-target species (Taylor et al., 2020).

A basic 25-year comparison based on catch to bycatch ratios suggests the contemporary OPTS generally has a lower discarding footprint. The ratio of overall bycatch to EKP harvest in the present study (5.8:1) is lower than historical estimate of 10.4:1 (Kennelly et al., 1998). Reductions in the proportion of the total catch discarded from the current survey can be attributed to the observed increase in the proportion of the main target and byproduct species retained. For example, the proportion of the catch of ESW discarded from the North (60.8%) and South (95.6%) zones in the 1990–92 survey (Kennelly et al., 1998) was greater than discard rates of 34.4% and 69.1% in the current survey from the North and South zones, respectively. Similarly, for SW, discard rates in the North (36.3%) and South (6.3%) in the current survey were lower than reported discard rates in the North (93.1%) and South (100%) in the 1990–92 survey. For abundant byproduct species including, Cuttlefishes and Bugs discard rates in the current survey were considerably lower than the 1990–92 survey (see Appendix 13 for comparison). For all species where rates of discarding can be directly compared between the previous and current observer-based surveys of the OPTS, only eight species were observed to discarded at higher rates in the current study. However, only one of the eight species (John Dory) for which discard rates are unlikely to be impacted by management changes (i.e., size limits, possession limits) were observed to be discarded at higher rates in both zones. The reduction in the proportion of target and byproduct species discarded may be due to a combination of factors, including but not limited to: 1) increased market price for a number of byproduct species, 2) changing consumer trends resulting in the utilisation of species historically discarded, and 3) the development of export markets and processing of trawl whiting species and improvements in gear that optimises the catch of economically desirable size classes of the target/byproduct species. Additional analyses comparing the size-structure of catches of target species between the 1990–92 and current survey should be completed to investigate the latter.

Current management regulations in the OPTS prohibit the take of BSFH and TFH south of Smoky Cape. Our results estimate that 63,500 BSFH and 216,037 TFH were discarded over the two-year period observed. The weighted size-structure of catches in the South zone indicate that ~70% of BSFH and ~30% of TFH caught were greater than the current MLL (33 cm TL) applied to OPTS vessels operating north of Smoky Cape and other commercial and recreational fisheries operating within NSW waters. Discarded catches of both species need to be accounted for in assessments in order to avoid bias in estimates of fishing mortality, stock biomass and reference points (Cook, 2019, Fernandez et al., 2010, Punt et al., 2006). Allowing fishers to retain legal-sized individuals, may facilitate ongoing monitoring of landed catches and allow inclusion in stock assessments. However, if individual OTF businesses operating in the South zone don't hold sufficient quota allocations to cover all incidental catches, reported landings may only represent a component of total fishing mortality on legal-sized individuals. Therefore, more frequent observation-based monitoring of catches may be required to inform future stock assessments of all species targeted or taken as bycatch in the OPTS.

The ratio of discards to retained catches in the OPTS (2.1:1 kg) is similar to the Qld ECOTF (2.3:1 kg, Wang et al., 2020) and the weighted-average discard rate estimated for tropical penaeid trawls globally (67.8% ~2.1:1 kg; Kelleher 2005). Observed discarded catches in the OPTS comprised a combination of unmarketable species with limited or no commercial value (e.g., Cocky Gurnard and Longspine Flathead) that are a bycatch of the fishery targeted at more valuable species and are discarded 100% of the time; target species discarded because of current size limits and possession limits (e.g., BSFH and TFH), and several species, including the quota-managed whiting species that were observed to be retained and discarded at the discretion of the fisher with behaviour influenced by market price and processing capability (e.g., on-board freezing capacity). In the present study the discarded portion of observed catches comprised 382 species including crustaceans (n = 42), echinoderms (n = 5), elasmobranchs (n = 44), molluscs (n = 24), teleosts (n = 264) and sponges (n = 1). By comparison, the previous observer survey of the OPTS (Kennelly et al., 1998), identified 84 bycatch species. Of the bycatch species reported in Kennelly et al., (1998), only Long-snouted Boarfish (*Pentaceropsis recurvirostris*), Giant Boarfish (*Paristiopterus labiosus*), Spotted Trevalla (*Seriolella punctata*), Australian Bonito (*Sarda australis*), Silver Dory (*Cyttus australis*), Barking Cray (*Linuparus trigonus*) and Ornate Rock Lobster (*Panulirus ornatus*) were not observed to be caught in the present study. The most likely explanations for the observed differences are: 1) differences in catch-sampling strategy between surveys; 2) changes in areas of operation of the OPTS; 3) long-term changes in the structure of populations being fished, and 4) differences in the configurations of gear sampled in the previous and current survey.

Prior to implementation of the current survey a dedicated pilot study to provide a quantitative basis to support sampling and sorting methodology for penaeid-trawl catches in NSW as well quantifying the implications of subsampling on the confidence in estimates of diversity or abundance was completed (Silburn et al., 2020). Specifically, this work identified that sorting of 12%, 35%, 84% and 100% of the catch biomass would be required to detect 50%, 75%, 95% and 99% of the species richness. With careful consideration of program objectives, available resources and to minimise the impacts of catch sampling by observers on normal fishing operations, the decision was made to sample at least 30% of the total discarded catch from observed shots in the current survey (mean sample fraction 36.4%). While, Kennelly *et al*., (1998) reported that the majority of bycatch organisms were identified to the species level, identified species appear to be restricted to byproduct species, with none of the bycatch species (i.e., discarded 100% of the time) observed within the current study reported in the previous observer survey.

With the development of improved navigation equipment (Global position systems, chart plotters), increased fishing power (vessel size and engine horsepower) and more efficient trawl systems (i.e., lower drag netting) the areas of operation of the OPTS has expanded from inshore coastal waters (<50 m deep) out to the continental shelf (200 m) over the last 20 years. Therefore, the increased diversity of species reported in the present study may be due to the increased proportion of trawls observed in deeper water (>60 m). Previous studies examining the bycatch composition of penaeid trawl fisheries across various spatial and temporal scales have reported significant spatial variation in the composition of catches (Dell et al., 2009). Differences in depth, seabed characteristics, commercial effort and prawn catch have been shown to influence bycatch composition and abundance of individual species (Rainer and Munro, 1982, Stobutzki et al., 2001, Watson et al., 1990).

Interactions with other important species

Excluding commercial and recreationally important species such as BSFH, TFH, Ocean Jacket, Yellowtail Scad and Blue Mackerel (Murphy et al., 2020, NSW DPI 2007), bycatch in the OPTS is dominated by non-commercial bycatch species and commercially important species predominately harvested by the OTF (e.g., Slender Founder (*Pseudorhombus tenuirastrum*), Soles (Soleidae – undifferentiated, Cynoglossidae – undifferentiated), Goatfishes (*Upeneichthys lineatus*, *U. moluccensis*), Lemon Tongue Sole (*Paraplagusia bilineata*)). Commercial and recreationally important species, including Snapper, Tailor, Mulloway and Teraglin were less frequently caught. Discarded catches of commercially important species harvested in the OTFN and adjacent SESSF included John Dory and Redfish. The South Eastern Australian biological stock of Redfish has been assessed as depleted since 1992 (Punt et al., 2006) and is currently managed under the Commonwealth Redfish stock rebuilding strategy 2016–21 (AFMA, 2016). However, the magnitude of total estimated catches of Redfish in the OPTS is unlikely to be significantly impacting the recovery of Redfish populations given the stocks broad spatial range (Morison et al., 2013).

Direct comparisons of the estimated total catches between the current and previous (Kennelly et al., 1998) observer-based surveys of the OPTS are limited by differences in the methodology used to extrapolate observed catches to fleet-wide estimates and catch-sampling strategies used. To improve the precision of fleet-wide estimates of catches, analyses within the current study compared two alternative estimators of total discards, a "direct" versus an "uncoupled" estimator giving mostly similar precisions but with the "uncoupled" estimator consistently more precise (Appendix 1). The main objective of this was to determine the variance of each of these estimates (and their coefficient of variation). The comprehensive method of accounting for all major sources of variation and developing an efficient estimator of fishery-wide discard number during the current study was only possible because of the detailed observations made, which included estimating the sample fraction of the shot weight counted and counting as well as weighing all observed discards and retains by species. Any future observer-based surveys of the OPTS should employ a similar catch-sampling strategy and use the comprehensive estimator of fishery-wide discards developed within the current study to allow temporal comparisons of estimates of discards.

Discard drivers

The trawling location in NSW waters significantly affected the numbers of organisms discarded for all species groups tested (Barnes et al., 2022). Spatial variation in discarding has been reported previously in the OPTS (Kennelly et al., 1998) and similarly by research on other demersal trawl fisheries (e.g., Feekings et al., 2012). The relationship between the discarding of fish and latitude is simple, partly due to the lack of interaction with longitude, and shows a north to south negative gradient. It is feasible that the relationship could be underpinned by the increase in fish species richness and abundance in a northerly direction due to the increase in water temperature and habitat diversity (Hall and Mainprize, 2005, Tsagarakis et al., 2014). The finding is supported by the North zone in the present study recording 33 more species than the South zone (see Barnes et al., 2022) and the Qld ECOTF discarding more fish on a lower latitude section of the same coastline (Kennelly, 2020). Latitude and longitude interacted to affect the discarding of all other species groups (elasmobranchs, crustaceans, fish, commercial crustaceans and commercial fish). The location effect was mainly different but there was a rough pattern of more consistent discarding of elasmobranchs and crustaceans whereas the commercial species groups were discarded in areas (herein hotspots). Elasmobranch diversity is generally greatest nearshore as diversity is bolstered by offshore species using nearshore areas as nurseries (White et al., 2004). As mentioned above, commercial species (crustaceans and fish) were discarded in location hotspots, a location effect was also reported by Kennelly et al. (1998). Previously, Kennelly et al. (1998) reported a negative north to south gradient of commercial species discarding based on observer sampling out of four ports separated by latitude (28.8628 – 32.7685°). The north to south commercial species discarding gradient isn't represented by the spatial analysis in the present study, although the species richness reported here does follow the latitudinal gradient (see Barnes et al., 2022). The lack of similarity in the spatial effect of discarding of commercial species could be for at least two reasons. First, marketability of species has changed over the last few decades with many more species now in demand, which has changed discarded bycatch communities (as discussed in estimates of catches). Second, there have been numerous Marine Protected Area (MPAs) implemented between studies (e.g., Solitary Islands Marine Park) meaning some grounds that were fished previously (e.g., Kennelly et al., 1998) were not in the present study and the punctuation of trawling grounds by MPAs has created the hotspots. The effect of discarding commercial species is complex because both fisheries and the underlying marine ecosystem could be negatively affected by such discarding (Broadhurst, 2000). As such, more research is warranted to determine the impact of the OPTS on elasmobranchs and commercial species and is discussed in more detail below (see Future research priorities).

Time drivers, (year and season), including a season depth interaction, were found to significantly affect the discarding of certain species groups. Time and depth drivers have been found to influence discarding in other model-based studies (see Tsagarakis et al., 2014). The effect of year on decreasing commercial fish discarding coincides with falling EKP catches (Helidoniotis et al., 2020). Fish were more likely to be discarded in summer, likely due to warm currents in the OPTS extent facilitating relatively rich and abundant fish fauna (Kennelly et al., 1998). Previous research has described an increase in assemblages and abundance of fish in coastal NSW in summer due to the timing of recruitment (Curley et al., 2013) and overlap of tropical and temperate species (Booth et al., 2007). Although, another important consideration is market forces (and other socioeconomic factors) on the fisher's decision making with a large summer coastal population in NSW increasing demand for seafood and EKPs fetching a premium price at times of high local demand such as Christmas. Approximately, 130 tonnes of NSW prawns were to be sold between 21–23 of December 2019 making prawns the third most popular Christmas seafood item (Heather, 2019).

A positive retained catch weight and discarding relationship was identified by the present study for all species groups, except elasmobranchs. A relationship of this nature has been described multiple times in the literature (Feekings et al., 2012, Murawski, 1996, Tsagarakis et al., 2014). There are some plausible theories describing why there might be such a relationship. Large catches may cause the gear to lose selectivity either by blocking of the codend or a mechanical reduction of the mesh when the gear is under increased load (Stergiou et al., 1998, Tsagarakis et al., 2014). However, the loss of selectivity would more likely be a logarithmic relationship (Tsagarakis et al., 2014) (rather than the observed linearity), although, it is possible that there is a counter force from increased net drag with increasing load causing a reduction in spread and therefore, net sweep. Also, trawls with BRDs such as the square mesh panel in the OPTS are unlikely to become blocked, at least by smaller bodied organisms. More of the catch, particularly fragile species such as some small commercial fish (e.g., ESW, SW), can become damaged in a heavily laden net and thus lead to increased discarding, also, larger catches may increase economic discarding to avoid oversupply (Tsagarakis et al., 2014). Further, small vessels are limited in what they can hold (Hall et al., 2000) and intuition suggests large catches may mean a generally more productive fishing ground. The range of theories suggests it is hard to determine an exact cause; a fishery-independent research program could provide some answers, by removing the socioeconomic component (Murawski, 1996). It is possible that large amounts of rays and other dorso-ventrally flattened species could block the net (despite square mesh BRDs) and crush the commercial taxa, leading to increased discarding; therefore, avoiding areas where rays are abundant could be worthwhile. However, our data suggests a weak relationship at best (see Barnes et al., 2022) although blocking of the net may be caused by a range of ventrally flat organisms.

Operational drivers trawl speed and engine capacity (track complexity not discussed see Barnes at al., (2022) for more) mainly influenced the discarding of commercial species groups. These type of drivers have seen little attention in the literature but Macbeth et al. (2012) tested the effect of trawl speed on discarding and others have expressed the research need (e.g., Hall, 1999). Increasing trawl speed and engine capacity generally had a negative relationship with discarding for the relevant species groups. The negative relationship is the opposite to what was expected. The expected result was that increasing speed would increase discarding because of greater interactions with organisms. For example, our hypothesis was a faster moving net would capture more but our discard models do not substantially support this hypothesis. A greater number of fish, including under MLL fish, are likely captured in faster moving gear as it becomes increasingly difficult to avoid (Itaya et al., 2007). Increasing trawl speed has been shown to increase the width of the trawl net in penaeid (Sterling, 2005) and other demersal trawl fisheries (e.g., Weinberg and Kotwicki, 2008) but any effect on discarding is not clear in the present study. Faster and larger trawls sometimes catch pelagic sharks (Campbell et al., 2020).

Engine capacity has a positive linear relationship with vessel size (Appendix 12) and larger boats have been shown to engage in less discarding in some fisheries (Feekings et al., 2012, Murawski, 1996). The function of storage capacity leading to less discarding (Feekings et al., 2012) wasn't normally the case in the present study (i.e., only commercial crustaceans showed a relationship) and is suggestive of multiple variables driving discarding. Larger more powerful vessels have been successful in trawling a broader range of grounds in other demersal trawl fisheries (Sink et al., 2012) and in a variety of weather conditions meaning discarding likely varies between trips. Trawl speed and engine capacity do not provide obvious mitigation options because some momentum is required for the net to function; however, in the OPTS vessels had a maximum of 400 kW engine capacity until 2018 when this restriction was removed.

The null hypothesis of no relationship between numbers of fish and all species groups discarded and weight of total catch (hypotheses 2) was rejected; however, the relationship was relatively weak. Near linear positive relationships of catch weight on discarding of fish has been reported previously (Feekings et al., 2012). Further evidence is provided by the fish discarding model from hypothesis 1 which did display a positive linear relationship with mean retained catch weight. However, this relationship considers the other drivers (i.e., significant environmental factors). The similarities between the model results (see Figures 13 and 17) highlight the substantial contribution of fish to the overall volume of discarding. The theories on the relationship, such as large catches leading to more discarding because of changes in net functionality and damage to sensitive taxa due to a large volume in the net (see hypothesis 1 above), suggest that this is not a simple function. However, the discard-to-retained catch ratio is the most used statistic to determine fishery-wide discarding from logbook data in unmonitored fisheries (Kennelly, 2020, Wang et al., 2020). While it initially appears this extrapolation would be reasonable in the OPTS, our further inspection of the relationship, suggests it is not a simple scale up to the fishery-wide level and may cause incorrect decision making. The lack of a strong relationship highlights the need to test each fishery, preferably, with observer (or other high quality) discard data collection programs.

Size-structure of retained and discarded catches

To reduce the likelihood of recruitment overfishing occurring (reduced egg production) and to maximise value of the catch, management actions including gear specifications that restrict the circumference of codends, define minimum mesh sizes and make recommendations regarding the orientation of meshes are often introduced to closely regulate selection in penaeid trawls (Broadhurst et al., 2006). The most commonly observed codend configuration comprised 41-mm diamond-shaped mesh attached to an anterior extension section at a ratio of 150 to 100 meshes (see Broadhurst et al., 2006). For the North zone, ~95% or more of the EKP captured exceeded L_{YPR} and >35% were caught at a size greater than the estimated L_{50}. In contrast, for the South zone, approximately 50% and <2% of EKP captured exceeded the L_{YPR} and L_{50}, respectively. However, given the small proportion of fishery landings taken in the South zone (~90 tonnes per year 2014/15 – 2019/20, 9.9 – 19.1% of total reported EKP landings), ~79.6 – 87.6 % of the total observed catch of EKP from the OPTS exceeded L_{YPR}. The most recent stock assessment of the Qld/NSW stock estimated the 2019 spawning biomass was 62% of the unfished level suggesting the stock is sustainable (Helidoniotis et al., 2020). Based on these findings, the capture of EKP below the optimum size of first capture in the South zone is currently not severely impacting the biological stock. It is important to point out that the L_{YPR} estimate used in this study (adapted from Taylor et al., 2021) was calculated from recent yield-per-recruit analyses for EKP (Courtney et al., 2014).

In contrast to Taylor et al. (2021), who reported negligible catches of EKP exceeding L_{50} within existing trawl closures and adjacent areas, ~34% of the observed catch of EKP from the combined North and Central zones exceeded L_{50} in year-1, and 29% exceeded L_{50} in year-2 of the survey. The observed size-structure of catches and low discard rates suggest that fishers predominately target trawl grounds known to support populations of larger more valuable EKP. However, targeting larger prawns in the known spawning grounds off northern NSW (Montgomery et al., 2007) likely impacts larval dispersal southward in the East Australian Current (Everett et al., 2017) and the level of recruitment into estuarine nurseries in the central and southern areas of NSW (Taylor et al., 2017). In NSW, EKP emigrate from estuarine nurseries into the inshore zone (<30 m depth), where they rapidly grow (Racek, 1959) before migrating northward (Taylor et al., 2021, Taylor and Johnson, 2020).

Stock assessment for the Qld/NSW stock of EKP utilises a length-based population dynamics model, with six spatially stratified zones across NSW and Queensland (Helidoniotis et al., 2020). Length frequency data collected during the current study should be used to quantify regional and monthly changes in EKP size to estimate prawn length selectivity of the NSW fleet to inform future stock assessments. To ensure future observer-based surveys of the OPTS accurately quantify the size-structure of populations fished, data collected during our study should be used to evaluate the effects of sample size on the quality of length composition data to improve observation efficiency (Candy et al., 2014, Wang et al., 2020). Effective sample sizes should be included in the consideration for a rational allocation of observation effort in future surveys.

Despite previous research, reporting codends constructed according to current regulations were non-selective for species, including SW (Broadhurst et al., 2006), throughout the duration of the current study; a substantial proportion of the estimated discards of both ESW and SW were larger than the estimated L_{50} (Gray et al., 2014). However, the size-structure of observed catches from our study is greater than those reported from a multi-year fishery-independent survey across the normal depth ranges of both ESW and SW (Gray et al., 2014). The observed differences in the size-structure of catches may be attributed to inter-vessel variability. Previously, Macbeth et al. (2012) reported considerable variability among vessels with respect to the relative differences in cumulative total catches of target-size whiting between codend types. A range of gear and operational factors, including headline length of trawls and towing speed were identified as possible causes. Vessels observed during the current study were rigged with standard regulated 'triple' gear, in which each of the three nets had a headline length ranging from 11.0 m to 18.3 m (Appendix 11). The mean headline length of trawls observed (~15.1 m) is greater than used by Gray et al. (2014) (10.8 m), but is similar to the mean headline length of trawls used by Taylor et al. (2021) (~13.8 m), who also reported catching SW at a noticeably larger size than Gray et al. (2014). Based on these findings, the comprehensive method of accounting for all major sources of variation and developing an efficient estimator of fishery-wide discard number developed during the current study, may need to be extended to further incorporate variability among vessels where possible. The design of any future fishery-independent surveys to estimate relative abundance or demographics of key species needs to consider the impact of gear specifications on catches.

Representativeness of sampling

Fisheries observer programs require appropriate stratification and replication and can be challenging to execute in a robust manner (Faunce and Barbeaux, 2011, Liggins et al., 1997). The level of observer coverage (fisher days) achieved within the current study (North; 4.2%, South; 3.2%) is greater than the proportion of effort observed from the four ports (~1.5%) and entire OPTS (~0.7%) between 1990–1992 (Kennelly et al., 1998). This is a direct result of a combination of increased sampling intensity between the previous (367 trips) and current (435) surveys, and large declines in reported effort in the OPTS. During the two years surveyed in Kennelly et al. (1998), the effort reported from the four ports sampled (24,961 trips) and the entire OPTS (49,561) is greater than total effort reported from the North (8,639 trips) and South (2,174 trips) zones in the current survey. Total reported effort from the OPTS during the current study (10,813 trips) represents approximately 22% of the total effort reported between 1990–1992. Using a hypothetical two-factor matrix to assign available observer sampling effort (~227 trip per year) across the three zones and four seasons sampled proportional to reported effort within the current study ensured sampling was more representative of fishing activity than simply observing a fixed number of trips across all seasons and strata as done in Kennelly et al. (1998). For example, during the 1990–92 survey, Kennelly et al. (1998) observed 93 fishing trips from a total of 15,307 fishing trips reported from the Clarence River (~0.6%), while during the current study, 206 fishing trips were observed on vessels departing from the port with the greatest number of vessels (i.e., Clarence River). However, the total number of trips observed from Ballina in the previous (88) and current (80) surveys were similar, and the number of trips observed from Coffs Harbour/South West Rocks (74) and Port Stephens/Newcastle (75) during the current survey were less than the total trips observed by Kennelly et al. (1998) from both Coffs Harbour (93) and Port Stephens (93).

Because discard estimates are based on fewer samples they tend to be more variable than landings data collected over many decades (Fernandez et al., 2010). The impact of ignoring the discard component of fishing mortality on assessment output may be replicated by the inclusion of inaccurate data about discarding. The main objective of the optimisation of sampling intensity (presented in full in Appendix 1) was to estimate the total number of discards over these years and estimate the precision of this estimate as a function of the number of trips observed (i.e., sampled). Results show that the percent coefficient of variation (%CV) for the estimates of total effort of discard number within the current study were variable between species groups and regions. For example, the %CV for commercial fish species in both Region 1 (49.92) and Region 2 (74.58) is greater than estimated %CV for non-commercial fish species in both regions (Region 1, 9.58; Region 2, 13.73, Table A1-2, A1-3). This can be inferred to be the result of the substantially greater between-trip variability in discarding rate for several of the most abundant commercial species, including ESW and SW. Estimation of equivalent number of trips (biannual) to improve the precision of estimates of discards (i.e., 20% CV) for commercial fish species in Region 1 (2,162) and Region 2 (1,028) are 4 – 8 x higher than the level of sampling intensity employed within the current study. In contrast, the level of sampling within the current study provided more precise estimates (i.e., lower %CV) of discards for combined commercial and non-commercial fish species in Region 1 (9.58%) and Region 2 (13.73%), combined commercial and non-commercial elasmobranchs (Region 1, 14.13%; Region 2, 9.88%) and combined commercial and non-commercial crustaceans (Region 1, 5.38%; Region 2, 17.68%). The differences in effective sample sizes among species groups should be included in the consideration for a rational allocation of observation effort in future observer-based surveys of the OPTS.

Despite participating vessels reporting approximately 50% of the total catch from the fishery during the current study and observed vessel capacity being representative of the fleet, the level of co-operation of OPTS fishers (~30% hosted an observer on multiple trips) likely compromises the representatives of components of the derived total catch estimates from the survey. Observer-based estimates of catch rates may be biased by the number of fishers sampled and changes in fishing practices when observers are present (Faunce, 2011, Faunce and Barbeaux, 2011, Liggins et al., 1997). Prior to the implementation of the current study, the NSW Government issued a statement of intent to outline its commitment to build and support a strong sustainable NSW commercial fishing industry through the implementation of the Fisheries Business Adjustment Program. During the second year of sampling in the current study, linkages between shares and catch and effort in the OTF were introduced which impacted the level of participation. However, vessels in the North zone, which account for a large proportion of the total catch and effort from the fishery, participated at higher rates than the Central and South zones. Unlike the North and Central zones, the level of participation in the South zone was impacted by vessel capacity and communication issues, with a large number of the fishers from non-English speaking backgrounds.

Threatened, endangered, and protected species interactions

Quantifying the magnitude of incidental wildlife mortality resulting from direct (e.g., bycatch) and indirect (e.g., interaction) effects is fundamental to the sustainable management and accreditation of commercial fisheries. For species with low resilience or where populations are critically low or declining throughout their distribution, even rare interactions can have significant effects on population viability (Lewison et al., 2004). The combined effects of life history traits and incidental mortality from harmful collisions between seabirds and commercial fishing gear is likely to be the most severe threat to Petrels (Procellaridae) and Albatrosses (Diomedeidae) (Phillips et al., 2016). A variety of seabirds, including threatened species were attracted close to vessels during trawl operations with a combination of intrinsic and extrinsic variables explaining variations in seabird vessel-attendance within the NSW OTF (Barnes et al., 2021). However, the NSW OPTS appears to not directly harm seabirds which is not always the case when considering worldwide trawl fisheries (Koopman et al., 2018, Pierre et al., 2012, Sullivan et al., 2006). Throughout the duration of the two-year study, no seabirds were observed to be caught, or negatively interact with vessels or fishing gear. These findings may be attributed to: 1) low abundance of seabirds within the designated waters of the fishery (Barnes et al., 2021), particularly Albatross species of conservation concern that are more susceptible to interactions with trawl vessels (Baker et al., 2002), 2) the configuration of trawl vessels, with all observed vessels towing multiple-rigged prawn trawls from booms located forward of the mid-point of the vessel (Macbeth et al., 2008), 3) fishing activity being largely restricted to targeting EKP at night which may have resulted in less foraging opportunities with less warp strikes occurring at night (Pierre et al., 2014), 4) the number of vessels and intensity of fishing not resulting in large numbers of seabirds being aggregated around groups of fishing vessels (Gonzalez-Zevallos et al., 2011) and, 5) traditionally, high levels of seabirds mortality is caused by collisions with trawlers using net sonde cables (Abraham and Thompson, 2009, Sullivan et al., 2006), which were not observed to be used in the OPTS.

All species of the family Syngnathidae captured during the current study are listed as protected under the NSW *Fisheries Management Act* 1994 and the *Environmental Protection and Biodiversity Conservation Act* 1999. Most syngnathids are considered by the International Union for Conservation of Nature (IUCN) as vulnerable to impacts of indirect (i.e., habitat degradation and modification) and direct (i.e., harvest and unaccounted fishing mortality) effects. Despite the low observed frequency of interactions with sygnathids in the current study (~4.4 % of total trips, ~2.2 % of total shots), the OPTS was estimated to interact with ~4750 individuals over the two-year duration of the survey. Sampling intensity in the current study was shown to precisely estimate interactions with syngnathids (%CV 17.1 – Appendix 1.1). However, estimates of equivalent number of trips (biannual) to improve the precision of estimates of syngnathid interactions (e.g., CV 10% ~1,000 trips) are ~3 x higher than the number of trips observed in Region 1. The only species of syngnathid identified as facing a very high risk of extinction in NSW waters (White's Seahorse – *Hippocampus whitei*), currently classified as endangered by NSW Fisheries Scientific Committee, was not observed to be caught during the present study (https://www.dpi.nsw.gov.au/fishing/threatened-species). The condition, and ultimate fate of released syngnathids is unable to be determined from the current study. Despite previous studies quantitatively assessing the mortality of discarded bycatch from prawn trawls (Hill and Wassenberg, 1990), estimation of species-specific survival rates for rare or infrequently caught species is problematic. However, the cumulative impacts of capture and handling stressors in trawl fisheries often result in high levels of mortality (Gamito and Cabral, 2003, Hill and Wassenberg, 1990, Hill and Wassenberg, 2000). The spatial, seasonal and bathymetric interaction hotspots in the Central zone (~77% of total observed catches) are worth further investigation as mitigation options. There may be depth, time and location interactions that could be aligned with trawling restrictions (i.e., spatiotemporal closures) to reduce interactions with syngnathids.

If OTF fishers are fishing in accordance with the accredited fishery management strategy it is not an offence to interact with a protected species. Under current legislation, OPTS fishers are required to report all interactions with TEPS species on mandatory monthly catch and effort returns. However, the rates of interaction with syngnathids in the present study and those reported from previous studies on OPTS fishing grounds (~15% occurrence, Macbeth et al., 2008) are greater than reported logbook interactions. A combination of the low observed capture rate, cryptic nature, small size and colouration of syngnathids make them difficult to find on the sorting tray among the bycatch likely resulting in underreporting of interactions by crew members (Fry et al., 2015). Further validation of fishery-dependent reporting of TEPS interactions in the OPTS using fishery-independent data collected over a longer time-frame and additional analysis identifying differences in reporting rates between endorsement holders may be required. Understanding both the rate and nature of interactions (including life status) is fundamental to developing strategies to mitigate the impacts of the OTF on TEPS populations and the broader marine ecosystem.

No marine mammals (e.g., dolphins and seals) or marine reptiles (e.g., sea turtles or sea snakes) were observed to be caught or negatively interact with vessels in the current study. Despite, the development and implementation of management measures nationally (Brewer et al., 2006, Robins and McGilvray, 1999) and internationally (Jenkins, 2012, Lucchetti et al., 2019) to address concerns regarding the mortality of sea turtles as a result of interactions in trawl fisheries, our results show that DPI Fisheries and OTF fishers are meeting obligations under current legislative and policy frameworks.

Catches of elasmobranchs

A combination of the demographics of elasmobranchs (e.g., slow growth, low reproductive rate and longevity) and the limited selectivity of penaeid trawls for larger individuals make these animals susceptible to overfishing (Campbell et al., 2018, Dulvy et al., 2008, Ellis et al., 2017). The mortality of elasmobranchs is a topical issue and has received increasing attention over the last decade (Dulvy et al., 2021, Kyne et al., 2021, Molina and Cooke, 2012). The present study is the first to accurately quantify and estimate the magnitude of catches of non-target elasmobranchs in the OPTS of the NSW OTF. The effectiveness of monitoring programs designed to assess variability of populations of bycatch species has rarely been examined (Heales et al., 2007, Kuhnert et al., 2011). Our study estimated the total number of discards over the observed period and estimated the precision of this estimate as a function of the number of trips observed (i.e., sampled). For combined commercial and non-commercial elasmobranchs, sampling intensity in Region 1 (350 trips) and Region 2 (75 trips) precisely estimated discards, with %CV of estimated proportion of 14.13 and 9.88 in Region 1 and Region 2, respectively. To estimate fishing impact of the OPTS and compare the impact to sustainability reference points, information collected from the current study and all available information on a species' taxonomy, distribution, population status, habitat and ecology, use and trade, and conservation measures (Kyne et al., 2021) should be incorporated in a quantitative ecological risk assessment (Zhou and Griffiths, 2008, Zhou et al., 2009). Previous studies have shown that attribute-based risk assessment methods may be inadequate for reflecting even the most obvious changes in fishing impacts on bycatch species (Griffiths et al., 2006). Using an estimate of abundance, catch rates and escapement probability in a quantitative Sustainability Assessment of Fishing Effects (SAFE), Zhou and Griffiths (2008) were able to estimate the impact of an Australian penaeid trawl fishery on the sustainability of 51 elasmobranch bycatch species and identify future monitoring priorities to obtain additional data for further sustainability evaluation.

In our study, a small number of Gulper Sharks, Sleeper Sharks, and Dogfishes (n = 14) were not identified to the species level (Appendix 4). Populations of upper-slope dogfish including Harrisson's (*Centrophorus harrissoni*) and Southern (*C. zeehani*) dogfish have undergone significant declines in south eastern Australia as a result of fishing pressure which has initiated the development of specific management measures for these species (AFMA, 2012). However, based on the depth distribution of observed trawl shots interacting with the 14 individuals, it is unlikely catches included the conservation dependent species (Harrison's and Southern Dogfish) that inhabit deeper waters (250–1,000 m) south of observed incidence of bycatches (AFMA, 2012).

Unfortunately, estimating post-trawl survival (PTS) of elasmobranchs is beyond the scope and sampling protocols associated with this study. However, survival estimates for byproduct (Eastern Shovelnose Ray) and bycatch species (Common Stingaree) of the OPTS presented in Campbell et al. (2018) are greater than generally assumed in qualitative risk assessments. For example, 86.8% of Eastern Shovelnose Rays, and 33.5% of female and 17.3% of male Common Stingarees were estimated to survive capture in trawls targeting EKP off Qld. The higher mortalities rates of male Common Stingarees (Campbell et al., 2017) and other male elasmobranchs in penaeid trawls (Stobutzki et al., 2002) may provide evidence of size-dependent mortality rates as the males of most elasmobranch species are smaller than the females. Approximately 55% of skates (Rajidae) caught by demersal trawlers fishing in UK waters (Enever et al., 2009) and 60% of rays (*Bathyraja* spp. and *Psammobatis* spp.) discarded by bottom trawlers in the Falkland Islands (Laptikhovsky, 2004) were estimated to survive capture. However, survival estimates for ray and shark species from a tropical prawn trawl fishery in northern Australia (Stobutzki et al., 2002) were lower (~44%). Several factors, including air exposure time, trawl duration and higher metabolic rates of tropical ray species likely increasing vulnerability to asphyxia impacted the PTS of species examined (Campbell et al., 2017, Laptikhovsky, 2004, Stobutzki et al., 2002). Quantifying the PTS of elasmobranchs discarded by the OTF is essential for improved management and conservation. Future observer-based surveys of the OTPS should measure the size-structure of elasmobranchs caught, estimate the immediate PTS of trawled individuals and apply a risk-based method to estimate delayed and total PTS of discarded elasmobranchs (Braccini et al., 2012).

Future research priorities

The present study, combined with other similar research (e.g., Feekings et al., 2012) demonstrates that discarding in demersal trawl fisheries is complex (i.e., multiple drivers of discarding). Therefore, more research is required to provide mitigation methods to ensure the sustainability of marine ecosystems interacting with trawl fisheries. Additional, research and monitoring programs will also ensure the accurate quantification of the volume of discarding in the future. The mixed messages on the effectiveness of mitigation measures and the likely species-specific (or at least species-group specific) efficacy highlights the requirement for regular monitoring. Especially given that the onset of climate change is gathering momentum globally and the environment along the OTF extent is one of the most rapidly changing (Hobday and Pecl, 2014). As drivers of discarding were identified for multiple species groups then ideally mitigation methods would reduce discarding of all groups. However, drivers often differed among species groups or the relationship between drivers and discarding differed at the species-group level. Therefore, identifying a global driver and associated mitigation method is ambitious.

Following the results of observer research in the OPTS of the NSW OTF (Kennelly et al., 1998) a range of gear and operational modifications designed to reduce the bycatch of small finfish have been developed and tested in the NSW via carefully controlled experiments, which have resulted in legislation to mandate the use of a range of BRDs in the NSW OPTS (Broadhurst, 2000, Broadhurst and Kennelly, 1996, Broadhurst and Kennelly, 1997, Broadhurst et al., 2002, Broadhurst et al., 2006, Kennelly and Broadhurst, 2002). However, the results of the current study identified that large quantities of target species, primarily ESW and SW, are often discarded during normal fishing operations (>30%). The impact of the implementation of ITQs on rates of discarding in the OTF (all sectors) has not been quantified. Discarded catches represent real losses from stocks and inclusions of data about discards in standard assessment models may alter the conclusions drawn from these models (Punt et al., 2006). Additional development of BRDs to reduce catches of ESW and SW may be required. However, the use of selective measures to reduce discarding may have negative effects on the ecosystem, such as changing the relative abundance of species, size distributions, sex ratios and trophic levels (Garcia et al., 2012, Zhou et al., 2010). Disproportionate mortality on target and non-target species may alter ecosystem structure and function affecting the sustainability of fisheries (Zhou and Smith, 2017).

The spatial, seasonal and bathymetric discarding hotspots identified within the current study, presented in full in Barnes et al. (2022) and in part above, may be further investigated as mitigation options. Using the important fish taxa as an example, Barnes et al. (2022) identified depth and time interactions that could be aligned with trawling restrictions (i.e., on gear and or spatiotemporal closures). Targeted spatial management, including an extensive network of inshore trawl closures that protects over 100,000 ha of inshore habitats from prawn trawling is currently regulated with the management plan for the NSW OTF. In addition to designated trawl closures, habitat protection zones and sanctuary zones within Marine Protected Areas (MPAs) prohibit trawling in almost 140,000 ha of which a large proportion is sand/soft sediment habitat exploited within the OTF. An extensive evaluation of the inshore trawl closures primarily targeted at protecting small juvenile EKP from fishing mortality, established that the closure network functioned effectively in the protection of small prawns (Taylor et al., 2021), and provided significant protection for other quota-managed and bycatch species (Taylor et al., 2020).

Existing management arrangements in the OPTS include a unitised effort quota (implemented 2019) with nights linked to units according to each vessels size. Between the previous and the current observer-based survey of the OPTS, reported effort has declined from >20,000 (Kennelly et al., 1998) to ~5,000–6,000 nights per year which has likely reduced fishery-level discarding. Large declines in fishing effort in the Qld ECOTF reduced discards from a peak of approximately 67,000 t in 1997 to 21,000 t in 2014 (Wang et al., 2020). However, current effort levels in the OPTS are lower than available quota, which approximates to ~14,000 nights per year (based on average 40 hull unit vessel). Thus, there is currently considerable scope for increases in trawl effort within the OPTS.

The global problem of fishery discarding continues despite developments in the last 20 years. Regular monitoring and research are required to continue the development of mitigation methods and to understand the impact of recent management changes (e.g., ITQs) on rates of discarding in the OTPS of the OTF. However, the choice of survey design to monitor the OPTS and frequency of monitoring will depend on the future management objectives of the fishery and sources of available funding. Undertaking standardised fishery-independent surveys which can control vessel and gear effects, spatial variation and potentially minimise the effects of environmental variables on samples from year to year, may provide a more precise assessment of bycatch composition on NSW OTF grounds. From 1990 to 1992 NSW DPI Fisheries completed an independent assessment of the relative abundances and size compositions of prawns and bycatch species on selected trawl grounds off central and northern NSW (Graham and Wood, 1997, Graham et al., 1993, Graham et al., 2001). Replicating the 1990-92 survey would allow comparisons of the relative abundance and size-structure of primary target and main bycatch species after ~30 years. However, interpreting differences in catch rates between surveys and attributing causal mechanisms is complicated by a plethora of factors that may have contributed to the changes observed (Graham et al., 2001). Despite the latter, examining the cost and benefits of these sorts of adaptive management experiments compared to other approaches of assessing the sustainability of trawl fisheries (e.g., species-specific and quantitative risk or stock assessments) remains an important area for future research.

Conclusions and recommendations

The data presented in this report are the first to describe the composition and the magnitude of discarded catches taken in the OPTS of the OTF in more than 20 years. Considering the findings, the following conclusions and recommendations are made:

1. The observed discard rate in the OPTS was generally lower than historical estimates in the main area of the fishery and is equivalent to national and international penaeid trawl fisheries.

2. Observed discarded catches in the OPTS included target species discarded because of current size limits and possession limits and several species, including the quota-managed whiting species, that were observed to be retained and discarded at the discretion of the fisher. Discarded catches need to be regularly estimated and accounted for in future stock assessments.

3. Estimated mortality from discards derived from current and future observer-surveys of the OPTS need to be incorporated into the assessment of indicators and resulting decision rules as outlined in New South Wales Fisheries Harvest Strategy Policy (https://www.dpi.nsw.gov.au/fishing/harvest-strategies/policy-and-guidelines).

4. The differences in effective sample sizes among species groups should be included in the consideration for a rational allocation of observation effort in future observer-based surveys of the OPTS. Ultimately, however, the choice of survey design to monitor the OPTS will depend on the future management objectives of the fishery and sources of available funding.

5. Research is needed to find practical and affordable solutions to minimise bycatch and maximise the survival of discarded elasmobranchs as a step towards ameliorating bycatch.

6. Quantifying the PTS of elasmobranchs discarded by the OPTS is essential for improved management and conservation. Research on the impact of the OPTS on elasmobranchs should include general fisheries biological monitoring analysis (e.g., age and growth) to form yardsticks for which to measure the impact over space and time.

7. No marine mammals, reptiles or seabirds were observed to be caught or negatively interact with OTF vessels in the current study. This result indicates that NSW DPI and OTF fishers are meeting obligations under current legislative and policy frameworks and that additional mitigation measures (e.g., polices, changes to fishing gear and industry practices) are not required. However, ongoing periodic monitoring is essential to evaluate the potential for climate induced changes to interactions as well as ecological effects of bird behavioural changes because of their attraction to vessels.

8. Current lawful modifications to prawn trawl gear (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/1217286/Inshore-Offshore-Prawn-Trawl-Fact-Sheet-Authorised-Modifications-to-Trawl-Gear.pdf) and those

authorised by section 37 order (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/1217288/Fisheries-Management-Inshore-and-Offshore-Prawn-Trawl-Nets-Order-2020.pdf) designed to improve catches of target species, while reducing bycatch and habitat impacts, should be periodically reviewed and updated to allow fishers to trial new developments in bycatch mitigation in penaeid trawls.

9. Industry should lead the development of BRDs to allow fishers restricted by quota holdings to reduce catches of ESW and SW and allow fishers with sufficient quota holdings to maximise catches of economically desirable size classes.

10. Fleet-wide implementation of vessel monitoring systems (VMS) will facilitate the collection of high-resolution data on the spatial distribution of trawling to quantify the trawl footprint of the OPTS which will inform any variation in risks.

11. Data collected during the current study should be incorporated in a quantitative ecological risk assessment of the OTF to ensure risks associated with the fishery are assessed and managed at both a whole-of-fishery and species-specific level with high emphasis placed on managing the impact of fishing activities on target, non-target, protected species, and the broader marine ecosystem.

12. The Fishery Management Strategies for all NSW Commercial Fisheries (excluding Lobster and Abalone) require the implementation of scientific observer programs to collect information on catch composition, retained and discarded catch, biological information on important species and interactions with threatened and protected species. To ensure all future observer-based surveys are representative and cost effective, regulation amendments to support Division 4B (Part 9) of the *Fisheries Management Act 1994* (Scientific observer program) that requires fishing business/endorsement holders to allow authorised scientific observers on board boats and facilitate observers in the course of their research/observation duties while on the vessel should be further developed and implemented with industry consultation to ensure consideration of vessel capacity issues.

13. Changes to current NSW catch and effort reporting regulations that require fishers to report additional information including trawl gear specifications, BRDs used, location fished (latitude, longitude), depth fished, reported catches and estimated discards for each trawl shot would improve precision of fishery-wide estimates of discards. This would allow logbook data to be portioned into strata that can weighted to the overall fishery enabling discards to be estimated with a higher degree of precision. Any changes to existing logbooks should be accompanied by formal education and training to ensure fishers provide the highest quality data possible. Strategies and technology to incorporate data from multiple streams to logbooks (e.g., location data from VMS or Automatic Identification System (AIS)) should be implemented in parallel with more detailed logbooks to minimise fisher reporting requirements and improve accuracy of reported data.

14. Because of vessel capacity constraints and other operational issues there is a need to consider the costs, logistics and deliverables of the alternative data sources and

sampling strategies for future monitoring of the OTF. Several studies have shown that Electronic Monitoring (EM) is a useful tool for monitoring bycatches and protected species interactions. The most easily quantifiable benefit expected from EM, is cost saving through reduced 'at-sea' observer coverage.

15. The development of standardised fishery-independent surveys, which can control spatial variation and potentially minimise the effects of environmental variables on samples from year to year, may provide a more precise assessment of bycatch composition on NSW trawl grounds. Fishery-independent surveys also allow for the collection of control data from trawl grounds subject to different levels of exploitation, including those rarely fished or protected from fishing.
16. Fishery-independent research should be extended to assess the impact of trawling on the seafloor across ecoregions and determine the costs and benefits for trawling different geographical regions (and temporally).
17. Monitoring of the OPTS bycatch and other fishery metrics should occur periodically to ensure its impact is being properly assessed. The temporal duration between the present survey and previous (i.e., ~27 years) was too long given the diversity of bycatch and potential for trawling to impact the ecosystem and other interacting fisheries.

References

ABRAHAM, E. R. & THOMPSON, F. N. 2009. Warp strike in New Zealand trawl fisheries, 2004-05 to 2005-06. New Zealand Aquatic Environment and Biodevrsity Report. Wellington: Ministry of Fisheries.

AFMA 2012. Upper-Slope Dogfish Management Strategy. *In:* AUSTRALIAN FISHERIES MANAGEMENT AUTHORITY, C. (ed.). Canberra.

AFMA 2016. Redfish (*Centroberyx affinis*) stock rebuilding strategy 2016–2021. *In:* AUSTRALIAN FISHERIES MANAGEMENT AUTHORITY, C. (ed.). Canberra.

AFZALI, S. F., BOURDAGES, H., LAPORTE, M., MÉROT, C., NORMANDEAU, E., AUDET, C. & BERNATCHEZ, L. 2021. Comparing environmental metabarcoding and trawling survey of demersal fish communities in the Gulf of St. Lawrence, Canada. *Environmental DNA,* 3**,** 22-42.

ALVERSON, D. L., FREEBERG, M. H., MURWASKI, S. A. & POPE, J. G. 1994. A global assessment of fisheries bycatch and discards. *FAO Fisheries Technical Paper.* Rome.

BAKER, G. B., GALES, R., HAMILTON, S. & WILKINSON, V. 2002. Albatrosses and petrels in Australia: a review of their conservation and management. *Emu-Austral Ornithology,* 102**,** 71-97.

BARNES, T. C., CANDY, S. G. & JOHNSON, D. D. 2021. Characterising seabird vessel interactions associated with demersal ocean trawling: vessel attendance by birds depends on intrinsic and extrinsic predictors. *Endangered Species Research,* 44**,** 327-338.

BARNES, T. C., CANDY, S. G., MORRIS, S. & JOHNSON, D. D. 2022. Understanding discarding in trawl fisheries: A model based demersal case study with implications for mitigating and assessing impacts. *PLOS ONE,* 17**,** e0264055.

