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Fisheries Victoria, Fisheries Research Branch,
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NON-TECHNICAL SUMMARY

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Objectives:

1. Determine optimum size and age-at-capture of Tiger Flathead and Eastern School Whiting by Danish seine gear.
2. To determine selectivities of Danish seine gear when targeting Tiger Flathead and Eastern School Whiting.
3. Construct and trial codends with mesh sizes to catch Tiger Flathead and Eastern School Whiting at their optimum sizes as determined by YPR analyses, and determine effect of changed mesh size on bycatch.

Non Technical Summary:

OUTCOMES ACHIEVED TO DATE

Yield-per-recruit and value-per-recruit modelling were completed for both Tiger Flathead and Eastern School Whiting to examine changes in response to a range of gear selectivities and fishing mortalities. Results showed that, particularly for Tiger Flathead, value-per-recruit was relatively insensitive to changes in selectivity, providing scope to alter selectivity through gear modification without impacting on value-per-recruit. This report quantifies the selectivity of current commercial gears for the Danish seine fishery, and the catch of retained, commercial discard and non-commercial discard species. While experimentation of modified gears was deemed unworkable for the Eastern School Whiting nets, comparisons between the 75 mm codend used for targeting Tiger Flathead and an experimental T90 codend clearly demonstrated the differences in the selectivity of those nets. The T90 codend caught comparable weights of commercial species to the control codend (a standard 75 mm commercial codend), but much less non-commercial discards. It is hoped that there will be some uptake of T90 mesh once results have been fully communicated to Industry, however doubt as to the suitability of the T90 net for the Danish seine fishery was raised because of the large increase in selectivity of Tiger Flathead in the T90 net, which allowed the escape of a large proportion of small but marketable Tiger Flathead. Further, because of the spatial and temporal heterogeneity in size range and availability of Tiger Flathead in the fishery, the T90 net may be unsuitable at certain times of the year or in certain areas of their fishery. When Flathead quota is a limiting factor in fishing operations however — which it has been in recent years — the loss of small fish may not necessarily translate to a decrease in the value of the total catch and yet would reduce the likelihood of discarding small commercial species. Video observations of fish behaviour in response to the net were quantified and summarised in accordance with established methods. These observations were useful in identifying areas of attempted escape by target and bycatch species. Results obtained will be important considerations for future gear modification trials.

Danish seine gear is used by fishers in the Commonwealth Trawl Sector of the Southern and Eastern and Scalefish and Shark Fishery (SESSF) to target Tiger Flathead (*Neoplatycephalus richardsoni*) and Eastern School Whiting (*Sillago flindersi*). The twelve vessels that use this gear operate almost exclusively out of Lakes Entrance, Victoria. During 2008, the Danish seine fleet landed 423 t of Eastern School Whiting and 1680 t of Tiger Flathead.

Discarding is a major problem facing commercial fisheries worldwide. The capture of fish that are later discarded is wasteful and may pose a threat to marine systems. It increases fishing costs through time spent sorting, reduces the quality of the retained fish, increases damage to gear, increases drag - causing increased fuel costs, and, ultimately, may affect the ecosystem on which target stocks rely. Moreover, there is a poor perception of fisheries with high discard levels. From various perspectives, therefore, there is a need to improve the selectivity of nets to reduce the capture of fish that are discarded.

While a considerable amount of work has been done to investigate improved selectivity of nets used by otter board trawlers, little work has been focused on Danish seine gear. There are no published studies on bycatch reduction in Danish seine gears in Australia, and few internationally.

Different sized codends are used to target each of the two main species in the Danish seine fishery, and an understanding of the selectivity of these gears is required before trials of modified gears are conducted. Once these selectivities — described as the length at which 50% of fish are captured (L_{50}) — are determined, results can then be used, along with knowledge of the behaviour of fish in response to the gear, to develop trial gears that may reduce bycatch while maintaining the profitability of fishing operations.

Before gear trials were conducted, an integrated bio-economic analysis of fish cohort dynamics was developed to model yield-per-recruit (YPR) and value-per-recruit (VPR) for Tiger Flathead and Eastern School Whiting. This modelling showed that the current fishery is catching Tiger Flathead at a length greater than would achieve maximum VPR, and that VPR is relatively insensitive to small changes in L_{50} at the levels of fishing mortalities observed. This insensitivity of VPR to small changes in L_{50} of Tiger Flathead means that there is flexibility to change L_{50} through gear modification without impacting greatly on VPR. Eastern School Whiting are caught at a length that is less than what would achieve the maximum VPR, but is greater than what would achieve the maximum YPR.

Covered codend experiments were used to determine the selectivity characteristics of 65 mm and 75 mm codends. L_{50} of Tiger Flathead for mesh sizes 65 mm and 75 mm were estimated to be 27.0 cm and 30.1 cm, respectively. The selectivity estimate for the 75 mm codend compares closely with that estimated from SS2 models used in stock assessments. Tiger Flathead was the most commonly caught species in the 75 mm codend, comprising nearly 50% of the total catch by weight. Southern Sawshark (*Pristiophorus nudipinnis*), Ocean Jacket (*Nelusetta ayraudi*), Latchet (*Pterygotrigla polyommata*), Elephantfish (*Callorhinchus milii*) and Red Gurnard (*Chelidonichthys kumu*) were the other most commonly caught retained species. Discarded commercial species comprised only 0.7% of the total catch weight in the 75 mm codend, while discarded non-commercial species comprised 39.6% of the total catch weight. Most commonly caught non-commercial discards were Sparsely-spotted Stingaree (*Urolophus paucimaculatus*), Blacktip Cucumberfish (*Paraulopus nigripinnis*), Grooved Gurnard (*Lepidotrigla modesta*) and Family Triglidae. Like the catch from the 75 mm codend, the catch from the 65 mm codend comprised largely of Tiger Flathead, with smaller amounts of other commercial species such as Southern Sawshark, Ocean Jacket and Red Gurnard. Discarded commercial species comprised only 0.3% of the total catch, while Blacktip Cucumberfish, Sparsely-spotted Stingaree, Roundsnout Gurnard (*Lepidotrigla mulhalli*) and Grooved Gurnard were the main non-commercial species caught, and together with other non-commercial species comprised 32.4% of the total catch weight.