BERGH, M., KNUCKEY, I., GAYLARD, J., MARTENS, K. & KOOPMAN, M. 2009. A revised sampling regime for the Southern and Eastern Scalefish and Shark Fishery-Final Report. *AFMA Project F,* 2008**,** 235.

BOOTH, D., FIGUEIRA, W., GREGSON, M., BROWN, L. & BERETTA, G. 2007. Occurrence of tropical fishes in temperate southeastern Australia: role of the East Australian Current. *Estuarine, Coastal and Shelf Science,* 72**,** 102-114.

BORGES, L., ZUUR, A. F., ROGAN, E. & OFFICER, R. 2004. Optimum sampling levels in discard sampling programs. *Canadian Journal of Fisheries and Aquatic Sciences,* 61**,** 1918-1928.

BRACCINI, M., VAN RIJN, J. & FRICK, L. 2012. High post-capture survival for sharks, rays and chimaeras discarded in the main shark fishery of Australia? *PloS one,* 7**,** e32547.

BRANCH, T. A. 2006. Discards and revenues in multispecies groundfish trawl fisheries managed by trip limits on the US West Coast and by ITQs in British Columbia. *Bulletin of Marine Science,* 78**,** 669-689.

BREWER, D., GRIFFITHS, S., HEALES, D., ZHOU, S., TONKS, M., DELL, Q., TAYLOR, B., MILLER, M., KUHNERT, P. & KEYS, S. 2007. Design, trial and implementation of an integrated, long-term bycatch monitoring program road tested in the Northern Prawn Fishery.

BREWER, D., HEALES, D., MILTON, D., DELL, Q., FRY, G., VENABLES, B. & JONES, P. 2006. The impact of turtle excluder devices and bycatch reduction devices on diverse tropical marine communities in Australia's northern prawn trawl fishery. *Fisheries Research,* 81**,** 176-188.

BRITON, F., MACHER, C., MERZEREAUD, M., L. E. GRAND, C., FIFAS, S. & THEBAUD, O. 2020. Providing Integrated Total Catch Advice for the Management of Mixed Fisheries with an Eco-viability Approach. *Environmental Modeling & Assessment,* 25**,** 307-325.

BROADHURST, M. K. 2000. Modifications to reduce bycatch in prawn trawls: A review and framework for development. *Reviews in Fish Biology and Fisheries,* 10**,** 27-60.

BROADHURST, M. K., BRAND, C. P. & KENNELLY, S. J. 2012. Evolving and devolving bycatch reduction devices in an Australian penaeid-trawl fishery. *Fisheries Research,* 113**,** 68-75.

BROADHURST, M. K. & KENNELLY, S. J. 1996. Effects of the circumference of codends and a new design of square-mesh panel in reducing unwanted by-catch in the New South Wales oceanic prawn-trawl fishery, Australia. *Fisheries Research,* 27**,** 203-214.

BROADHURST, M. K. & KENNELLY, S. J. 1997. The composite square-mesh panel: a modification to codends for reducing unwanted bycatch and increasing catches of prawns throughout the New South Wales oceanic prawn-trawl fishery. *Fishery Bulletin,* 95**,** 653-664.

BROADHURST, M. K., KENNELLY, S. J. & GRAY, C. A. 2002. Optimal positioning and design of behavioural-type by-catch reduction devices involving square-mesh panels in penaeid prawn-trawl codends. *Marine and Freshwater Research,* 53**,** 813-823.

BROADHURST, M. K., MILLAR, R. B., WOODEN, M. E. L. & MACBETH, W. G. 2006. Optimising codend configuration in a multispecies demersal trawl fishery. *Fisheries Management and Ecology,* 13**,** 81-92.

CAMPBELL, M., COURTNEY, T., WANG, N., MCLENNAN, M. & ZHOU, S. 2017. Estimating the impacts of management changes on bycatch reduction and sustainability of high-risk bycatch species in the Queensland East Coast Otter Trawl Fishery. *In:* 2015/014, F. R. F. F. P. N. (ed.). . Brisbane, Qld, Australia: Queensland Department of Agriculture and Fisheries.

CAMPBELL, M. J., MCLENNAN, M. F., COURTNEY, A. J. & SIMPFENDORFER, C. A. 2018. Post-release survival of two elasmobranchs, the eastern shovelnose ray *(Aptychotrema rostrata*) and the common stingaree (*Trygonoptera testacea*), discarded from a prawn trawl fishery in southern Queensland, Australia. *Marine and Freshwater Research,* 69**,** 551-561.

CAMPBELL, M. J., TONKS, M. L., MILLER, M., BREWER, D. T., COURTNEY, A. J. & SIMPFENDORFER, C. A. 2020. Factors affecting elasmobranch escape from turtle excluder devices (TEDs) in a tropical penaeid-trawl fishery. *Fisheries Research,* 224.

CANDY, S., ZIEGLER, P. & WELSFORD, D. 2014. A nonparametric model of empirical length distributions to inform stratification of fishing effort for integrated assessments. *Fisheries research,* 159**,** 34-44.

CATCHPOLE, T. L., FRID, C. L. J. & GRAY, T. S. 2005. Discarding in the English north-east coast Nephrops norvegicus fishery: the role of social and environmental factors. *Fisheries Research,* 72**,** 45-54.

COOK, R. M. 2019. Inclusion of discards in stock assessment models. *Fish and Fisheries,* 20**,** 1232-1245.

COURTNEY, A. J., CAMPBELL, M. J., TONKS, M. L., ROY, D. P., GADDES, S. W., HADDY, J. A., KYNE, P. M., MAYER, D. G. & CHILCOTT, K. E. 2014. Effects of bycatch reduction devices in Queensland's (Australia) deepwater eastern king prawn (Melicertus plebejus) trawl fishery. *Fisheries Research,* 157**,** 113-123.

CURLEY, B. G., JORDAN, A. R., FIGUEIRA, W. F. & VALENZUELA, V. C. 2013. A review of the biology and ecology of key fishes targeted by coastal fisheries in south-east Australia: identifying critical knowledge gaps required to improve spatial management. *Reviews in Fish Biology and Fisheries,* 23**,** 435-458.

DAVIS, M. W. & OLLA, B. L. 2002. Mortality of lingcod towed in a net as related to fish length, seawater temperature, and air exposure: A laboratory bycatch study. *North American Journal of Fisheries Management,* 22**,** 1095-1104.

DELL, Q., BREWER, D. T., GRIFFITHS, S. P., HEALES, D. S. & TONKS, M. L. 2009. Bycatch in a tropical schooling - penaeid fishery and comparisons with a related, specialised trawl regime. *Fisheries Management and Ecology,* 16**,** 191-201.

DULVY, N. K., BAUM, J. K., CLARKE, S., COMPAGNO, L. J. V., CORTES, E., DOMINGO, A., FORDHAM, S., FOWLER, S., FRANCIS, M. P., GIBSON, C., MARTINEZ, J., MUSICK, J. A., SOLDO, A., STEVENS, J. D. & VALENTI, S. 2008. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. *Aquatic Conservation-Marine and Freshwater Ecosystems,* 18**,** 459-482.

DULVY, N. K., PACOUREAU, N., RIGBY, C. L., POLLOM, R. A., JABADO, R. W., EBERT, D. A., FINUCCI, B., POLLOCK, C. M., CHEOK, J. & DERRICK, D. H. 2021. Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Current Biology,* 31**,** 4773-4787. e8.

ELLIS, J. R., PHILLIPS, S. R. M. & POISSON, F. 2017. A review of capture and post-release mortality of elasmobranchs. *Journal of Fish Biology,* 90**,** 653-722.

ENEVER, R., CATCHPOLE, T., ELLIS, J. & GRANT, A. 2009. The survival of skates (Rajidae) caught by demersal trawlers fishing in UK waters. *Fisheries Research,* 97**,** 72-76.

EVERETT, J. D., VAN SEBILLE, E., TAYLOR, M. D., SUTHERS, I. M., SETIO, C., CETINA-HEREDIA, P. & SMITH, J. A. 2017. Dispersal of Eastern King Prawn larvae in a western boundary current: New insights from particle tracking. *Fisheries Oceanography,* 26**,** 513-525.

FAO 2011. Report of the technical consultation to develop internattional guidelines on bycatch management and reduction of discards. Rome, 6-10 December 2010. *FAO Fisheries and Aquaculture Report No. 957.* Rome: Food and Agriculture Organization of the United Nations.

FAUNCE, C. H. 2011. A comparison between industry and observer catch compositions within the Gulf of Alaska rockfish fishery. *Ices Journal of Marine Science,* 68**,** 1769-1777.

FAUNCE, C. H. & BARBEAUX, S. J. 2011. The frequency and quantity of Alaskan groundfish catcher-vessel landings made with and without an observer. *Ices Journal of Marine Science,* 68**,** 1757-1763.

FEEKINGS, J., BARTOLINO, V., MADSEN, N. & CATCHPOLE, T. 2012. Fishery discards: factors affecting their variability within a demersal trawl fishery. *PloS one,* 7**,** e36409.

FERNANDEZ, C., CERVINO, S., PEREZ, N. & JARDIM, E. 2010. Stock assessment and projections incorporating discard estimates in some years: an application to the hake stock in ICES Divisions VIIIc and IXa. *Ices Journal of Marine Science,* 67**,** 1185-1197.

FRY, G. C., BARWICK, M., LAWRENCE, E. & TONKS, M. 2015. Monitoring interactions with bycatch species using crew-member observer data collected in the Northern Prawn Fishery: 2013 – 2014. *In:* AUSTRALIAN FISHERIES MANAGEMENT AUTHORITY, C. (ed.) *Final Report.* Australia: CSIRO.

FULTON, E. A., PUNT, A. E., DICHMONT, C. M., HARVEY, C. J. & GORTON, R. 2019. Ecosystems say good management pays off. *Fish and Fisheries,* 20**,** 66-96.

GAMITO, R. & CABRAL, H. 2003. Mortality of brown-shrimp discards from the beam trawl fishery in the Tagus estuary, Portugal. *Fisheries Research,* 63**,** 423-427.

GARCIA, S. M., KOLDING, J., RICE, J., ROCHET, M. J., ZHOU, S., ARIMOTO, T., BEYER, J. E., BORGES, L., BUNDY, A., DUNN, D., FULTON, E. A., HALL, M., HEINO, M., LAW, R., MAKINO, M., RIJNSDORP, A. D., SIMARD, F. & SMITH, A. D. M. 2012. Reconsidering the Consequences of Selective Fisheries. *Science,* 335**,** 1045-1047.

GELL, F. R. & ROBERTS, C. 2003. The fishery effects of marine reserves and fishery closures. *WWF-US*.

GONZALEZ-ZEVALLOS, D., YORIO, P. & SVAGELJ, W. S. 2011. Seabird attendance and incidental mortality at shrimp fisheries in Golfo San Jorge, Argentina. *Marine Ecology Progress Series,* 432**,** 125-135.

GRAHAM, K. J., ANDREW, N. L. & HODGSON, K. E. 2001. Changes in relative abundance of sharks and rays on Australian South East Fishery trawl grounds after twenty years of fishing. *Marine and Freshwater Research,* 52**,** 549-561.

GRAHAM, K. J., LIGGINS, G. W., WILDFORSTER, J. & KENNELLY, S. J. 1993. Relative abundances and size compositions of prawns and bycatch species on New South Wales prawn grounds during surveys VI-VIII (May 1991 – May 1992). . *In:* FISHERIES, N. (ed.) *Kapala Cruise Report No. 112*. Cronulla, NSW, Australia.

GRAHAM, K. J. & WOOD, B. R. 1997. The 1995-96 survey of Newcastle and Clarence River prawn grounds. . *In:* FISHERIES, N. (ed.) *Kapala Cruise Report No. 116*. Cronulla, NSW, Australia.

GRAY, C. A., BARNES, L. M., VAN DER MEULEN, D. E., KENDALL, B. W., OCHWADA-DOYLE, F. A. & ROBBINS, W. D. 2014. Depth interactions and reproductive ecology of sympatric Sillaginidae: *Sillago robusta* and *S. flindersi*. *Aquatic Biology,* 21**,** 127-142.

GRIFFITHS, S. P., BREWER, D. T., HEALES, D. S., MILTON, D. A. & STOBUTZKI, I. C. 2006. Validating ecological risk assessments for fisheries: assessing the impacts of turtle excluder devices on elasmobranch bycatch populations in an Australian trawl fishery. *Marine and Freshwater Research,* 57**,** 395-401.

HALL, M. A. 1996. On bycatches. *Reviews in Fish Biology and Fisheries,* 6**,** 319-352.

HALL, M. A., ALVERSON, D. L. & METUZALS, K. I. 2000. By-catch: Problems and solutions. *Marine Pollution Bulletin,* 41**,** 204-219.

HALL, S. J. 1999. *Effects of fishing on marine ecosystems and communities*, Blackwell Science.

HALL, S. J. & MAINPRIZE, B. 2004. Towards ecosystem-based fisheries management. *Fish and Fisheries,* 5**,** 1-20.

HALL, S. J. & MAINPRIZE, B. M. 2005. Managing by-catch and discards: how much progress are we making and how can we do better? *Fish and Fisheries,* 6**,** 134-155.

HEALES, D. S., BREWER, D. T., KUHNERT, P. M. & JONES, P. N. 2007. Detecting declines in catch rates of diverse trawl bycatch species, and implications for monitoring. *Fisheries Research,* 84**,** 153-161.

HEATHER, M. 2019. 130 tonnes of prawns to be sold at Xmas. *The Northern Daly Leader*. Australia: Australian Associated Press.

HELIDONIOTIS, F., O'NEILL, M. F. & TAYLOR, M. D. 2020. Stock Assessment of Eastern King Prawn (*Melicertus Plebejus*). *In:* FISHERIES, Q. D. O. A. A. (ed.). Brisbane.

HILL, B. & WASSENBERG, T. 1990. Fate of discards from prawn trawlers in Torres Strait. *Marine and Freshwater Research,* 41**,** 53-64.

HILL, B. J. & WASSENBERG, T. J. 2000. The probable fate of discards from prawn trawlers fishing near coral reefs - A study in the northern Great Barrier Reef, Australia. *Fisheries Research,* 48**,** 277-286.

ITAYA, K., FUJIMORI, Y., SHIMIZU, S., KOMATSU, T. & MIURA, T. 2007. Effect of towing speed and net mouth size on catch efficiency in framed midwater trawls. *Fisheries Science,* 73**,** 1007-1016.

JAITEH, V. F., ALLEN, S. J., MEEUWIG, J. J. & LONERAGAN, N. R. 2014. Combining in-trawl video with observer coverage improves understanding of protected and vulnerable species by-catch in trawl fisheries. *Marine and Freshwater Research,* 65**,** 830-837.

JENKINS, L. D. 2012. Reducing sea turtle bycatch in trawl nets: a history of NMFS turtle excluder device (TED) research. *Marine Fisheries Review,* 74**,** 26-44.

KELLEHER, K. 2005. *Discards in the world's marine fisheries: An update 131*, Food and Agriculture Organisation.

KENCHINGTON, T. J. 2011. Encounter protocols for avoidance of harm to Vulnerable Marine Ecosystems: A global review of experience to 2010. *Research document (Canadian Science Advisory Secretariat).* Ottawa, ON.

KENNELLY, S. 2018. Developing a National Bycatch Reporting System. *In:* CORPORATION, F. R. A. D. (ed.) *Final Report.* Canberra.

KENNELLY, S. J. 1995. The issue of bycatch in Australian demersal trawl fisheries. *Reviews in Fish Biology and Fisheries,* 5**,** 213-234.

KENNELLY, S. J. 2020. Bycatch Beknown: Methodology for jurisdictional reporting of fisheries discards - Using Australia as a case study. *Fish and Fisheries,* 21**,** 1046-1066.

KENNELLY, S. J. & BORGES, L. 2018. Proceedings of the 9th International Fisheries Observer and Monitoring Conference. Vigo, Spain.

KENNELLY, S. J. & BROADHURST, M. K. 2002. By-catch begone: changes in the philosophy of fishing technology. *Fish and Fisheries,* 3**,** 340-355.

KENNELLY, S. J., LIGGINS, G. W. & BROADHURST, M. K. 1998. Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia. *Fisheries Research,* 36**,** 217-236.

KOOPMAN, M., BOAG, S., TUCK, G. N., HUDSON, R., KNUCKEY, I. & ALDERMAN, R. 2018. Industry-based development of effective new seabird mitigation devices in the southern Australian trawl fisheries. *Endangered Species Research,* 36**,** 197-211.

KUHNERT, P. M., GRIFFITHS, S. & BREWER, D. 2011. Assessing population changes in bycatch species using fishery-dependent catch rate data. *Fisheries Research,* 108**,** 15-21.

KYNE, P. M., HEUPEL, M. R., WHITE, W. T. & SIMPFENDORFER, C. A. 2021. The Action Plan for Australian Sharks and Rays 2021. *In:* HUB, M. B. (ed.) *National Environmental Science Program.* Hobart.

LAPTIKHOVSKY, V. V. 2004. Survival rates of rays discarded by the bottom trawl squid fishery off the Falkland Islands. *Falkland Islands Government Fisheries Department.* Stanley, Falkland Islands.

LEWISON, R. L., CROWDER, L. B., READ, A. J. & FREEMAN, S. A. 2004. Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology & Evolution,* 19**,** 598-604.

LIGGINS, G. W., BRADLEY, M. J. & KENNELLY, S. J. 1997. Detection of bias in observer-based estimates of retained and discarded catches from a multi species trawl fishery. *Fisheries Research,* 32**,** 133-147.

LITTLE, A. S., NEEDLE, C. L., HILBORN, R., HOLLAND, D. S. & MARSHALL, C. T. 2015. Real-time spatial management approaches to reduce bycatch and discards: experiences from Europe and the United States. *Fish and Fisheries,* 16**,** 576-602.

LUCCHETTI, A., BARGIONE, G., PETETTA, A., VASAPOLLO, C. & VIRGILI, M. 2019. Reducing Sea Turtle Bycatch in the Mediterranean Mixed Demersal Fisheries. *Frontiers in Marine Science,* 6.

MACBETH, W. G., GRAY, C. A. & JOHNSON, D. D. 2008. Assessment of a 35-mm square-mesh codend and composite square-mesh panel configuration in the ocean prawn-trawl fishery of northern New South Wales. *Fisheries Final Report Series.* Cronulla, Australia: NSW Department of Primary Industries.

MACBETH, W. G., MILLAR, R. B., JOHNSON, D. D., GRAY, C. A., KEECH, R. S. & COLLINS, D. 2012. Assessment of relative performance of a square-mesh codend design across multiple vessels in a demersal trawl fishery. *Fisheries Research,* 134**,** 29-41.

MACHIAS, A., VASSILOPOULOU, V., VATSOS, D., BEKAS, P., KALLIANIOTIS, A., PAPACONSTANTINOU, C. & TSIMENIDES, N. 2001. Bottom trawl discards in the northeastern Mediterranean Sea. *Fisheries Research,* 53**,** 181-195.

MCCONNAUGHEY, R. A., HIDDINK, J. G., JENNINGS, S., PITCHER, C. R., KAISER, M. J., SUURONEN, P., SCIBERRAS, M., RIJNSDORP, A. D., COLLIE, J. S., MAZOR, T., AMOROSO, R. O., PARMA, A. M. & HILBORN, R. 2020. Choosing best practices for managing impacts of trawl fishing on seabed habitats and biota. *Fish and Fisheries,* 21**,** 319-337.

MOLINA, J. M. & COOKE, S. J. 2012. Trends in shark bycatch research: current status and research needs. *Reviews in Fish Biology and Fisheries,* 22**,** 719-737.

MONTGOMERY, S. S., COURTNEY, A. J., BLOUNT, C., STEWART, J., DIE, D. J., COSGROVE, M. & O'NEILL, M. F. 2007. Patterns in the distribution and abundance of female eastern king prawns, Melicertus plebejus (Hess, 1865), capable of spawning and reproductive potential in waters off eastern Australia. *Fisheries Research,* 88**,** 80-87.

MORISON, A., KNUCKEY, I., SIMPFENDORFER, C. & BUCKWORTH, R. 2013. South East Scalefish and Shark Fishery: draft 2012 stock assessment summaries for species assessed by GABRAG. *ShelfRAG and Slope/DeepRAG, report for the Australian Fisheries Management Authority, Canberra*.

MURAWSKI, S. 1996. Factors influencing by-catch and discard rates: analyses from multispecies/multifishery sea sampling. *Journal of Northwest Atlantic Fishery Science,* 19.

MURPHY, J., OCHWADA-DOYLE, F., WEST, L., STARK, K. & HUGHES, J. 2020. The NSW Recreational Fisheries Monitoring Program - survey of recreational fishing, 2017/18. *In:* DPI, N. (ed.).

NSW DPI 2007. Fishery Management Strategy for the Ocean Trawl Fishery *In:* INDUSTRIES, N. D. O. P. (ed.). Cronulla NSW.

PHILLIPS, R. A., GALES, R., BAKER, G. B., DOUBLE, M. C., FAVERO, M., QUINTANA, F., TASKER, M. L., WEIMERSKIRCH, H., UHART, M. & WOLFAARDT, A. 2016. The conservation status and priorities for albatrosses and large petrels. *Biological Conservation,* 201**,** 169-183.

PIERRE, J., GERNER, M. & PENROSE, L. 2014. Assessing the effectiveness of seabird mitigation devices in the trawl sectors of the Southern and Eastern Scalefish and Shark Fishery in Australia. *JPEC Ltd, Wellington*.

PIERRE, J. P., ABRAHAM, E. R., RICHARD, Y., CLEAL, J. & MIDDLETON, D. A. J. 2012. Controlling trawler waste discharge to reduce seabird mortality. *Fisheries Research,* 131**,** 30-38.

PUNT, A. E., SMITH, D. C., TUCK, G. N. & METHOT, R. D. 2006. Including discard data in fisheries stock assessments: Two case studies from south-eastern Australia. *Fisheries Research,* 79**,** 239-250.

RACEK, A. A. 1959. *Prawn investigations in eastern Australia*, Government Printer, South Africa.

RAINER, S. & MUNRO, I. 1982. Demersal fish and cephalopod communities of an unexploited coastal environment in northern Australia. *Marine and Freshwater Research,* 33**,** 1039-1055.

ROBINS, J. & MCGILVRAY, J. 1999. The AusTED II, an improved trawl efficiency device 2. Commercial performance. *Fisheries Research,* 40**,** 29-41.

ROBINS, J. B., CAMPBELL, M. J. & MCGILVRAY, J. G. 1999. Reducing prawn-trawl bycatch in Australia: an overview and an example from Queensland. *Marine Fisheries Review,* 61**,** 46-55.

SAILA, S. B. 1983. Importance and assessment of discards in commercial fisheries. Rome: FAO Fisheries

SILBURN, J., JOHNSON, D. D., BOOTH, D. J. & TAYLOR, M. D. 2020. The effect of subsampling when monitoring bycatch in a penaeid trawl fishery. *Fisheries Research,* 224.

SINK, J., WILKINSON, S., ATKINSON, L. J., SIMS, P. F., LESLIE, R. W. & ATTWOOD, C. G. 2012. The potential impacts of South Africa's demersal hake trawl fishery on benthic habitats: Historical perspectives, spatial analyses, current review, and potential management actions. *In:* INSTITUTE, S. A. N. B. (ed.). Unpublished Report.

STEPHENSON, P. C., WELLS, S. & KING, J. 2008. Evaluation of Exclusion Grids to Reduce the Bycatch of Dolphins, Turtles, Sharks, and Rays in the Pilbara Trawl Fishery. *FISHERIES RESEARCH REPORT NO. 171.* Department of Fisheries Government of Western Australia: Fisheries Research Division

STERGIOU, K., ECONOMOU, A., PAPACONSTANTINOU, C., TSIMENIDES, N. & KAVADAS, S. 1998. Estimates of discards in the Hellenic commercial trawl fishery. *Rapport Commission Internationale pour l'Exploration Scientifique de la mer Méditerranée,* 35**,** 490-491.

STERLING, D. J. 2005. *Modelling the physics of prawn trawling for fisheries management.* PhD PhD, Curtin University of Technology.

STOBUTZKI, I., JONES, P. & MILLER, M. 2003. A comparison of fish bycatch communities between areas open and closed to prawn trawling in an Australian tropical fishery. *Ices Journal of Marine Science,* 60**,** 951-966.

STOBUTZKI, I. C., MILLER, M. J., HEALES, D. S. & BREWER, D. T. 2002. Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. *Fisheries Bulletin,* 100**,** 800-821.

STOBUTZKI, I. C., MILLER, M. J., JONES, P. & SALINI, J. P. 2001. Bycatch diversity and variation in a tropical Australian penaeid fishery; the implications for monitoring. *Fisheries Research,* 53**,** 283-301.

SULLIVAN, B. J., BRICKLE, P., REID, T. A., BONE, D. G. & MIDDLETON, D. A. J. 2006. Mitigation of seabird mortality on factory trawlers: trials of three devices to reduce warp cable strikes. *Polar Biology,* 29**,** 745-753.

TAYLOR, M. D., FRY, B., BECKER, A. & MOLTSCHANIWSKYJ, N. 2017. Recruitment and connectivity influence the role of seagrass as a penaeid nursery habitat in a wave dominated estuary. *Science of the Total Environment,* 584**,** 622-630.

TAYLOR, M. D., HALE, D. & JOHNSON, D. D. 2021. Biological evaluation of an existing spatial management network for an exploited penaeid species. *Regional Studies in Marine Science,* 47**,** 101924.

TAYLOR, M. D. & JOHNSON, D. D. 2020. Evaluation of adaptive spatial management in a multi-jurisdictional trawl fishery. *Regional Studies in Marine Science,* 35.

TAYLOR, M. D. & JOHNSON, D. D. 2021. Connectivity between a spatial management network and a multi-jurisdictional ocean trawl fishery. *Ocean & Coastal Management,* 210.

TAYLOR, M. D., SILBURN, J., BOOTH, D. J. & JOHNSON, D. D. 2020. Impact of Spatial Management on Nontarget Species in an Oceanic Penaeid Trawl Fishery. *North American Journal of Fisheries Management,* 40**,** 509-520.

TONKS, M. L., GRIFFITHS, S. P., HEALES, D. S., BREWER, D. T. & DELL, Q. 2008. Species composition and temporal variation of prawn trawl bycatch in the Joseph Bonaparte Gulf, northwestern Australia. *Fisheries Research,* 89**,** 276-293.

TSAGARAKIS, K., PALIALEXIS, A. & VASSILOPOULOU, V. 2014. Mediterranean fishery discards: review of the existing knowledge. *ICES Journal of Marine Science,* 71**,** 1219-1234.

ULRICH, C., REEVES, S. A., VERMARD, Y., HOLMES, S. J. & VANHEE, W. 2011. Reconciling single-species TACs in the North Sea demersal fisheries using the Fcube mixed-fisheries advice framework. *Ices Journal of Marine Science,* 68**,** 1535-1547.

WALLACE, S., TURRIS, B., DRISCOLL, J., BODTKER, K., MOSE, B. & MUNRO, G. 2015. Canada's Pacific groundfish trawl habitat agreement: A global first in an ecosystem approach to bottom trawl impacts. *Marine Policy,* 60**,** 240-248.

WANG, N., COURTNEY, A. J., CAMPBELL, M. J. & YANG, W. H. 2020. Quantifying long-term discards from Queensland's (Australia) east Coast otter trawl fishery. *Ices Journal of Marine Science,* 77**,** 680-691.

WATSON, R. A., DREDGE, M. L. C. & MAYER, D. G. 1990. Spatial and seasonal-variation in demersal trawl fauna associated with a prawn fishery on the central Great-Barrier-Reef, Australia. *Australian Journal of Marine and Freshwater Research,* 41**,** 65-77.

WEINBERG, K. L. & KOTWICKI, S. 2008. Factors influencing net width and sea floor contact of a survey bottom trawl. *Fisheries Research,* 93**,** 265-279.

WHITE, W., PLATELL, M. & POTTER, I. 2004. Comparisons between the diets of four abundant species of elasmobranchs in a subtropical embayment: implications for resource partitioning. *Marine Biology,* 144**,** 439-448.

YE, Y. M., ALSAFFAR, A. H. & MOHAMMED, H. M. A. 2000. Bycatch and discards of the Kuwait shrimp fishery. *Fisheries Research,* 45**,** 9-19.

ZHOU, S. & SMITH, A. D. 2017. Effect of fishing intensity and selectivity on trophic structure and fishery production. *Marine Ecology Progress Series,* 585**,** 185-198.

ZHOU, S. J. & GRIFFITHS, S. P. 2008. Sustainability Assessment for Fishing Effects (SAFE): A new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. *Fisheries Research,* 91**,** 56-68.

ZHOU, S. J., GRIFFITHS, S. P. & MILLER, M. 2009. Sustainability assessment for fishing effects (SAFE) on highly diverse and data-limited fish bycatch in a tropical prawn trawl fishery. *Marine and Freshwater Research,* 60**,** 563-570.

ZHOU, S. J., SMITH, A. D. M., PUNT, A. E., RICHARDSON, A. J., GIBBS, M., FULTON, E. A., PASCOE, S., BULMAN, C., BAYLISS, P. & SAINSBURY, K. 2010. Ecosystem-based fisheries management requires a change to the selective fishing philosophy. *Proceedings of the National Academy of Sciences of the United States of America,* 107**,** 9485-9489.

APPENDICES

Appendix 1. Observer optimisation of the Ocean Trawl – prawn trawl sector (discard).

Daniel Johnson[1], Steven Candy[2] and Thomas Barnes[1]
[1]NSW Department of Primary Industries, Fisheries Resource Assessment, Port Stephens Fisheries Institute, Taylors Beach, NSW 2316
[2]SCANDY STATISTICAL MODELLING PTY LTD, 70 Burwood Drive, Blackmans Bay, TASMANIA 7052

Executive summary (non-technical summary)

The prawn trawl sector of the NSW Ocean Trawl Fishery (OTF) is characterised by relatively high discard rates for the diverse range of fish and other species caught, and negligible interactions with threatened, endangered and protected species (TEPS). In order to recommend sampling strategy for future commercial fishery observer programs (CFOP) for this fishery, historical CFOP and commercial logbook data obtained for the 2017–2019 fishing seasons were used to estimate the total number of discards over these years and estimate the precision of this estimate as a function of the number of trips observed (i.e., sampled). These estimates were obtained for commercial and non-commercial species (and species-groups) of fish, crustaceans, molluscs, and elasmobranch species. The CFOP consisted of a total of 3969.8 hours of trawls observed over 425 trips which represented a 3.6% sample of the total fishery hours trawled and a 36.4% weighted-average sample fraction of the total discarded weight of individual shots per trip. The percent coefficient of variation (%CV) for the estimates of total effort of discard number was variable between species/species groups and regions (Region 1 = Northern + Central zones and Region 2 = South zone). For example, the %CV for commercial fish species in both Region 1 (49.92) and Region 2 (74.58) was greater than the estimated %CV for combined commercial and non-commercial fish species in both regions (Region 1, 9.58; Region 2, 13.73). The estimated %CV in Region 2 for both commercial (51.04) and combined commercial and non-commercial (41.48) mollusc species was greater than both commercial (17.52) and combined commercial and non-commercial (16.93) molluscs in Region 1. In contrast, for commercial elasmobranch species, the estimated %CV in Region 1 (18.93) and Region 2 (21.44) were similar.

The analyses also compared two alternative estimators of total discards, a “direct” versus an “uncoupled” estimator, which gave mostly similar precisions but with the “uncoupled” estimator consistently more precise. The %CV for estimated total discards using the

"uncoupled" estimator is given for a range of sampling intensities (i.e., number of trips observed) for each species group.

Methods

Data

There were two sources of data used in the calculation of observer effort prioritisation. Data source one is the NSW commercial fishery observer collected information (CFOP) which includes number, weight and fate of all animals interacting with the fishing operations for each shot within each of 425 trips in the NSW CFOP (2017–2019). Shot-level weights were recorded by species at the aggregate and not individual animal level. In addition, the sampling fraction by weight for the shot where the sample weight is the sum over all species landed by the shot and the hours trawled for each shot were recorded. Data source two is the fisher reported commercial catch data for each trip over the 2017–2019 seasons, this data includes weight of retained catch (i.e., excluding discards) by species but does not include catch numbers. The hours trawled for each trip in the commercial catch data were recorded.

Analyses

Analyses were performed separately for the north and south zones because of differences in regulations relating to permitted species caught north and south of 30° 54′ S, hereafter, termed Region 1 and Region 2 (Region 1 = North + Central zones or fisher reporting Ocean Zones (OZ) 1:3 and Region 2 = South zone or OZ4:5 in other sections). There were 350 and 75 trips observed in Region 1 and Region 2, respectively. The average sample fraction of the shot-level discarded catch in terms of weight sampled was 35.81 ± 0.01% in Region 1 (range; 9.91–100%) and 39.62 ± 0.01% in Region 2 (range; 10.14–100%). Average number of total hours trawled per trip in Region 1 (9.55) was greater than the Region 2 (7.55). The hours trawled in total for the commercial fishery for 2017–2019 was 90, 910 in Region 1 and 20, 419 in Region 2 with the CFOP observing 3404.5 hours of trawling in Region 1 and 565.3 hours in Region 2 giving a sample fraction of 3.75% and 2.77% in Region 1 and Region 2, respectively.

Statistical estimation

The statistical rationale for the specific statistical methods applied is described next in general terms with the full details on the theory and statistical calculations given in the Appendices.

The first requirement is that discard rate and total discards estimates for the fishery be made in terms of counts of animals and not in terms of weights. Numbers rather than weights are required for studies of stock status, stock assessments to provide allowable catch limits, for both target and bycatch species and for studies of population dynamics with regard to threatened and endangered species. Therefore, in order to take advantage of the census provided by the commercial catch data, the total weight landed by species in this data needed to be converted to numbers.

Given an estimate of the discard proportion by species, $\hat{p}_j^{(d)}$ for species j, and over all species (using sums of number of discards and retains ignoring species) of $\hat{p}'$ as obtained from the CFOP, a "direct" estimate of the fishery total (2017–2019) number of discards is estimated as $\hat{M}' = \sum_j \frac{W_j}{\overline{w}_j^{(r)}} \hat{p}_j^{(d)} \left(1 - \hat{p}_j^{(d)}\right)^{-1} I_j + \frac{H}{h} \sum_j s_j^{(d)} \left(1 - I_j\right)$

where W_j is the total weight landed (only retains recorded) from the commercial data for species j, $\overline{w}_j^{(r)}$ is the average weight of individuals retained, I_j is an indicator variable that takes the value of 1 if the species is commercial (and is represented in the commercial dataset) and there was more than a single shot in the CFOP for which the species had a retained catch (i.e., so that the variance of $\overline{w}_j^{(r)}$ could be estimated) otherwise it takes the value zero, $s_j^{(d)}$ is the total number discarded for species j (after scaling up shot-level numbers observed by the inverse of the shot-level sample fraction) , H is the total hours trawled by the fishery in 2017–2019, and h is the total hours of trawl observed in the CFOP. It can be seen that the term $\frac{H}{h} \sum_j s_j^{(d)} \left(1 - I_j\right)$ is effectively a scaled-up CPUE estimate of fishery total discards across species for which $I_j = 0$.

An alternative "uncoupled" estimate is given by

$$\hat{M} = \hat{p}' \left[\sum_j \frac{W_j}{\overline{w}_j^{(r)}} \left(1 - \hat{p}_j^{(d)}\right)^{-1} I_j + \frac{H}{h} \sum_j s_j \left(1 - I_j\right) \right].$$

where s_j is the total number of discards and retains for this species (after scaling up to the shot total weight). This estimate (partially) uncouples the estimate of proportion of discards and the estimate of the total fishery numbers landed of both retains and discards (i.e., $\hat{S}$ as given by the term in the square brackets).

The main objective is to determine the variance of each of these estimates (and their coefficient of variance) as a function of a particular measure of sampling effort that is applicable in planning a CFOP. For this fishery a “trip” is considered to be this unit since an observer is assigned to a trip.

As in all studies of this nature certain quantities that must not depend on the number of trips and are estimated from the pilot study data (i.e., the 2017–2019 CFOP) must be assumed to take similar values in any future CFOP. In this case these include variance parameter estimates along with average hours of trawling observed per trip, average catch-per-unit effort (CPUE) of numbers of landings totalled over all species (scaled up to the shot total weight) and divided by trawl hours, the mean number of discards per trip (scaled up to the shot total weight) for non-commercial species, the (weighted) average of sampling fractions across shots, and the proportional representation (by number) of each species to the total landings where all of these quantities are estimated using the CFOP data.

It is also important in studies such as this to account for all sources of variation that contribute in a non-trivial (i.e., practically significant) way to the estimate of the precision of each of $\hat{M}$ and $\hat{M}'$. This is important to both give reliable estimates of precision as a function of number of trips observed and in allowing a valid comparison of precision between these two estimates. Investigating extra-binomial variation in the estimate of variance for both the estimates $\hat{p}_j^{(d)}$ and $\hat{p}'$ was carried out after aggregating to the trip level by using the binomial special case (i.e., beta-binomial) of the algorithm for estimating effective sample size for the Dirichlet-multinomial distribution as described by Candy (2008) which derives a scaling by an estimated overdispersion factor (see Appendix A1). If that factor is greater than 1 then there is extra-binomial variation. In addition, for each of the estimates $\hat{M}$ and $\hat{M}'$, in order to adequately estimate the variance for the particular CPUE term, all non-commercial species were aggregated into a single "non-comm" class and denoted as the last "species" (i.e., $j = J$) where by definition $s_J = s_J^{(d)}$ so that the CPUE term in this case is identical for both estimates. In order to consider if s_{kJ} (where $s_J = \sum_k^K s_{kJ}$) for the k^{th} trip is over-dispersed relative to a theoretical Poisson distribution for the s_{kJ} a Generalized Linear Mixed Model (GLMM) (Pinheiro and Bates, 2004) with Poisson error combined with a "units-level" random effect and a single intercept for the fixed effect term was fitted using the glmer function in the lme4 R-library (Bates et al., 2015). Because of this simple fixed effect model, this GLMM is equivalent to an Additive Generalized Mixed Model (AGLMM) (Candy, 2000) which is convenient since it allows a simple expression for the variance of s_J and its linear functional relationship with number of trips, K (see Appendix A2) which simplifies the relationship between %CV and $s = \sum_{j=1,k=1}^{J,K} s_{kj}$ (see Appendix A1). This relationship was linear for the estimator $\hat{M}'$ and quadratic for the estimator $\hat{M}$, which are each easily solved for a given %CV in terms of s which is then simply converted to number of trips required using average CPUE and average hours trawled per trip.

Finally, the availability of a census of an auxiliary variable such as landed and retain catch weight by (commercial) species is extremely useful in avoiding the complete reliance on scaled-up CPUE estimates (i.e., the second term in the equation for $\hat{M}'$ and the second term inside the brackets in the equation for $\hat{M}$). Given the low sampling fraction of trawl hours (i.e., h/H) of the order of 2.77 – 3.75%, exploiting a census of an auxiliary variable (i.e., total landings of retains by weight) with a strong relationship with the variable of interest (i.e., total landings discarded by number) will consistently give greater precision than an estimate that ignores this auxiliary variable (Cochran, 1977).

All data formatting, statistical summaries and mathematical operations were done in R v. 4.0.2 (R Core Team, 2022).

Results and discussion

Table A1- 1 describes the CFOP trip-level data and estimated overall proportion discards, $\hat{p}'$, and CPUE for total landings (weighted average across species for each) for each species-group's subset of the CFOP.

Tables A1- 2 to A1- 9 are summary tables for each species group of optimised sampling intensity and associated CVs estimated from the CFOP and total fishery-wide catch data for a range of proposed number of trips observed. The first row of each table corresponds to the sample intensity in terms of number of trips observed for the 2017–2019 CFOP and commercial catch census and the corresponding %CV achieved.

Tables A1- 10 and A1- 11 give estimates of fishery total landed numbers (i.e., including discards and retains), percent discards, and average weight of retains and discards per animal from the CFOP by fish species (aggregated to common names) and combined non-commercial fish species for Region 1 and Region 2, respectively.

Tables A1- 12 and A1- 13 give estimates of fishery total landings, percent discards, and average weight of retains and discards per animal from the CFOP by crustacean species (aggregated to common names) and combined non-commercial crustacean species for Region 1 and Region 2, respectively.

Tables A1- 14 and A1-15 give estimates of fishery total landings, percent discards, and average weight of retains and discards per animal from the CFOP by mollusc species (aggregated to common names) and combined non-commercial mollusc species for Region 1 and Region 2, respectively.

Tables A1- 16 and A1- 17 give estimates of fishery total landings, percent discards, and average weight of retains and discards per animal from the CFOP by elasmobranch species (aggregated to common names) and combined non-commercial elasmobranch species for Region 1 and Region 2, respectively.

Table A1- 18 gives the fishery-wide estimated number of discards from Region 1 and 2 using the estimate applied to obtain Tables 2 to 17 of $\hat{M}$ and the alternative estimate of $\hat{M}'$ (with each described in the Methods section earlier and in Appendices A1 to A1.4) for each of the species groups. The standard error of estimate and corresponding coefficient of variation for each estimate is also given. The estimate of total numbers landed, $\hat{s}$, its standard error, and %CV are also given. In addition, an estimate of the fishery-wide (Region 1) number of syngnathids (SYG_TEPS) caught is given along with %CVs estimated across a range of values for number of CFOP trips observed. The method used to estimate number of SYG_TEPS uses CFOP observed SYG_TEPS numbers as a proportion of the combined discarded number across all fish species plus SYG_TEPS numbers given by $\hat{p}_{TEPS}\hat{M}'$. The statistical estimation method is described in Appendix A1.5.

Table A1- 19 gives statistics from CFOP for the quota species for retains, discards, and the total counted including both retains and discards with statistics of the number of shots with non-zero counts, average weight (i.e., the average weight of combined retains and discards used a weighted average), standard deviation of weight (the estimate for retains is described in Appendices A1 and A1.2 denoted by $\hat{\sigma}_j$) and the CV of weight.

Table A1.20 gives the overdispersion factor estimates, $\varphi\left(\hat{\omega}_j\right)$, for each quota species and the number of trips that provided data in each case.

Table A1.1 shows that the proportion discards calculated by accumulating observed numbers of discards and retains across species within the species group for the 2017–2019 CFOP is quite precisely estimated with %CVs of estimated proportion, $\hat{p}'$, ranging from 1.25% to 16.25% for all species groups, excluding; commercial crustaceans (93.45%), commercial (50.31%) and combined commercial and non-commercial (440.71%) molluscs in Region 2. When this proportion was applied to the decoupled estimate of total landings by calculating their product (i.e., species were not matched within each component of proportion discards and total landings) giving, $\hat{M}$, the %CVs of this fishery-wide estimate over the 2017–2019 seasons was generally smaller, sometimes by a substantially amount, than the coupled and direct estimate, $\hat{M}'$, obtained by accumulating species-specific fishery-wide estimates of number of discards (Table A1- 18). The smaller %CV of the uncoupled estimate $\hat{M}$ compared to the coupled estimate $\hat{M}'$ for total discard number might seem counter-intuitive, however, after correctly accounting for all sources of variance it can be seen that the standard error of $\hat{M}'$ is not much smaller than that for the considerable larger, by a factor of approximately

$1/\left(1-\hat{p}'\right)$, estimate of total landings, $\hat{s}$, so that %CVs are consistently lower in this last case. Taking into account the relatively small %CV for overall proportion discards, $\hat{p}'$, in calculating the %CV of $\hat{M}$ explains why $\hat{M}$ is the preferred estimate, in terms of precision, and for this reason the uncoupled estimation method was used for calculating the precision for the range of sampling intensities investigated, in terms of number of trips observed (Tables 2 to 9).

Combined with the above, the species groups of commercial fish species had substantially higher %CVs for $\hat{M}$ being of the order of 49.92% and 74.58%, for Region 1 and Region 2, respectively. This can be inferred to be the result of the substantially greater between-trip variability in discarding rate for several of the most abundant commercial species, including; Eastern School Whiting and Stout Whiting (Tables A1- 10 and A1- 11). The discard proportion for the quota whiting species is likely to be driven mostly by fisher-preferences combined with between-shot average size variation which would explain the higher variability in this proportion.

The comprehensive method of accounting for all major sources of variation and developing an efficient estimator of fishery-wide discard number was only possible because of the detailed observations in the NSW observer program that included estimating the sample fraction of the shot weight counted at the shot level and counting as well as weighing all observed discards and retains by species.

References

BATES, D. M., MACHLER, M., BOLKER. B. & WALKER, S. 2015. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software* 67, 1-48.

BORGES, L., ZUUR, A. F., ROGAN E. & OFFICER, R. 2004. Optimum sampling levels in discard sampling Programs. *Canadian Journal of Fisheries and Aquatic Sciences* 61: 1918–1928.

CANDY, S. G. 2000. The application of generalized linear mixed models to multi-level sampling for insect population monitoring. *Environmental and Ecological Statistics* 7, 217-238.

CANDY, S. G. 2008. Estimation of effective sample size for catch-at-age and catch-at-length data using simulated data from the Dirichlet-multinomial distribution. *CCAMLR Science* 15, 115-138.

COCHRAN, W. G. 1977. Sampling Techniques. Third Edition. John Wiley & Sons, New York.

PINHEIRO, J. C. & BATES, D. M. 2004. *Mixed-effect Models in S and S-PLUS*. Springer, New York.

R CORE TEAM. 2022. R*:* A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

SEBER, G. A. F. 1982. The estimation of animal abundance and related parameters, Edn. 2.Charles Griffin, London (see supplementary section)

Figures and tables

Table A1- 1 CFOP trip-level results.

Species subset	Proportion discards (% CV)[1]	CPUE[2] (no. per hr)
Region 1		
Fish – commercial	0.46 (10.36)	255.63
Fish – all species	0.91 (1.25)	1499.80
Crustacean – commercial	0.10 (3.75)	350.94
Crustacean – all species	0.23 (4.58)	413.19
Mollusc – commercial	0.16 (16.25)	34.64
Mollusc – all species	0.16 (15.65)	35.00
Elasmobranch – commercial	0.91 (10.38)	6.22
Elasmobranch – all species	0.94 (1.83)	8.72
Region 2		
Fish – commercial	0.96 (2.46)	57.55
Fish – all species	0.99 (0.25)	555.98
Crustacean – commercial	0.02 (93.45)	682.20
Crustacean – all species	0.32 (16.93)	980.43
Mollusc – commercial	0.14 (50.31)	23.00
Mollusc – all species	0.19 (40.71)	24.42
Elasmobranch – commercial	0.79 (8.73)	7.72
Elasmobranch – all species	0.89 (4.53)	14.08

[1] Discard proportion from CFOP.

[2] Combined discard and retain number in CFOP.

Table A1- 2 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for commercial fish (see Tables A1- 10 and A1- 11).

% CV	Number of fish in the CFOP	CFOP trips	CFOP discard
Region 1			
49.92	855052	350	389045
5	84375420	34538	38390455
10	21100445	8637	9600612
15	9382853	3841	4269158
20	5281691	2162	2403147
25	3383434	1385	1539448
30	2352276	963	1070275
35	1730515	708	787377
Region 2			
74.58	32165	74	30847
5	7151426	16453	6858388
10	1787871	4113	1714611
15	794620	1828	762060
20	446982	1028	428667
25	286076	658	274353
30	198670	457	190529
35	145967	336	139985

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 3 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for combined commercial and non-commercial fish (see tables A1-10 and A1- 11).

% CV	Number of fish in the CFOP	CFOP trips	CFOP discard
Region 1			
9.58	5016610	350	4550603
5	18424511	1285	16713007
10	4606707	321	4178777
15	2047854	143	1857623
20	1152256	80	1045219
25	737721	51	669192
30	512542	36	464930
35	376766	26	341767
Region 2			
13.73	310719	74	309401
5	2343309	558	2333369
10	585829	140	583344
15	260369	62	259265
20	146459	35	145837
25	93734	22	93337
30	65094	16	64818
35	47825	11	47622

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 4 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for commercial crustaceans (see Tables A1- 12 and A1- 13).

% CV	Number of crustaceans in the CFOP	CFOP trips	CFOP discard
Region 1			
9.02	1173841	350	113026
5	3814603	1137	367298
10	954484	285	91905
15	424831	127	40906
20	239451	71	23056
25	153645	46	14794
30	107032	32	10306
35	78924	24	7599
Region 2			
93.60	385646	75	8345
5	134934795	26242	2919856
10	33734131	6561	729973
15	14993267	2916	324440
20	8433965	1640	182503
25	5397945	1050	116806
30	3748749	729	81119
35	2754336	536	59601

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 5 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for combined commercial and non-commercial crustaceans (see Tables A1- 12 and A1 -13).

% CV	Number of crustaceans in the CFOP	CFOP trips	CFOP discard
Region 1			
5.38	1382053	350	321238
5	1602133	406	372392
10	401131	102	93237
15	178721	45	41541
20	100876	26	23447
25	64842	16	15072
30	45266	11	10521
35	33460	8	7777
Region 2			
17.68	554238	75	176937
5	6916019	936	2207896
10	1729971	234	552282
15	769591	104	245687
20	433457	59	138378
25	277873	38	88709
30	193357	26	61728
35	142395	19	45459

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 6 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for commercial molluscs (see Tables A1- 14 and A1- 15).

% CV	Number of molluscs in the CFOP	CFOP trips	CFOP discard
Region 1			
17.52	115867	350	18008
5	1418617	4285	220481
10	354968	1072	55169
15	157996	477	24556
20	89055	269	13841
25	57144	173	8881
30	39810	120	6187
35	29356	89	4563
Region 2			
51.04	13002	75	1832
5	1346923	7770	189783
10	336787	1943	47454
15	149725	864	21096
20	84253	486	11871
25	53949	311	7601
30	37487	216	5282
35	27561	159	3883

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 7 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total data for combined commercial and non-commercial molluscs(see Tables A1- 14 and A1- 15).

% CV	Number of molluscs in the CFOP	CFOP trips	CFOP discard
Region 1			
16.93	117082	350	19223
5	1338779	4002	219806
10	335003	1001	55002
15	149118	446	24483
20	84057	251	13801
25	53943	161	8857
30	37584	112	6171
35	27719	83	4551
Region 2			
41.48	13805	75	2635
5	945253	5135	180423
10	236368	1284	45116
15	105093	571	20059
20	59146	321	11289
25	37880	206	7230
30	26328	143	5025
35	19362	105	3696

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 8 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for commercial elasmobranchs (see Tables A1- 16 and A1- 17).

% CV	Number of elasmobranchs in the CFOP	CFOP trips	CFOP discard
Region 1			
18.93	16842	286	15386
5	241193	4096	220342
10	60307	1024	55093
15	26809	455	24492
20	15085	256	13781
25	9658	164	8823
30	6711	114	6130
35	4933	84	4507
Region 2			
21.44	4123	71	3260
5	75329	1297	59562
10	18852	325	14906
15	8393	145	6636
20	4733	81	3742
25	3038	52	2402
30	2118	36	1674
35	1563	27	1236

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 9 Summary table of optimised sampling intensity and associated CVs estimated from the CFOP and total catch data for combined commercial and non-commercial elasmobranchs (see Tables A1- 16 and A1- 17).

% CV	Number of elasmobranchs in the CFOP	CFOP trips	CFOP discard
Region 1			
14.13	23632	286	22176
5	188698	2284	177072
10	47180	571	44273
15	20973	254	19681
20	11801	143	11074
25	7555	91	7090
30	5249	64	4926
35	3859	47	3621
Region 2			
9.88	7520	71	6657
5	29298	277	25936
10	7334	69	6492
15	3266	31	2891
20	1842	17	1631
25	1183	11	1048
30	825	8	731
35	610	6	540

CFOP trips – Estimate of equivalent number of trips (biannual) of observer coverage corresponding to CFOP discard. CFOP discard – Observer program recorded discards.

Table A1- 10 Region 1 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by fish species (aggregated to common names) and combined non-commercial species (subset of 20 greatest by number landed shown).

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Non-commercial spp.	111126372	100.0	0.000	NA
Eastern School Whiting[1]	12874369	34.4	0.072	0.057
Slender Flounder	3499060	99.3	0.216	0.071
Common Silverbiddy	3140864	99.1	0.099	0.072
Stout Whiting[1]	2724704	36.3	0.067	0.045
Yellowtail Scad[2]	1211641	61.3	0.091	0.087
Soles	762823	96.8	0.116	0.05
Bluespotted Flathead[1]	483430	68.1	0.370	0.189
Goatfishes	216504	13.8	0.111	0.086
Fourline Striped Grunter	215194	95.7	0.068	0.074
Lemon Tongue Sole	180302	60.0	0.120	0.069
Ocean Jacket	29845	53.9	0.579	0.302
Marbled Flathead	28274	95.8	0.333	0.122
Pearl Perch	26630	99.5	1.494	0.056
John Dory	16535	88.6	0.311	0.064
Tailor	9727	99.3	0.226	0.205
Snapper	9194	93.4	1.464	0.130
Tiger Flathead[1]	8066	82.8	0.373	0.148
Flutemouthes	7660	97.7	0.322	0.105
Teraglin	6649	99.2	0.935	0.249

[1]Quota-managed NSW Ocean Trawl Fishery

[2] Quota-managed NSW Ocean Haul Fishery

NA - not calculated

Table A1- 11 Region 2 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by fish species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	%Discard	CFOP average weight (kg)	
			Retained	Discarded
Non-commercial spp.	10128396	99.3	0.000	NA
Eastern School Whiting[1]	3702862	69.1	0.048	0.024
Yellowtail Scad[2]	1308910	94.6	0.081	0.064
Tiger Flathead[1]	216037	100.0	0.000	0.253
Stout Whiting[1]	201559	6.3	0.047	0.015
Bluespotted Flathead[1]	63500	100.0	0.000	0.315
Blue Mackerel[2]	42780	98.9	0.091	0.101
Redfish	36446	100.0	0.000	0.068
Ocean Jacket	35123	97.4	0.270	0.125
Australian Sardine[2]	34712	100.0	0.000	0.058
Slender Flounder	26801	100.0	0.000	0.017
Goatfishes	23592	40.3	0.112	0.085
John Dory	20628	97.3	0.408	0.072
Striped Trumpeter	12100	100.0	0.000	0.056
Stargazers	11522	99.7	1.500	0.240
Largehead Hairtail	9830	89.5	1.340	0.148
Pikes	5021	100.0	0.000	0.121
Reef Ocean Perch	4876	100.0	0.000	0.036
Eastern Scorpionfish	3142	100.0	0.000	0.065
Dusky Flathead	2601	100.0	0.000	0.737
Lizardfishes	2095	100.0	0.000	0.037
Flutemouthes	614	100.0	0.000	0.070
Soles	361	0.0	0.200	0.000

Common Names	Estimated total numbers landed 2017–2019	%Discard	CFOP average weight (kg)	
			Retained	Discarded
Red Gurnard	322	47.4	0.414	0.222
Mulloway	289	100.0	0.000	0.994
Latchet	244	99.4	0.891	0.357
Tarwhine	217	100.0	0.000	0.073
Gemfish[3]	108	0.0	0.400	0.000
Grey Morwong	108	100.0	0.000	0.020
Silver Trevally[1]	108	100.0	0.000	0.297
Common Silverbiddy	72	100.0	0.000	0.065

[1]Quota-managed NSW Ocean Trawl Fishery

[2] Quota-managed NSW Ocean Haul Fishery

[3] Quota-managed NSW Ocean Trap and Line Fishery

NA - not calculated

Table A1- 12 Region 1 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by crustacean species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Eastern King Prawn	21753321	0.0*	0.046	0.061
Non-commercial spp.	5559899	100.0	0.000	NA
Bugs	2165859	77.5	0.147	0.053
Eastern School Prawn	1304485	72.4	0.010	0.007
Mantis Shrimps	164987	95.2	0.045	0.039
Brown Tiger Prawn	110933	1.2	0.061	0.055
Blue Swimmer Crab	38211	47.3	0.358	0.272
Coral Crab	8129	91.7	0.366	0.092
Giant Scarlet Prawn	1860	18.4	0.233	0.159
Eastern Rock Lobster	1282	100.0	0.000	1.490

*<0.01%, NA – not calculated

Table A1- 13 Region 2 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by crustacean species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Eastern King Prawn	7977337	0.5	0.021	0.013
Non-commercial spp.	6167375	98.7	0.000	NA
Australian Rose Prawn	776129	69.3	0.016	0.007
Bugs	145520	53.8	0.128	0.078
Coral Crab	43481	14.3	0.087	0.041
Mantis Shrimps	38902	99.7	0.100	0.040
Blue Swimmer Crab	13573	64.8	0.347	0.260

NA – not calculated

Table A1- 14 Region 1 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by mollusc species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Octopuses	1292284	2.8	0.129	0.066
Cuttlefishes	1258920	28.5	0.099	0.044
Gould's Squid	84097	2.7	0.158	0.072
Non-commercial spp.	32444	100.0	0.000	NA
Loligo Squids	26440	12.4	0.130	0.095
Scallops	22743	93.5	0.096	0.044
Southern Calamari	6031	0.0	0.215	0.000
Pinstripe Bottletail Squid	4860	100.0	0.000	0.035
Volutes	4403	21.6	1.179	0.517
Luminous Bay Squid	214	100.0	0.000	0.108

NA – not calculated

Table A1- 15 Region 2 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by mollusc species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Octopuses	495255	4.8	0.127	0.061
Non-commercial spp.	34423	84.3	0.000	0.000
Cuttlefishes	131869	23.3	0.122	0.077
Loligo Squids	9017	1.4	0.072	0.083
Southern Calamari	5624	6.9	0.172	0.119
Gould's Squid	3635	69.6	0.142	0.072

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Volutes	934	75.8	2.433	0.424

Table A1- 16 Region 1 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by elasmobranch species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	% Discard	CFOP average weight (kg)	
			Retained	Discarded
Stingarees	260595	100.0	0.000	0.294
Eastern Fiddler Ray	186821	91.4	0.928	0.638
Non-commercial spp.	181314	100.0	0.000	NA
Eastern Shovelnose Ray	58137	80.2	1.031	0.368
Gummy Shark	10081	49.7	1.761	0.458
Wobbegongs	5020	98.9	15.730	1.932
Sawsharks	1606	86.0	0.850	0.490
Angelsharks	1055	59.2	15.383	1.433
Whaler Sharks	602	0.0	5.132	0.000
School Shark	531	0.0	2.081	0.000
Dogfishes	381	78.9	0.777	0.518
Australian Blacktip Shark	351	0.0	10.800	0.000
Ghostsharks	287	46.0	1.587	1.273
Tiger Shark	39	25.0	49.333	45.000
Sandbar Shark	27	0.0	6.000	0.000
Guitarfishes	20	0.0	24.083	0.000

NA – not calculated

Table A1- 17 Region 2 estimates of total landings, percent discards, and average weight of retains and discards per animal from the CFOP by elasmobranch species (aggregated to common names) and combined non-commercial species.

Common Names	Estimated total numbers landed 2017–2019	%Discard	CFOP average weight (kg)	
			Retained	Discarded
Non-commercial spp.	118769	98.549	NA	NA
Eastern Shovelnose Ray	31258	68.526	0.969	0.753
Stingarees	21810	100.000	NA	0.418
Eastern Fiddler Ray	11823	88.062	1.184	0.899
Wobbegongs	881	61.538	11.972	5.600
Angelsharks	772	38.000	4.558	0.712
Sawsharks	241	85.714	0.800	0.195
Whaler Sharks	34	0.000	100.000	NA

NA – not calculated

Table A1- 18 Estimated number of discards in Region 1 and Region 2 using $\hat{M}$ or $\hat{M}'$

Species subset	Estimated total fishery discards (2017–2019) (SE)			
	$\hat{M}$	$\hat{M}'$	%CV $\hat{M}$	%CV $\hat{M}'$
Region 1				
Fish commercial	11647023 (5814270)	14345260 (12416050)	49.92	86.55
Fish non-commercial	124023746 (11884800)	125471600 (12971990)	9.58	10.34
Crustacean commercial	2460069 (221809)	2810791 (713551)	9.02	25.39
Crustacean non-commercial	7230867 (389282)	8370690 (751740)	5.38	8.98
Mollusc commercial	419631 (73538)	428052 (105001)	17.52	24.53
Mollusc non-commercial	448622 (75972)	460496 (105088)	16.93	22.82
Elasmobranch commercial	480119 (90874)	490370 (97700)	18.93	19.92
Elasmobranch non-commercial	663316 (93732)	671684 (98237)	14.13	14.63
Region 2				
Fish commercial	1767321 (1318018)	1753831 (1369463)	74.58	78.08
Fish non-commercial	11392070 (1564245)	11351600 (1567408)	13.73	13.81
Crustacean commercial	194603 (182142)	711718 (225558)	93.60	31.69
Crustacean non-commercial	4725478 (835526)	6520670 (696358)	17.68	10.68
Mollusc commercial	91069 (46477)	58026 (41111)	51.04	70.85
Mollusc non-commercial	128649 (53365)	85694 (41311)	41.48	48.21
Elasmobranch commercial	52833 (11325)	54683 (12967)	21.44	23.71
Elasmobranch non-commercial	162765 (16073)	171730 (16111)	9.88	9.38

Table A1- 19 Statistics from CFOP for quota species for retains, discards, and the total counted including both retains and discards with statistics of the number of shots with non-zero counts, average weight (i.e., the average weight of combined retains and discards used a weighted average), standard deviation of weight (i.e., the estimate for retains is described in Appendices A1 and A2 denoted by $\hat{\sigma}_j$) and the CV of weight.

Species	No. shots[1] (Count > 0)			Total no. Counted[2]			Average weight (kg)			SD[3] of weight (kg)			CV (SD/Average)		
	D	R	D+R	D	R	D+R	D	R	D+R	D	R	D+R	D	R	D+R
Region 1															
Eastern School Whiting	285	454	589	31820	66176	97996	0.057	0.072	0.066	0.041	0.081	0.069	0.708	1.132	1.039
Stout Whiting	173	328	481	32624	50652	83276	0.045	0.067	0.059	0.018	0.057	0.048	0.407	0.844	0.812
Bluespotted Flathead	648	820	915	5380	3171	8551	0.189	0.370	0.247	0.117	0.254	0.205	0.616	0.685	0.829
Tiger Flathead	27	18	43	107	33	140	0.148	0.373	0.238	0.050	0.095	0.131	0.334	0.256	0.552
Silver Trevally	5	1	6	16	1	17	0.120	0.087	0.115	0.061	NA	0.056	0.509	NA	0.492
Yellowtail Scad[4]	478	162	627	24516	16440	40956	0.087	0.091	0.088	0.045	0.055	0.048	0.520	0.603	0.543
Gemfish[5]	11	12	22	29	111	140	0.544	0.635	0.591	0.290	0.595	0.467	0.534	0.938	0.789
Region 2															
Eastern School Whiting	115	23	129	5564	902	6466	0.024	0.048	0.028	0.024	0.048	0.028	0.493	0.611	0.652
Stout Whiting	4	9	13	114	904	1018	0.015	0.047	0.037	0.015	0.047	0.037	0.500	0.070	0.441
Bluespotted Flathead	116	0	116	612	0	612	0.315	NA	0.315	0.315	NA	0.315	0.377	NA	0.377
Tiger Flathead	145	0	145	2150	0	2150	0.253	0.350	0.254	0.253	NA	0.254	0.436	NA	0.435
Silver Trevally	1	0	1	1	0	1	0.297	NA	0.297	NA	NA	NA	NA	NA	0.297
Yellowtail Scad[4]	120	4	123	3741	360	4101	0.064	0.081	0.065	0.064	0.081	0.065	0.594	0.469	0.588

Species	No. shots[1] (Count > 0)			Total no. Counted[2]			Average weight (kg)			SD[3] of weight (kg)			CV (SD/Average)		
	D	R	D+R	D	R	D+R	D	R	D+R	D	R	D+R	D	R	D+R
Gemfish[5]	0	1	1	0	1	1	NA	0.400	0.400	NA	NA	NA	NA	NA	NA
Blue Mackerel[4]	22	5	27	380	12	392	0.101	0.091	0.099	0.101	0.091	0.099	0.554	0.143	0.511

1. Number of shots for which the count of discards (D), retains (R), or total landings (D+R) that were non-zero
2. Total estimated number counted before scaling up to total catch for each shot. Estimates based on sample weight converted to counts based on subsample of counted and weighed individuals either at the shot level or combined across shots
3. Standard deviation of weight ($\hat{\sigma}_j$ for discards, see Appendix 1).
4. Quota-managed NSW Ocean Haul Fishery
5. Quota-managed NSW Ocean Trap and Line Fishery

NA – not calculated

Appendix A1.1: Supplementary section

Notation and statistical methods

Definitions:

H : *(H) total fishing effort measured as total hours trawled (September 2017 – August 2019)*

h : *(h) total fishing effort measured as total hours trawled sampled in CFOP (September 2017 – August 2019)*

T : *(T) total fishing effort measured as total trips*

t : *(t) total fishing effort measured as total trips in CFOP*

h_i : *(h_i) total hours trawled for the i^{th} trip sampled in CFOP (September 2017 – August 2019)*

$f_k^{(r)}$: *(fr_k) unscaled number caught and retained for trip k for the CFOP totalled across all species caught on the i^{th} shot ($f_k^{(r)} = \sum_{i \in k} \frac{w_i^{(t_r)}}{W_i^{(t_r)}} \sum_{j=1}^{J} s_{ij}^{(r)}$) where $i \in k$ denotes that the i^{th} shot occurred within the k^{th} trip*

$f_k^{(d)}$: *(fd_k) unscaled number caught and discarded for trip k for the CFOP totalled across all species caught on the i^{th} shot within the k^{th} trip ($f_k^{(d)} = \sum_{i \in k} \frac{w_i^{(t_d)}}{W_i^{(t_d)}} \sum_{j=1}^{J} s_{ij}^{(d)}$).*

f_k : *(f_k) unscaled total caught* $f_k^{(r)} + f_k^{(d)}$

$n_j^{(r)}$: *(n) number of shot for the CFOP with retained numbers for species j greater than zero.*

n : *(n) number of shots for the CFOP*

K : *(K) number of trips for the CFOP*

$s_{ij}^{(d)}$: *(s_d_j) number caught for species j in shot i that was discarded ($f_{ij}^{(d)}$) scaled up to total catch weight (i.e., discards only) during CFOP. Scaling gives* $s_{ij}^{(d)} = f_{ij}^{(d)} W_i^{(t_d)} / w_i^{(t_d)}$

$s_{kJ}^{(d)}$: *(s_d_Jk) number caught and discarded on CFOP trip for k and "species" J (non-commercial) scaled up to correspond to total catch weight for each shot within trip k (i.e.,* $s_{kJ}^{(d)} = \sum_{i \in k}^{n} s_{iJ}^{(d)}$ *)*

$s_J^{(d)}$: *(s_d_J) number caught and discarded over all CFOP trips for "species" J where this "species" is an amalgamation of all species not recorded with a catch in the commercial logbook dataset (i.e., species="non-commercial") so that* $s_J^{(d)} = \sum_{k=1}^{K} s_{kJ}^{(d)}$ *and for all intents and purposes it can be assumed that total retains for non-commercial species is zero (i.e.,* $s_J^{(r)} \equiv 0$*)*

$s_{ij}^{(r)}$: *(s_r_j) number caught for species j in shot i that was retained (* $f_{ij}^{(r)}$ *) scaled up to total catch weight (i.e., retains only) during CFOP. Scaling gives* $s_{ij}^{(r)} = f_{ij}^{(r)} W_i^{(t_r)} / w_i^{(t_r)}$

$w_{ij}^{(r)}$: *(w_r_ij) weight caught for species j in shot i that was retained (*$W_{ij}^{(r)}$*) scaled up to total catch weight (i.e., retains only) during CFOP. Scaling gives* $w_{ij}^{(r)} = W_{ij}^{(r)} W_i^{(t_r)} / w_i^{(t_r)}$

$\overline{w}'_j$: *(w_mean_j) mean weight of species j in catch during CFOP (sum of both discarded and retained total weight divided by total number caught)*

σ_j^2: *variance of weights of species j retained in catch during CFOP*

$\hat{\sigma}_j^2$: *(var_est_j) sample estimate of variance of weights of species j retained in catch during CFOP*

$\overline{w}_j^{(r)}$: *(w_mean_r_j) weighted mean weight of retains of species j in catch during CFOP=*

$$\overline{w}_j^{(r)} = \sum_{i=1}^{n} w_{ij}^{(r)} / \sum_{i=1}^{n} s_{ij}^{(r)}$$

$w_i^{(t_r)}$: *(w_tr_i) weight of retained catch from shot i sampled in CFOP*

$W_i^{(t_r)}$: *(W_tr_i) total retained weight of catch for shot i in CFOP*

$w_i^{(t_d)}$: *(w_td_i) weight of discarded catch from shot i sampled in CFOP*

$W_i^{(t_d)}$: *(W_td_i) total discarded weight of catch for shot i in CFOP*

$\overline{F}^{(t)}$: *(Shot_Sample_frac) weighted-average sampling fraction by weight summed across discards and retains for CFOP* $\sum_{i=1}^{n}\left(w_i^{(t_r)} + w_i^{(t_d)}\right) / \sum_{i=1}^{n}\left(W_i^{(t_r)} + W_i^{(t_d)}\right)$

W_j: *(W_j) total weight of species j in catch (i.e., retains only) by fishery in years 2014-2016*

c_j: *(c_j) average CPUE per species (catch number per hour trawled)*

$$\sum_{i=1}^{n}\left(s_{ij}^{(r)} + s_{ij}^{(d)}\right) / \sum_{i=1}^{n} h_i$$

c: *(c) average CPUE (total all species) (catch number per hour trawled)*

$$\sum_{j=1}^{J}\sum_{i=1}^{n}\left(s_{ij}^{(r)}+s_{ij}^{(d)}\right)/\sum_{i=1}^{n}h_i$$

$\hat{S}$: *(S) estimated total catch numbers (i.e., including retains and discards) by fishery*

P' : *Proportion of all species caught in fishery that were discards*

$\hat{p}'$: *(p_dash_est) estimate of* P'

$P_j^{(d)}$: *Proportion of numbers caught in fishery of species j that were discards*

$\hat{p}_j^{(d)}$: *(p_dash_est) estimate of* $P_j^{(d)}$

M : *Number of discards in fishery (2014-2016)*

$\hat{M}$: *(M_est) Estimate of* M

$SE_{\hat{M}}$: *(SE_M_est) Estimate of the standard error of* $\hat{M}$

$CV_{\hat{M}}$: *(CV_M_est) Estimate of CV of* $\hat{M}$

$\hat{T}^{(tCV)}$: *(T) Estimate of number of observer days by fishery for a given stratum (North/Central vs South regions) to obtain target CV for* $\hat{M}$

1.1 Estimating total discards by commercial fishing aggregated across regions

$$\hat{M} = \hat{p}'\hat{S} \qquad (1.1)$$

$$\hat{p}' = \frac{1}{\sum_{i,j}\left(s_{ij}^{(r)}+s_{ij}^{(d)}\right)}\sum_{i,j}s_{ij}^{(d)} \qquad (1.2)$$

$$s_j^{(r)} = \sum_i s_{ij}^{(r)} \quad , \quad s_j^{(d)} = \sum_i s_{ij}^{(d)}$$

$$\hat{S} = \sum_j \frac{W_j}{\overline{w}_j^{(r)}}\left(1-\hat{p}_j^{(d)}\right)^{-1} I_j + \frac{H}{h}\sum_j s_j^{(d)}\left(1-I_j\right) \qquad (1.3)$$

where

$$I_j = 1; \quad s_j^{(r)} > 0$$
$$= 0; \quad s_j^{(r)} = 0 \;\; or \;\; \mathrm{var}\left(\overline{x}_j^{(r)}\right) = 0$$

$$s_j = s_j^{(r)} + s_j^{(d)}$$

$$s = \sum_j s_j$$

$$\hat{p}_j^{(d)} = \frac{\sum_i s_{ij}^{(d)}}{\sum_i \left(s_{ij}^{(d)} + s_{ij}^{(r)} \right)}.$$

An alternative estimate of M is

$$\hat{M}' = \sum_j \frac{W_j}{\overline{w}_j^{(r)}} \hat{p}_j^{(d)} \left(1 - \hat{p}_j^{(d)}\right)^{-1} I_j + \frac{H}{h} \sum_j s_j^{(d)} \left(1 - I_j\right) \qquad (1.4)$$

Which uses the species-specific proportion retains, $\hat{p}_j^{(d)}$, rather than a total across species, $\hat{p}'$, as in Equation (1.1).

1.2 Estimating CV of total discards by commercial fishing aggregated across regions

The standard error of the estimate of total discards for region r is given by

$$SE_{\hat{M}} = \left[\operatorname{var}(\hat{p}') S^2 + \left\{ P'^2 \operatorname{var}\left(\hat{S}\right) \right\} + \operatorname{var}(\hat{p}') \operatorname{var}\left(\hat{S}\right) \right]^{\frac{1}{2}} \qquad (2.1)$$

, since $\hat{p}'$ and $\hat{s}$ are independent. Further, assuming a beta-binomial distribution as a special case of the Dirichlet-multinomial used in Candy (2008) for $s^{(d)}$ conditional on s and S, then

$$\operatorname{var}(\hat{p}') = P'(1 - P')\varphi(\omega) / \sum_{k=1}^{K} f_k \qquad (2.2)$$

$$\varphi(\omega) = \left(\frac{1}{n\overline{f}} \sum_{k=1}^{K} f_k^2 + \omega \right) (1 + \omega)^{-1}$$

$$\mathrm{v}(\hat{p}') = \hat{p}'(1 - \hat{p}')\varphi(\hat{\omega}) / \sum_{k=1}^{K} f_k$$

where

$$\overline{f} = \frac{1}{K} \sum_{k=1}^{K} f_k .$$

For the OTFN (Johnson et al., 2021) discard proportions the $\hat{\omega}$ is the overdispersion parameter estimate obtained by profile maximum likelihood estimation and $s / \hat{\omega}$ is the corresponding estimate of effective sample size (Candy, 2008). However, in the OTFN CFOP the sampling *fraction was the same for discards as retains since one bulk weight subsample,* $W_i^{(t)}$*, was taken for each shot so that the expected sampling fractions are equal so that* $E\left\{w_i^{(t_r)}/\left[\left(1-p'\right)W_i^{(t)}\right]\right\}=E\left\{w_i^{(t_d)}/\left(p'W_i^{(t)}\right)\right\}$*. However, when* $E\left\{w_i^{(t_r)}/W_i^{(t_r)}\right\}\neq E\left\{w_i^{(t_d)}/W_i^{(t_d)}\right\}$ *then estimation of* ω *and species-specific* ω_j *(see below) becomes considerably more complex since sampling for discards relative to retains is no longer equal probability selection of individuals that are then determined to be either discarded of retained but sampling is response-biased (Candy 2007, Chen 2001, Pfeffermann et al. 1998) whereby the binary response (discard, retain) has different selection probabilities for each value of the response variable. How this was dealt with is described in Appendix A1.4.*

Expressing $\mathrm{v}\left(\hat{p}'\right)$ *as a function of within-shot sampling fraction gives*

$$\mathrm{v}\left(\hat{p}'\right)=\hat{p}'\left(1-\hat{p}'\right)\varphi\left(\hat{\omega}\right)\left(s\bar{F}^{(t)}\right)^{-1}$$

where

$$\bar{F}^{(t)}=\sum_{i=1}^{n}\left(w_i^{(t_r)}+w_i^{(t_d)}\right)/\sum_{i=1}^{n}\left(W_i^{(t_r)}+W_i^{(t_d)}\right)$$

The estimate $\mathrm{v}\left(\hat{p}'\right)$ *is a close to unbiased as an estimate of* $\mathrm{var}\left(\hat{p}'\right)$ *since Eqn (2.1) is derived from a 1st order Taylor series approximation with higher order terms equal to zero and* $\hat{s}$ *should be close to its expectation* S*. Further,*

$$\mathrm{var}\left(\hat{S}\right)=\sum_j\left[I_j\left(\frac{W_j}{E\left(\bar{w}_j^{(r)}\right)}\right)^2\left\{\frac{\varphi\left(\omega_j\right)P_j^{(d)}}{\bar{F}^{(t)}s_j(1-P_j^{(d)})^3}+\frac{n_j^{(r)}\sigma_j^2P_j^{(d)2}}{\bar{F}^{(t)}s_j^{(r)}E\left(\bar{w}_j^{(r)}\right)^2(1-P_j^{(d)})^2}\right\}\right]+\sum_{j=1}^{J-1}\left[\left(1-I_j\right)\frac{H^2}{h^2}E\left(s_j\right)\right]+\left[\left(1-I_J\right)\frac{H^2}{h^2}\left\{1+\theta_J^2\mu\right\}E\left(s_J\right)\right] \tag{2.3}$$

Equation (2.3) employs the exact formula for the variance of the ratio, with $\bar{w}_j^{(r)}$ *as the denominator and* $(1-\hat{p}_j^{(d)})^{-1}$ *as the numerator, assuming these two random quantities are independent. However, the variance of* $(1-\hat{p}_j^{(d)})^{-1}$ *employed in Equation (2.3) is based on a 1st Order Taylor series approximation. Interestingly, the variance of* $(1-\hat{p}_j^{(d)})^{-1}$ *is the same as* *that for* $\hat{p}_j^{(d)}(1-\hat{p}_j^{(d)})^{-1}$ *. based on a 1st order, or any higher order Taylor series expansion, since their first derivatives are the same. This is relevant for the calculating the variance of the estimator* $\hat{M}'$ *, described below, since* $\hat{M}'$ *employs* $\hat{p}_j^{(d)}(1-\hat{p}_j^{(d)})^{-1}$ *in its calculation as seen in Equation (1.4).*

The term $\left\{1+\theta_J^2\mu\right\}E\left(s_J\right)$ *in Eqn (2.3) is the assumed variance at the trip level of the number of non-commercial species (within the species group considered e.g., all fish species, elasmobranch species, etc) caught and assumed all discarded. The justification for this formula, based on an over-dispersed Poisson distribution, and the corresponding sample estimate, when scaled up by total fishing effort, as given by the last term in Equation (2.4) below is given in Appendix A1.2. The estimate* $\mathrm{v}\left(\hat{S}\right)$ *below is close to an unbiased estimate of* $\mathrm{var}\left(\hat{S}\right)$ *where*

$$\mathrm{v}\left(\hat{S}\right)=\frac{1}{s}\sum_{j=1}^{J} I_j\left(\frac{W_j}{\bar{w}_j^{(r)}}\right)^2 \frac{\left\{\varphi\left(\hat{\omega}_j\right)\hat{p}_j^{(d)}+\bar{s}_j^{(r)}\left(\hat{\sigma}_j^2/\bar{w}_j^{(r)}\right)^2\left(1+\left(1-\bar{f}_j^{(r)}e^{-\bar{f}_j^{(r)}}\right)/\bar{f}_j^{(r)}\right)\right\}}{\bar{F}^{(t)}q_j(1-\hat{p}_j^{(d)})^3} + \frac{1}{s}\sum_{j=1}^{J-1}\left(1-I_j\right)H^2\frac{c_j^2}{q_j} + \frac{1}{s}\left(1-I_J\right)\left\{1+\hat{\theta}_J^2\bar{s}_J^{(d)}\right\}H^2\frac{c_J^2}{q_J} \qquad (2.4)$$

and where $s_j=q_js$ *(i.e.,* $q_j=s_j/\sum_{j=1}^{J-1}s_j$ *),* $c_j=s_j/h$ *is the estimated catch-per-unit effort of catch (i.e., retains and discards combined) of species j and* $\bar{s}_J^{(d)}=s_J^{(d)}/K=s_J/K$ *. The species-specific estimate of the overdispersion factor,* $\varphi\left(\hat{\omega}_j\right)$*, was obtained using the same method as that used to obtain the overall estimate* $\varphi\left(\hat{\omega}\right)$ *described above but estimated from the number of retains and discards observed totalled to the trip level for species j. In order to obtain reliable estimates only species for which there were at least 20 trips with the total of discards and retains greater than zero was* $\varphi\left(\hat{\omega}_j\right)$ *obtained, otherwise the estimate was set a priori to 1.0. The effect of this constraint on estimates* $\varphi\left(\hat{\omega}_j\right)$ *was investigated (see Results). The commercial species for which* $I_j=0$ *due to* $\mathrm{var}\left(\bar{x}_j^{(r)}\right)=0$ *as a result of less than a minimum of 2 shots in the CFOP recording retains for these species (see below) then because of the corresponding very low incidence of capture so that the values of* s_j *were relatively very small leaving this leaves little room for overdispersion; therefore, a theoretical Poisson was* *applied to obtain the corresponding component of the estimate of variance of* $\mathrm{v}\left(\hat{S}\right)$ *given by*

$$\frac{1}{s}\sum_{j=1}^{J-1}\left(1-I_j\right)H^2\frac{c_j^2}{q_j}.$$

Additionally,

$\hat{\sigma}_j^2=\sum_{i=1}^{n}I_{ij}^{(r)}\left(\widehat{w}_{ij}^{(r)}-\overline{w}_j^{(r)}\right)^2/\left(n_j^{(r)}-1\right)$ *for* $n_j^{(r)}>1$, *and* $\hat{\sigma}_j^2\equiv 0$ *for* $n_j^{(r)}<2$,

$\widehat{w}_{ij}^{(r)}=W_{ij}^{(r)}/f_{ij}^{(r)}$, $n_j^{(r)}=\sum_i^n I_{ij}^{(r)}$ *where* $I_{ij}^{(r)}=1, f_{ij}^{(r)}>0; I_{ij}^{(r)}=0, f_{ij}^{(r)}=0$, $\overline{f}_j^{(r)}=\sum_{i=1}^{n}f_{ij}^{(r)}/n_j^{(r)}$

where $f_{ij}^{(r)}$ *is the number of retained catch for species j and shot i and n is the number of shots observed in the CFOP.*

The justification for the approximate estimate of $Var\left(\overline{w}_j^{(r)}\right)$ *given by*

$$v\left(\overline{w}_j^{(r)}\right)=\frac{\overline{s}_j^{(r)}\hat{\sigma}_j^2\left[1+\left(1-\overline{f}_j^{(r)}e^{-\overline{f}_j^{(r)}}\right)/\overline{f}_j^{(r)}\right]}{s\,q_j(1-\hat{p}_j^{(d)})}$$

where $s_j^{(r)}=\sum_{i=1}^{n}I_{ij}^{(r)}s_{ij}=n_j^{(r)}\overline{s}_j^{(r)}$ and $s_j^{(r)}=s\,q_j(1-\hat{p}_j^{(d)})$ *is given in Appendix A3.*

An estimate of $SE_{\hat{M}_r}$ *given by* $\hat{SE}_{\hat{M}_r}$ *can be obtained by replacing* $\mathrm{var}\left(\hat{p}'\right)$ *by* $\mathrm{v}\left(\hat{p}'\right)$, S *by* $\hat{S}$ *, and* $\mathrm{var}\left(\hat{S}\right)$ *by* $\mathrm{v}\left(\hat{S}\right)$ *in Equation (2.1).*

It is assumed that $\hat{\theta}_J^2$, $\overline{s}_J^{(d)}$, *and the set of values for* $\hat{p}_j^{(d)}$, $\overline{w}_j^{(r)}$, $\overline{s}_j^{(r)}$, $\hat{\sigma}_j^2$, $\overline{f}_j^{(r)}$, c_j *and* q_j *are all assumed to take fixed values for the purpose and determining the target number of days of observer coverage required in the CFOP.*

The estimate of the variance of the alternative estimate of M, $\hat{M}'$, *is given by Equation (2.4) but with the term* $\overline{s}_j^{(r)}\left(\hat{\sigma}_j^2/\overline{w}_j^{(r)}\right)^2$ *augmented to* $\hat{p}_j^{(d)2}\overline{s}_j^{(r)}\left(\hat{\sigma}_j^2/\overline{w}_j^{(r)}\right)^2$ *and* $c_j=s_j^{(d)}/h$ *. Note that by definition* $c_J=s_J^{(d)}/h=s_J/h$.

The corresponding CV, given $\hat{M}$ *(i.e.,* $\hat{SE}_{\hat{M}}/\hat{M}$ *) can be obtained which is a function of* s*. This assumes the values of the* q_j *and* c_j *are fixed which is appropriate for the purpose of estimating the required sample size of CFOP observed trips.*

Note that the estimated sampling fraction, $s\,\hat{S}^{-1}$*, is negligible compared to unity while the scaling of assumed the binomial variance relationship due to overdispersion by the factors* $\varphi(\hat{\omega})$ *are substantial in size as shown in the results. Therefore, it was more important to use the beta-binomial as the underlying distribution and corresponding variance relationship than a hypergeometric that accounts for sampling fraction (Seber, 1982). The number of discards per trip was high enough to be the subject to such overdispersion. Note also that the first component of the estimate* $\hat{S}$ *given by Equation (2.3) accounts for the commercial fish species (i.e., both retains and discards) which have retained catch weight recorded for both the overall fishery and CFOP while the second component accounts for non-commercial species which do not have a weight recorded for the total fishery since they are all discards. Therefore, in order to scale up from the CFOP to the total fishery, effort measured as hours trawled was required. In calculating* $\mathrm{var}(\hat{S})$ *considering this non-commercial component of the catch, a Poisson distribution was assumed for* s_j*.*

1.3 Estimating number of observer CFOP trips required to achieve a target CV for total discards by commercial fishing

Once a value of s *to achieve a given CV is obtained, by solving the following relation for* s*, to give* $s^{(T)}$ *where*

$$CV^{(T)}\left(s^{(T)}\right)^2 = \frac{1}{s^{(T)}\hat{M}^2}s\left[\mathrm{v}(\hat{p}')\hat{S}^2 + \hat{p}'^2\,\mathrm{v}(\hat{S})\right] + \frac{1}{s^{(T)2}\hat{M}^2}s^2\left[\mathrm{v}(\hat{p}')\mathrm{v}(\hat{S})\right] \qquad (3.1)$$

then the target number of trips to be observed is $T^{(T)} = s^{(T)}/\left(c\,\bar{h}\right)$ *where* c *is the mean CPUE of animals caught (including discards) per trip in the CFOP, after aggregating over all species, based on historical CFOP data. Note that the number of fish actually counted and weighed by species is* $\bar{F}^{(t)}s^{(T)}$ *assuming the within-shot sampling fractions in future CFOPs have a weighted average close to the* $\bar{F}^{(t)}$ *value obtained in the 2017-2019 CFOP.*

The solution, $s^{(T)}$*, to (3.1) for a given value of* $CV^{(T)}$ *can be found by solving a quadratic equation*

to give

$$s^{(T)} = \left(\frac{-b + \sqrt{b^2 - 4ac}}{2a} \right)^{-1} \quad (3.2)$$

where

$$a = s^2 \, \mathrm{v}(\hat{p}') \, \mathrm{v}(\hat{S})$$

$$b = \mathrm{v}(\hat{p}') \hat{S}^2 + s \, \hat{p}'^2 \, \mathrm{v}(\hat{S}),$$

$$c = -\left(CV^{(T)} \hat{M} \right)^2.$$

Appendix A1.2: Estimating $Var\left(s_J^{(d)}\right)$

The values of $s_{kJ}^{(d)}$ *were obtained from the 2017–2019 CFOP by aggregating all species counts for non-commercial species (i.e., species in the species group not recorded in the commercial catch data) to the trip level using scaled counts (i.e., scaled to total catch for each shot within trip) since it was necessary to consider between shot and between-trip variation in the sampling fraction (by weight) of the shot-level catch as well as trip-level variation in numbers of non-commercial species discarded with the assumption that all such catch was discarded. Using an observation-level random effect within a Poisson Generalized Linear Mixed Model (GLMM) (Candy, 2000).*

The GLMM fitted to the trip-level count of non-commercial catch numbers was $E\left(s_{kJ}^{(d)} \middle| \nu_k\right) = \mu_k = \exp(\beta + \nu_k)$ *where* $s_{kJ}^{(d)} \middle| \nu_k \sim \mathrm{Poisson}(\lambda_k)$ *where* $\lambda_k = \beta + \nu_k$ *so that* $P\left(S_J^{(d)} = s_{kJ}^{(d)} \middle| \nu_k\right) = \lambda_k^{s_{kJ}^{(d)}} e^{-\lambda_k} / \left[s_{kJ}^{(d)}! \right]$ *and* $\nu_k \sim N\left(0, \theta_J^2\right)$*. The conditional variance is given by* $\mathrm{var}\left(s_{kJ}^{(d)} \middle| \nu_k\right) = \mu_k$ *and the marginal variance by* $\mathrm{var}\left(s_{kJ}^{(d)}\right) = \mu + \theta_J^2 \mu^2$ *where* $\mu = \exp(\beta)$*. Of importance for Equation (2.3) it can be seen that* $\mathrm{var}\left(\sum_{k=1}^{K} s_{kJ}^{(d)}\right) = \mathrm{var}\left(s_J^{(d)}\right) = K\mu + \left(\theta_J^2 \mu\right) K\mu$ *and* $E\left(s_J^{(d)}\right) = K\mu$*. The result that* $\mathrm{var}\left(s_J^{(d)}\right) = (1+\phi) E\left(s_J^{(d)}\right)$ *where* $\phi = \theta^2 \mu$ *corresponds to the marginal mean-variance relationship of a Poisson Additive Generalized Linear Mixed Model (AGLMM) described by Candy (2000). The AGLMM and GLMM are equivalent in this case where*

μ *is a scalar and not a vector as in Candy (2000). Using the scaled counts* $s_{kJ}^{(d)}$ *to calculate variances was required since* μ_k *and* μ *are scaled expected values (therefore, depend on the shot-level sampling fraction).*

Appendix A1.3: Estimating ($\sigma_j^2 =$**)** $Var\left(\bar{w}_j^{(r)}\right)$

For the set of shots let the average weight of retains for species j for shot i be

$$\hat{w}_{ij}^{(r)} = W_{ij}^{(r)} / f_{ij}^{(r)} = \mu_j + \varepsilon_{ij} + e_{ij}$$

where the linear model defines between-shot error, ε_{ij}*, and within-shot error,* e_{ij} *where* $E\left(\varepsilon_{ij}\right) = E\left(e_{ij}\right) = 0$, $Var\left(\varepsilon_{ij}\right) = \sigma_j''^2$ *and* $Var\left(e_{ij}\right) = \left(1 - w_i^{(t_r)} / W_i^{(t_r)}\right)\sigma_{ij}'^2 / f_{ij}^{(r)}$ *where* $W_{ij}^{(r)}$ *and* $f_{ij}^{(r)}$ *are the unscaled total weight and unscaled total number, respectively, of species j retains in the sample for shot i and* $w_i^{(t)}$ *is the total weight of the sample (across species for retains) sub-sampled from the total weight of retains,* $W_i^{(t_r)}$*, of the shot. Therefore,*

$$W_{ij}^{(r)} = w_{ij}^{(r)} w_i^{(t_r)} / W_i^{(t_r)} \text{ and } f_{ij}^{(r)} = s_{ij}^{(r)} w_i^{(t_r)} / W_i^{(t_r)}.$$

This assumes random sampling of the catch for that shot so that the sampling fraction, $w_i^{(t_r)} / W_i^{(t_r)}$ *has the same expectation for all species for retains.*

Note that an estimate of $\sigma_{ij}'^2$ *is not available because individual captures are not weighed but only the combined weight and number of captures by species is measured and recorded by observers.*

The weighted average, $\bar{w}_j^{(r)}$*, used in Eqn (2.3) is given by* $n_j^{(r)} = \sum_i^n I_{ij}^{(r)}$

$$\bar{w}_j^{(r)} = \sum_{i=1}^{n_j^{(r)}} f_{ij}^{(r)} \hat{w}_{ij}^{(r)} / \sum_{i=1}^{n_j^{(r)}} f_{ij}^{(r)}$$

where the variables are ordered so that all non-zero values take the first $n_j^{(r)}$ *values.*

The variance of $\bar{w}_j^{(r)}$ *is given by*

$$Var\left(\bar{w}_j^{(r)}\right) = \sum_{i=1}^{n_j^{(r)}} f_{ij}^{(r)2} Var\left(\hat{w}_{ij}^{(r)}\right) / \left(\sum_{i=1}^{n_j^{(r)}} f_{ij}^{(r)}\right)^2$$

where

$Var\left(\widehat{w}_{ij}^{(r)}\right)=\sigma_j''^2+\nu_{ij}^2$ *and* $\nu_{ij}^2=\left(1-w_i^{(t_r)}/W_i^{(t_r)}\right)\sigma_{ij}'^2/f_{ij}^{(r)}$

Replacing $f_{ij}^{(r)2}$ *and* ν_{ij}^2 *with their expectations over the* $n_j^{(r)}$ *shots where species j is present gives*

$$E\left\{Var\left(\overline{w}_j^{(r)}\right)\right\}\cong\sum_{i=1}^{n_j^{(r)}}E\left(f_{ij}^{(r)2}\right)\left\{\sigma_j''^2+E\left(\nu_{ij}^2|j\right)\right\}/E\left(\sum_{i=1}^{n_j^{(r)}}f_{ij}^{(r)}\right)^2$$

Now, if we assume a zero-truncated Poisson for $f_{ji}^{(r)}$ *(i.e.,*

$P\left(F=f_{ij}^{(r)}|j,F>0\right)=\lambda^{f_{ij}^{(r)}}e^{-\lambda}/\left[f_{ij}^{(r)}!\left(1-e^{-\lambda}\right)\right]$*) then*

$$E\left(f_{ij}^{(r)2}\right)=E\left(f_{ij}^{(r)}\right)^2+Var\left(f_{ij}^{(r)}\right)=E\left(f_{ij}^{(r)}\right)^2+E\left(f_{ij}^{(r)}\right)\left[1+\lambda-E\left(f_{ij}^{(r)}\right)\right].$$

Using sample estimates of $\hat{E}\left(f_{ij}^{(r)}\right)=\overline{f}_j^{(r)}$ *and a first-order approximation of the maximum likelihood estimate of* $\hat{\lambda}_{MLE}\cong\overline{f}_j^{(r)}\left(1-e^{-\overline{f}_j^{(r)}}\right)$ *then* $\hat{E}\left(f_{ij}^{(r)2}\right)=\overline{f}_j^{(r)2}+\overline{f}_j^{(r)}\left(1-\overline{f}_j^{(r)}e^{-\overline{f}_j^{(r)}}\right)$ *and* $\hat{E}\left(f_{ij}^{(r)2}\right)\cong E\left(f_{ij}^{(r)2}\right)$*. Therefore, after noting that*

$Var\left(\overline{w}_j^{(r)}\right)=\sum_{i=1}^{n_j^{(r)}}f_{ij}^{(r)2}Var\left(\widehat{w}_{ij}^{(r)}\right)/\left[n_j^{(r)2}\overline{f}_j^{(r)2}\right]$ *and*

$E\left\{Var\left(\widehat{w}_{ij}^{(r)}\right)|j\right\}=\sigma_j''^2+E\left(\nu_{ij}^2|j\right)\cong\sigma_j''^2+\left(1-\overline{w}^{(t_r)}/\overline{W}^{(t_r)}\right)\overline{\sigma}_j'^2/\overline{f}_j^{(r)}$ *so that given* $\hat{E}\left(f_{ij}^{(r)2}\right)$ $\sum_{i=1}^{n_j^{(r)}}f_{ij}^{(r)2}$ *can be replaced by* $n_j^{(r)}E\left(f_{ij}^{(r)2}\right)$ *in*

$E\left\{Var\left(\overline{w}_j^{(r)}\right)\right\}=\left\{\sigma_j''^2+E\left(\nu_{ij}^2|j\right)\right\}n_j^{(r)}E\left(f_{ij}^{(r)2}\right)/\left[n_j^{(r)2}\overline{f}_j^{(r)2}\right]$*. Note that if all the* $w_i^{(t_r)}/W_i^{(t_r)}$ *are all close to 1 and/or all the* $f_{ij}^{(r)}$ *are very large then* $E\left\{Var\left(\widehat{w}_{ij}^{(r)}\right)|j\right\}$ *is very close* $\sigma_j''^2$*.*

An estimate of $\sigma_j^2=\left[\sigma_j''^2+E\left(\nu_{ij}^2|j\right)\right]$ *can be obtained as*

$$\hat{\sigma}_j^2=\sum_{i=1}^{n}I_{ij}^{(r)}\left(\widehat{w}_{ij}^{(r)}-\overline{w}_j^{(r)}\right)^2/\left(n_j^{(r)}-1\right).$$

Therefore, given $\hat{E}\left(f_{ij}^{(r)2}\right)$ *and* $\hat{\sigma}_j^2$ *an estimate of* $Var\left(\overline{w}_j^{(r)}\right)$ *is given by*

$$v\left(\overline{w}_j^{(r)}\right)\cong\left(\hat{\sigma}_j^2/n_j^{(r)}\right)\left[1+\left(1-\overline{f}_j^{(r)}e^{-\overline{f}_j^{(r)}}\right)/\overline{f}_j^{(r)}\right].$$

Further,

$$v\left(\overline{w}_j^{(r)}\right)=\frac{\overline{s}_j^{(r)}\hat{\sigma}_j^2\left[1+\left(1-\overline{f}_j^{(r)}e^{-\overline{f}_j^{(r)}}\right)/\,\overline{f}_j^{(r)}\right]}{s\,q_j(1-\hat{p}_j^{(d)})}$$ *where* $s_j^{(r)}=\sum_{i=1}^{n}s_{ij}=n_j^{(r)}\overline{s}_j^{(r)}$ *and*

$s_j^{(r)}=s\,q_j(1-\hat{p}_j^{(d)})$. All values in $v\left(\overline{w}_j^{(r)}\right)$ except S are assumed to take the same or close to the same values in future surveys as those for the historical CFOP (September 2014 – August 2016). The substitution of the expectation $n_j^{(r)}E\left(f_{ij}^{(r)2}\right)$ for $\sum_{i=1}^{n_j^{(r)}}f_{ij}^{(r)2}$ was required in order to express $v\left(\overline{w}_j^{(r)}\right)$ as a function of S so that the required value of $s^{(T)}$ to achieve a target CV can be obtained using Equations (3.1) and (3.2).

Appendix 1.4: Estimating ω and ω_j under response-biased sampling

Let $P_{kj}^{(d)}$ be the proportion of species j discarded on trip k for where the species was caught on this trip where the sample estimate at the trip level is

$$\hat{p}_{kj}^{(d)}=\sum_{i\in k}s_{ij}^{(d)}\left(\sum_{i\in k}^{K}s_{ij}^{(r)}+s_{ij}^{(d)}\right)^{-1}.$$

Let the following alternative estimate

$$\hat{p}_{kj}''^{(d)}=f_{kj}^{(d)}/\left(f_{kj}^{(r)}+f_{kj}^{(d)}\right)$$

where

$$f_{kj}^{(d)}=\sum_{i\in k}\frac{w_i^{(t_d)}}{W_i^{(t_d)}}s_{ij}^{(d)}\ \ \text{and}\ \ f_{kj}^{(r)}=\sum_{i\in k}\frac{w_i^{(t_r)}}{W_i^{(t_r)}}s_{ij}^{(r)}.$$

If $\frac{w_i^{(t_d)}}{W_i^{(t_d)}}\equiv\frac{w_i^{(t_r)}}{W_i^{(t_r)}}\equiv\frac{w_k^{(t)}}{W_k^{(t)}};i\in k$ *then* $\hat{p}_{kj}''^{(d)}\equiv\hat{p}_{kj}^{(d)}$.

A more consistently met set of assumptions, at least to a close approximation is

$\frac{w_i^{(t_d)}}{W_i^{(t_d)}}\equiv\frac{w_k^{(t_d)}}{W_k^{(t_d)}};i\in k$ *combined with* $\frac{w_i^{(t_r)}}{W_i^{(t_r)}}\equiv\frac{w_k^{(t_r)}}{W_k^{(t_r)}};i\in k$ *and applying these gives*

$\hat{p}_{kj}''^{(d)}=a_{kj}\,\hat{p}_{kj}^{(d)}$ *where*

$$a_{kj}=r_k^{(d)}\left(f_{kj}^{(r)}/r_k^{(r)}+f_{kj}^{(d)}/r_k^{(d)}\right)\left(f_{kj}^{(r)}+f_{kj}^{(d)}\right)^{-1}$$

$r_k^{(d)} = \dfrac{w_k^{(t_d)}}{W_k^{(t_d)}}$ and $r_k^{(r)} = \dfrac{w_k^{(t_r)}}{W_k^{(t_r)}}$. *Again if* $r_k^{(d)} = r_k^{(r)}$ *and therefore* $a_{kj} \equiv 1$ *then* $\hat{p}_{kj}^{\prime\prime(d)} = \hat{p}_{kj}^{(d)}$ *and the correct binomial sample size conditional on trip k is* $f_{kj}^{(r)} + f_{kj}^{(d)}$ *and not* $f_{kj}^{(r)} / r_k^{(r)} + f_{kj}^{(d)} / r_k^{(d)}$. *Generally, both will be close to 1/3 since* $w_i^{(t_d)}$ *is the sample weight of discards (undifferentiated) from one of three nets landing the catch in a single shot that is then separated and weighed by species and* $W_i^{(t_d)}$ *is the total weight of discards (undifferentiated) across all three nets. Therefore,* a_{kj} *will vary about an average of 1 with this variation due to the random differences between nets in the retained versus discard proportion when totalled across species. The sample weights by species are converted to counts using either within-shot subsamples of actual counts and weights to give a mean weight per individual [mostly target species, e.g., usually 50 Eastern King Prawn (EKP) individuals per shot] or using standard mean weights for non-target species based on aggregations of subsamples across shots and trips. For target species such as EKP the actual total retained weight is measured for that species as required for logbook entry of commercial catch so that* $f_{kj}^{(r)} = \sum_{i \in k} s_{ij}^{(r)}$ *whereas for these species the same is not true of discards and* $f_{kj}^{(d)} \neq \sum_{i \in k} s_{ij}^{(d)}$ *since the discard sample is drawn from the general weighted sample across species of* $w_i^{(t_d)}$. *In these cases,*

$a_{kj} = r_k^{(d)} \left(f_{kj}^{(r)} + f_{kj}^{(d)} / r_k^{(d)} \right) \left(f_{kj}^{(r)} + f_{kj}^{(d)} \right)^{-1}$ *so that does not average around 1 but a value substantially less than 1.*

In both cases of target and non-target species the estimation of both ω *and* ω_j *using trip-level samples of* $\left(\sum_j f_{kj}^{(r)}, \sum_j f_{kj}^{(d)} \right)$ *and* $\left(f_{kj}^{(r)}, f_{kj}^{(d)} \right)$*, respectively, is correct since it is adjusted for response-biased sampling (ARBS). This can be seen since the beta-distribution assumed for the* $p_k^{(d)}$ *or the species-specific* $p_{kj}^{(d)}$ *across trips give respective variances of* $P'(1-P')/(1+\omega)$ *and* $P_j^{(d)}\left(1-P_j^{(d)}\right)/\left(1+\omega_j\right)$ *where the estimates for* ω *and* ω_j *are determined from* $\left(\sum_j f_{kj}^{(r)}, \sum_j f_{kj}^{(d)} \right)$ *and* $\left(f_{kj}^{(r)}, f_{kj}^{(d)} \right)$*, respectively, even though the corresponding estimates* $\hat{p}_k^{\prime\prime(d)}$ $(= \sum_j f_{kj}^{(d)} / \sum_j f_{kj}^{(r)} + f_{kj}^{(d)})$ *and* $\hat{p}_{kj}^{\prime\prime(d)}$ *may be biased estimates of* P' *and species-specific*

$P_j^{(d)}$, *respectively, due to the response-biased sampling. This can be seen by noting that Equations (2.2) and (2.4) use the imputed ARBS-estimates of* ω *and* ω_j *in* $p^{(d)}\left(1-p^{(d)}\right)/\left(1+\omega\right)$ *and* $p_j^{(d)}\left(1-p_j^{(d)}\right)/\left(1+\omega_j\right)$, *respectively, while using unbiased estimates for* P' *and* $P_j^{(d)}$ *since the estimates for* P' *and* $P_j^{(d)}$, *respectively, use the scaled counts of* $\left(s_j^{(r)}, s_j^{(d)}\right)$ *and not the raw (unscaled) counts* $\left(f_{kj}^{(r)}, f_{kj}^{(d)}\right)$ *for these estimates to adjust for response-biased sampling. However, the variance of these estimates employed in formula for* $\mathrm{v}\left(\hat{p}'\right)$ *and* $\mathrm{v}(\hat{S})$, *respectively, apart from the terms involving* P' *and* $P_j^{(d)}$, *are based on aggregated values of these raw counts via imputed ARBS-estimates of* ω *and* ω_j *and* $s\bar{F}^{(t)}$. *Figure A1.4- 1 shows the relationship between the (imputed) ARBS-estimates* $\hat{\omega}_j$ *and the unadjusted (naïve) estimates* $\hat{\omega}'_j$ *based on fitting the beta-binomial to the scaled counts* $\left(s_{kj}^{(r)}, s_{kj}^{(d)}\right)$ *for commercial fish species for the combined North and Central strata that were present in at least 20 trips (i.e., in order to obtain reliable estimates). The corresponding estimates for totals across species of* $\hat{\omega}$ *and the unadjusted estimate* $\hat{\omega}'$ *were 2948.24 and 3433.94, respectively. The estimate of the* $CV^{(T)}$ *for the CFOP sample of trips corresponding to* $\left(\hat{\omega}, \hat{\omega}_j\right)$ *(see Table 3) and* $\left(\hat{\omega}', \hat{\omega}'_j\right)$ *were 9.61 and 16.56, respectively. This example demonstrates the importance of using the ARBS-estimates since they give substantially different results for* $CV^{(T)}$. *Finally, the justification of imputing the value of* ω *and* ω_j *in (2.2) and (2.4) using* $\hat{\omega}$ *and* $\hat{\omega}_j$, *respectively, is that the since the beta-distribution variance is factorised into terms involving* $p^{(d)}$ *or* $p_j^{(d)}$ *and a separate term involving only* ω *or* ω_j *then any bias in* $\hat{p}_k''^{(d)}$ or $\hat{p}_k''^{(d)}$ *relative to* P' *and* $P_j^{(d)}$, *respectively, does not affect the validity of these imputations when combined with the property that* $\left(\hat{\omega}, \hat{\omega}_j\right) \rightarrow \left(\omega, \omega_j\right)$ *as* $MSE\left(a_k, a_{jk} \middle| 1,1\right) \rightarrow 0$ *where MSE is the mean square error of* a_k *or* a_{jk} *about a value of 1 and* $\left(\omega, \omega_j\right)$ *are the true values from equations (2.2) and (2.4), respectively.*

References

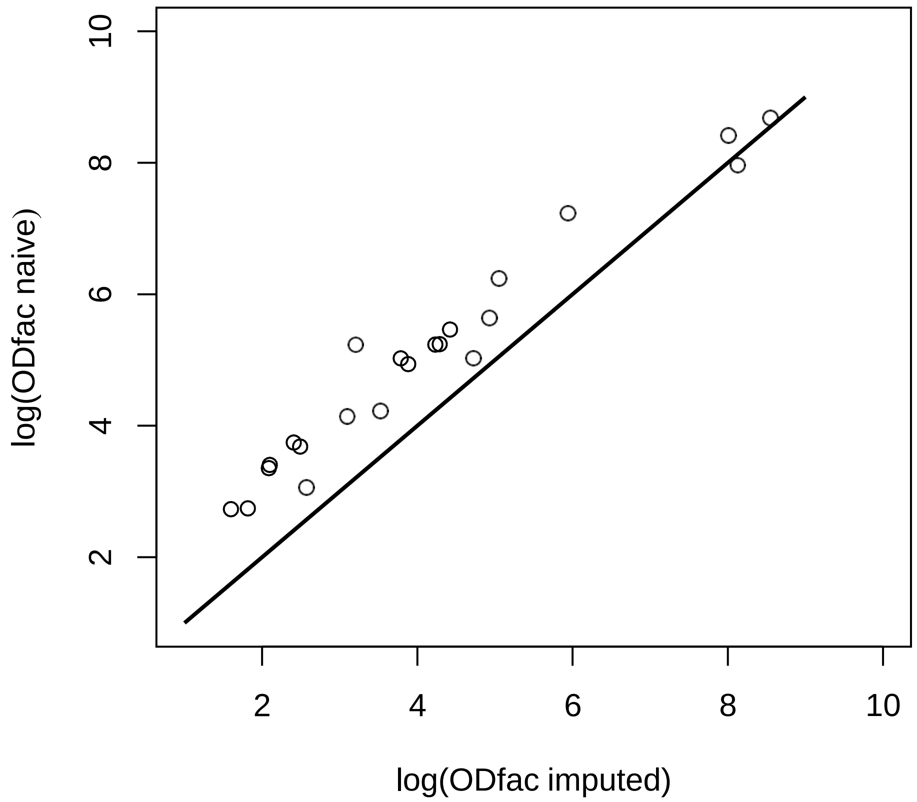
CANDY, S. G., CONSTABLE, A. J., LAMB, T. & Williams, R. 2007. A von Bertalanffy growth model for toothfish at Heard Island fitted to length-at-age data and compared to observed growth from mark-recapture studies. *CCAMLR Science* 14, 43-66.

CHEN, K. 2001. Parametric models for response-biased sampling. Royal Statistical Society, 63 (4): 775–789.

JOHNSON, D. D., CANDY, S. G. & BARNES, T. C. 2021. Survey design research for allocating observer effort for the Ocean Trawl Fishery Northern Zone (OTFN). Draft report for Fisheries Research, NSW Department of Primary Industries

PFEFFERMANN, D., SKINNER, C. J., HOLMES, D. J., GOLDSTEIN, H. & RASBASH, J. 1998. Weighting for unequal selection probabilities in multilevel models. Royal Statistical Society, 60 (1): 23–40.

Figure A1.4- 1 Comparison of naïve estimate of ω, $\hat{\omega}'$, with imputed estimate $\hat{\omega}'$ on the log scale showing the 1:1 line for Region 1 combined commercial and non-commercial fish.



Appendix A1.5: Estimating total fishery-wide catch of syngnathids (SYG-TEPS)

The estimate of total fishery-wide SYG-TEPS was obtained as

$$\hat{M}_T = \hat{p}'_T \hat{M}'$$

where $\hat{p}'_T = s_{Teps} / \left(s_{Teps} + s_d\right)$, s_{Teps} *is the scaled number (by scaling raw counts using*

$W_i^{(t_d)} / w_i^{(t_d)}$*)*

of SYG species counted in the CFOP aggregated across SYG species and trips, s_d *is scaled number of the reference species group discarded aggregated across all trips. The "all fish species" group (combined commercial and non-commercial) was used because these species were in aggregate consistently across trips caught and a reasonable proportion discarded and the CV for* $\hat{M}'$ *was relatively small compared to other species groups. The SYG-TEPS counts* *were included with the* s_d *to calculate* $\hat{M}'$ *but since* s_{Teps} *is negligible compared to* s_d *(i.e., 133 versus 4,550,520) the estimate with and without* s_{Teps} *included are for practical purposes the same. The variance of* $\hat{p}'_T$ *is assumed to be purely binomial with no overdispersion because of the very small value of* $\hat{p}'_T$ *and therefore, its expected value* P'_T*. Therefore,*

$$\mathrm{var}\left(\hat{p}'_T\right) = P'_T\left(1-P'_T\right) / \sum\nolimits_{k,j} f_{kj}^{(d)}$$

and in terms suitable for calculating CVs for a range of sample size of trips then

$$\mathrm{v}\left(\hat{p}'_T\right) = \hat{p}'_T\left(1-\hat{p}'_T\right)\left(s_d \bar{F}_d^{(t)}\right)^{-1}$$

where

$$\bar{F}_d^{(t)} = \sum\nolimits_{i=1}^{n} w_i^{(t_d)} / \sum\nolimits_{i=1}^{n} W_i^{(t_d)} .$$

The calculation of the variance of $\hat{M}'$ *was described in Appendix A1.*

The variance of $\hat{M}_T$ *is given by*

$$SE_{\hat{M}_T} = \left[\mathrm{var}\left(\hat{p}'_T\right)M'^2 + \left\{P'^2_T\,\mathrm{var}\left(\hat{M}'\right)\right\} + \mathrm{var}\left(\hat{p}'_T\right)\mathrm{var}\left(\hat{M}'\right)\right]^{\frac{1}{2}} .$$

The objective of determining CVs for given sampling levels in terms of total CFOP counts of both discards and retains which are subsequently converted to trips based on average of the counted landings per trip requires solving

$$CV^{(T)}\left(s^{(T)}\right)^2 = \frac{1}{s^{(T)}\hat{M}_T^2} s\left[\mathrm{v}\left(\hat{p}'_T\right)\hat{M}'^2 + \hat{p}'^2_T\,\mathrm{v}\left(\hat{M}'\right)\right] + \frac{1}{s^{(T)2}\hat{M}_T^2} s^2\left[\mathrm{v}\left(\hat{p}'_T\right)\mathrm{v}\left(\hat{M}'\right)\right]$$

for $s^{(T)}$ *given a value for* $CV^{(T)}$*. The solution,* $s^{(T)}$*, to* $CV^{(T)}\left(s^{(T)}\right)^2$ *for a given value of* $CV^{(T)}$ *can be found by solving the quadratic equation constructed in the same way as (3.2). Explicitly*

The solution, $s^{(T)}$*, to* $CV^{(T)}\left(s^{(T)}\right)^2$ *for a given value of* $CV^{(T)}$ *can be found by solving a quadratic equation*

to give

$$s^{(T)} = \frac{-b+\sqrt{b^2-4ac}}{2a}$$

where

$$a = \left(CV^{(T)}\hat{M}_T\right)^2 + k_2 k_3,$$

$$b = -\left\{\left(CV^{(T)}\hat{M}_T\right)^2 + k_2 k_3^2 + k_1 \hat{p}_T'^2 - k_1 k_2 / k_3\right\},$$

$$c = k_1 \hat{p}_T'^2 - k_1 k_2,$$

$$k_1 = s_d \, \mathrm{v}\left(\hat{M}'\right),$$

$$k_2 = \hat{p}_T' \left(1 - \hat{p}_T'\right), \text{ and}$$

$$k_3 = \hat{M}'.$$

Table A1.5- 1: Summary table of optimised sampling intensity and associated CVs estimated from the CFOP for syngnathid interactions

% CV	Number sampled	CFOP trips	syngnathids
Region 1			
17.08	4550690	359	133
5	43045159	3396	1608
10	12696497	1002	474
15	5852401	462	219
20	3345506	264	125
25	2164492	171	81
30	1517273	120	57
35	1124994	89	42

Appendix 1.6: Supplementary Figures for species optimisation groups

Figure A1.6- 1 Retained and discarded catches (no per trip^{-1} ± SE) of commercial fish.

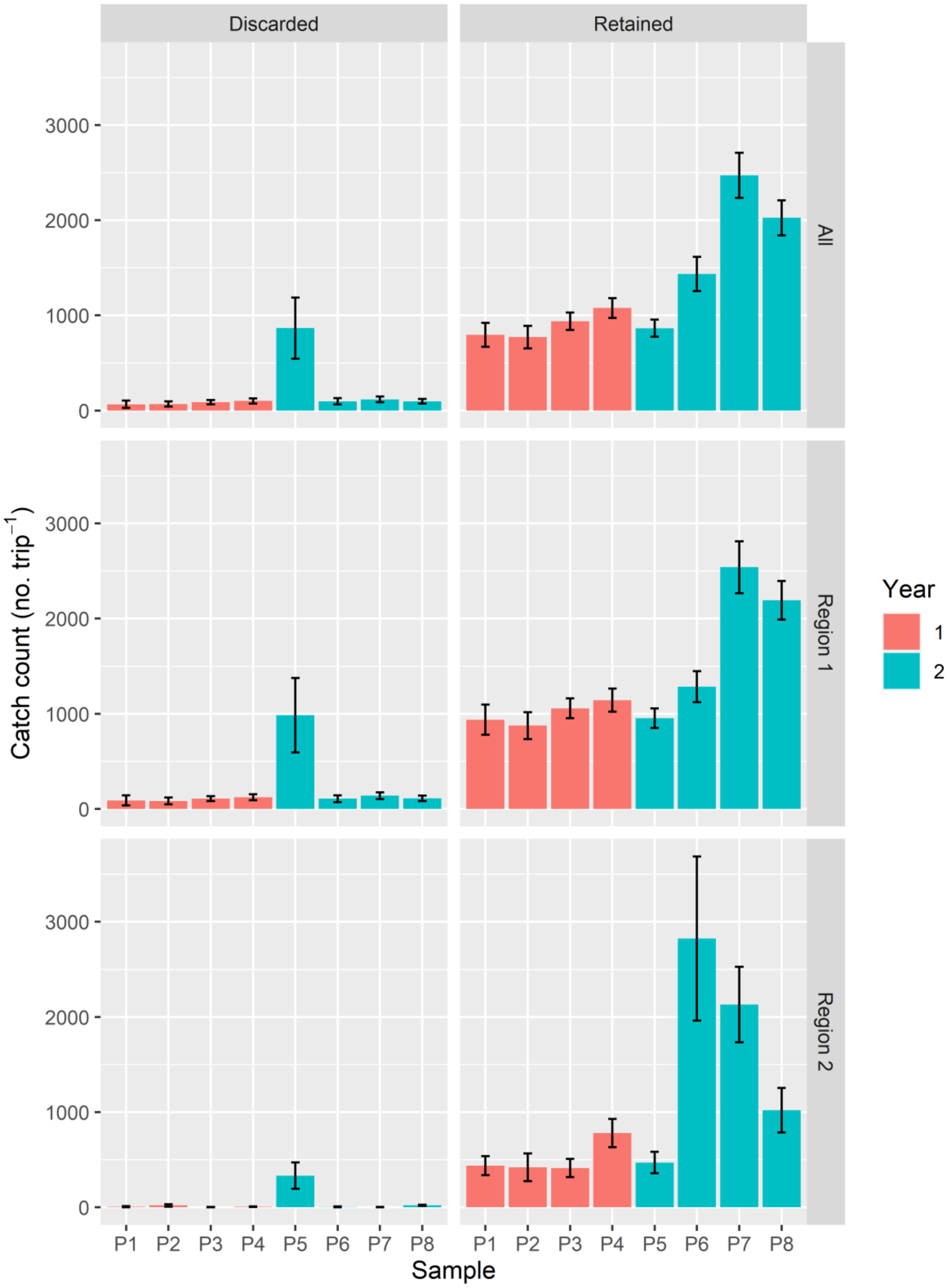


Figure A1.6- 2 Retained and discarded catches (kg per trip^{-1}± SE) of commercial fish.

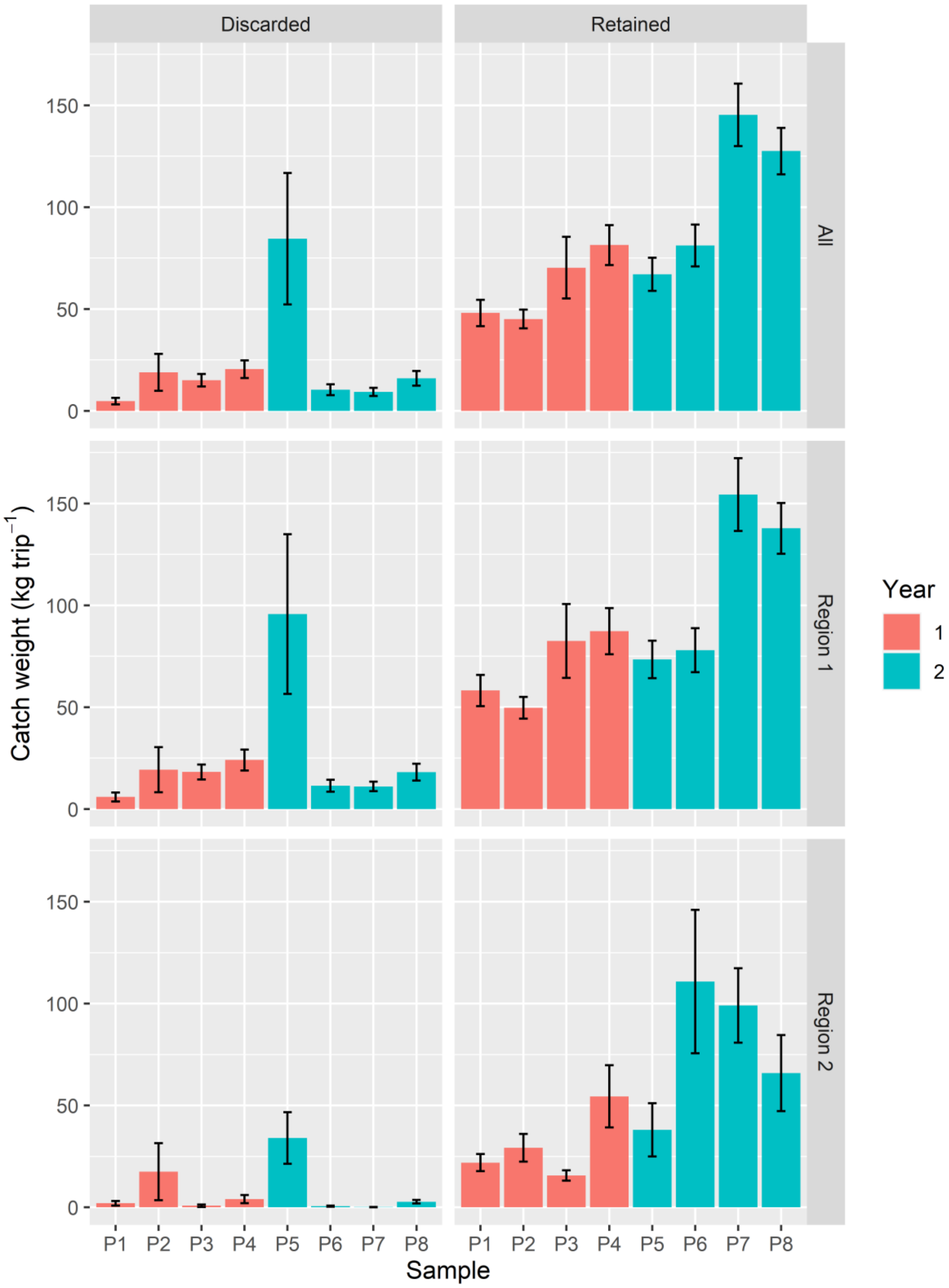


Figure A1.6- 3 Discarded catches (no and kg per trip^{-1}) of non-commercial fish. Y-axis scale variable.

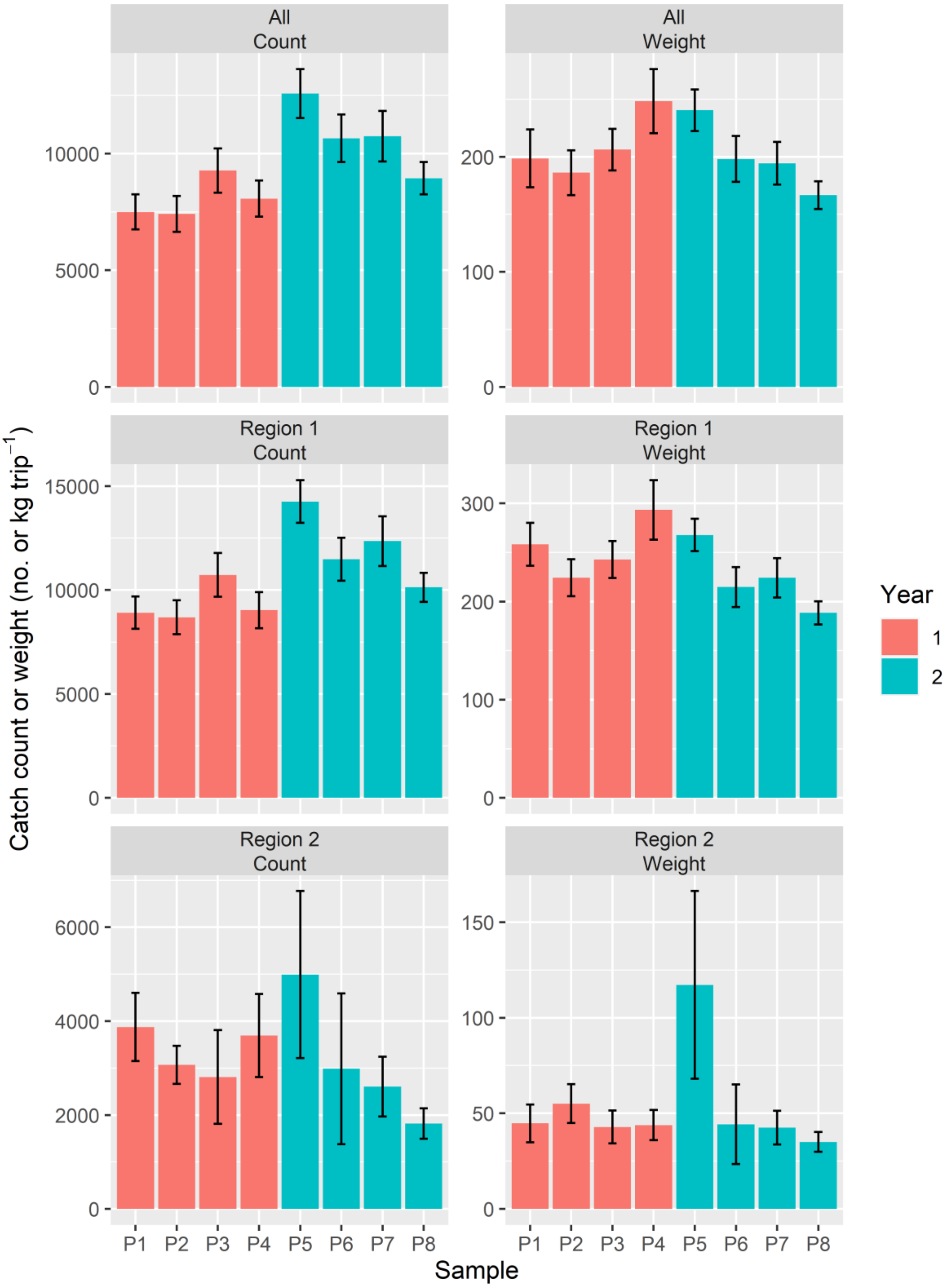


Figure A1.6- 4 Retained and discarded catches (no per trip^{-1} ± SE) of commercial crustaceans.

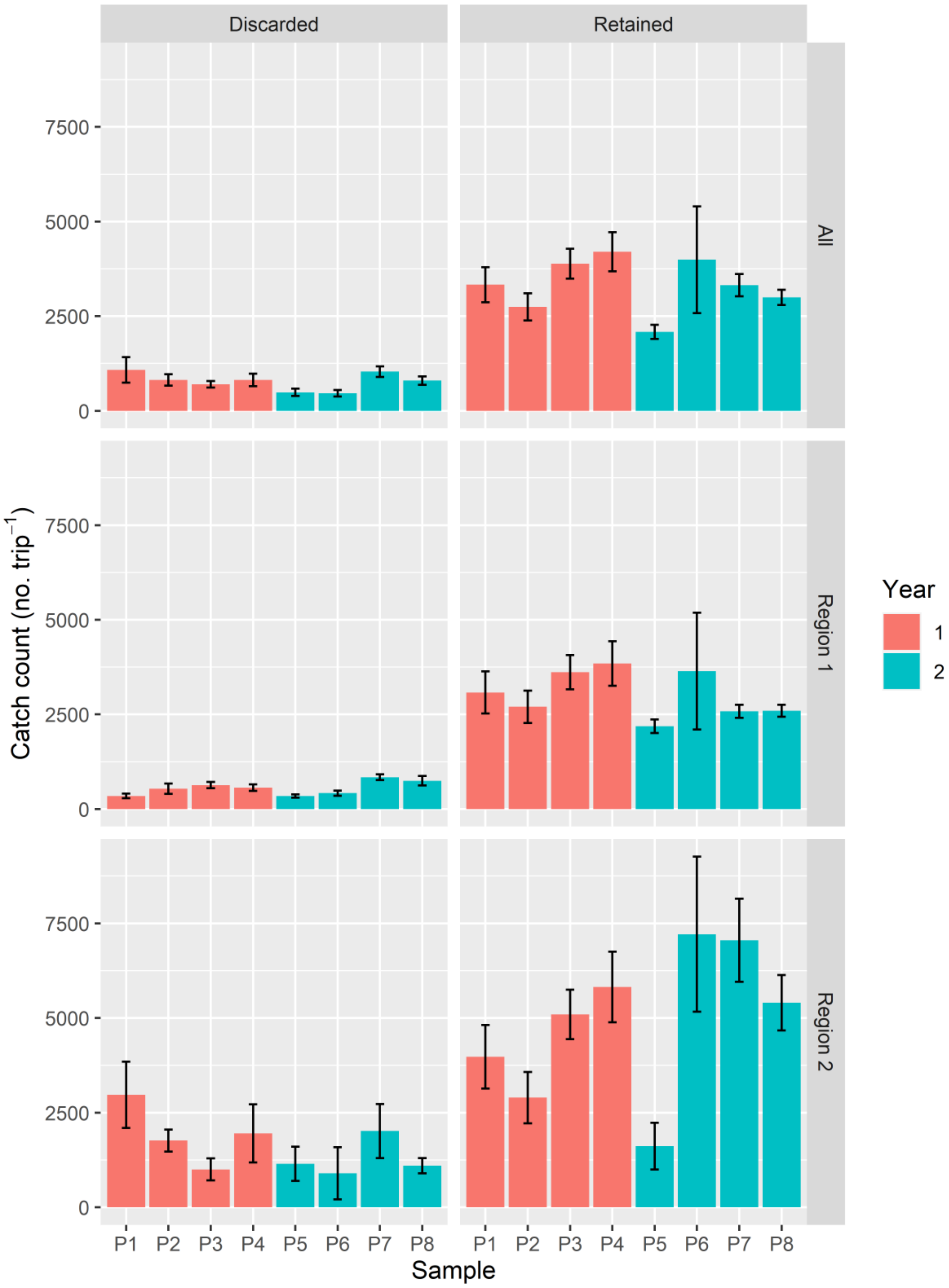


Figure A1.6- 5 Retained and discarded catches (kg per trip^{-1} ± SE) of commercial crustaceans.

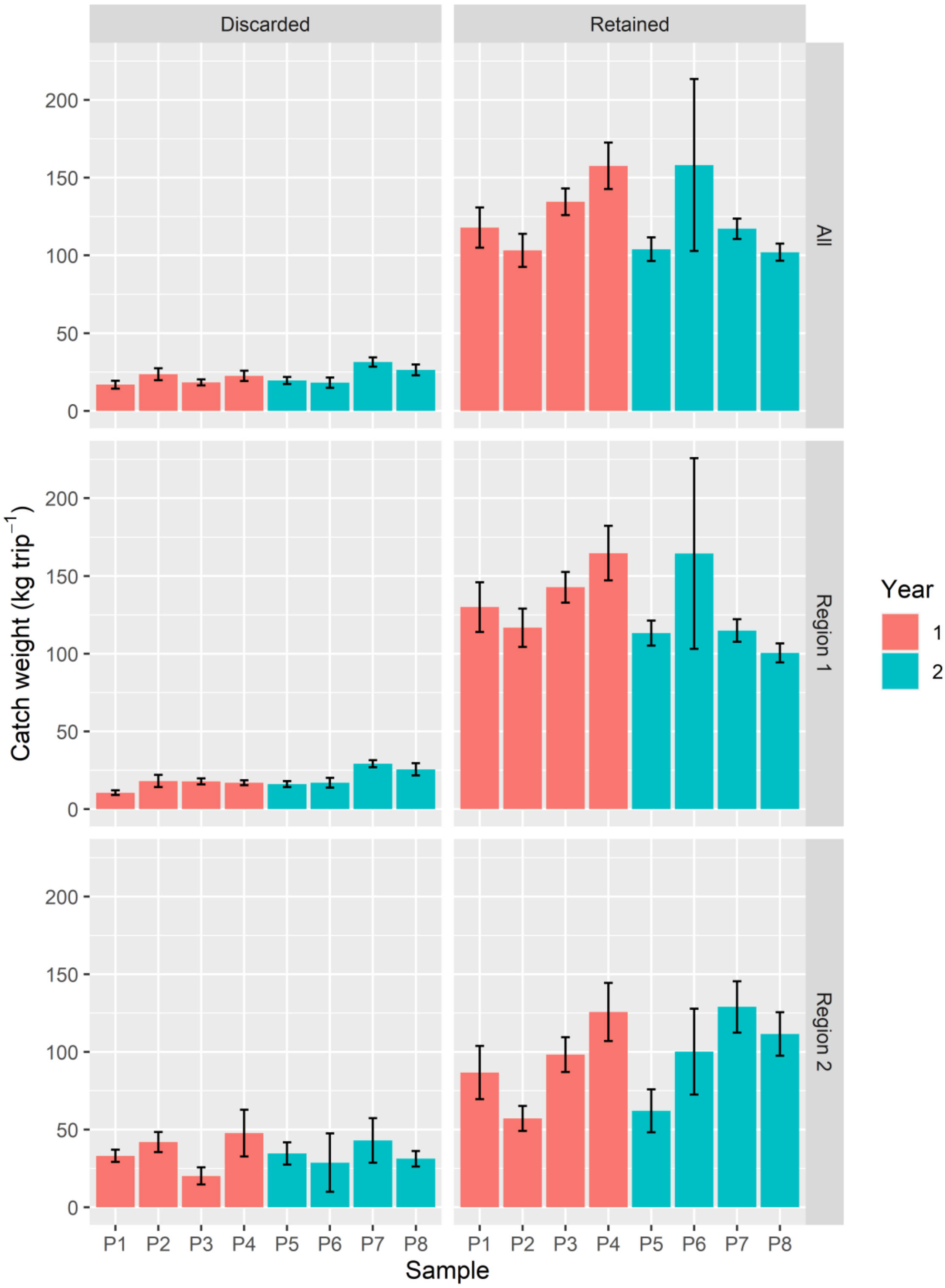


Figure A1.6- 6 Discarded catches (no and kg per trip^{-1}± SE) of non-commercial crustaceans. Y-axis scale variable.

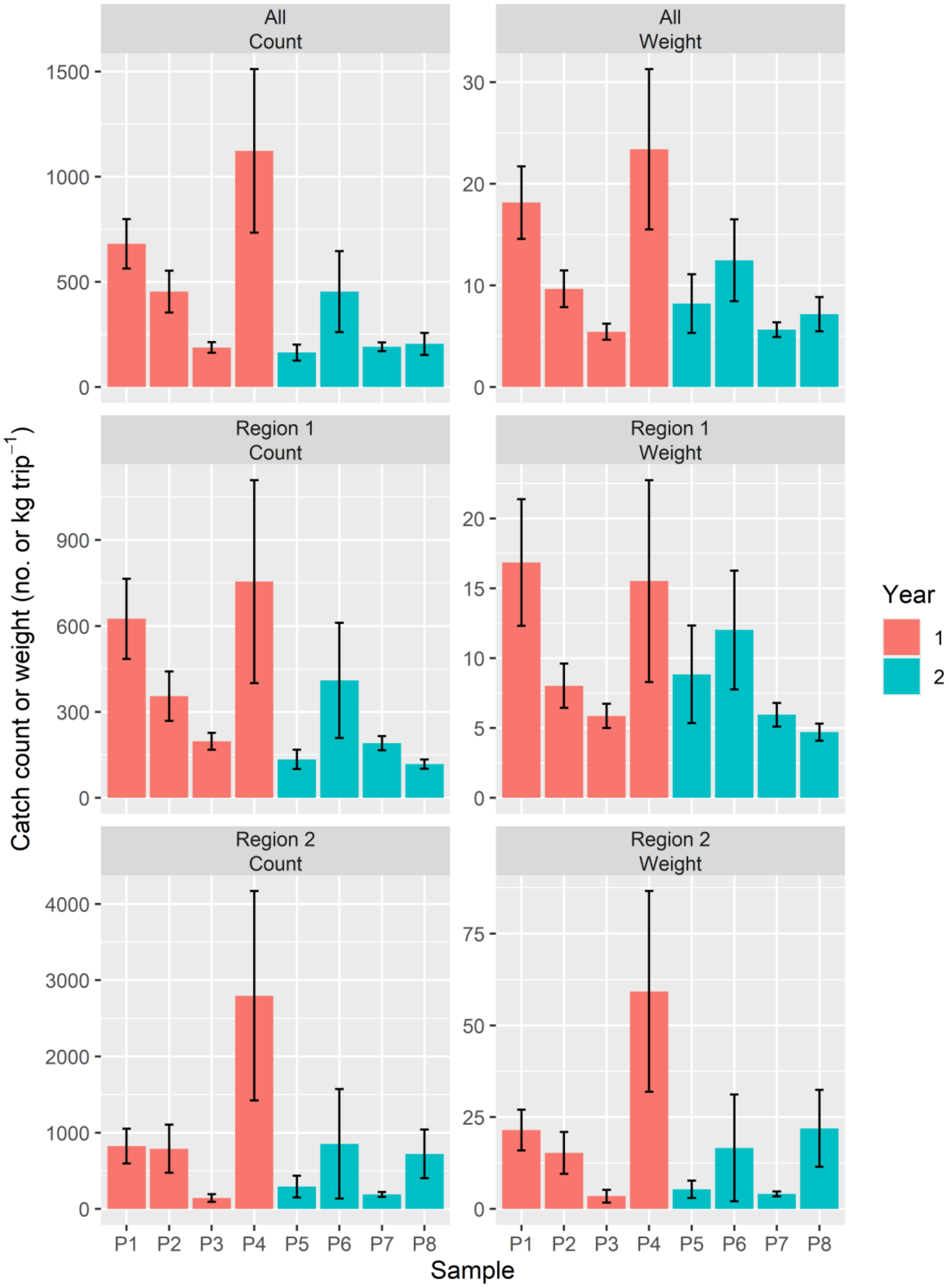


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Figure A1.6- 7 Retained and discarded catches (no per trip^{-1} ± SE) of commercial molluscs.

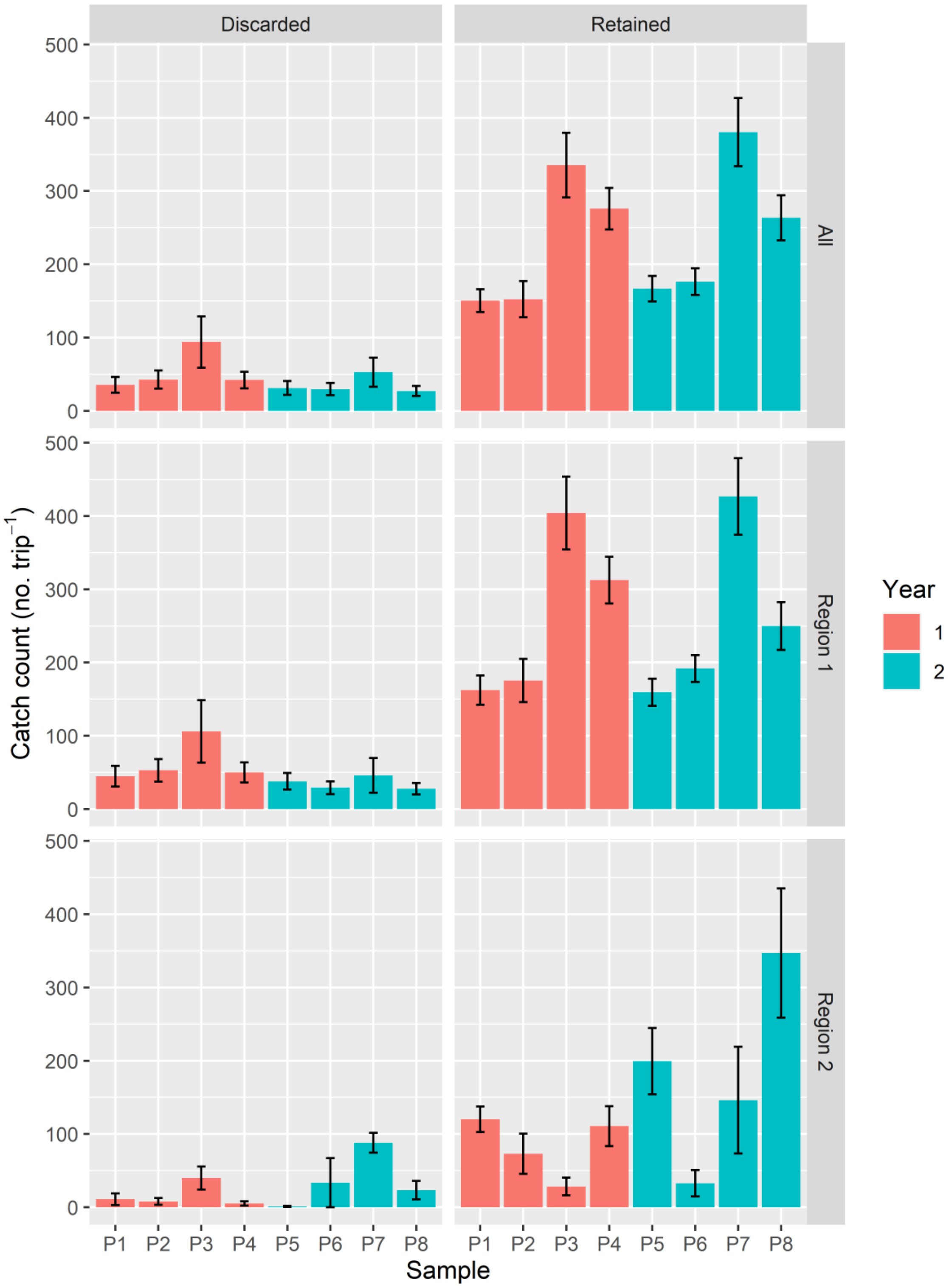


Figure A1.6- 8 Retained and discarded catches (kg per trip^{-1} ± SE) of commercial molluscs.

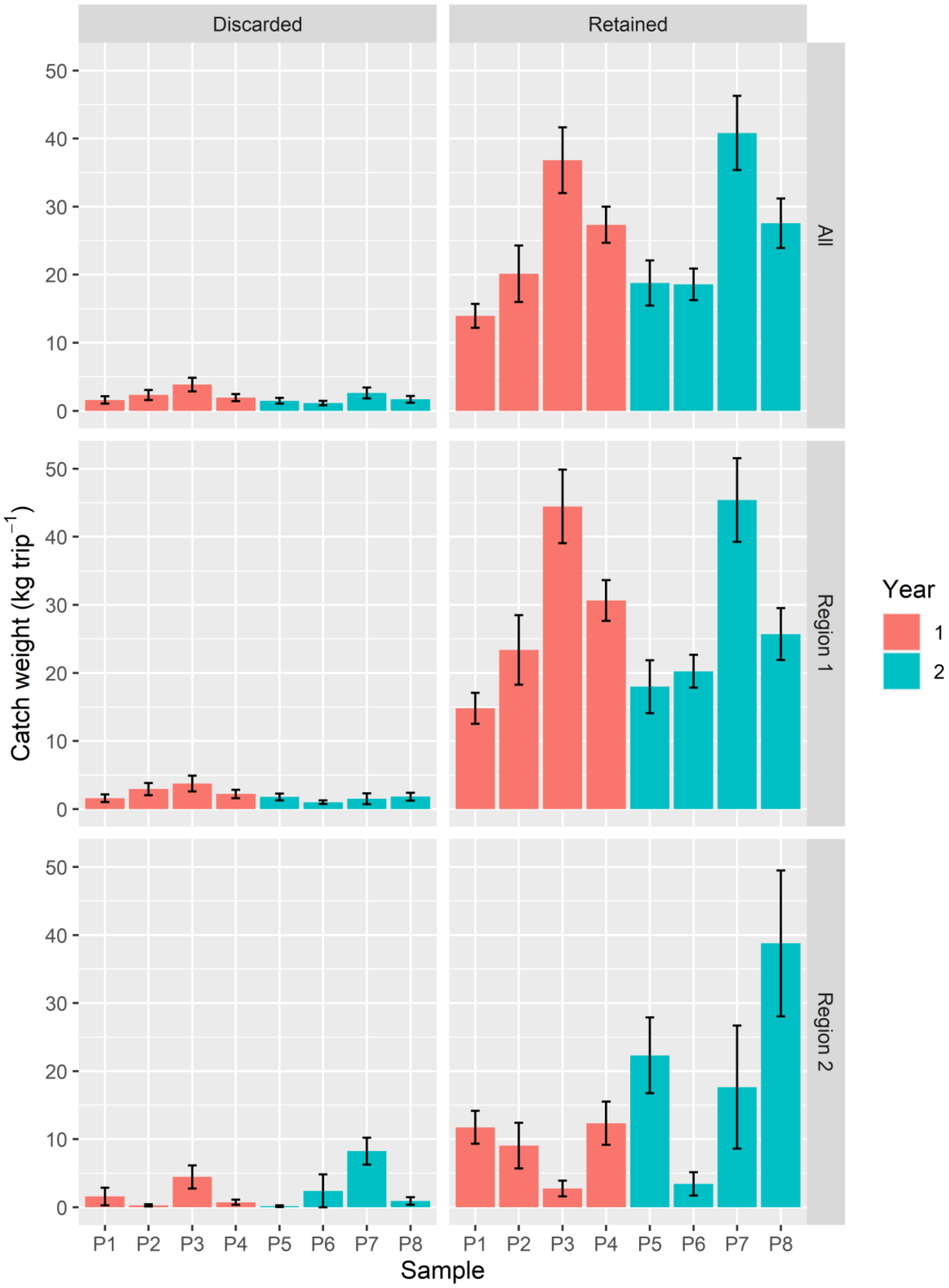


Figure A1.6- 9 Discarded catches (no and kg per trip^{-1} ± SE) of non-commercial molluscs. Y-axis scale variable.

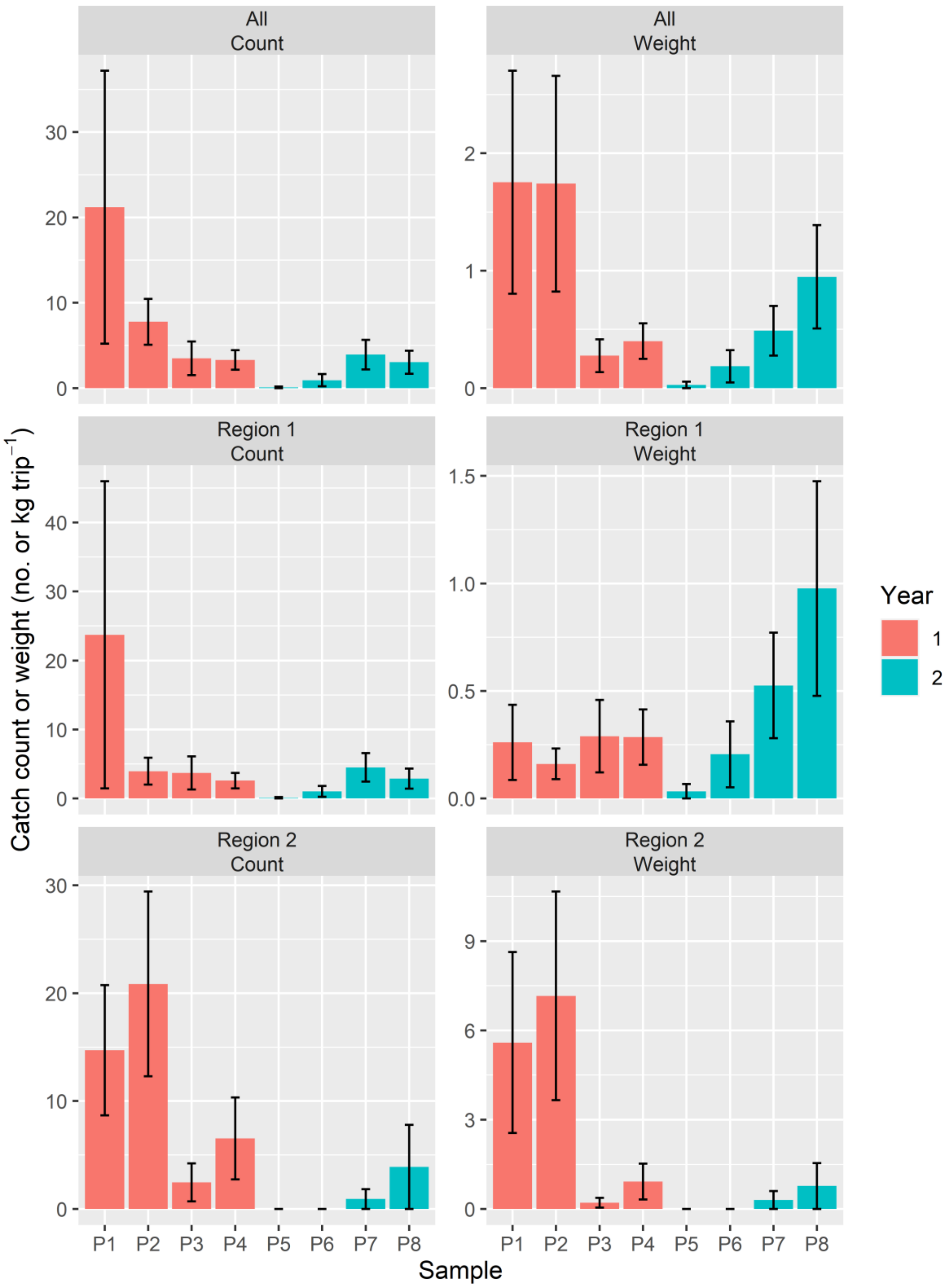


Figure A1.6- 10 Retained and discarded catches (no per trip^{-1}± SE) of commercial elasmobranchs.

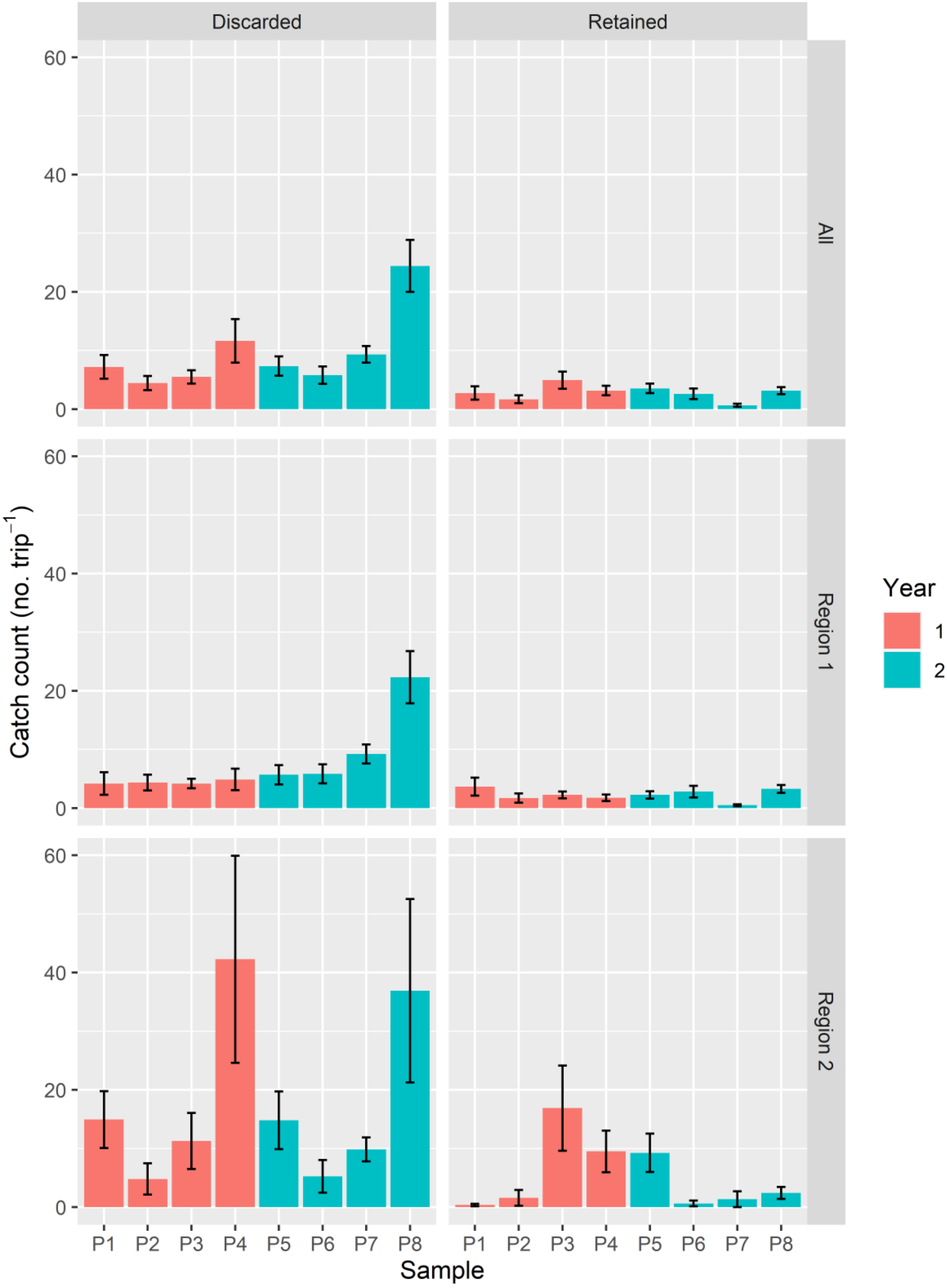


Figure A1.6- 11 Retained and discarded catches (kg per trip^{-1}± SE) of commercial elasmobranchs.

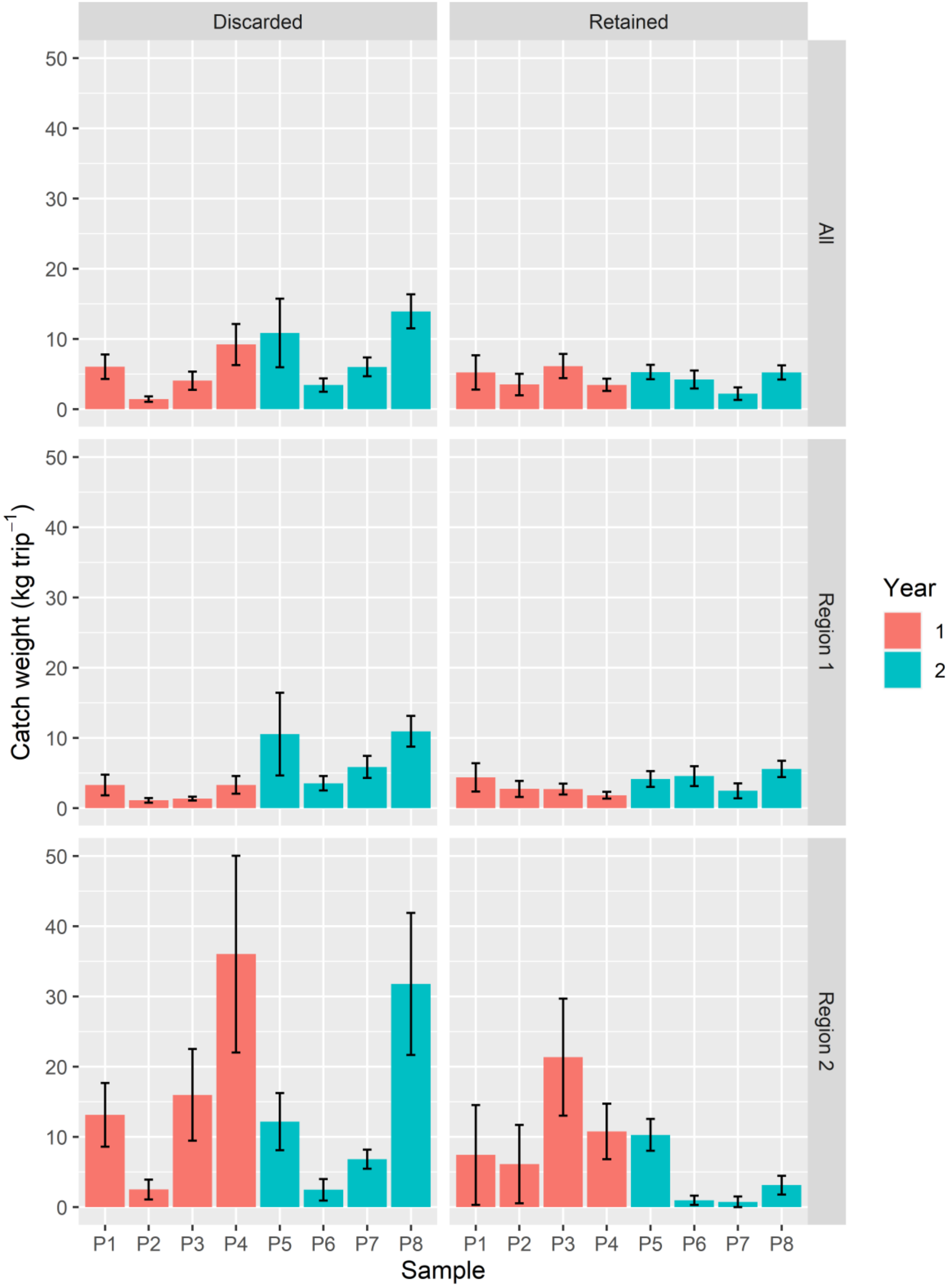
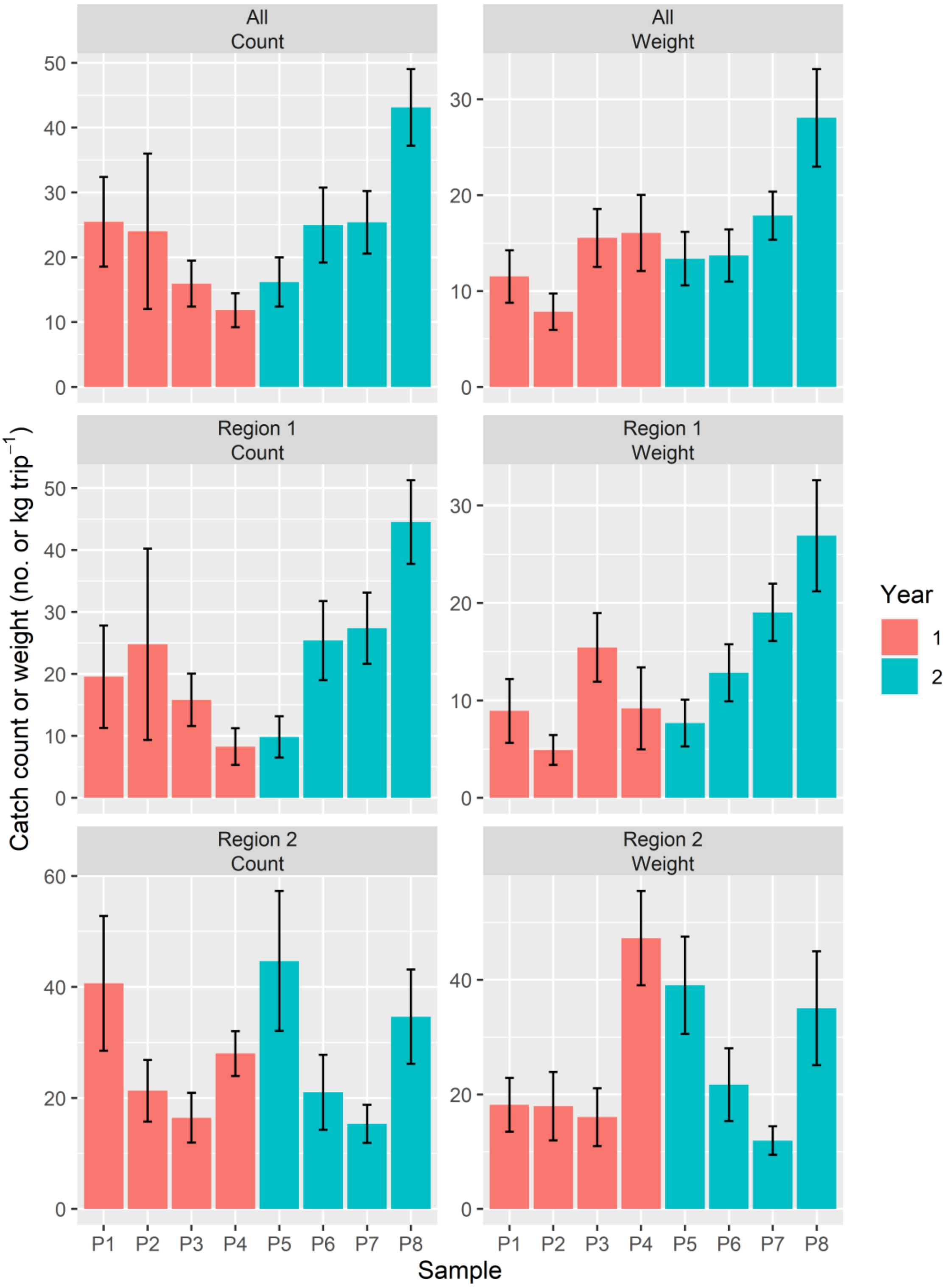


Figure A1.6- 12 Discarded catches (no and kg per trip^{-1} ± SE) of non-commercial elasmobranchs. Y-axis scale variable.



Appendix 2. List of all commercially harvested species caught during the survey (pooled across zones). Data are the number of shots each species was retained from. CAAB Nos are the Codes for Australian Aquatic Biota (http://www.marine.csiro.au/caab).

CAAB	Species group	Common name	Species	No. Shots
28030000	CRUST	Mantis Shrimps	Order Stomatopoda – undifferentiated	57
28711022	CRUST	Greentail prawn	*Metapenaeus bennettae*	6
28711029	CRUST	Eastern School Prawn	*Metapenaeus macleayi*	52
28711031	CRUST	Coral Prawn	*Kishinouyepenaeopsis cornuta*	7
28711035	CRUST	Australian Rose Prawn	*Parapenaeus australiensis*	7
28711044	CRUST	Brown Tiger Prawn	*Penaeus esculentus*	100
28711050	CRUST	Banana Prawn	*Penaeus merguiensis*	2
28711051	CRUST	Black Tiger Prawn	*Penaeus monodon*	7
28711052	CRUST	Eastern King Prawn	*Melicertus plebejus*	1457
28712008	CRUST	Giant Scarlet Prawn	*Aristaeopsis edwardsiana*	3
28714005	CRUST	Royal Red Prawn	*Haliporoides sibogae*	1
28821004	CRUST	Balmain Bug	*Ibacus peronii*	4
28821010	CRUST	Honey Bug	*Ibacus brucei*	6
28821019	CRUST	Smooth Bug	*Ibacus chacei*	763
28821901	CRUST	Balmain Bugs	Ibacus spp.	181
28850000	CRUST	Crabs	Infraorder Brachyura – undifferentiated	1
28865001	CRUST	Spanner Crab	*Ranina*	2
28911000	CRUST	Swimmer Crabs	Portunidae, Polybiidae, Ovalipidae, Brusiniidae, Carcinidae – undifferentiated	15
28911001	CRUST	Coral Crab	*Charybdis feriata*	32
28911005	CRUST	Blue Swimmer Crab	*Portunus armatus*	250
28911006	CRUST	Three-Spotted Crab	*Portunus sanguinolentus*	185
28911019	CRUST	Swimmer crab	*Charybdis miles*	58
37063001	FISH	Bigeye Pike Eel	*Oxyconger leptognathus*	3
37067000	FISH	Conger & Short-tail Conger Eels	Congridae, Colocongridae – undifferentiated	4
37068000	FISH	Snake Eels	Ophichthidae – undifferentiated	2
37085002	FISH	Australian Sardine	*Sardinops sagax*	3
37085906	FISH	Sardinella	*Sardinella* spp.	1
37118000	FISH	Lizardfishes and Deepsea Lizardfishes	Bathysauridae, Synodontidae – undifferentiated	82
37118001	FISH	Largescale Saury	*Saurida undosquamis*	45
37118002	FISH	Painted Grinner	*Trachinocephalus trachinus*	22
37228901	FISH	Ling	*Genypterus* spp.	1
37233000	FISH	Flyingfishes	Exocoetidae – undifferentiated	2

CAAB	Species group	Common name	Species	No. Shots
37236000	FISH	Sauries	Scomberesocidae – undifferentiated	2
37258003	FISH	Redfish	*Centroberyx affinis*	8
37264003	FISH	Mirror Dory	*Zenopsis nebulosus*	1
37264004	FISH	John Dory	*Zeus faber*	22
37278000	FISH	Flutemouths	Fistulariidae –= undifferentiated	9
37287001	FISH	Reef Ocean Perch	*Helicolenus percoides*	3
37287066	FISH	Eastern Scorpionfish	*Scorpaena cardinalis*	1
37287066	FISH	Eastern Red Scorpionfish	*Scorpaena jacksoniensis*	1
37287901	FISH	Ocean Perch	*Helicolenus barathri* & *Helicolenus percoides*	4
37288001	FISH	Red Gurnard	*Chelidonichthys kumu*	17
37288006	FISH	Latchet	*Pterygotrigla polyommata*	3
37296001	FISH	Tiger Flathead	*Platycephalus richardsoni*	19
37296011	FISH	Freespine Flathead	*Ratabulus diversidens*	166
37296004	FISH	Dusky Flathead	*Platycephalus fuscus*	6
37296007	FISH	Bluespotted Flathead	*Platycephalus caeruleopunctatus*	830
37296038	FISH	Marbled Flathead	*Platycephalus marmoratus*	10
37311001	FISH	Eastern Orange Perch	*Lepidoperca pulchella*	10
37311002	FISH	Butterfly Perch	*Caesioperca lepidoptera*	1
37311147	FISH	Banded Rockcod	*Hyporthodus ergastularius*	7
37320003	FISH	Pearl Perch	*Glaucosoma scapulare*	5
37326000	FISH	Bigeyes	Priacanthidae – undifferentiated	13
37326001	FISH	Spotted Bigeye	*Priacanthus macracanthus*	104
37327002	FISH	Longfin Pike	*Dinolestes lewini*	2
37330000	FISH	Whitings	Sillaginidae – undifferentiated	9
37330005	FISH	Stout Whiting	*Sillago robusta*	359
37330014	FISH	Eastern School Whiting	*Sillago flindersi*	479
37330901	FISH	School Whiting	*Sillago bassensis*, *S. flindersi* & *S. robusta*	8
37331006	FISH	Pink Tilefish	*Branchiostegus wardi*	3
37334002	FISH	Tailor	*Pomatomus saltatrix*	2
37335001	FISH	Cobia	*Rachycentron canadum*	7
37337003	FISH	Yellowtail Scad	*Trachurus novaezelandiae*	175
37337062	FISH	Silver Trevally	*Pseudocaranx georgianus*	1
37346054	FISH	Ornate Snapper	*Pristipomoides argyrogrammicus*	12
37346905	FISH	Sea Perch	*Lutjanus* spp.	1
37347036	FISH	Theodore's Threadfin Bream	*Nemipterus theodorei*	10
37347901	FISH	Butterflybream	*Nemipterus* spp.	3

CAAB	Species group	Common name	Species	No. Shots
37349000	FISH	Silverbiddies	Gerreidae – undifferentiated	15
37350007	FISH	Goldspotted Sweetlips	*Plectorhinchus flavomaculatus*	1
37353001	FISH	Snapper	*Chrysophrys auratus*	5
37354020	FISH	Teraglin	*Atractoscion atelodus*	1
37355000	FISH	Goatfishes	Mullidae – undifferentiated	35
37355001	FISH	Bluestriped Goatfish	*Upeneichthys lineatus*	194
37355003	FISH	Goldband Goatfish	*Upeneus moluccensis*	27
37355900	FISH	Goatfish	*Parupeneus* spp.	405
37367000	FISH	Boarfishes	Pentacerotidae – undifferentiated	2
37367004	FISH	Bigspine Boarfish	*Pentaceros decacanthus*	2
37367005	FISH	Blackspot Boarfish	*Zanclistius elevatus*	2
37377004	FISH	Blue Morwong	*Nemadactylus valenciennesi*	1
37378001	FISH	Striped Trumpeter	*Latris lineata*	4
37382000	FISH	Pikes	Sphyraenidae – undifferentiated	2
37382001	FISH	Striped Barracuda	*Sphyraena pinguis*	1
37382901	FISH	Striped Seapike	*Sphyraena* spp.	1
37384074	FISH	Bridled Tuskfish	*Choerodon frenatus*	1
37384904	FISH	Pigfishes	*Bodianus* spp.	4
37390000	FISH	Grubfishes	Pinguipedidae – undifferentiated	5
37400000	FISH	Stargazers	Uranoscopidae – undifferentiated	1
37439002	FISH	Gemfish	*Rexea solandri*	13
37440004	FISH	Largehead Hairtail	*Trichiurus lepturus*	17
37441000	FISH	Mackerels	Scombridae – undifferentiated	3
37441001	FISH	Blue Mackerel	*Scomber australasicus*	20
37460001	FISH	Crested Flounder	*Lophonectes gallus*	1
37460002	FISH	Smalltooth Flounder	*Pseudorhombus jenynsii*	45
37460009	FISH	Largetooth Flounder	*Pseudorhombus arsius*	22
37460010	FISH	Threespot Flounder	*Grammatobothus polyophthalmus*	9
37460015	FISH	Bigtooth Twinspot Flounder	*Pseudorhombus diplospilus*	2
37460031	FISH	Slender Flounder	*Pseudorhombus tenuirastrum*	28
37462000	FISH	Soles	Soleidae – undifferentiated	6
37462010	FISH	Manyband Sole	*Zebrias scalaris*	14
37462017	FISH	Black Sole	*Brachirus nigra*	14
37463000	FISH	Tongue Soles	Cynoglossidae – undifferentiated	8
37463001	FISH	Lemon Tongue Sole	*Paraplagusia bilineata*	36
37465005	FISH	Velvet Leatherjacket	*Meuschenia scaber*	13

CAAB	Species group	Common name	Species	No. Shots
37465006	FISH	Ocean Jacket	*Nelusetta ayraud*	41
37465036	FISH	Sixspine Leatherjacket	*Meuschenia freycineti*	2
37465065	FISH	Dusky Leatherjacket	*Paramonacanthus otisensis*	1
37465903	FISH	Leatherjackets	Monacanthidae – undifferentiated	41
37990009	FISH	Flounder	Bothidae, Psettodidae & Pleuronectidae (all spp.)	64
23607000	MOLLUSC	Cuttlefish	Sepiidae – undifferentiated	977
23607001	MOLLUSC	Giant Cuttlefish	*Sepia apama*	2
23607012	MOLLUSC	Mourning Cuttlefish	*Sepia plangon*	31
23608000	MOLLUSC	Bottletail Squids	Sepiadariidae spp.	14
23615000	MOLLUSC	Squids	Order Teuthoidea – undifferentiated	521
23617000	MOLLUSC	Loligo Squids	Loliginidae – undifferentiated	295
23617005	MOLLUSC	Southern Calamari	*Sepioteuthis australis*	45
23636004	MOLLUSC	Gould's Squid	*Nototodarus gouldi*	145
23659000	MOLLUSC	Octopus	Octopodidae, Eledonidae, Megaleledonidae, Bathypolypodidae, Enteroctopodidae - undifferentiated	1188
23659001	MOLLUSC	Hammer Octopus	*Octopus australis*	20
23999999	MOLLUSC	Shells	Shells	8
24207000	MOLLUSC	Volutes	Volutidae – undifferentiated	26
24207073	MOLLUSC	Bailer Shell	*Melo umbilicatus*	39
37990028	SHARK	Chimaeras	Order Chimaeriformes – undifferentiated	1
37013003	SHARK	Spotted Wobbegong	Orectolobus maculatus	2
37013900	SHARK	Wobbegong	Orectolobidae – undifferentiated	8
37017001	SHARK	Gummy Shark	*Mustelus antarcticus*	56
37017008	SHARK	School Shark	*Galeorhinus galeus*	3
37018000	SHARK	Whaler & Weasel Sharks	Carcharhinidae, Hemigaleidae – undifferentiated	4
37018001	SHARK	Bronze Whaler	*Carcharhinus brachyurus*	1
37018003	SHARK	Dusky Whaler	*Carcharhinus obscurus*	5
37018007	SHARK	Sandbar Shark	*Carcharhinus plumbeus*	1
37018014	SHARK	Australian Blacktip Shark	*Carcharhinus tilstoni*	3
37018022	SHARK	Tiger Shark	*Galeocerdo cuvier*	3
37020901	SHARK	Greeneye Dogfish	*Squalus* spp.	8
37023900	SHARK	Sawshark	*Pristiophorus* spp.	7
37024000	SHARK	Angelsharks	Squatinidae – undifferentiated	24
37026002	SHARK	Shark Ray	*Rhina ancylostoma*	3
37026005	RAY	Whitespotted Guitarfish	*Rhynchobatus australiae*	8

CAAB	Species group	Common name	Species	No. Shots
37027006	RAY	Eastern Fiddler Ray	*Trygonorrhina fasciata*	29
37027009	RAY	Eastern Shovelnose Ray	*Aptychotrema rostrata*	314
37039000	RAY	Eagle Rays	Myliobatidae, Aetobatidae – undifferentiated	3
37042000	CHIMAER	Shortnose Chimaeras	Chimaeridae – undifferentiated	3
37042001	CHIMAER	Ogilby's Ghostshark	*Chimaera ogilbyi*	4

Appendix 3. Weight (t) of the most abundant species observed to be retained from catches sampled in all regions in both year-1 and year-2 of the survey. Species are ranked according to the total observed weight (pooled across zones). Scientific names of all species are shown in Appendix 2.

	North		Central		South		
Species	year-1	year-2	year-1	year-2	year-1	year-2	Total
Grand Total	29.6	45.6	8.3	10.8	5.4	6.3	106.0
Eastern King Prawn	16.4	16.5	4.0	3.7	3.6	3.9	48.1
Eastern School Whiting	1.8	8.0	1.4	1.0	0.1	0.2	12.5
Stout Whiting	2.7	7.9	0.1	0.7	0.1	0.2	11.7
Octopuses	1.6	1.9	1.0	2.1	0.1	0.7	7.4
Yellowtail Scad	0.3	3.9	0.0	0.2	0.0	0.0	4.4
Cuttlefishes	1.1	0.8	0.5	0.6	0.2	0.2	3.4
Smooth Bug	0.9	1.8	0.0	0.0	0.0	0.0	2.7
Bluespotted Flathead	1.0	1.3	0.1	0.2	0.0	0.0	2.6
Eastern Shovelnose Ray	0.3	0.3	0.1	0.3	0.5	0.1	1.6
Eastern School Prawn	0.3	0.2	0.0	0.5	0.0	0.0	1.0
Ocean Leatherjacket	0.6	0.3	0.0	0.0	0.0	0.0	0.9
Goatfishes	0.2	0.5	0.0	0.0	0.0	0.0	0.7
Whitings	0.0	0.2	0.1	0.0	0.0	0.3	0.6
Blue Swimmer Crab	0.1	0.2	0.0	0.1	0.0	0.0	0.5
Deep-water Flathead	0.2	0.1	0.2	0.0	0.0	0.0	0.5
Squids	0.1	0.3	0.0	0.1	0.0	0.0	0.5
Loligo Squids	0.3	0.2	0.0	0.0	0.0	0.0	0.5
Leatherjackets	0.4	0.0	0.0	0.0	0.0	0.0	0.5
Angelsharks	0.0	0.1	0.1	0.1	0.1	0.0	0.4
Gummy Shark	0.1	0.2	0.0	0.0	0.0	0.0	0.4
Bugs	0.0	0.0	0.1	0.1	0.0	0.1	0.3
Three-Spotted Swimmer Crab	0.1	0.2	0.0	0.0	0.0	0.0	0.3
Eastern Fiddler Ray	0.0	0.0	0.1	0.0	0.2	0.0	0.3
Spotted Bigeye	0.0	0.0	0.2	0.1	0.0	0.0	0.3
Gould's Squid	0.1	0.0	0.1	0.0	0.0	0.0	0.2
Largehead Hairtail	0.0	0.0	0.0	0.0	0.1	0.1	0.2

Appendix 4. List of all species discarded during the survey (pooled across zones and years). Data are the number of shots each species discarded from. CAAB Nos are the Codes for Australian Aquatic Biota (http://www.marine.csiro.au/caab).

CAAB	Species group	Common name	Species	No. Shots
28852000	CRUST	Sponge Crabs	Dromidae – undifferentiated	8
28030000	CRUST	Mantis Shrimp	Order Stomatopoda – undifferentiated	643
28051003	CRUST	Smooth Mantis Shrimp	*Belosquilla laevis*	14
28710000	CRUST	Prawns & Shrimps	Penaeoidea & Caridea – undifferentiated	362
28711029	CRUST	Eastern School Prawn	*Metapenaeus macleayi*	41
28711031	CRUST	Coral Prawn	*Kishinouyepenaeopsis cornuta*	6
28711035	CRUST	Australian Rose Prawn	*Parapenaeus australiensis*	5
28711044	CRUST	Brown Tiger Prawn	*Penaeus esculentus*	1
28711052	CRUST	Eastern King Prawn	*Melicertus plebejus*	14
28711915	CRUST	Penaeid Prawn	*Parapenaeus* spp.	1
28712008	CRUST	Giant Scarlet Prawn	*Aristaeopsis edwardsiana*	4
28725000	CRUST	Shrimps	Stenopodidae – undifferentiated	27
28770000	CRUST	Pandalid Prawns	Pandalidae – undifferentiated	156
28770023	CRUST	Carid Prawn	*Plesionika spinipes*	3
28820002	CRUST	Eastern Rock Lobster	*Sagmariasus verreauxi*	37
28821004	CRUST	Balmain Bug	*Ibacus peronii*	6
28821014	CRUST	Shovel-nosed or Slipper Lobster	*Biarctus sordidus*	20
28821019	CRUST	Smooth Bug	*Ibacus chacei*	811
28821901	CRUST	Balmain Bugs	*Ibacus* spp.	171
28825901	CRUST	Hermit Crabs	Superfamily Paguroidea	221
28827002	CRUST	Red Hermit Crab	*Strigopagurus strigimanus*	5
28843000	CRUST	Porcelain Crabs	Porcellanidae – undifferentiated	60
28850000	CRUST	Crabs	Infraorder Brachyura – undifferentiated	76
28865001	CRUST	Spanner Crab	*Raninaranina*	3
28875003	CRUST	Box crab	*Mursia curtispina*	2
28880012	CRUST	Spider	*Hyastenus elatus*	14
28880021	CRUST	Spider Crab	*Teratomaia richardsoni*	3
28880038	CRUST	Spider Crab	*Phalangipus australiensis*	12
28880143	CRUST	Spider Crab	*Naxioides robillardi*	4
28880911	CRUST	Spider Crabs	Majidae – undifferentiated	99
28911000	CRUST	Swimmer Crabs	Portunidae, Polybiidae, Ovalipidae, Brusiniidae, Carcinidae – undifferentiated	788
28911001	CRUST	Coral Crab	*Charybdis feriata*	32

CAAB	Species group	Common name	Species	No. Shots
28911002	CRUST	Hairyback Crab	*Charybdis natator*	37
28911005	CRUST	Blue Swimmer Crab	*Portunus armatus*	112
28911006	CRUST	Three-spotted Crab	*Portunus sanguinolentus*	121
28911019	CRUST	Swimmer Crab	*Charybdis miles*	187
28911026	CRUST	Swimmer Crab	*Monomia rubromarginatus*	356
28911901	CRUST	Sand Crabs	*Ovalipes* spp.	3
28911931	CRUST	Swimmer Crabs	Portunidae – undifferentiated	78
28922007	CRUST	Crab	*Ommatocarcinus macgillivrayi*	21
28821010	CRUST	Honey Bug	*Ibacus brucei*	9
28821902	CRUST	Slipper Lobsters	*Scyllarides* spp.	11
25000000	ECHINO	Echinoderms	Phylum Echinodermata – undifferentiated	2
25001000	ECHINO	Crinoids	Class Crinoidea – undifferentiated	8
25102000	ECHINO	Seastars	Class Asteroidea – undifferentiated	241
25200000	ECHINO	Sea Urchins	Class Echinoidea – undifferentiated	298
25400000	ECHINO	Holothurians	Class Holothuroidea - undifferentiated	5
37372000	FISH	Damselfishes	Pomacentridae – undifferentiated	11
37354000	FISH	Jewfishes	Sciaenidae – undifferentiated	10
37056001	FISH	Southern Shortfin Eel	*Anguilla australis*	16
37060000	FISH	Moray Eels	Muraenidae – undifferentiated	2
37063001	FISH	Bigeye Pike Eel	*Oxyconger leptognathus*	50
37063002	FISH	Darkfin Pike Eel	*Muraenesox cinereus*	3
37067000	FISH	Conger & Short-tail Conger Eels	Congridae, Colocongridae – undifferentiated	522
37067002	FISH	Little Conger	*Gnathophis longicaudus*	1
37068000	FISH	Snake Eels	Ophichthidae – undifferentiated	28
37068001	FISH	Serpent Eel	*Ophisurus serpens*	1
37085002	FISH	Australian Sardine	*Sardinops sagax*	23
37085906	FISH	Sardinella	Sardinella spp.	21
37086000	FISH	Anchovies	Engraulidae – undifferentiated	2
37117001	FISH	Sergeant Baker	*Latropiscis purpurissatus*	23
37118000	FISH	Lizardfishes and Deepsea Lizardfishes	Bathysauridae, Synodontidae – undifferentiated	294
37118001	FISH	Largescale Saury	*Saurida undosquamis*	311
37118002	FISH	Painted Grinner	*Trachinocephalus trachinus*	294
37118032	FISH	Deepsea Lizardfish	*Saurida filamentosa*	46
37120000	FISH	Cucumberfishes, Greeneyes & Flathead Lizardfishes	Chlorophthalmidae, Paraulopidae & Bathysauroididae, Bathysauropsidae – undifferentiated	2
37120001	FISH	Blacktip Cucumberfish	*Paraulopus nigripinnis*	6

CAAB	Species group	Common name	Species	No. Shots
37120905	FISH	Cucumberfishes	*Paraulopus* spp.	10
37141001	FISH	Beaked Salmon	*Gonorynchus greyi*	498
37192000	FISH	Eeltail Catfishes	Plotosidae – undifferentiated	19
37192002	FISH	Striped Catfish	*Plotosus lineatus*	3
37205000	FISH	Frogfishes	Batrachoididae – undifferentiated	40
37205008	FISH	Eastern Frogfish	*Batrachomoeus dubius*	40
37208001	FISH	Broadhead Goosefish	*Lophiomus setigerus*	2
37210000	FISH	Frogfishes, & Doublefin & Straightback Frogfishes	Antennariidae, Tetrabrachiidae, Lophichthyidae – undifferentiated	68
37210009	FISH	Striate Anglerfish	*Antennarius striatus*	109
37210015	FISH	Whitespotted Anglerfish	*Phyllophryne scortea*	1
37212000	FISH	Seabats	Ogcocephalidae – undifferentiated	40
37212001	FISH	Shortfin Seabat	*Halieutaea brevicauda*	2
37224003	FISH	Bearded Rock Cod	*Pseudophycis barbata*	22
37224005	FISH	Largetooth Beardie	*Lotella rhacina*	59
37224011	FISH	Bastard Red Cod	*Pseudophycis breviuscula*	11
37224902	FISH	Pelagic Cod	*Lepidion* spp.	3
37225000	FISH	Codlets	Bregmacerotidae – undifferentiated	2
37227001	FISH	Blue Grenadier	*Macruronus novaezelandiae*	1
37228008	FISH	Rock Ling	*Genypterus tigerinus*	14
37228901	FISH	Ling	*Genypterus* spp.	128
37232000	FISH	Whiptails and Rat-tails	Macrouridae & Bathygadidae – undifferentiated	19
37232002	FISH	Banded Whiptail	*Coelorinchus fasciatus*	1
37233000	FISH	Flyingfishes	Exocoetidae – undifferentiated	1
37234006	FISH	Snubnose Garfish	*Arrhamphus sclerolepis*	4
37234014	FISH	Eastern Sea Garfish	*Hyporhamphus australis*	1
37235005	FISH	Crocodile Longtom	*Tylosurus crocodilus*	1
37236000	FISH	Sauries	Scomberesocidae – undifferentiated	3
37255000	FISH	Roughies	Trachichthyidae – undifferentiated	83
37255007	FISH	Violet Roughy	*Optivus agastos*	681
37255010	FISH	Little Pineapplefish	*Sorosichthys ananassa*	16
37258003	FISH	Redfish	*Centroberyx affinis*	144
37259000	FISH	Pineapplefishes	Monocentrididae – undifferentiated	52
37261000	FISH	Squirrelfishes	Holocentridae – undifferentiated	16
37264000	FISH	Dories & Lookdown Dories	Zeidae, Cyttidae – undifferentiated	1
37264004	FISH	John Dory	*Zeus faber*	93
37264010	FISH	Rosy Dory	*Cyttopsis rosea*	5

CAAB	Species group	Common name	Species	No. Shots
37267000	FISH	Deepsea Boarfishes	Caproidae – undifferentiated	132
37269001	FISH	Common Veilfin	*Metavelifer multiradiatus*	2
37278000	FISH	Flutemouths	Fistulariidae – undifferentiated	51
37278001	FISH	Smooth Flutemouth	*Fistularia commersonii*	19
37279000	FISH	Bellowsfishes	Centriscidae: Macroramphosinae - undifferentiated	1
37279002	FISH	Common Bellowsfish	*Macroramphosus scolopax*	9
37280902	FISH	Razorfishes	*Centriscidae* spp.	29
37282029	SYG	Spiny Pipehorse	*Solegnathus spinosissimus*	3
37282002	SYG	Common Seadragon	*Phyllopteryx taeniolatus*	5
37282006	SYG	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	14
37282900	SYG	Seahorses	*Hippocampus* spp.	9
37287001	FISH	Reef Ocean Perch	*Helicolenus percoides*	23
37287022	FISH	Pacific Monkeyfish	*Erosa erosa*	7
37287048	FISH	Eastern Fortescue	*Centropogon australis*	50
37287058	FISH	Bullrout	*Notesthes robusta*	11
37287066	FISH	Eastern Scorpionfish	*Scorpaena cardinalis*	7
37287066	FISH	Eastern Red Scorpionfish	*Scorpaena jacksoniensis*	24
37287081	FISH	False Stonefish	*Scorpaenopsis diabolus*	1
37287076	FISH	Cheekspot Scorpionfish	*Scorpaenodes evides*	1
37287901	FISH	Ocean Perch	*Helicolenus barathri* & *Helicolenus percoides*	21
37287904	FISH	Scorpionfishes	*Scorpaena* spp.	42
37287912	FISH	Lionfishes	*Dendrochirus* spp.	24
37287927	FISH	Gurnard Perches	*Neosebastes* spp.	335
37288001	FISH	Red Gurnard	*Chelidonichthys kumu*	5
37288003	FISH	Butterfly Gurnard	*Lepidotrigla vanessa*	3
37288006	FISH	Latchet	*Pterygotrigla polyommata*	11
37288901	FISH	Butterfly Gurnard	*Lepidotrigla* spp.	1244
37292001	FISH	Red Indian Fish	*Pataecus fronto*	2
37292002	FISH	Red Velvetfish	*Gnathanacanthus goetzeei*	1
37296001	FISH	Tiger Flathead	*Platycephalus richardsoni*	176
37296041	FISH	Mud Flathead	*Ambiserrula jugosa*	455
37296011	FISH	Freespine Flathead	*Ratabulus diversidens*	129
37296004	FISH	Dusky Flathead	*Platycephalus fuscus*	17
37296007	FISH	Bluespotted Flathead	*Platycephalus caeruleopunctatus*	781
37296021	FISH	Northern Sand Flathead	*Platycephalus endrachtensis*	9
37296036	FISH	Longspine Flathead	*Platycephalus grandispinis*	1020

CAAB	Species group	Common name	Species	No. Shots
37296038	FISH	Marbled Flathead	*Platycephalus marmoratus*	106
37308001	FISH	Largespot Flying Gurnard	*Dactyloptena papilio*	33
37308004	FISH	Purple Flying Gurnard	*Dactyloptena orientalis*	22
37311000	FISH	Temperate Seabasses & Rockcods	Percichthyidae, Serranidae, Acropomatidae, Polyprionidae, Moronidae, Callanthiidae, Centrogeniidae, Ostracoberycidae – undifferentiated	2
37311001	FISH	Eastern Orange Perch	*Lepidoperca pulchella*	14
37311017	FISH	Sixbar Grouper	*Epinephelus sexfasciatus*	1
37311095	FISH	Longfin Perch	*Caprodon longimanus*	17
37311147	FISH	Banded Rockcod	*Hyporthodus ergastularius*	101
37320003	FISH	Pearl Perch	*Glaucosoma scapulare*	182
37321000	FISH	Striped Grunters	Terapontidae – undifferentiated	47
37326000	FISH	Bigeyes	Priacanthidae – undifferentiated	89
37326001	FISH	Spotted Bigeye	*Priacanthus macracanthus*	885
37327002	FISH	Longfin Pike	*Dinolestes lewini*	92
37327013	FISH	Flagfin Cardinalfish	*Jaydia truncata*	2
37327129	FISH	Bullseye cardinalfish	*Apogonichthyoides atripes*	5
37327158	FISH	Cardinalfish	*Ostorhinchus fasciatus*	26
37327931	FISH	Cardinalfishes	*Ostorhinchus* spp.	22
37330000	FISH	Whitings	Sillaginidae – undifferentiated	5
37330005	FISH	Stout Whiting	*Sillago robusta*	199
37330014	FISH	Eastern School Whiting	*Sillago flindersi*	404
37330901	FISH	School Whiting	*Sillago bassensis*, *S. flindersi* & *S. robusta*	5
37331005	FISH	Australian Barred Tilefish	*Branchiostegus serratus*	1
37331006	FISH	Pink Tilefish	*Branchiostegus wardi*	2
37334002	FISH	Tailor	*Pomatomus saltatrix*	101
37336000	FISH	Remoras	Echeneidae – undifferentiated	2
37337000	FISH	Trevallies	Carangidae – undifferentiated	60
37337002	FISH	Common Jack Mackerel	*Trachurus declivis*	1
37337003	FISH	Yellowtail Scad	*Trachurus novaezelandiae*	602
37337015	FISH	Yellowstripe Scad	*Selaroides leptolepis*	1
37337021	FISH	Onion Trevally	*Carangoides caeruleopinnatus*	30
37337024	FISH	Barred Yellowtail Scad	*Atule mate*	6
37337025	FISH	Amberjack	*Seriola dumerili*	3
37337027	FISH	Giant Trevally	*Caranx ignobilis*	1
37337039	FISH	Bigeye Trevally	*Caranx sexfasciatus*	2
37337047	FISH	Fringefin Trevally	*Pantolabus radiatus*	2

CAAB	Species group	Common name	Species	No. Shots
37337062	FISH	Silver Trevally	*Pseudocaranx georgianus*	6
37337077	FISH	Peruvian Jack Mackerel	*Trachurus murphyi*	2
37337901	FISH	Amberfish	*Decapterus* spp.	20
37337904	FISH	Dart	*Trachinotus* spp.	2
37337911	FISH	Samsonfish	*Seriola dumerili* & *S. hippos*	5
37338001	FISH	Mahi	*Coryphaena hippurus*	1
37341000	FISH	Ponyfishes	Leiognathidae – undifferentiated	8
37345001	FISH	Redbait	*Emmelichthys nitidus*	1
37346000	FISH	Fusiliers, Tropical Snappers & Slopefishes	Caesionidae, Lutjanidae, Symphysanodontidae – undifferentiated	7
37346002	FISH	Goldband Snapper	*Pristipomoides multidens*	4
37346014	FISH	Ruby Snapper	*Etelis carbunculus*	4
37346017	FISH	Chinamanfish	*Symphorus nematophorus*	3
37346054	FISH	Ornate Snapper	*Pristipomoides argyrogrammicus*	15
37346905	FISH	Sea Perch	*Lutjanus* spp.	9
37347000	FISH	Threadfin Breams	Nemipteridae - undifferentiated	7
37347036	FISH	Theodore's Threadfin Bream	*Nemipterus theodorei*	166
37347901	FISH	Butterflybream	*Nemipterus* spp.	45
37349000	FISH	Silverbiddies	Gerreidae – undifferentiated	59
37351006	FISH	Grass Emperor	*Lethrinus laticaudis*	1
37353000	FISH	Breams	Sparidae – undifferentiated	3
37353001	FISH	Snapper	*Chrysophrys auratus*	40
37353004	FISH	Yellowfin Bream	*Acanthopagrus australis*	2
37353013	FISH	Tarwhine	*Rhabdosargus sarba*	8
37353903	FISH	Snappers	*Chrysophrys* spp.	7
37354001	FISH	Mulloway	*Argyrosomus japonicus*	9
37354020	FISH	Teraglin	*Atractoscion atelodus*	1
37355000	FISH	Goatfishes	Mullidae – undifferentiated	29
37355001	FISH	Bluestriped Goatfish	*Upeneichthys lineatus*	8
37355003	FISH	Goldband Goatfish	*Upeneus moluccensis*	5
37355014	FISH	Bartail Goatfish	*Upeneus tragula*	5
37355900	FISH	Goatfish	*Parupeneus* spp.	20
37356000	FISH	Silver Batfishes	Monodactylidae – undifferentiated	10
37356002	FISH	Diamondfish	*Monodactylus argenteus*	2
37357006	FISH	Bronze Bullseye	*Pempheris analis*	2
37357904	FISH	Bullseyes	Pempheridae – undifferentiated	9
37361004	FISH	Sea Sweep	*Scorpis aequipinnis*	2

CAAB	Species group	Common name	Species	No. Shots
37361005	FISH	Stripey	*Microcanthus strigatus*	61
37361009	FISH	Silver Sweep	*Scorpis lineolata*	1
37361010	FISH	Mado	*Atypichthys strigatus*	30
37362003	FISH	Shortfin Batfish	*Zabidius novemaculeatus*	1
37362004	FISH	Roundface Batfish	*Platax teira*	4
37363002	FISH	Spotted Scat	*Scatophagus argus*	6
37365039	FISH	Gunther's Butterflyfish	*Chaetodon guentheri*	1
37365063	FISH	Ballina Angelfish	*Chaetodontoplus ballinae*	4
37365900	FISH	Chaetodon reef fish	Chaetodontidae – undifferentiated	9
37366001	FISH	Old Wife	*Enoplosus armatus*	4
37367000	FISH	Boarfishes	Pentacerotidae – undifferentiated	87
37367004	FISH	Bigspine Boarfish	*Pentaceros decacanthus*	2
37367005	FISH	Blackspot Boarfish	*Zanclistius elevatus*	5
37372030	FISH	Biglip Damsel	*Cheiloprion labiatus*	7
37372031	FISH	Deepsea Puller	*Chromis abyssicola*	20
37372058	FISH	Twospot Demoiselle	*Chrysiptera biocellata*	2
37372000	FISH	Damselfishes	*Pomacentridae* – undifferentiated	4
37372083	FISH	Immaculate Damsel	*Mecaenichthys immaculatus*	1
37377001	FISH	Magpie Perch	*Cheilodactylus nigripes*	3
37377002	FISH	Grey Morwong	*Nemadactylus douglasii*	5
37378000	FISH	Trumpeters	Latridae – undifferentiated	30
37378001	FISH	Striped Trumpeter	*Latris lineata*	69
37382000	FISH	Pikes	Sphyraenidae – undifferentiated	10
37382003	FISH	Sharpfin Barracuda	*Sphyraena acutipinnis*	5
37384000	FISH	Wrasses	Labridae – undifferentiated	6
37384010	FISH	Blackspot Tuskfish	*Choerodon schoenleinii*	9
37384074	FISH	Bridled Tuskfish	*Choerodon frenatus*	232
37388000	FISH	Jawfishes	Opistognathidae – undifferentiated	104
37390000	FISH	Grubfishes	Pinguipedidae – undifferentiated	50
37390001	FISH	Barred Grubfish	*Parapercis allporti*	28
37390005	FISH	Pinkbanded Grubfish	*Parapercis nebulosa*	11
37390012	FISH	Redbanded Grubfish	*Parapercis binivirgata*	49
37400000	FISH	Stargazers	Uranoscopidae – undifferentiated	155
37400002	FISH	Fringe Stargazer	*Ichthyscopus barbatus*	1
37400003	FISH	Common Stargazer	*Kathetostoma laeve*	32
37408000	FISH	Blennies	Blenniidae – undifferentiated	3

CAAB	Species group	Common name	Species	No. Shots
37427000	FISH	Deepsea Dragonets and Dragonets	Draconettidae, Callionymidae – undifferentiated	680
37427001	FISH	Common Stinkfish	*Foetorepus calauropomus*	34
37427015	FISH	Spotted Dragonet	*Repomucenus calcaratus*	1
37428000	FISH	Gobies	Gobiidae - undifferentiated	2
37437031	FISH	Bluespine Unicornfish	*Naso unicornis*	1
37438014	FISH	Threespot Rabbitfish	*Siganus trispilos*	12
37439001	FISH	Barracouta	*Thyrsites atun*	1
37439002	FISH	Gemfish	*Rexea solandri*	11
37440004	FISH	Largehead Hairtail	*Trichiurus lepturus*	75
37441000	FISH	Mackerels	Scombridae – undifferentiated	4
37441001	FISH	Blue Mackerel	*Scomber australasicus*	60
37445000	FISH	Trevallas	Centrolophidae – undifferentiated	3
37445001	FISH	Blue-eye Trevalla	*Hyperoglyphe antarctica*	6
37445005	FISH	Blue Warehou	*Seriolella brama*	1
37445006	FISH	Silver Warehou	*Seriolella punctata*	1
37445901	FISH	Blue and Silver Warehou	*Seriolella brama* & *Seriolella punctata*	1
37460000	FISH	Lefteye Flounders	Bothidae, Achiropsettidae, Paralichthyidae – undifferentiated	3
37460001	FISH	Crested Flounder	*Lophonectes gallus*	296
37460002	FISH	Smalltooth Flounder	*Pseudorhombus jenynsii*	171
37460004	FISH	Three Twinspot Flounder	*Pseudorhombus dupliciocellatus*	8
37460009	FISH	Largetooth Flounder	*Pseudorhombus arsius*	10
37460010	FISH	Threespot Flounder	*Grammatobothus polyophthalmus*	23
37460013	FISH	Olive Wide-eye Flounder	*Engyprosopon maldivensis*	47
37460015	FISH	Bigtooth Twinspot Flounder	*Pseudorhombus diplospilus*	4
37460031	FISH	Slender Flounder	*Pseudorhombus tenuirastrum*	382
37460038	FISH	Peacock Flounder	*Pseudorhombus argus*	1
37460050	FISH	Bleeker's Flounder	*Engyprosopon bleekeri*	17
37460066	FISH	Broadbrow Flounder	*Crossorhombus valderostratus*	290
37461001	FISH	Longsnout Flounder	*Ammotretis rostratus*	3
37461002	FISH	Banded-fin Flounder	*Azygopus pinnifasciatus*	1
37461006	FISH	Cockatoo Flounder	*Samaris cristatus*	530
37462000	FISH	Soles	Soleidae – undifferentiated	46
37462010	FISH	Manyband Sole	*Zebrias scalaris*	230
37462017	FISH	Black Sole	*Brachirus nigra*	2
37462018	FISH	Narrowbanded Sole	*Synclidopus macleayanus*	47
37463000	FISH	Tongue Soles	Cynoglossidae – undifferentiated	90

CAAB	Species group	Common name	Species	No. Shots
37463001	FISH	Lemon Tongue Sole	*Paraplagusia bilineata*	55
37464902	FISH	Deep-water Tripodfishes	*Halimochirurgus* spp.	153
37465005	FISH	Velvet Leatherjacket	*Meuschenia scaber*	204
37465006	FISH	Ocean Jacket	*Nelusetta ayraud*	115
37465007	FISH	Rough Leatherjacket	*Scobinichthys granulatus*	4
37465025	FISH	Southern Pygmy Leatherjacket	*Brachaluteres jacksonianus*	1
37465039	FISH	Black Reef Leatherjacket	*Eubalichthys bucephalus*	1
37465059	FISH	Yellowfin Leatherjacket	*Meuschenia trachylepis*	70
37465065	FISH	Dusky Leatherjacket	*Paramonacanthus otisensis*	54
37465903	FISH	Leatherjacket	Monacanthidae – undifferentiated	77
37466000	FISH	Boxfishes	Ostraciidae, Aracanidae – undifferentiated	20
37466002	FISH	Eastern Smooth Boxfish	*Anoplocapros inermis*	461
37466004	FISH	Longhorn Cowfish	*Lactoria cornuta*	2
37466007	FISH	Roundbelly Cowfish	*Lactoria diaphana*	38
37466008	FISH	Smallspine Turretfish	*Tetrosomus reipublicae*	309
37467000	FISH	Toadfishes	Tetraodontidae – undifferentiated	74
37467003	FISH	Smooth Toadfish	*Tetractenos glaber*	119
37467004	FISH	Balloonfish	*Sphoeroides pachygaster*	11
37467005	FISH	Starry Toadfish	*Arothron firmamentum*	59
37467007	FISH	Silver Toadfish	*Lagocephalus sceleratus*	11
37467014	FISH	Starry Puffer	*Arothron stellatus*	3
37467023	FISH	Ocean Puffer	*Lagocephalus*	3
37467038	FISH	Clown Toby	*Canthigaster callisterna*	6
37467050	FISH	Halstead's Toadfish	*Reicheltia halsteadi*	7
37467054	FISH	Common Toadfish	*Tetractenos hamiltoni*	80
37467065	FISH	Cheeseman's Puffer	*Lagocephalus cheesemanii*	477
37469000	FISH	Porcupinefishes	Diodontidae – undifferentiated	55
37469013	FISH	Threebar porcupinefish	*Dicotylichthys punctulatus*	82
37990009	FISH	Flounder	Bothidae, Psettodidae & Pleuronectidae (all spp.)	578
23608000	MOLLUSC	Bottletail Squids	Sepiadariidae – undifferentiated	1
23000000	MOLLUSC	Molluscs	Phylum Mollusca – undifferentiated	2
23199000	MOLLUSC	Bivalves	Class Bivalvia – undifferentiated	3
23220000	MOLLUSC	Mussels	Mytilidae – undifferentiated	1
23270000	MOLLUSC	Scallops	Pectinidae – undifferentiated	66
23270007	MOLLUSC	Commercial Scallop	*Pecten fumatus*	1
23607000	MOLLUSC	Cuttlefish	Sepiidae – undifferentiated	302

CAAB	Species group	Common name	Species	No. Shots
23607010	MOLLUSC	Rosecone Cuttlefish	*Sepia rozella*	5
23607012	MOLLUSC	Mourning Cuttlefish	*Sepia plangon*	2
23608001	MOLLUSC	Pinstripe Bottletail Squid	*Sepioloidea Lineolata*	19
23615000	MOLLUSC	Squids	Order Teuthoidea – undifferentiated	52
23617000	MOLLUSC	Loligo Squids	Loliginidae – undifferentiated	5
23617005	MOLLUSC	Southern Calamari	*Sepioteuthis australis*	2
23617010	MOLLUSC	Luminous Bay Squid	*Uroteuthis noctiluca*	1
23636004	MOLLUSC	Gould's Squid	*Nototodarus gouldi*	15
23659000	MOLLUSC	Octopus	Octopodidae, Eledonidae, Megaleledonidae, Bathypolypodidae, Enteroctopodidae – undifferentiated	56
23659001	MOLLUSC	Hammer Octopus	*Octopus australis*	1
23999999	MOLLUSC	Shells	Shells	82
24000000	MOLLUSC	Gastropods	Class Gastropoda – undifferentiated	1
24177010	MOLLUSC	Tun Shell	*Tonna sulcosa*	3
24207000	MOLLUSC	Volutes	Volutidae – undifferentiated	8
24207008	MOLLUSC	Lightening Volute	*Ericusa fulgetra*	1
24207073	MOLLUSC	Bailer Shell	*Melo umbilicatus*	3
24222901	MOLLUSC	Cone Snail	*Conus* spp.	6
37038022	RAY	Coastal Stingaree	*Urolophus orarius*	1
37039001	RAY	Southern Eagle Ray	*Myliobatis tenuicaudatus*	21
37038904	RAY	Stingarees	Urolophidae – undifferentiated	161
37027006	RAY	Eastern Fiddler Ray	*Trygonorrhina fasciata*	204
37027009	RAY	Eastern Shovelnose Ray	*Aptychotrema rostrata*	437
37027011	RAY	Southern Fiddler Ray	*Trygonorrhina dumerilii*	6
37028000	RAY	Torpedo Rays, Coffin Rays and Numbfishes	Torpedinidae, Narcinidae, Hypnidae – undifferentiated	40
37028001	RAY	Coffin Ray	*Hypnos monopterygius*	366
37028003	RAY	Short-tail Torpedo Ray	*Tetronarce nobiliana*	4
37031000	RAY	Skates	Rajidae, Arhynchobatidae – undifferentiated	58
37031002	RAY	Sydney Skate	*Dentiraja australis*	90
37035000	RAY	Stingrays	Dasyatidae – undifferentiated	13
37035001	RAY	Smooth Stingray	*Bathytoshia brevicaudata*	14
37035002	RAY	Black Stingray	*Bathytoshia lata*	33
37035004	RAY	Bluespotted Maskray	*Neotrygon australiae*	13
37038006	RAY	Common Stingaree	*Trygonoptera testacea*	140
37038007	RAY	Greenback Stingaree	*Urolophus viridis*	88
37038018	RAY	Kapala Stingaree	*Urolophus kapalensis*	3

CAAB	Species group	Common name	Species	No. Shots
37039000	RAY	Eagle Rays	Myliobatidae, Aetobatidae – undifferentiated	31
37042000	SHARK	Shortnose Chimaeras	Chimaeridae – undifferentiated	2
37007000	SHARK	Horn Sharks	Heterodontidae – undifferentiated	1
37007001	SHARK	Port Jackson Shark	*Heterodontus portusjacksoni*	147
37007003	SHARK	Crested Hornshark	*Heterodontus galeatus*	2
37008001	SHARK	Grey Nurse Shark	*Carcharias taurus*	1
37012000	SHARK	Thresher Sharks	Alopiidae – undifferentiated	2
37008003	SHARK	Sandtiger Shark	*Odontaspis ferox*	1
37013002	SHARK	Collar Carpetshark	*Parascyllium collare*	14
37013006	SHARK	Zebra Shark	*Stegostoma tigrinum*	2
37013007	SHARK	Blind Shark	*Brachaelurus waddi*	1
37013900	SHARK	Wobbegong	Orectolobidae – undifferentiated	42
37015000	SHARK	Catsharks	Scyliorhinidae, Pentanchidae – undifferentiated	89
37015005	SHARK	Banded Catshark	*Atelomycterus fasciatus*	13
37015027	SHARK	Grey Spotted Catshark	*Asymbolus analis*	18
37015029	SHARK	Blackspotted Catshark	*Aulohalaelurus labiosus*	8
37017001	SHARK	Gummy Shark	*Mustelus antarcticus*	53
37018012	SHARK	Bignose Shark	*Carcharhinus altimus*	1
37018022	SHARK	Tiger Shark	*Galeocerdo cuvier*	1
37020000	SHARK	Gulper Sharks, Sleeper Sharks & Dogfishes	Centrophoridae, Dalatiidae, Squalidae, Somniosidae & Etmopteridae – undifferentiated	8
37020901	SHARK	Greeneye Dogfish	*Squalus* spp.	4
37023002	SHARK	Common Sawshark	*Pristiophorus cirratus*	3
37023900	SHARK	Sawshark	*Pristiophorus* spp.	9
37024000	SHARK	Angelsharks	Squatinidae - undifferentiated	10
37990003	SHARK	Sharks (other)	Sharks – other	1
37990029	SHARK	Carpet Sharks	Order Orectolobiformes – undifferentiated	1
10000000	SPONGE	Sponges	Phylum Porifera – undifferentiated	1

Appendix 5. Weight (t) of the most abundant species observed to be discarded from catches sampled in all regions in both year-1 and year-2 of the survey. Species are ranked according to the total observed weight (pooled across zones). Scientific names of all species are shown in Appendix 4.

	North		Central		South		
Species	**year-1**	**year-2**	**year-1**	**year-2**	**year-1**	**year-2**	**Total**
Grand Total	50.6	75.8	10.6	23.9	9.9	10.6	181.4
Butterfly Gurnards	20.7	22.0	2.4	5.0	0.6	0.8	51.5
Longspine Flathead	3.8	6.1	0.8	2.1	0.1	0.8	13.7
Spotted Bigeye	1.6	4.5	0.6	3.4	0.0	0.7	10.8
Yellowtail Scad	1.2	5.2	0.0	0.2	0.3	0.6	7.5
Eastern School Whiting	0.3	2.2	1.8	2.1	0.2	0.2	6.8
Coffin Ray	1.3	2.3	0.3	0.9	0.3	0.4	5.5
Stout Whiting	0.4	4.0	0.1	0.7	0.1	0.1	5.4
Trawl Crabs[1]	1.4	1.6	0.1	0.2	1.0	0.9	5.2
Flounders[2]	0.1	2.7	0.0	1.3	0.0	0.7	4.8
Smooth Bug	1.0	2.4	0.1	0.0	0.0	0.0	3.5
Bluespotted Flathead	0.9	1.4	0.1	0.3	0.3	0.2	3.2
Stingarees[3]	0.3	0.7	0.2	1.6	0.0	0.2	3.0
Dragonets	1.1	0.8	0.1	0.6	0.0	0.0	2.6
Eastern Shovelnose Ray	0.1	0.7	0.1	0.7	0.5	0.5	2.6
Eastern Smooth Boxfish	1.4	0.7	0.0	0.2	0.0	0.0	2.3
Pandalid Prawns	0.1	0.1	0.6	0.3	0.8	0.3	2.2
Mud Flathead	1.0	0.7	0.1	0.2	0.0	0.1	2.1
Slender Flounder	1.3	0.3	0.1	0.0	0.0	0.0	1.7
Starry Toadfish	1.3	0.4	0.0	0.0	0.0	0.0	1.7
Eastern Fiddler Ray	0.0	0.1	0.1	0.3	0.6	0.4	1.5
Tiger Flathead	0.0	0.0	0.0	0.0	0.7	0.8	1.5
Port Jackson Shark	0.0	0.0	0.0	0.0	0.6	0.8	1.4
Trumpeters	0.0	1.3	0.0	0.0	0.0	0.0	1.3
Cheeseman's Puffer	0.6	0.5	0.1	0.0	0.0	0.0	1.2
Smooth Stingray	0.1	0.1	0.0	0.9	0.1	0.0	1.2
Southern Eagle Ray	0.0	0.4	0.1	0.4	0.2	0.1	1.2

	North		Central		South		
Velvet Leatherjacket	0.5	0.7	0.0	0.0	0.0	0.0	1.2
Urchins	0.5	0.6	0.0	0.0	0.0	0.0	1.1
Cockatoo Flounder	0.5	0.1	0.1	0.0	0.2	0.1	1.0
Largescale Saury	0.2	0.3	0.1	0.1	0.0	0.3	1.0
Leatherjackets	0.8	0.0	0.0	0.1	0.0	0.0	0.9
Ocean Leatherjacket	0.7	0.1	0.0	0.0	0.1	0.0	0.9
Beaked Salmon	0.4	0.4	0.0	0.0	0.0	0.0	0.8
Lizardfishes	0.2	0.6	0.0	0.0	0.0	0.0	0.8
Smalltooth Flounder	0.5	0.2	0.1	0.0	0.0	0.0	0.8

[1] Flounders (*Lophonectes gallus, Pseudorhombus argus*, *Engyprosopon bleekeri*, *Crossorhombus valderostratus*, *Ammotretis rostratus*, *Azygopus pinnifasciatus*)

[2] Swimmer Crabs (*Charybdis miles*, *Monomia rubromarginatus*, Portunidae, Polybiidae, Ovalipidae, Brusiniidae, Carcinidae – undifferentiated)

[3] Stingarees (*Trygonoptera testacea*, *Urolophus viridis*, *U. kapalensis*)

Appendix 6. Quota species summaries (number per-trip^{-1} ± SE). Corresponding weight graphs shown in report (Figs 5, 7 & 8).

Figure A6 - 1 Mean catch rates (number per-trip^{-1} ± SE) of retained and discarded catches of Bluespotted Flathead (*Platycephalus caeruleopunctatus*) for all, North, Central, and South zones.

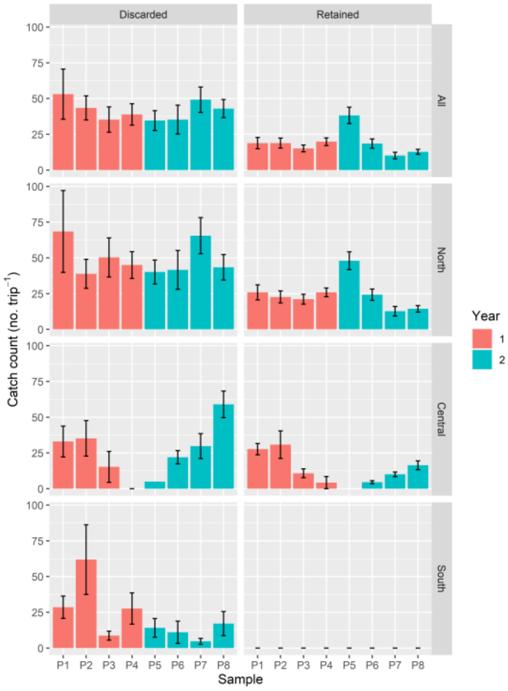


Figure A6 - 2 Mean catch rates (number per-trip^{-1} ± SE) of retained and discarded catches of Tiger Flathead (*Platycephalus richardsoni*) for all, North, Central, and South zones.

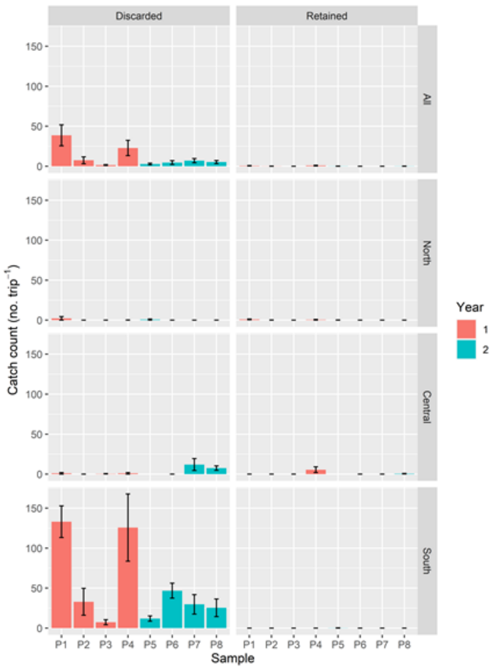


Figure A6 - 3 Mean catch rates (number per-trip^{-1} ± SE) of retained and discarded catches of Eastern School Whiting (*Sillago flindersi*) for all, North, Central, and South zones.

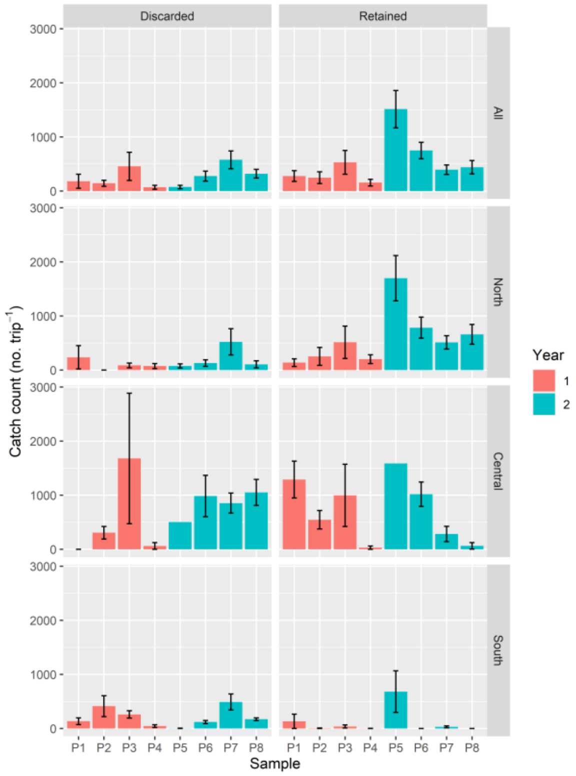
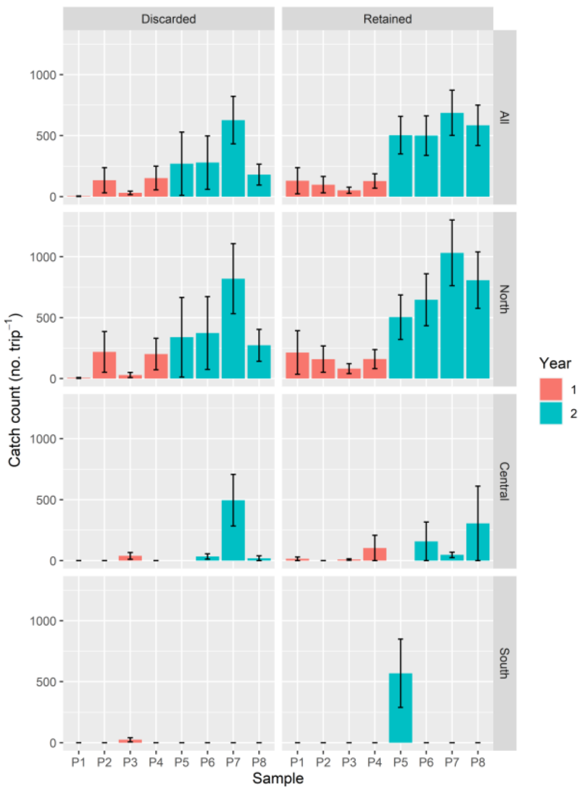


Figure A6 - 4 Mean catch rates (number per-trip^{-1} ± SE) of retained and discarded catches of Stout Whiting (*Sillago robusta*) for all, North, Central, and South zones.



Appendix 7. Commercial (byproduct) species summaries.

Figure A7- 1 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Blue Swimmer Crabs (*Portunus armatus*) for all, North, Central, and South zones.

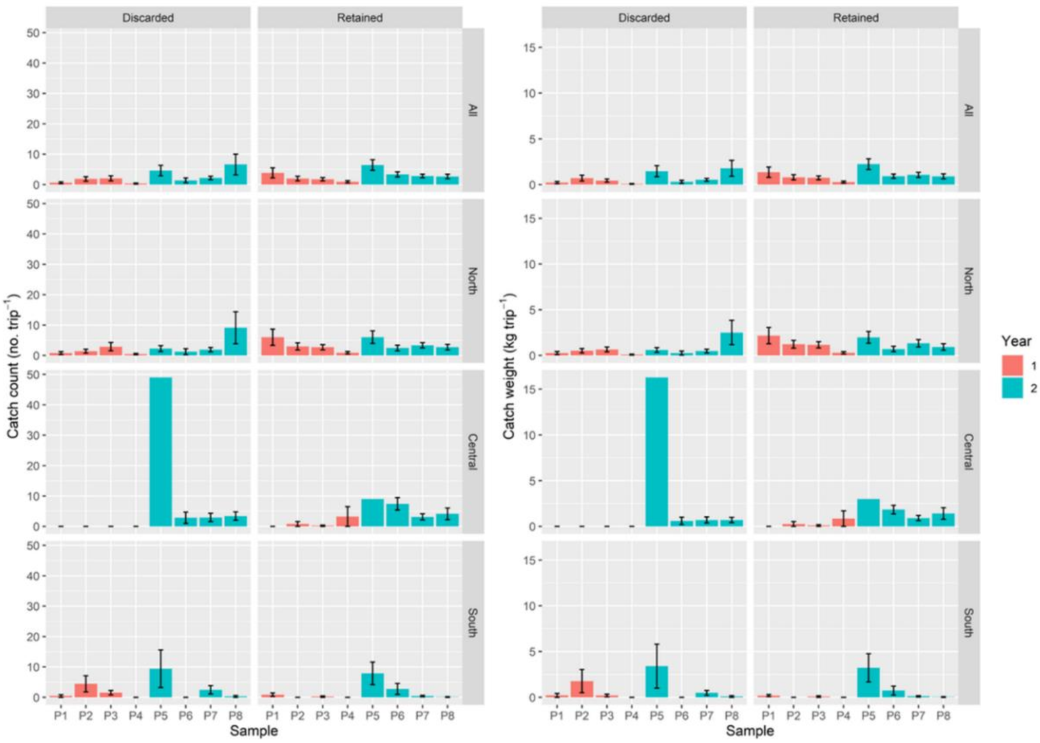


Figure A7- 2 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Coral Crab (*Charybdis feriata*) for all, North, Central, and South zones.

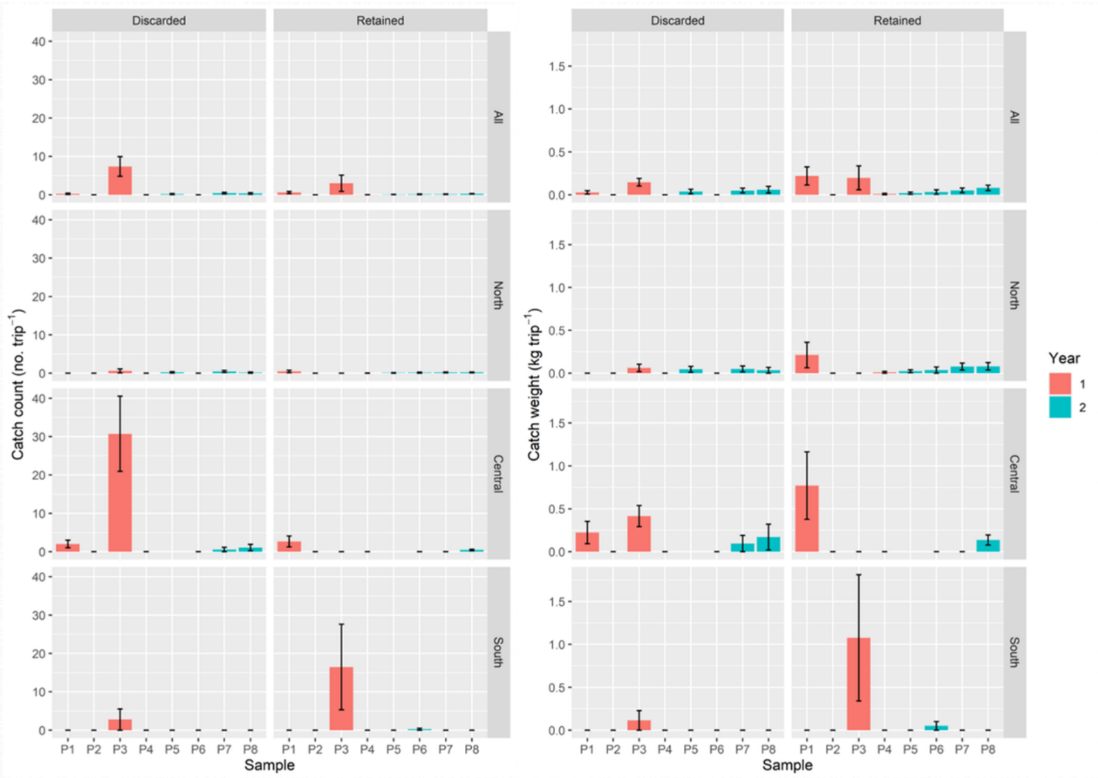


Figure A7- 3 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Smooth Bug (*Ibacus chacei*) for all, North, Central, and South zones.

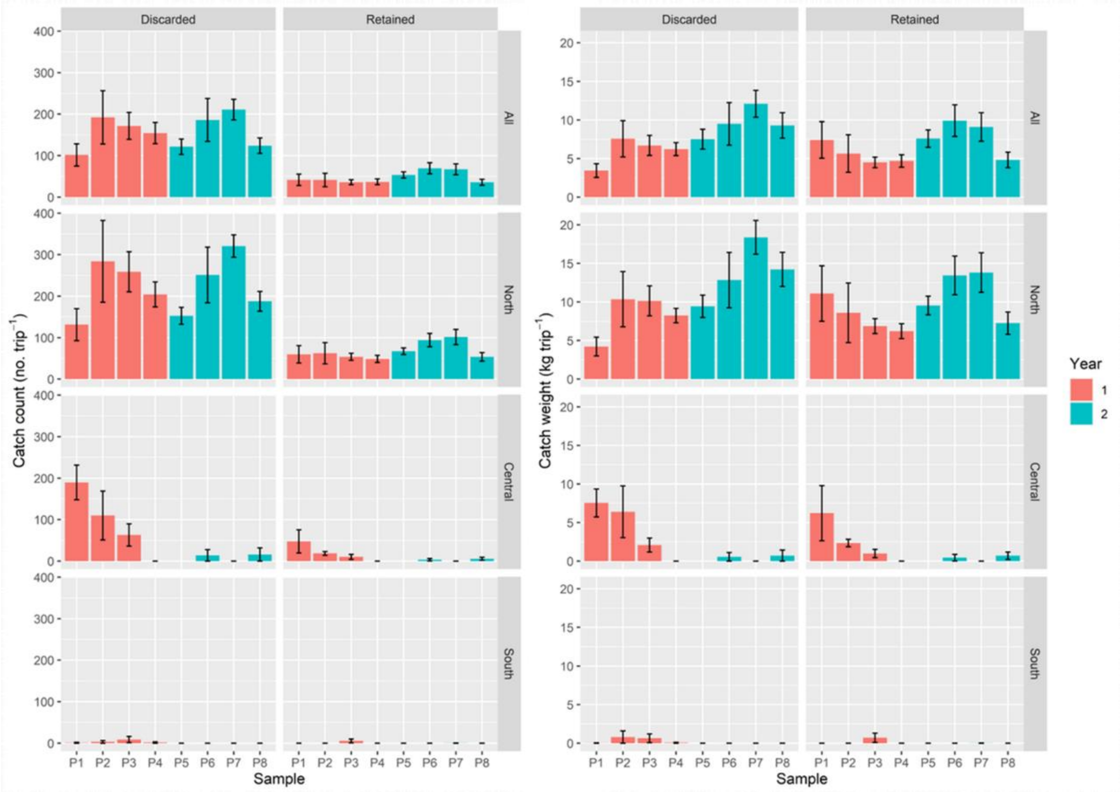


Figure A7- 4 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Bugs (Ibacus spp.) for all, North, Central, and South zones.

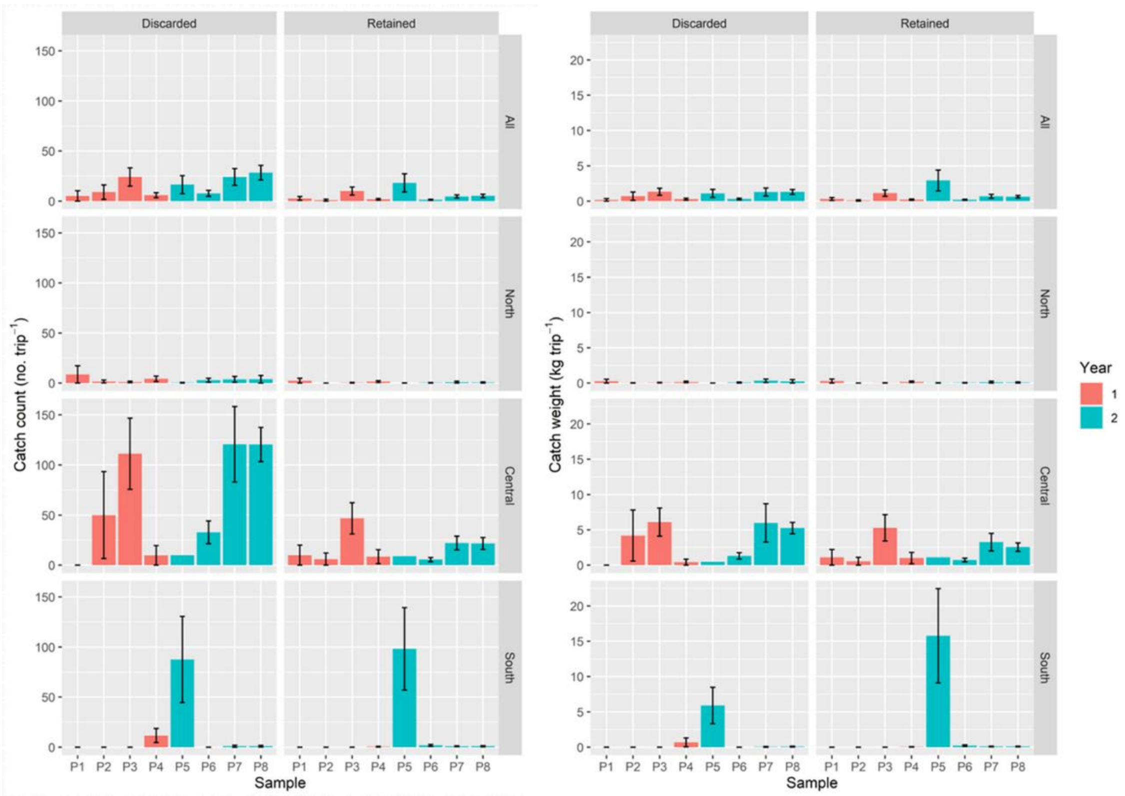


Figure A7- 5 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Mantis Shrimps (Stomatopoda) for all, North, Central, and South zones.

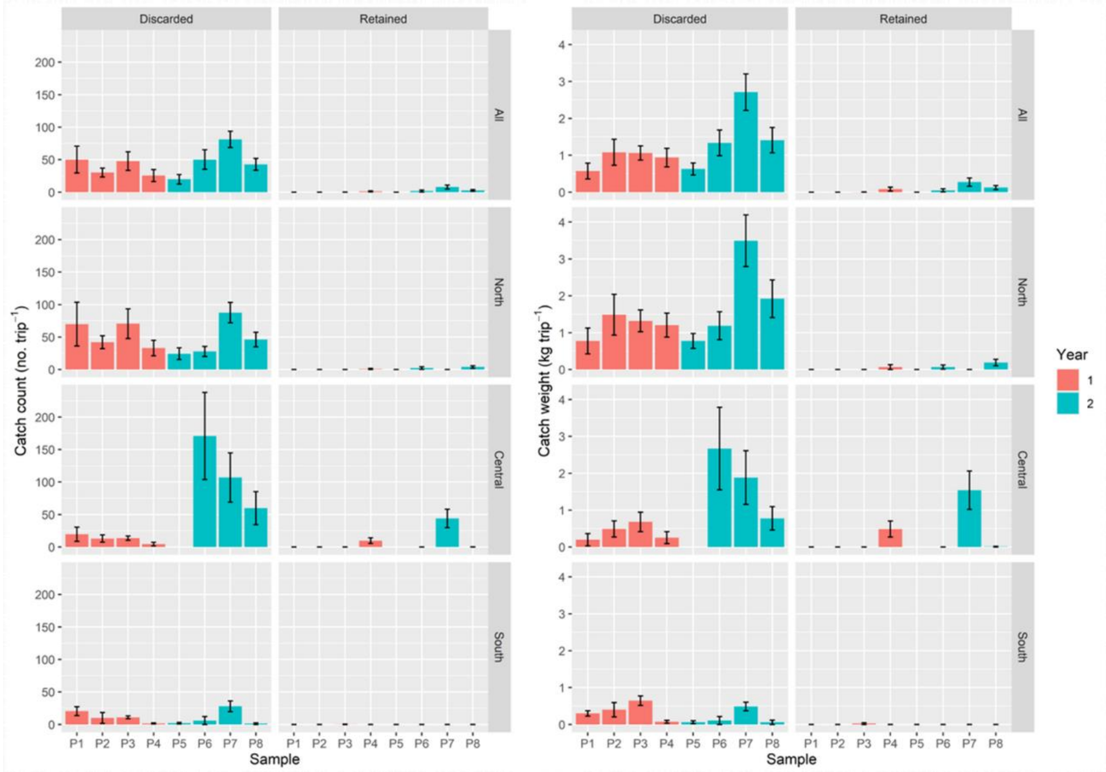


Figure A7- 6 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Brown Tiger Prawn (*Penaeus esculentus*) for all, North, Central, and South zones.

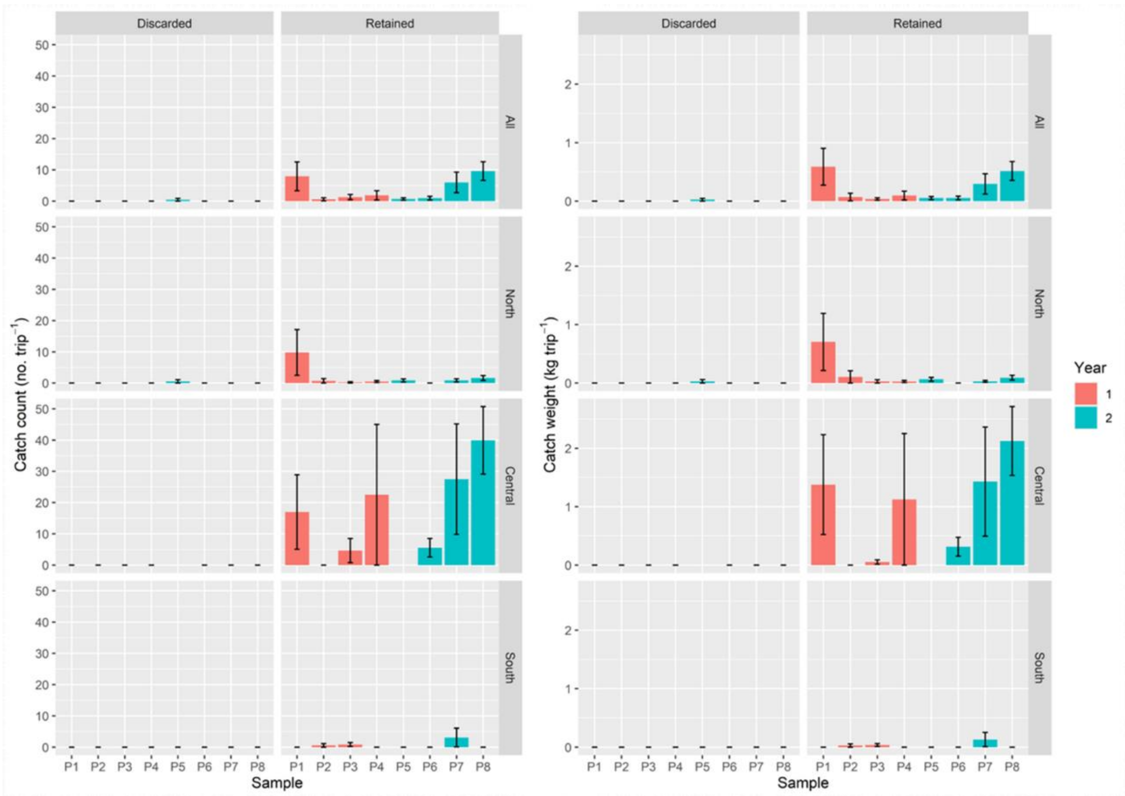


Figure A7- 7 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Cuttlefishes (Sepiidae) for all, North, Central, and South zones.

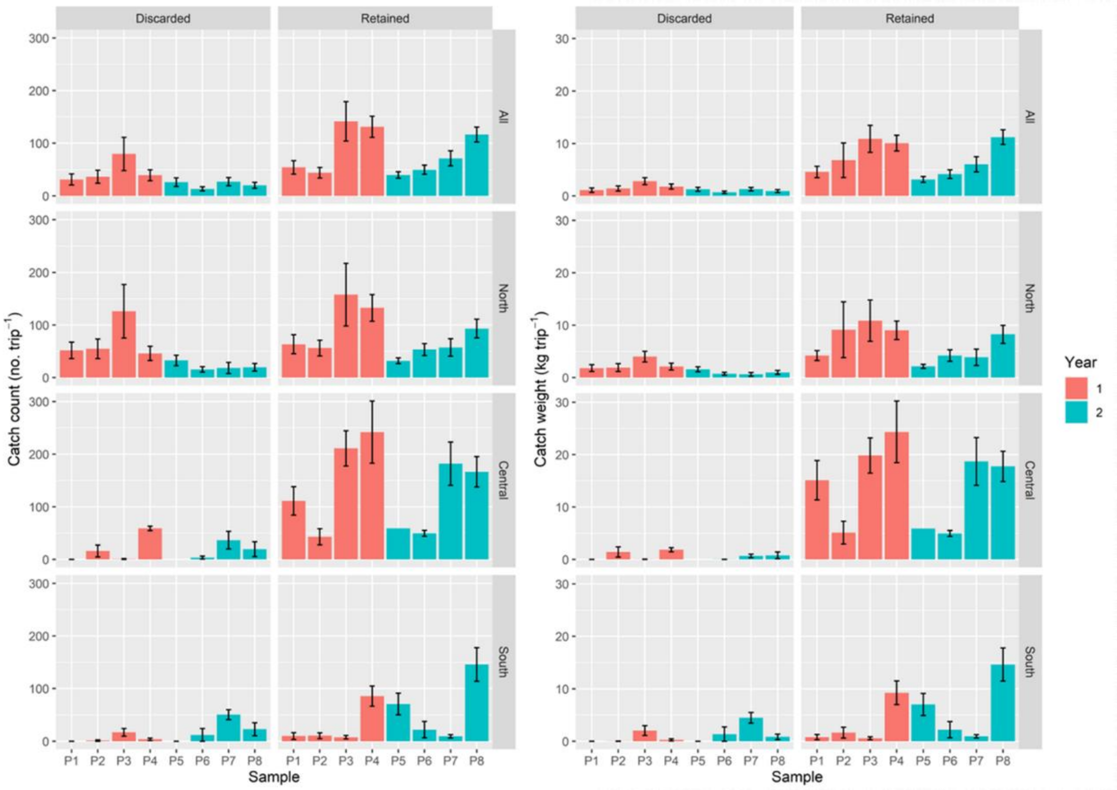


Figure A7- 8 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Octopuses (Octopodidae) for all, North, Central, and South zones.

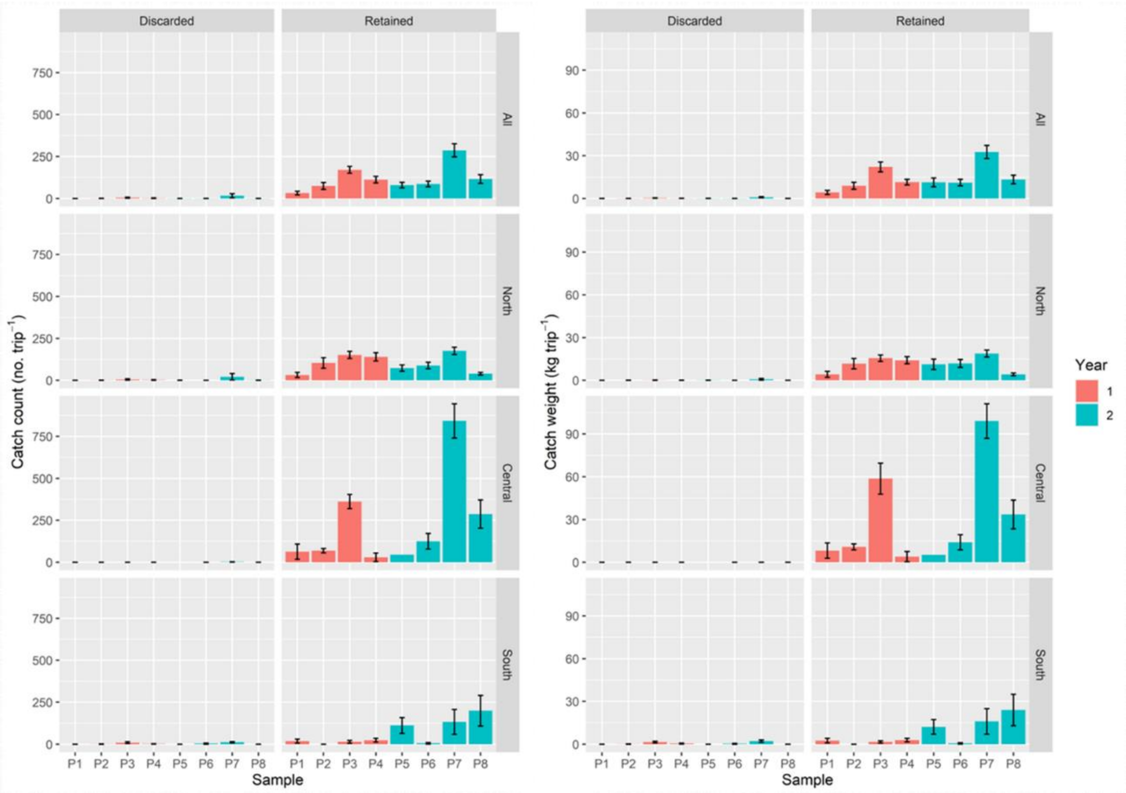


Figure A7- 9 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Southern Calamari (*Sepioteuthis australis*) for all, North, Central, and South zones.

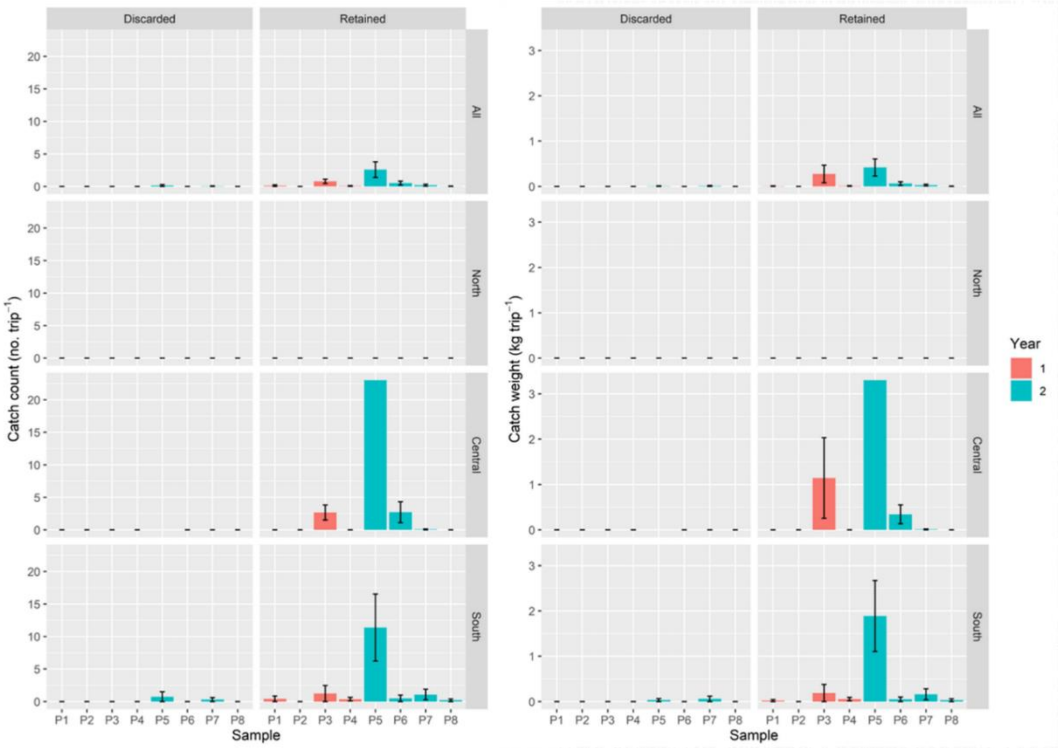


Figure A7- 10 Mean catch rates (no an kg per-trip^{-1} ± SE) of retained and discarded catches of Loligo Squids (Loliginidae) for all, North, Central, and South zones.

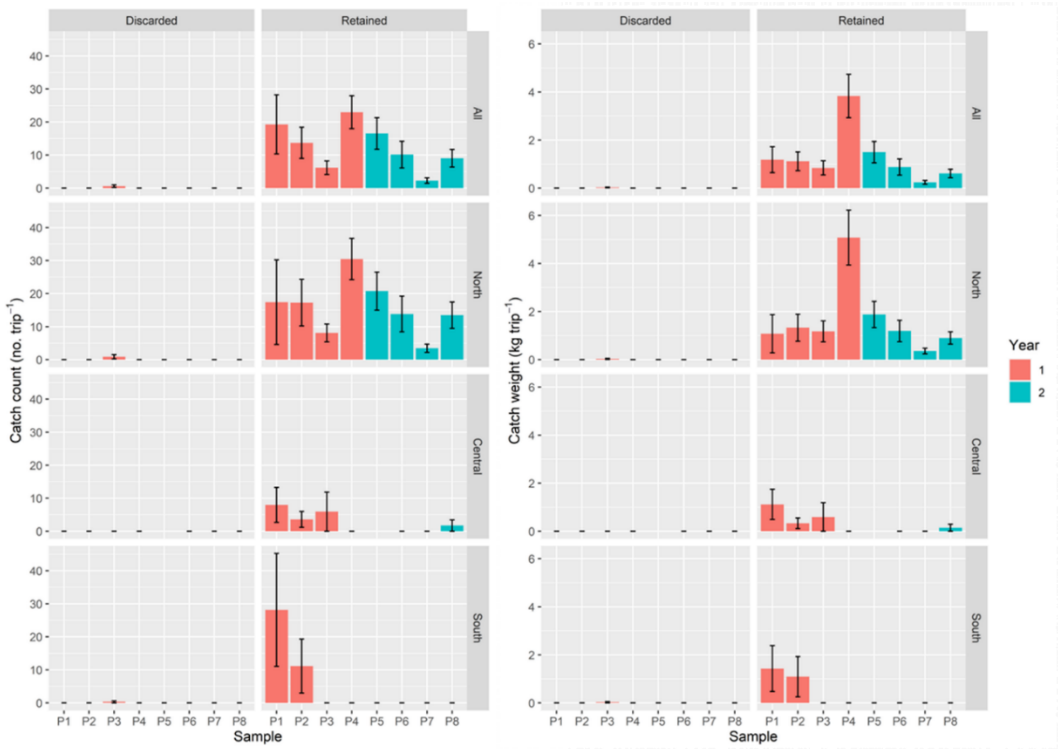


Figure A7- 11 Mean catch rates (no an kg per-trip^{-1} ± SE) of retained and discarded catches of Gould's Squid (*Nototodarus gouldi*) for combined all, North, Central, and South zones.

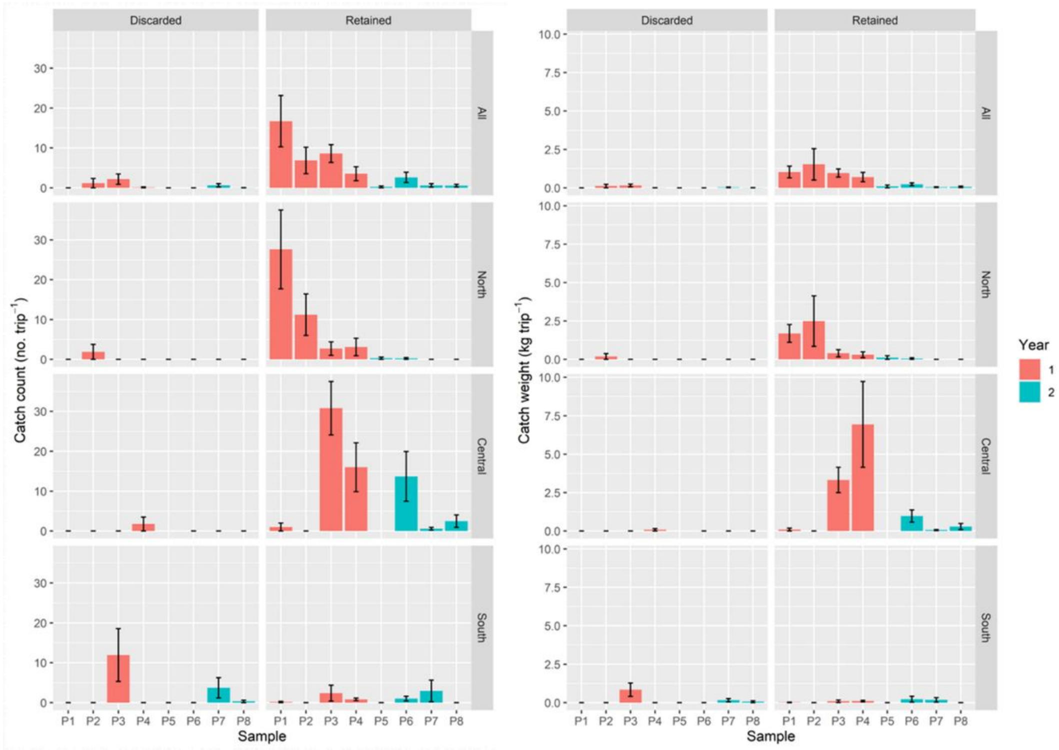


Figure A7- 12 Mean catch rates (no an kg per-trip^{-1} ± SE) of retained and discarded catches of Freespine Flathead (*Ratabulus diversidens*) for all, North, Central, and South zones.

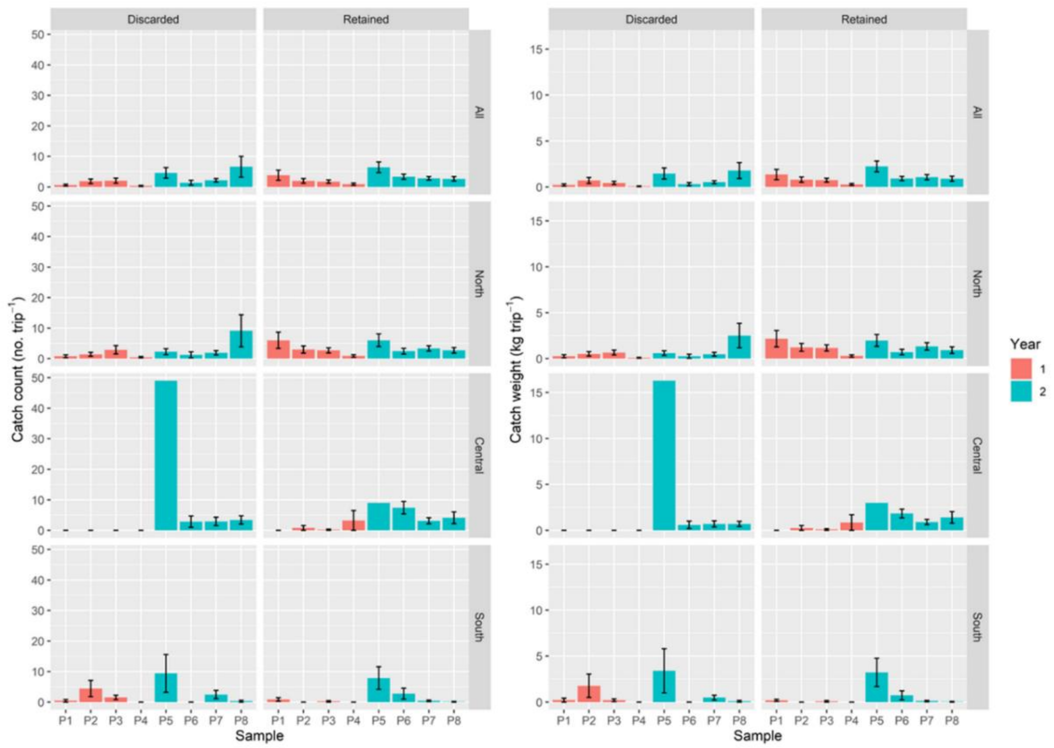


Figure A7- 13 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Flounders (Bothidae, Psettodidae & Pleuronectidae) for all, North, Central, and South zones.

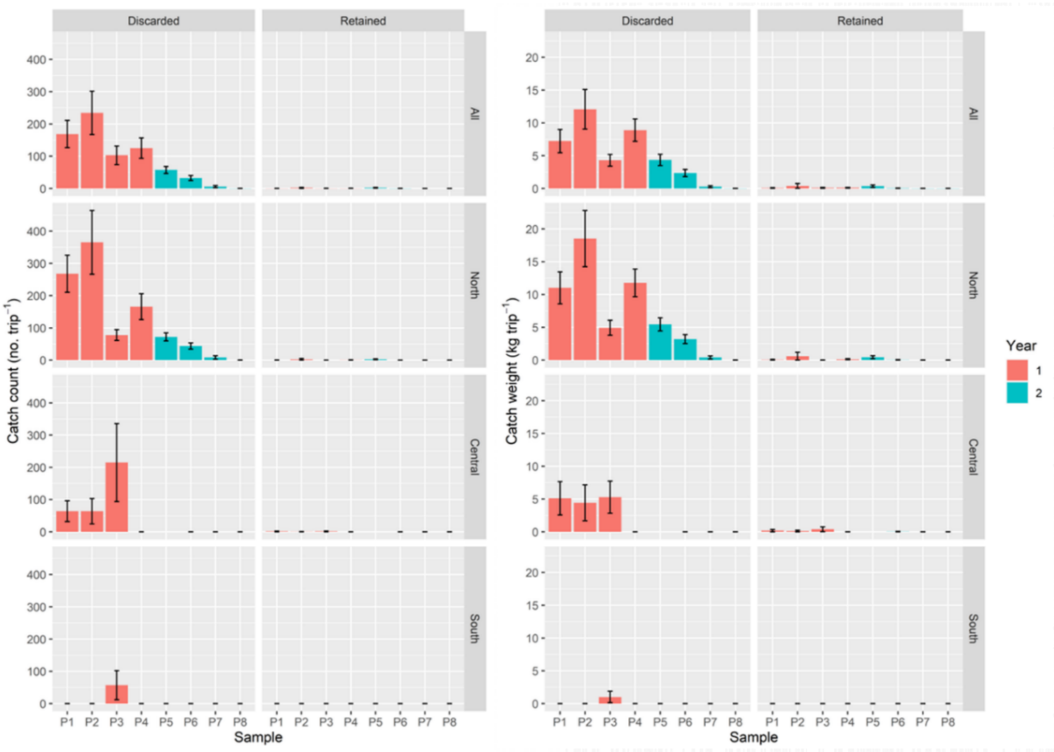


Figure A7- 14 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Goatfishes (Mullidae) for all, North, Central, and South zones.

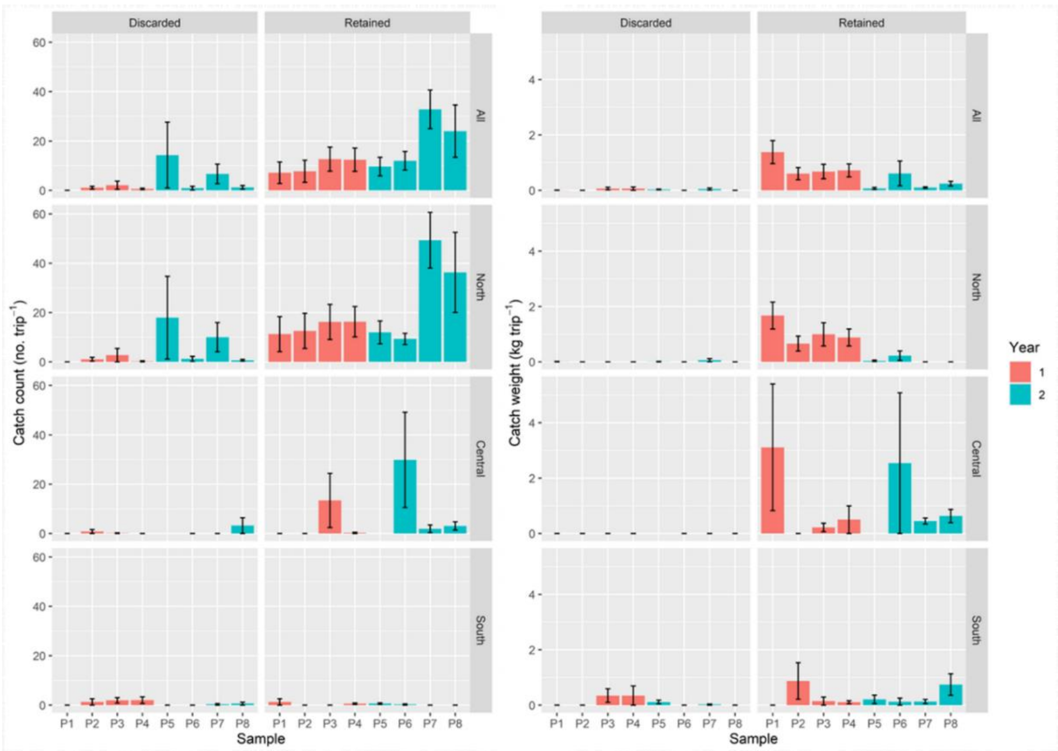


Figure A7- 15 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Lemon Tongue Sole (*Paraplagusia bilineata*) for all, North, Central, and South zones.

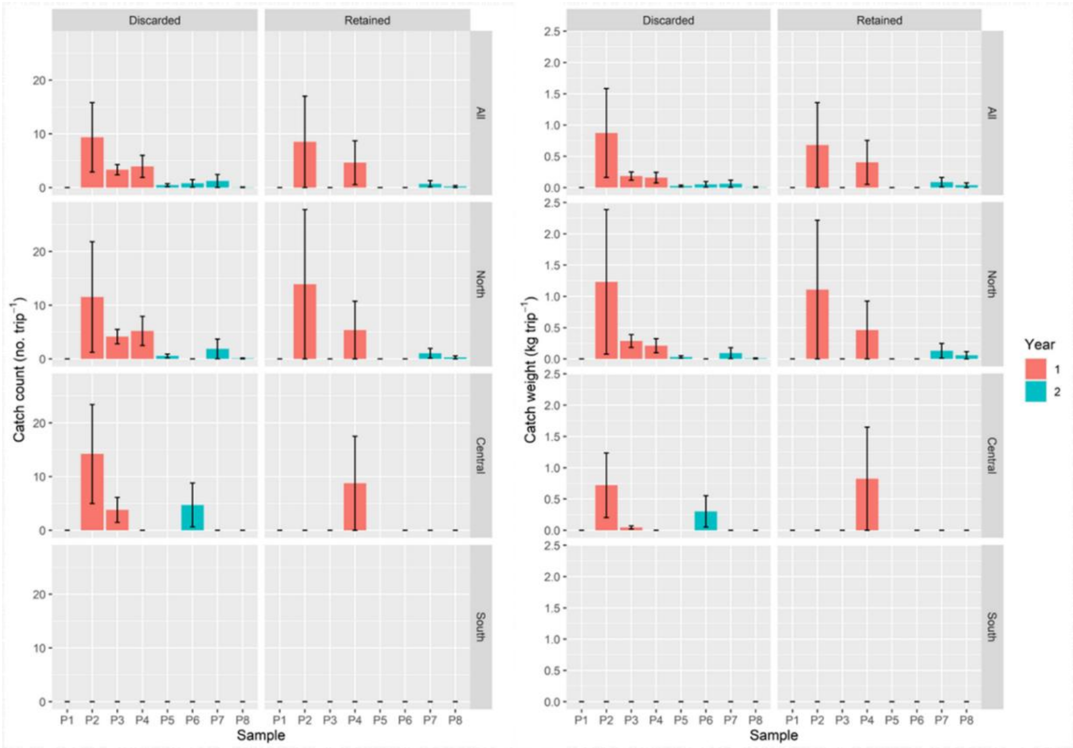


Figure A7- 16 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Redfish (*Centroberyx affinis*) for all, North, Central, and South zones.

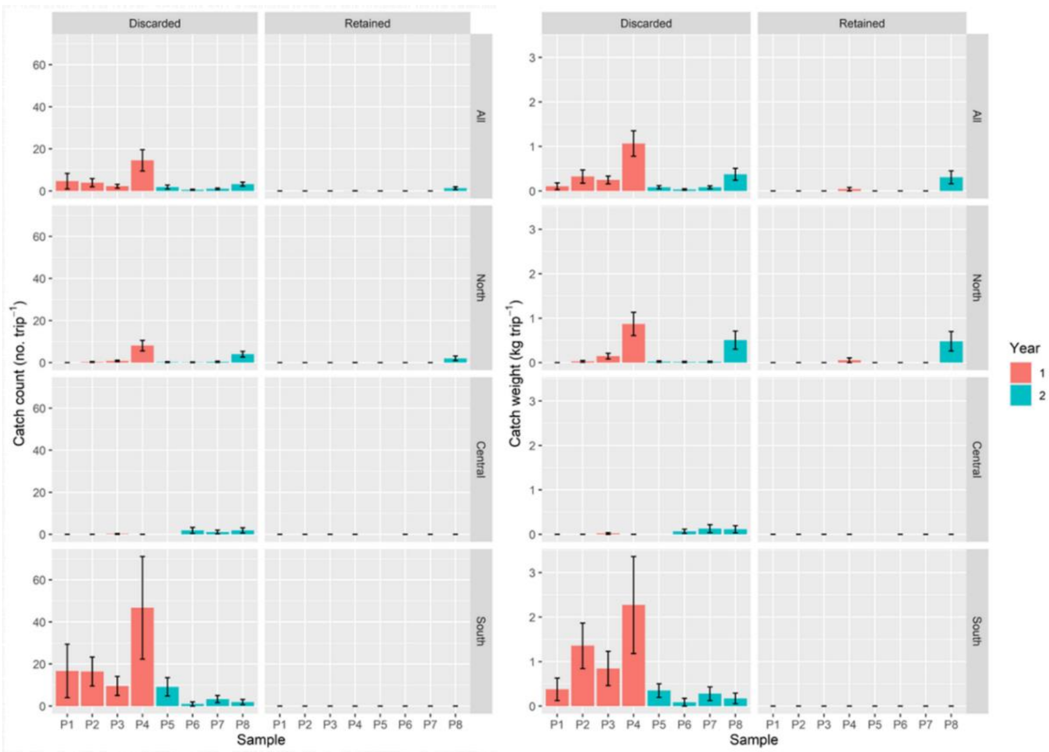


Figure A7- 17 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Yellowtail Scad (*Trachurus novaezelandiae*) for all, North, Central, and South zones.

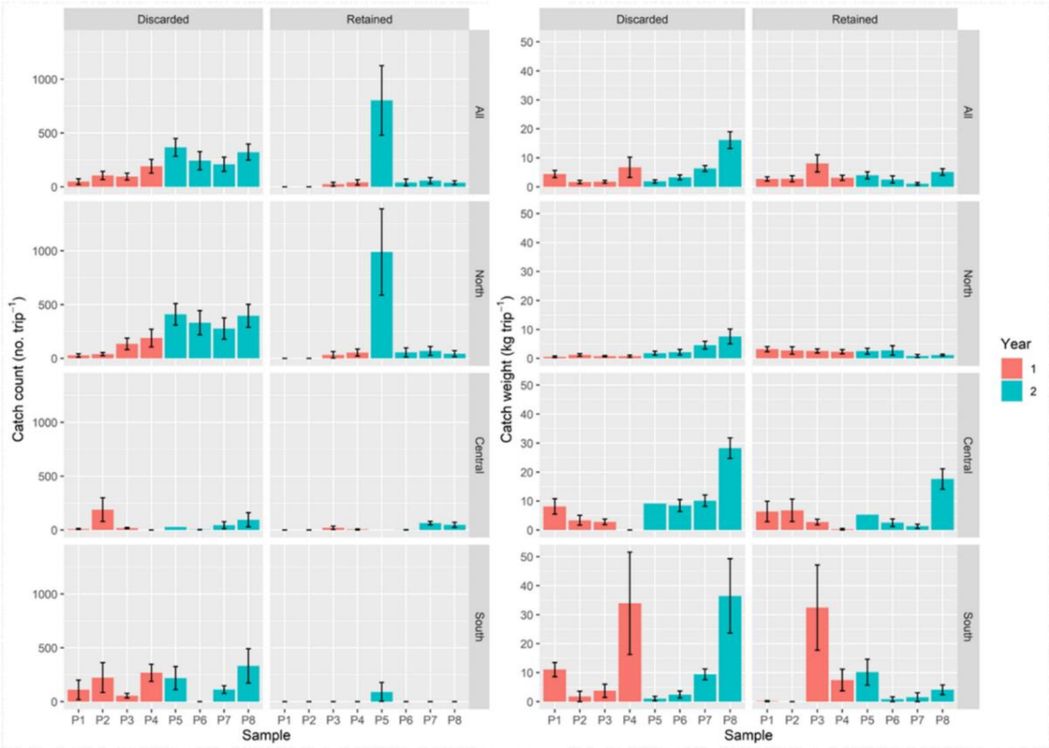


Figure A7- 18 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Silverbiddies (Gerreidae) for all, North, Central, and South.

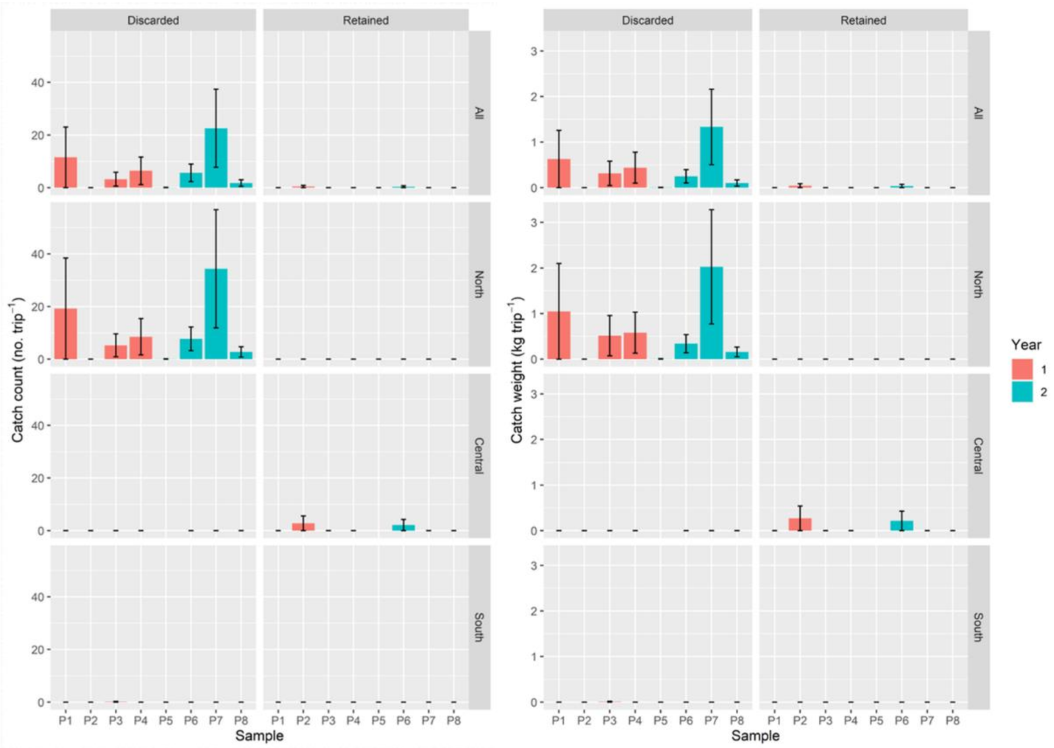


Figure A7- 19 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Eastern Shovelnose Ray (*Aptychotrema rostrata*) for all, North, Central, and South zones.

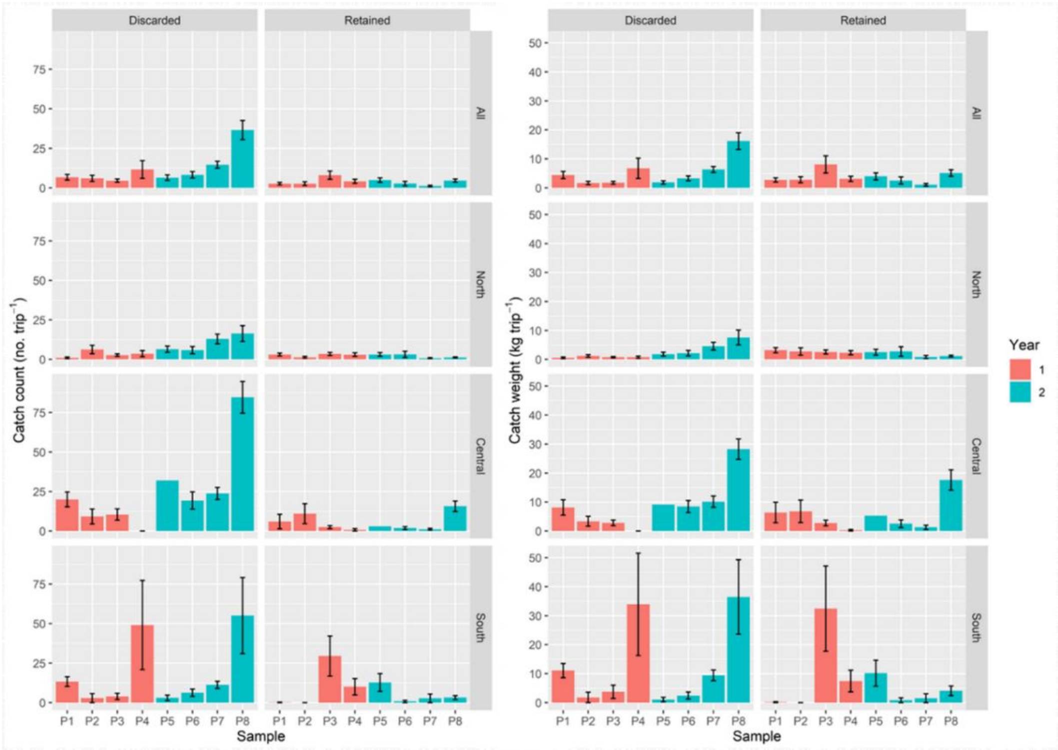
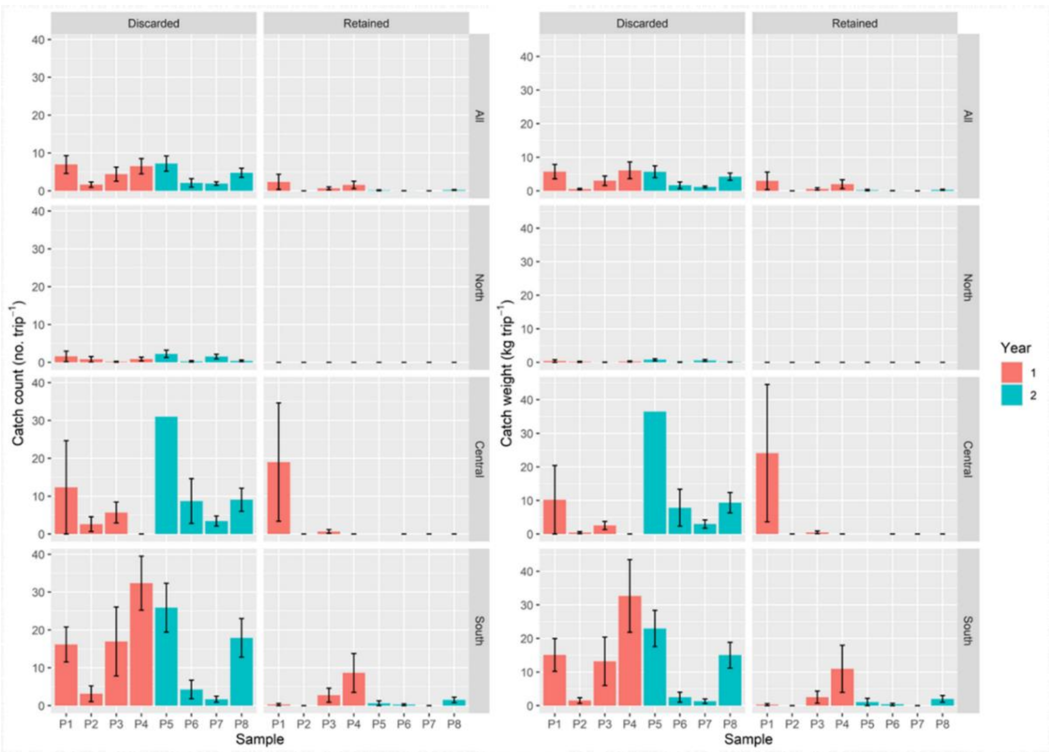


Figure A7- 20 Mean catch rates (no and kg per-trip^{-1} ± SE) of retained and discarded catches of Eastern Fiddler Ray (*Trygonorrhina fasciata*) for all, North, Central, and South zones.



Appendix 8. Non-commercial bycatch species summaries

Figure A8- 1 Mean discarded catch rates (± SE) of Gurnards (Lepidotrigla spp.), Longspine Flathead (*Platycephalus longispinis*), Crested Flounder (*Lophonectes gallus*) and Cockatoo Flounder (*Samaris cristatus*) for all, North, Central, and South zones.

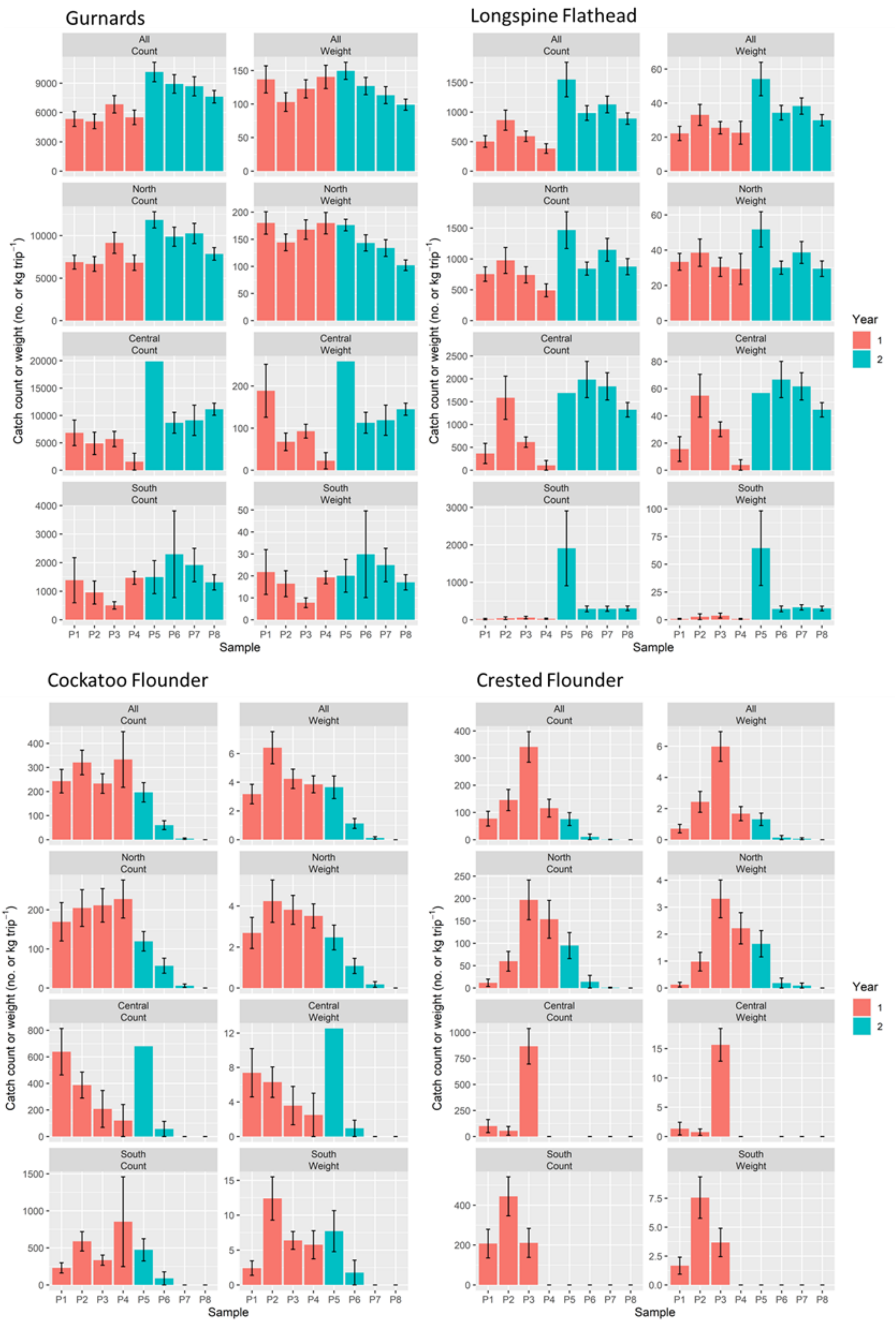


Figure A8- 2 Mean discarded catch rates (± SE) of Boxfishes (Ostraciidae & Aracanidae), Grubfishes (Pinguipedidae), Jawfishes (Opistognathidae), and Toadfishes (Tetraodontidae) for all, North, Central, and South zones.

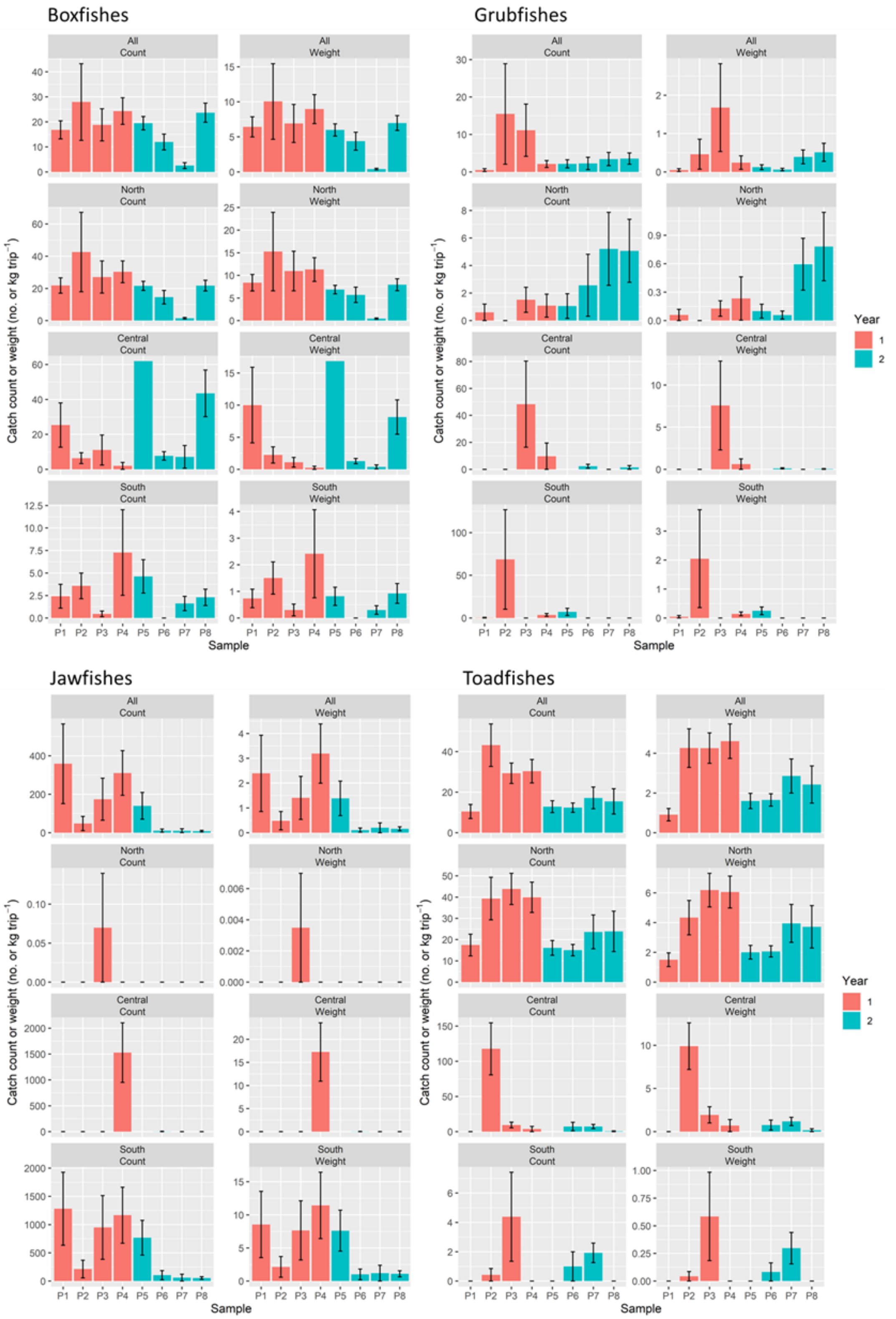


Figure A8- 3 Mean discarded catch rates (± SE) of Porcupinefishes (Diodontidae), Yellowfin Leatherjacket (*Meuschenia trachylepis*), Gurnard Perches (Neosebastes), and Deepsea Boarfishes (Pentacerotidae) for all, North, Central, and South zones.

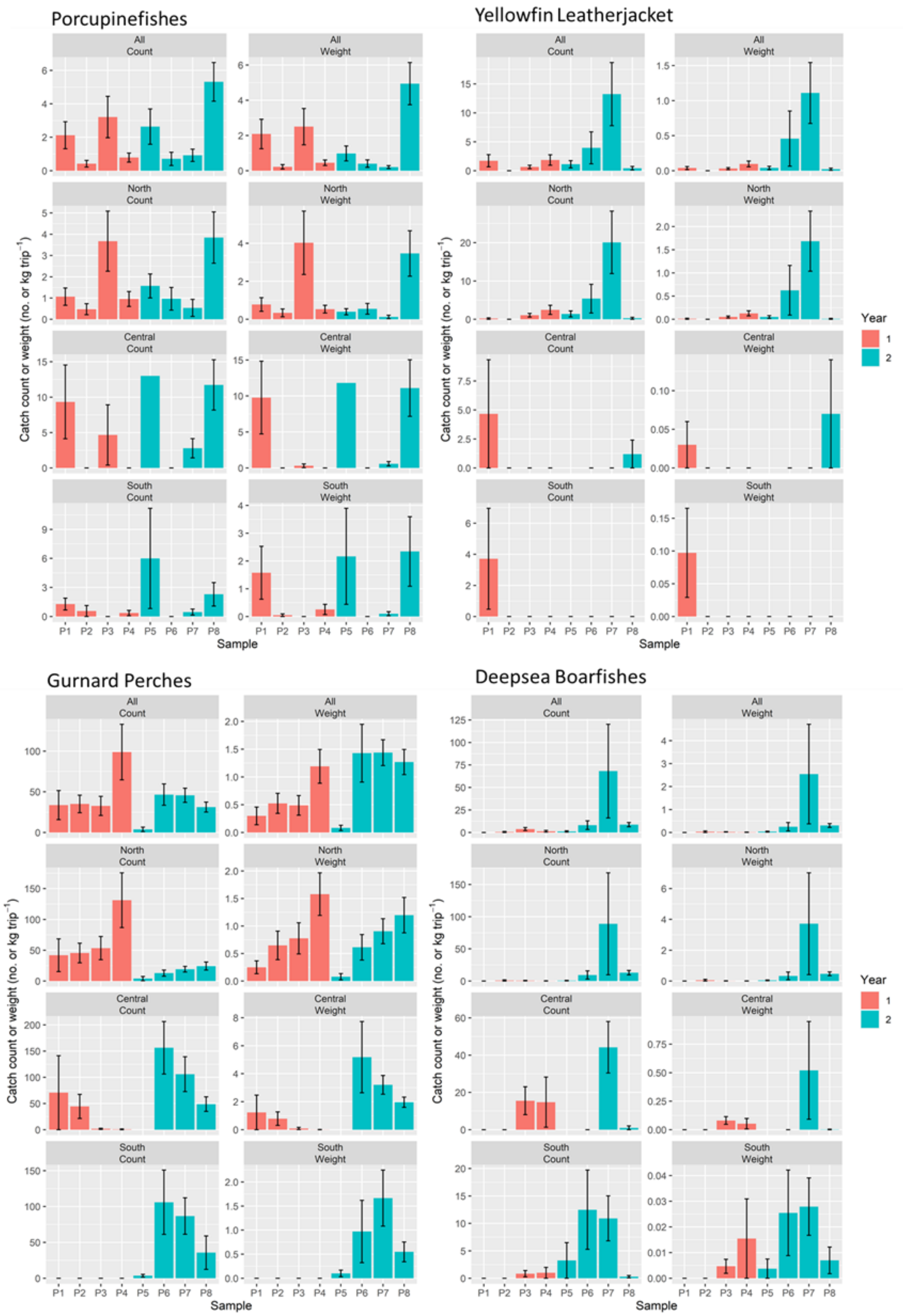


Figure A8- 4 Mean discarded catch rates (± SE) of Striate Anglerfish (*Antennarius striatus*), Beaked Salmon (*Gonorynchus greyi*), Violet Roughy (*Optivus agastos*), and Deepsea Dragonets and Dragonets (Draconettidae & Callionymidae) for all, North, Central, and South zones.

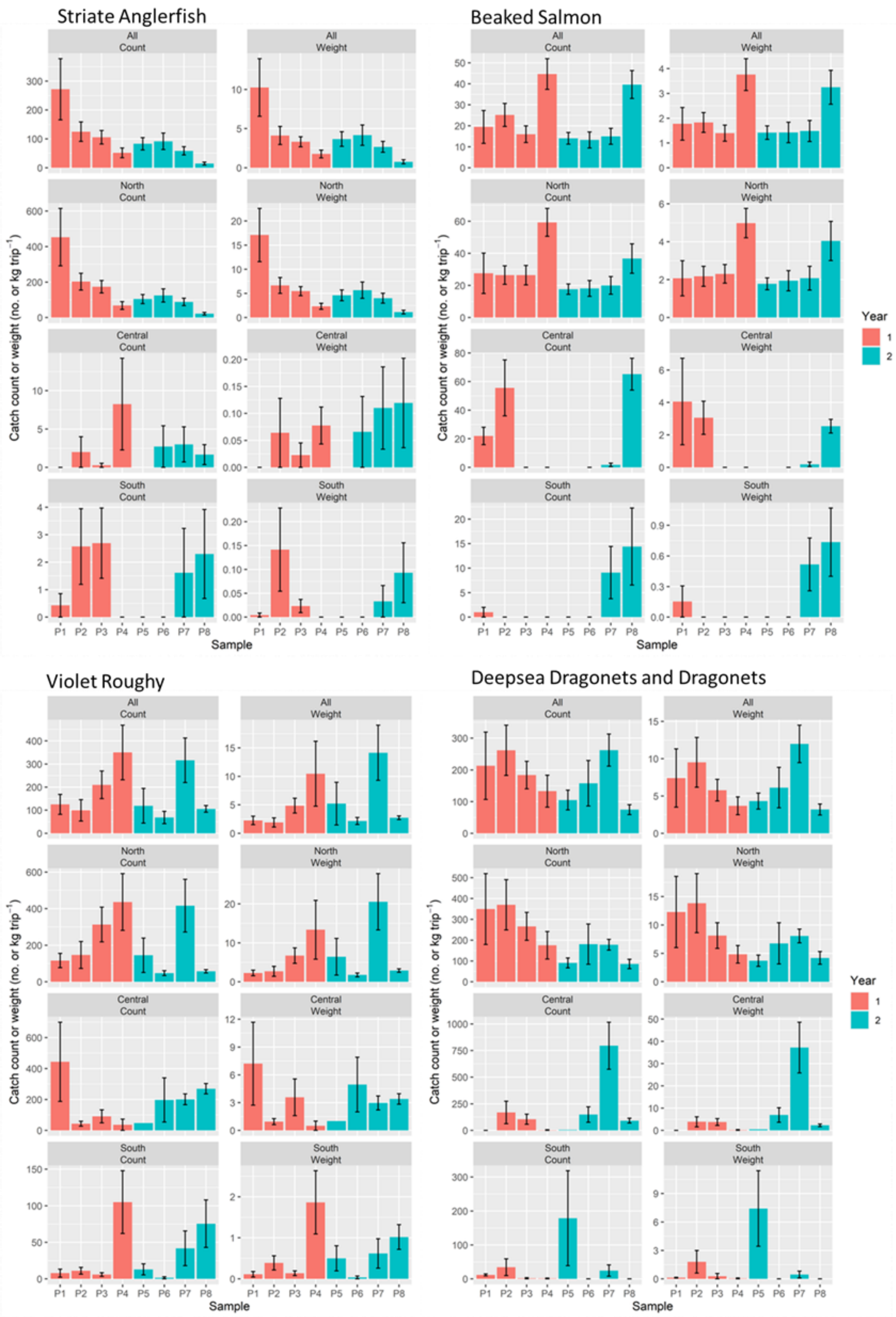


Figure A8- 5 Mean discarded catch rates (± SE) of Lizardfish and Deepsea Lizardfishes (Bathysauridae & Synodontidae), Deepwater Tripodfishes (Halimochirurgus spp.), Eastern Fortescue (*Centropogon australisc*), and Mud Flathead (*Ambiserrula jugosa*) for all, North, Central, and South zones.

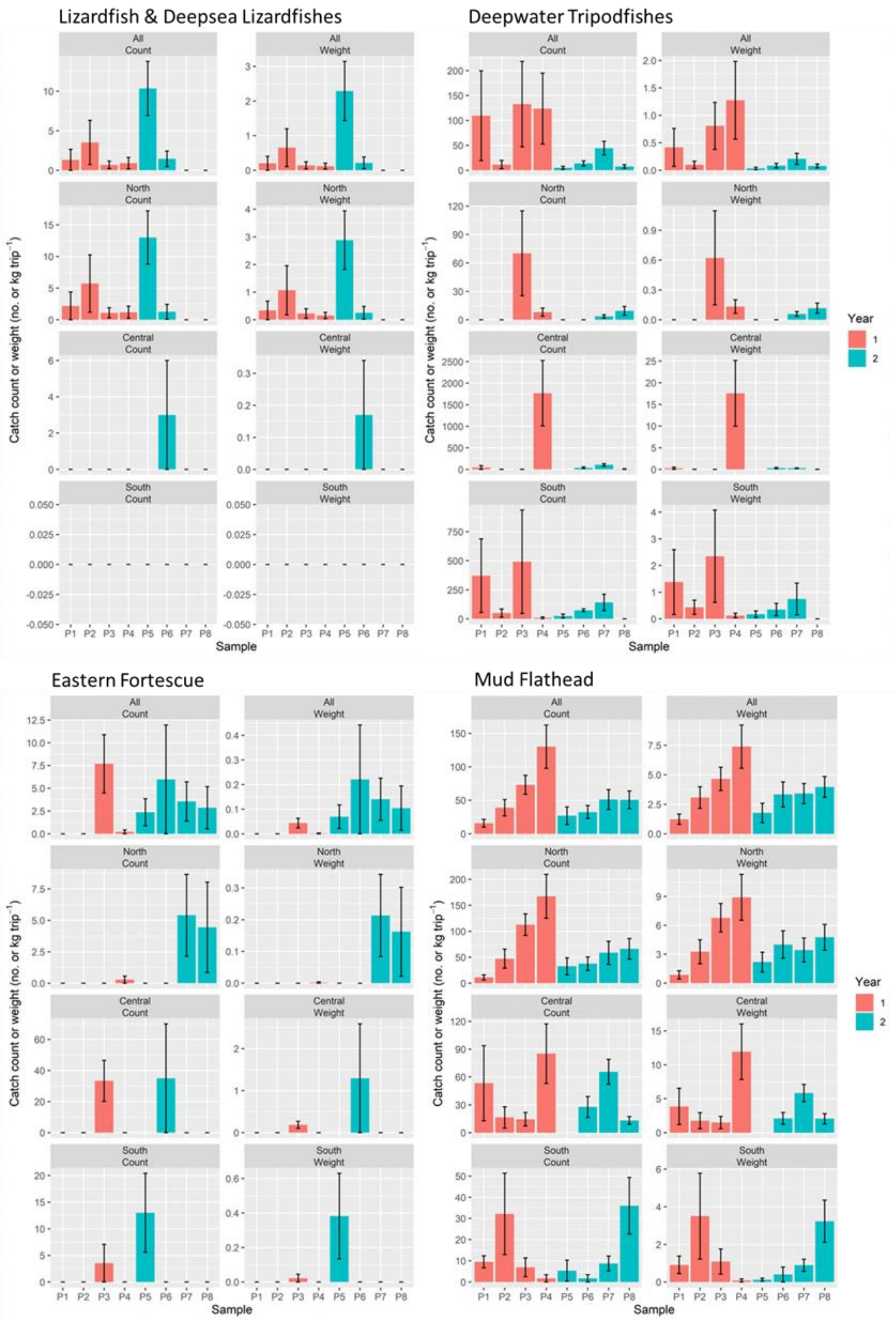


Figure A8- 6 Mean discarded catch rates (± SE) of Stingarees (Urolophidae), Stingrays (Dasyatidae), Coffin Ray (*Hypnos monopterygius*), and Torpedo Rays (Torpedinidae) for all, North, Central, and South zones.

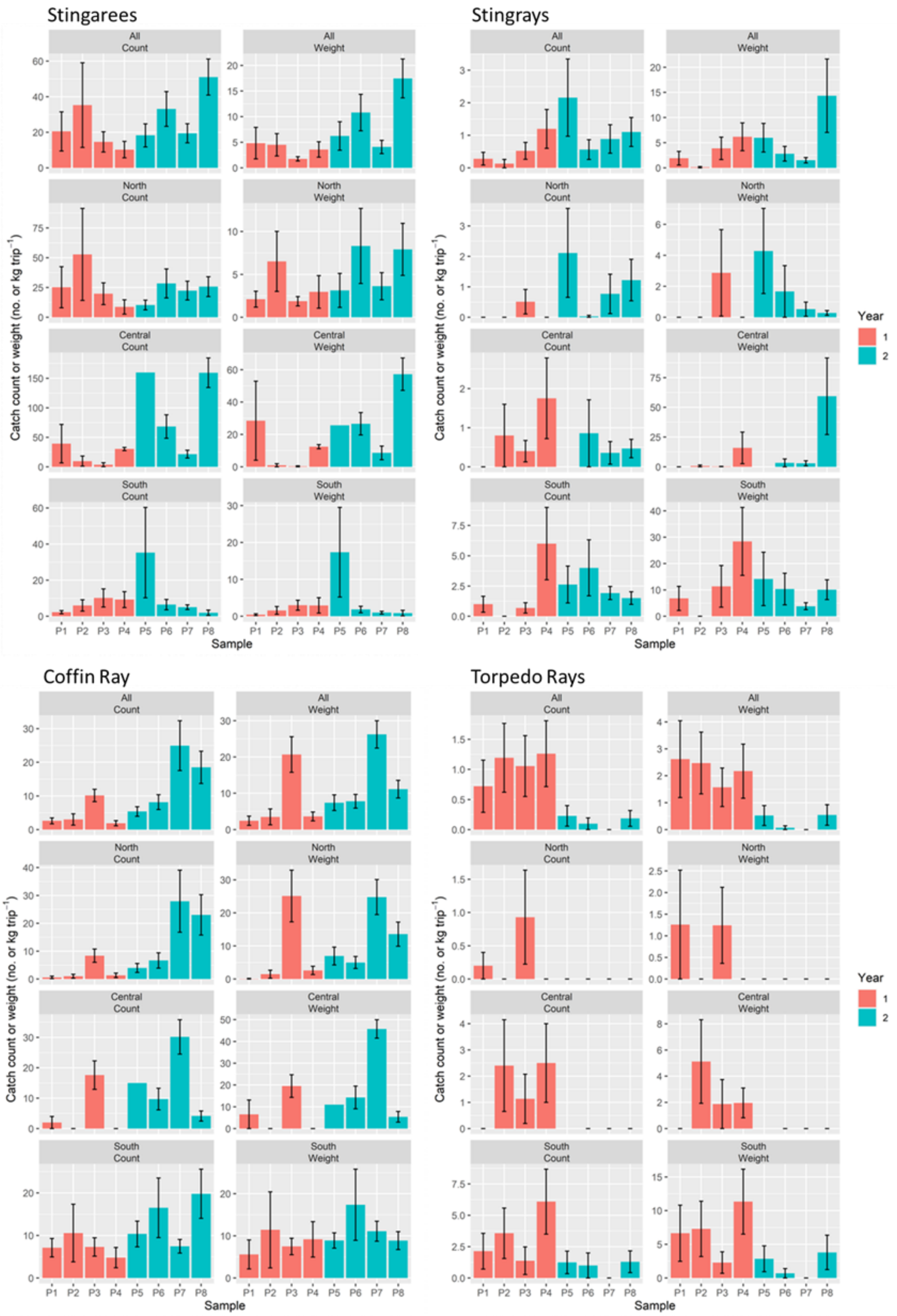


Figure A8- 7 Mean discarded catch rates (± SE) of Port Jackson Shark (*Heterodontus portusjacksoni*), Skates (Rajidae), and Catsharks (Scyliorhinidae & Pentanchidae) for all, North, Central, and South zones.

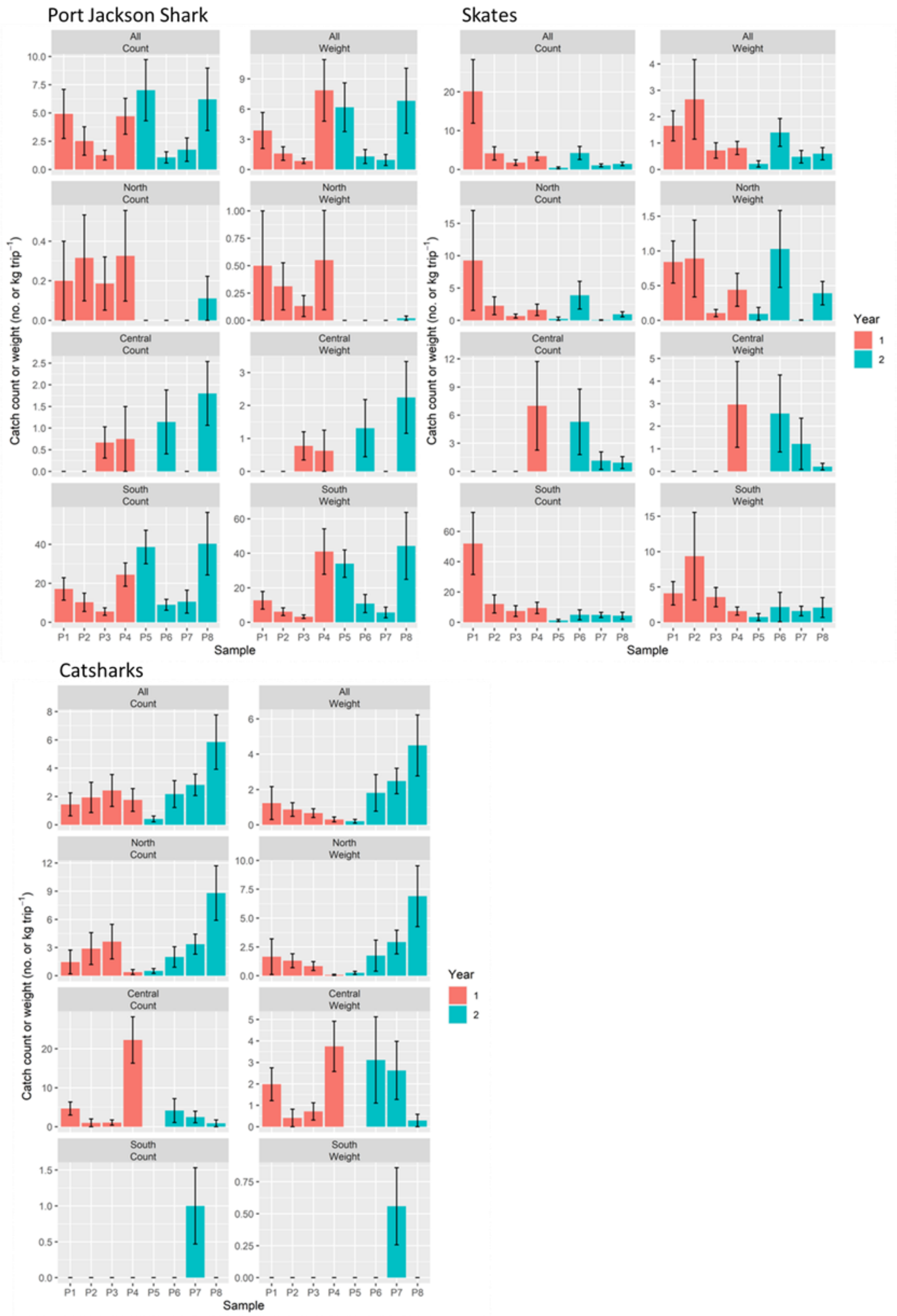
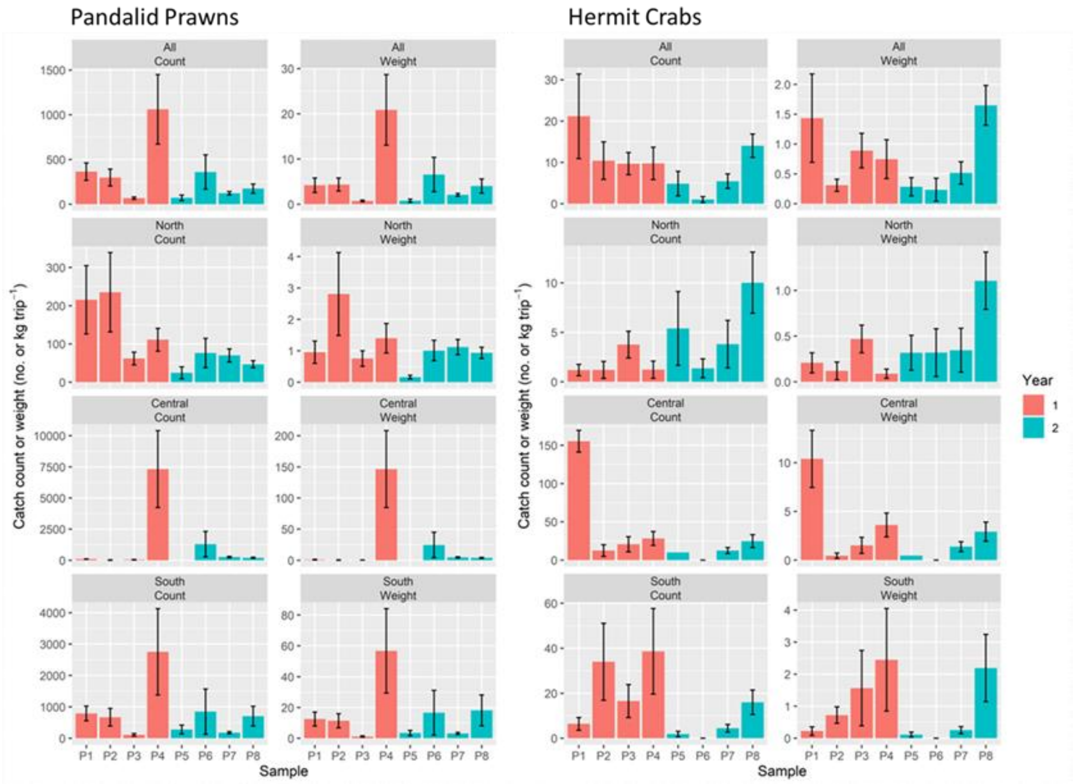
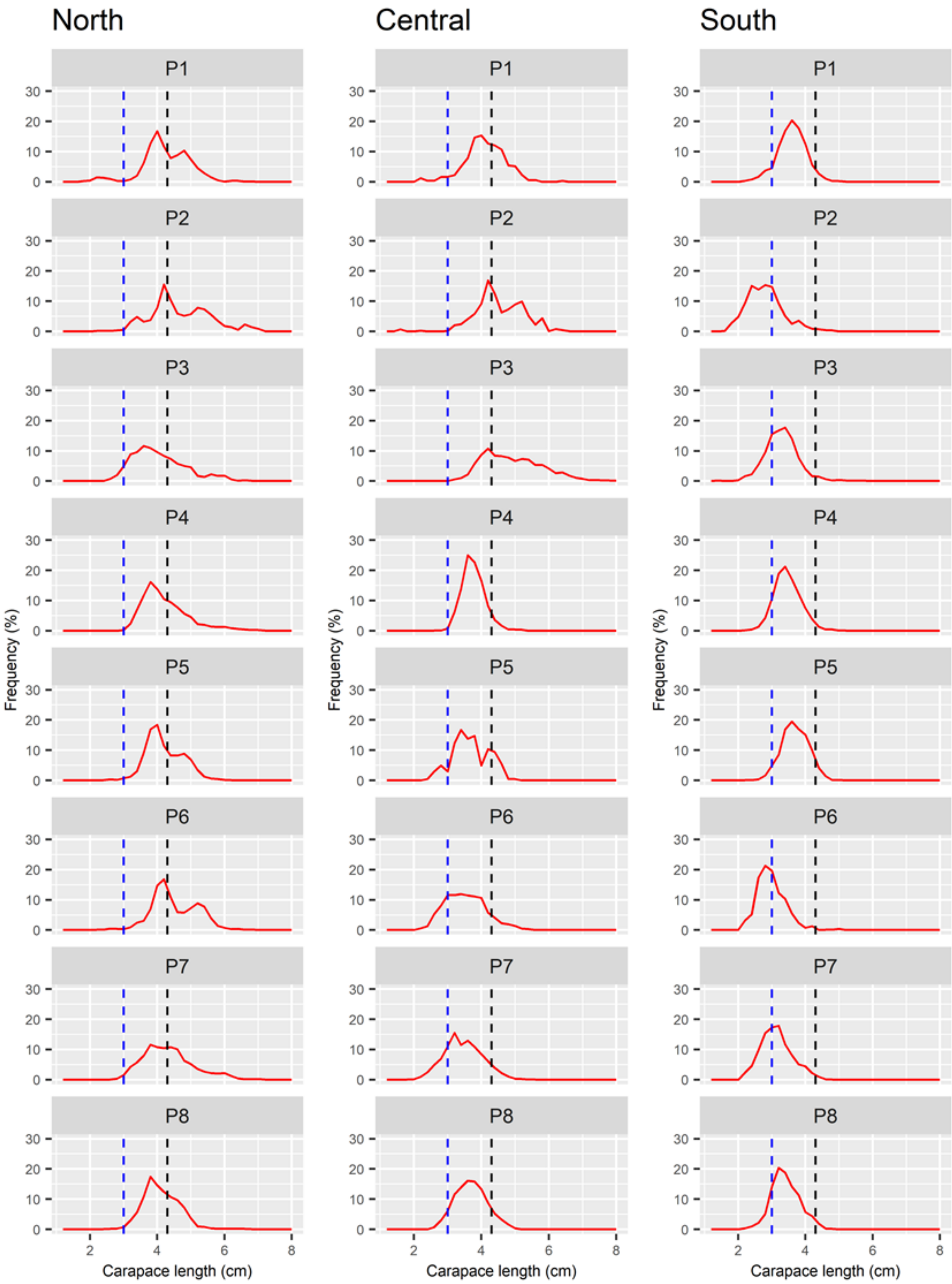


Figure A8- 8 Mean discarded catch rates (± SE) of Pandalid Prawns (Pandalidae) and Hermit Crabs (Paguroidea) for all, North, Central, and South zones.



Appendix 9. Relative size-structure of observed catches of Eastern King Prawn for the North, Central, and South zones in each sampling period. Also indicated is the optimal length at first capture (L_{YPR}, vertical blue dashed line; Taylor et al., 2021) and an estimate of length-at-maturity (L_{50}, vertical black dashed line; Montgomery et al., 2007).



Appendix 10. Mean retained and discarded catch rates (no per-trip^{-1} ± SE) of commercially and recreationally important species.

Figure A10- 1 Mean retained and discarded catch rates (± SE) of Mulloway (*Argyrosomus japonicus*), Snapper (*Chrysophrys auratus*), Tailor (*Pomatomus saltatrix*), and Teraglin (*Atractoscion aequidens*) for all, North, Central and South zones.

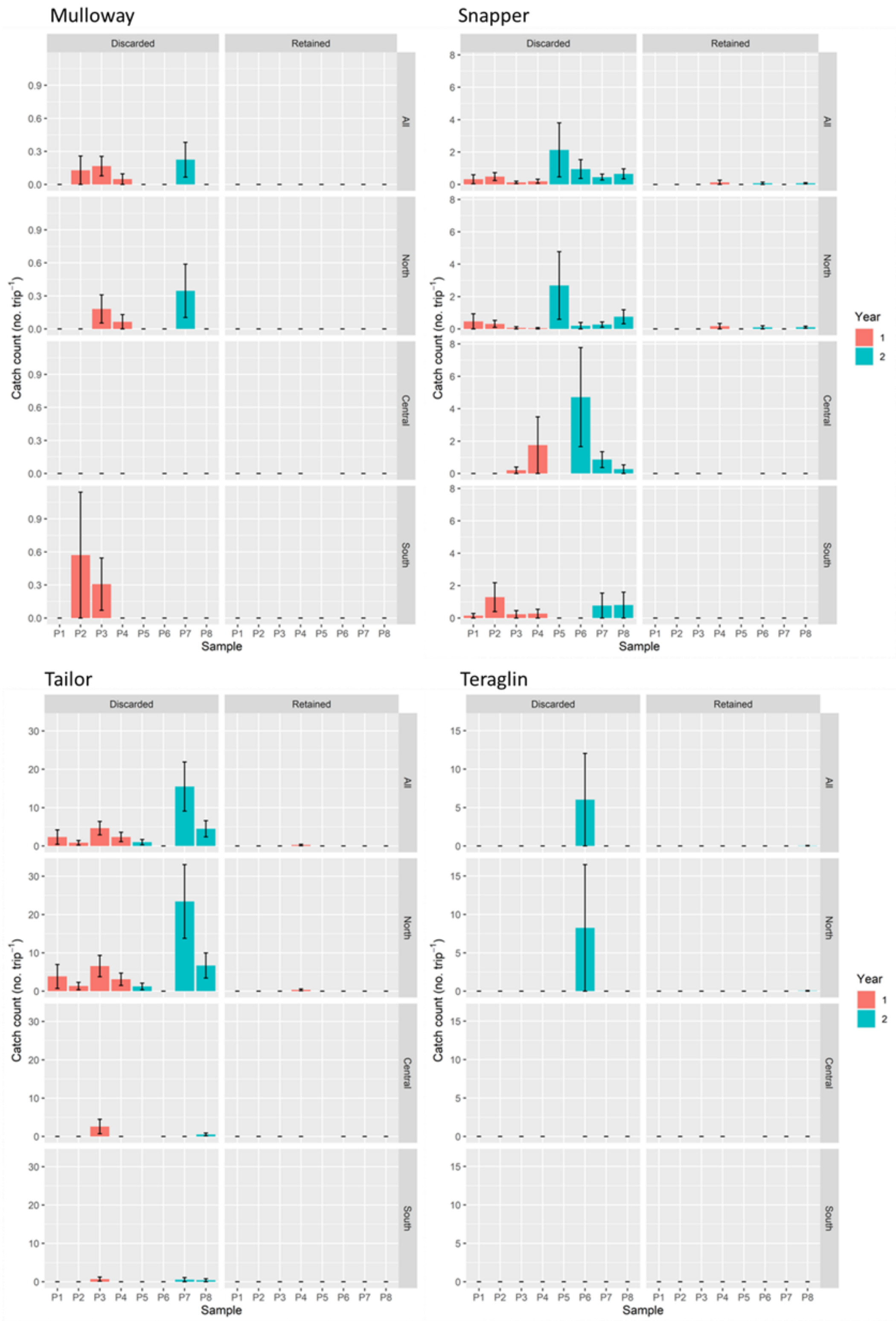
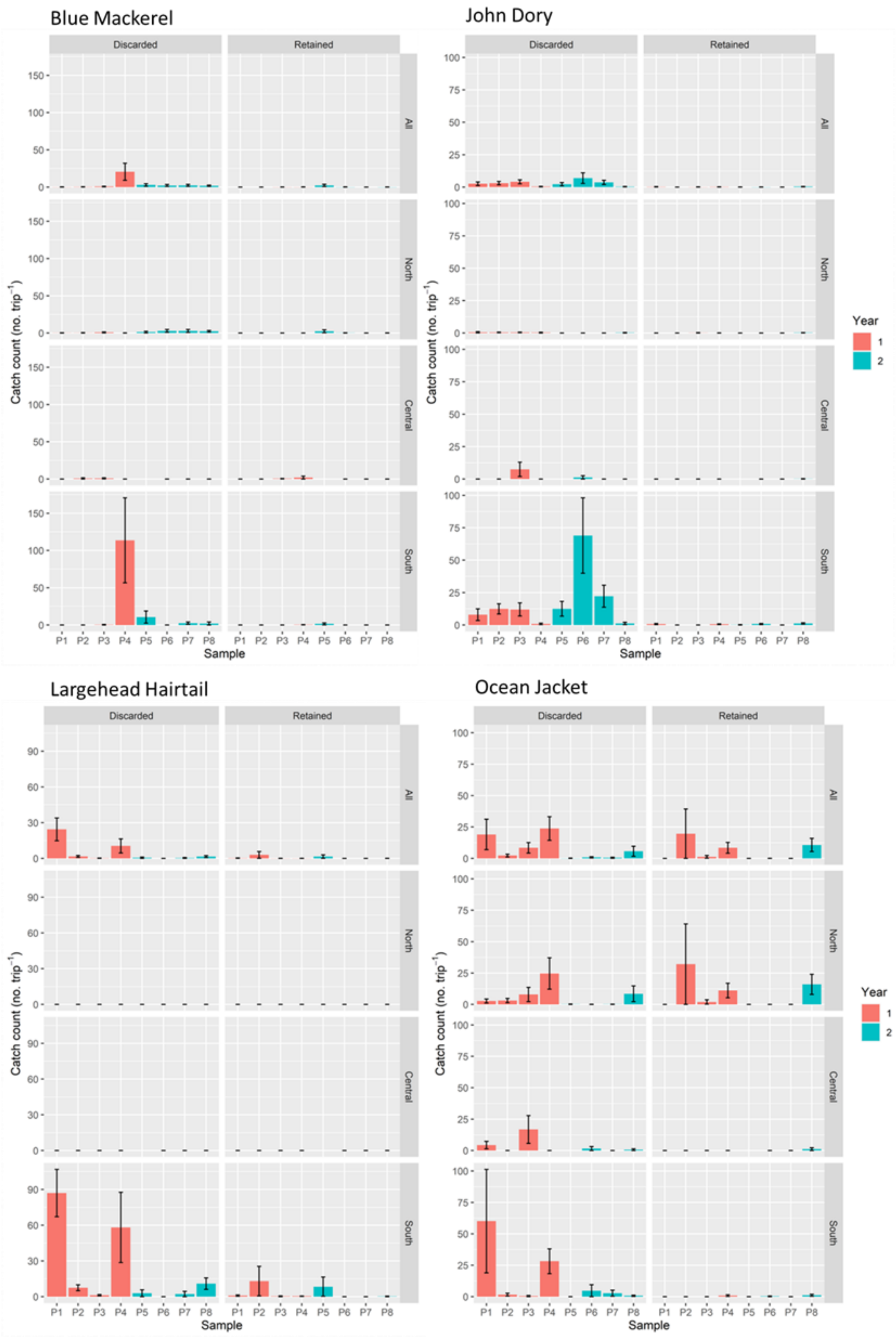


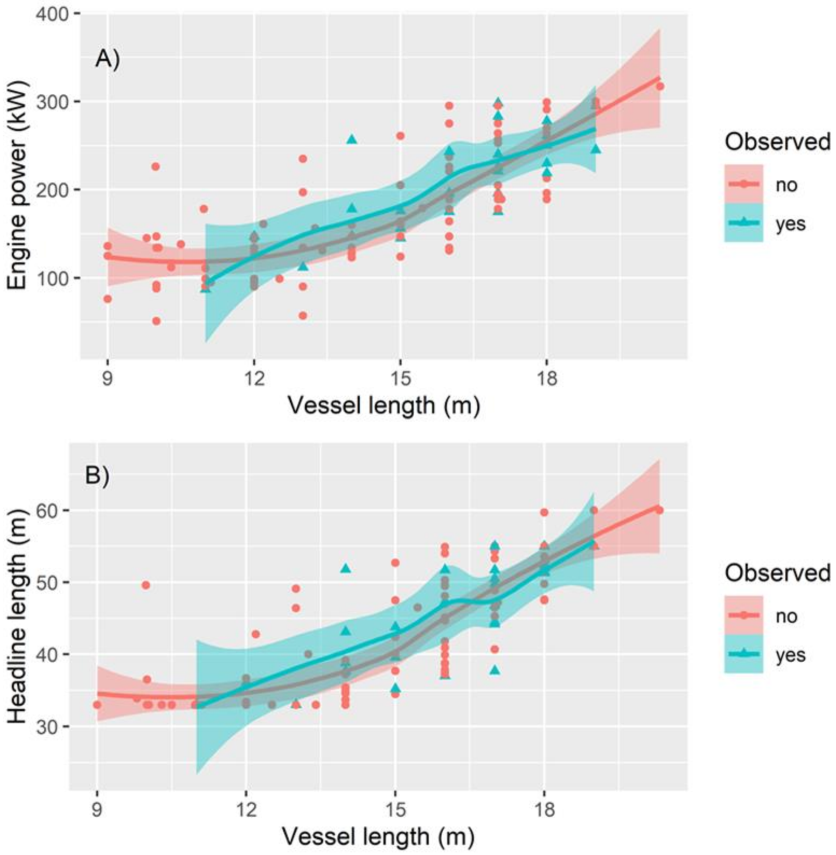
Figure A10- 2 Mean retained and discarded catch rates (± SE) of Blue Mackerel (*Scomber australasicus*), John Dory (*Zeus Faber*), Largehead Hairtail (*Trichiurus lepturus*), and Ocean Jacket (*Nelusetta ayraudi*) for all, North, Central, and South zones.



Appendix 11. Specifications of participating vessels

Vessel length (m)	Horsepower (kW)	Hull units	Headrope length (m)
11.1	86	12	33
11.5	123	13	36.1
13.1	112	16	33
13.2	228	32	51.8
13.2	175.2	23	43.1
13.7	134	22	37.7
13.8	145	28	38.8
14.1	145	28	35.2
14.1	134	22	37.7
14.4	156	24	39.6
14.6	160	29	43.8
15.2	220	43	51.7
15.2	220	43	51.7
15.6	186	38	47.3
15.8	179	29	44.5
15.9	172	32	37
16	179	33	46.8
16.4	205	39	49.8
16.4	254	41	55
16.4	298	48	51.7
16.5	205	46	50.5
16.8	175	32	44.2
17.1	223.7	42	52.5
17.2	251	42	53.1
17.2	269	46	52
17.2	178	43	51.5
17.4	250	51	55
18	224	51	51.3
18.1	268	57	55
18.5	240	47	55

Figure A11- 1 Relationship (with loess smooth) between A) trawl vessel length (m) and engine capacity (kW) and B) trawl vessel length (m) and total headline length (m) for observed (yes) and non-observed (no) vessels.



Appendix 12. List of all species observed during wildlife observation counts. Data are the number of times each species was observed from observation periods in year-1 (*n* = 467) and year-2 (*n* = 581) of the survey. CAAB Nos are the Codes for Australian Aquatic Biota (http://www.marine.csiro.au/caab).

CAAB No.	Common name	Scientific name	Family	Yr-1	Yr-2
Birds					
40040000	Albatrosses	Diomedeidae – undifferentiated	Diomedeidae	4	12
40040002	Shy Albatross	*Thalassarche cauta*	Diomedeidae	1	0
40040007	Black Browed Albatross	*Thalassarche melanophrys*	Diomedeidae	2	0
40041000	Petrels Prions and Shearwaters	Procellariidae – undifferentiated	Procellariidae	0	1
40041045	Wedge Tailed Shearwater	*Puffinus pacificus*	Procellariidae	37	11
40041047	Short Tailed Shearwater	*Puffinus tenuirostris*	Procellariidae	14	0
40041050	Shearwaters	*Puffinus* spp. – undifferentiated	Procellariidae	86	94
40128000	Gulls Skuas Noddys and Terns	Laridae – undifferentiated	Laridae	1	0
40128005	Great Skua	*Catharacta skua*	Laridae	1	0
40128013	Silver Gull	*Larus novaehollandiae*	Laridae	180	155
40128901	Terns	Sterna spp. – undifferentiated	Laridae	1	7
40128025	Crested Tern	*Sterna bergii*	Laridae	164	144
Mammals					
41116000	Dolphins	Delphinidae – undifferentiated	Delphinidae	0	6
41116001	Common Dolphin	*Delphinus delphis*	Delphinidae	55	109
41112006	Humpback Whale	*Megaptera novaeangliae*	Balaenopteridae	1	1
41131000	Eared Seals	Otariidae – undifferentiated	Otariidae	2	2
41131001	New Zealand Fur Seal	*Arctocephalus forsteri*	Otariidae	1	0

Appendix 13. Record of all observed TEPS interactions

Zone	Trip ID	Shot ID	Common name	Species	Number
Central	238	238.2	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	15
Central	238	238.3	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	16
Central	304	304.1	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	5
Central	304	304.2	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	15
Central	304	304.3	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	7
Central	311	311.4	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	5
Central	336	336.1	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	1
Central	350	350.4	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	2
Central	407	407.1	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	4
Central	407	407.2	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	2
Central	429	429.3	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	2
Central	436	436.2	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	7
Central	436	436.3	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	5
Central	436	436.3	Bentstick Pipefish	*Trachyrhamphus bicoarctatus*	7
Central	224	224.1	Spiny Pipehorse	*Solegnathus spinosissimus*	5
Central	225	225.1	Spiny Pipehorse	*Solegnathus spinosissimus*	3
Central	225	225.2	Spiny Pipehorse	*Solegnathus spinosissimus*	2
North	97	97.2	Common Seadragon	*Phyllopteryx taeniolatus*	1
North	101	101.3	Common Seadragon	*Phyllopteryx taeniolatus*	1
North	103	103.2	Common Seadragon	*Phyllopteryx taeniolatus*	5
North	103	103.3	Common Seadragon	*Phyllopteryx taeniolatus*	2
North	371	371.4	Common Seadragon	*Phyllopteryx taeniolatus*	1
North	170	170.3	Seahorses & Pipefishes	Syngnathidae – undifferentiated	1
North	170	170.3	Seahorses & Pipefishes	Syngnathidae – undifferentiated	2
North	171	171.1	Seahorses & Pipefishes	Syngnathidae – undifferentiated	1
North	171	171.2	Seahorses & Pipefishes	Syngnathidae – undifferentiated	4
North	171	171.3	Seahorses & Pipefishes	Syngnathidae – undifferentiated	4
North	295	295.2	Seahorses & Pipefishes	Syngnathidae – undifferentiated	2
North	295	295.3	Seahorses & Pipefishes	Syngnathidae – undifferentiated	3
North	82	82.1	Seahorses & Pipefishes	Syngnathidae – undifferentiated	2
North	411	411.1	Seahorses & Pipefishes	Syngnathidae – undifferentiated	1
Central	195	195.2	Grey Nurse Shark	*Carcharias taurus*	1
Central	240	240.3	Sandtiger Shark	*Odontaspis ferox*	1

Appendix 14. Comparison of estimated total catches ('000's of individuals) and percentage of total catch discarded (% Dis) from the 1990–1992 observer survey (Kennelly et al., 1998) and the 2017–2019 survey. Estimates for Ballina, Clarence River and Coffs Harbour from Kennelly et al. (1998) were combined to match regions applied in the 2017–2019 survey.

	Region 1				**Region 2**			
	1990-1992		2017-19		1990-92		2017-19	
	Total	% Dis	Total	% Dis	Total	% Dis	Total	% Dis
Crustaceans								
Blue Swimmer Crab	152.6	53.3	38.2	47.3	6.5	24.6	13.6	64.8
Bugs	19542.4	93.5	2165.9	77.5	27.6	2.2	145.5	53.8
Coral Crab	64.2	55.9	8.1	91.7	0.0	0.0	43.5	14.3
Teleosts								
Australian Hairtail	2.7	63.0	0.0	0.0	34.1	100.0	9.8	89.5
Blue Mackerel	6.5	87.7	NA	NA	45.5	49.7	42.8	98.9
Bluespotted Flathead	2756.7	71.3	483.4	68.1	10.2	61.8	63.5	100.0
Dusky Flathead	38.4	32.6	1.9	33.3	0.7	28.6	2.6	100.0
Eastern School Whiting	20855.2	60.8	12874.4	34.4	396.5	95.8	3702.9	69.1
Goatfishes	2950.1	29.6	216.5	13.8	16.8	48.2	23.6	40.3
John Dory	71.8	47.9	16.5	88.6	52.4	56.1	20.6	97.3
Marbled Flathead	179	97.2	28.3	95.8	0.4	0.0	NA	NA
Mulloway	49.5	97.8	0.8	100.0	0.6	0.0	0.3	100.0
Ocean Jacket	12.2	59.0	29.8	53.9	6.6	45.5	35.1	97.4
Pearl Perch	25.3	100.0	26.6	99.5	0.0	0.0	0.0	0.0
Red gurnard	32.4	67.9	0.0	0.0	25.9	81.5	0.3	47.4
Redfish	217.9	97.1	83.2	94.7	461.4	81.2	36.4	100.0
Snapper	2572.3	100.0	9.2	93.4	1.1	81.8	NA	NA
Stout Whiting	26160.4	93.1	2724.7	36.3	0.0	0.0	201.6	6.3
Tailor	15.7	84.1	9.7	99.3	0.3	0.0	NA	NA
Tarwhine	327.7	98.4	1.1	100	0.0	0.0	0.2	100.0
Teraglin	32.4	92.0	6.6	99.2	0.0	0.0	0.0	0.0
Tiger Flathead	23.2	30.6	8.1	82.8	281.4	85.4	216.0	100
Molluscs								
Bottle squid	176.8	8.2	4.9	100	18.9	63.5	NA	NA

	Region 1				Region 2			
	19901992		2017-2019		1990-1992		2017-1919	
	Total	% Dis	Total	% Dis	Total	% Dis	Total	% Dis
Cuttlefishes	7817.4	66.6	1258.9	28.5	163.0	42.6	131.9	23.3
Loligo squids	887.2	29.2	26.4	12.4	121.6	53.4	9.0	1.4
Octopuses	10004.6	0.4	1292.3	2.8	15.3	20.9	495.3	4.8
Southern Calamari	829.4	1.3	6.0	0.0	11.3	17.7	5.6	6.9
Elasmobranchs								
Eastern Fiddler Ray	21.5	90.2	186.8	91.4	0.9	0.0	11.8	88.1
Eastern Shovelnose Ray	254.5	32.5	58.1	80.2	4.6	0.0	31.3	68.5
Gummy Shark	47.7	41.7	10.1	49.7	1.0	50.0	2.5	81.1

NA – not estimated because of low observed catch rates

Other titles in this series

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