Alternate haul experiments were used to estimate the selectivity of a 45 mm Eastern School Whiting codend. L_{50} for Eastern School Whiting caught by the 45 mm codend was 15.6 cm, 1.6 cm smaller than that estimated by SS2 during routine stock assessment. Eastern School Whiting, Tiger Flathead, Southern Bluespotted Flathead (*Platycephalus speculator*) and Elephantfish comprised the greatest portions of the retained catch. Main discard species were Silverbelly (*Parequula melbournensis*), Common Stinkfish (*Foetorepus calauropomus*) and Roundsnout Gurnard. Large differences in catches of small Tiger Flathead between the 45 mm commercial codend and the 25 mm control codend show that considerable quantities of small Tiger Flathead escape the 45 mm codend during normal fishing practices.

The behaviours of different commercial and non-commercial species in response to the net were quantified using underwater video footage. Like the main bycatch species, Tiger Flathead attempted escape from the codend through the top, side and bottom panels. This means that selective panels of increased mesh (or rotated mesh) in the codend are unlikely to reduce bycatch without the loss of that target species. This does inform future work that might aim at reducing bycatch of small Tiger Flathead from 45 mm Eastern School Whiting codends. The behaviour of Eastern School Whiting in the codends was not adequately quantified here because the footage taken during Eastern School Whiting fishing was too dark for analysis, and further opportunities for filming underwater video using 45 mm net were lost because of operational concerns of conducting experiments using those nets.

A T90 codend was trialled to investigate the potential to reduce bycatch. There were no differences in catch weight of commercial species by the T90 codend (including Tiger Flathead) compared to the 75 mm control codend, but the T90 codend caught about 27% less discarded non-commercial species. The lack of difference in the commercial catch weight was a curious result given that L_{50} of Tiger Flathead caught by the T90 codend was significantly larger than that of the 75 mm codend, meaning that a lot more small Tiger Flathead escaped the T90 net. It is possible that this was caused by increased water flow through the T90 net resulting in improved catchability of large Tiger Flathead. At this stage it is unlikely that there would be wholesale adoption of T90 nets by Danish seine operators for a number of reasons. The current project was carried out over a fairly limited time period with a relatively small number of shots. As such, we have not been able to adequately encompass the full spatial and temporal coverage of the Danish seine fishery. The size range and availability of Tiger Flathead and other commercial species can vary considerably at relatively small spatial and temporal scales. There is a real and understandable concern amongst commercial fishers that T90 codends may not be suitable at certain times of the year or in certain areas of their fishery. Further commercial trials of T90 codends over extended spatial and temporal scales may help alleviate these concerns. Also, the use of T90 netting is a somewhat new and radical change to net making in a fishery that is known for its conservative and traditional approach to fishing techniques across many generations. This approach has served the fishery well over many years, so it is probably unrealistic to expect quick and extensive adoption over a small period of time.

The only Threatened, Endangered or Protected (TEP) species caught during these trials were seven Spiny Pipehorse (*Solegnathus spinosissimus*), three of which were found in the codend cover showing that they do escape commercial fishing gear. Insufficient quantities were caught to enable interpretation of the effect of gear type on the catch of this species; however catch rate in the commercial codends was lower compared to an earlier study.

Keywords:

Danish seine fishery, Tiger Flathead, Eastern School Whiting, selectivity, bycatch reduction, T90.

Acknowledgments

We would like to thank the owner and skippers of the fishing vessel Nungurner, Wayne and Ryan Cheers and their crew. Wayne Cheers, Peter Clarke and David Guillot provided advice on sampling methodology and codend and codend cover construction. The codend cover was designed and built by David Guillot and staff from Corporate Alliance Enterprises Pty Ltd. Robert Stevenson from LEFCOL gear store was a great help in sourcing netting materials. Neil Klaer (CSIRO) and Jemery Day (CSIRO) provided outputs from SS2 models that provided the basis for YPR modelling. We are grateful for the assistance of Associate Professor Russell Millar (The University of Auckland) and Dr Matt Broadhurst (Industry and Investment NSW) for advice of statistical analysis of selectivity data. Simon Boag (SETFIA) provided comments on results and facilitated a meeting with Industry members. The use of LEFCOL facilities for Industry meetings was appreciated. Thanks to Matt Piasente (AFMA) for discussion on behavioural analysis of underwater video footage. Crispian Ashby (FRDC) made valuable comments on the draft of this report.

FINAL REPORT

07/040 Selectivity and bycatch reduction of Tiger Flathead and Eastern School Whiting nets in the Danish seine fishery

Background

The Integrated Scientific Monitoring Program (ISMP) was specifically designed to provide statistically rigorous sampling of the catch composition and size structure of the retained and discarded catch of all quota species and important non-quota species caught in all sectors of the now Southern and Eastern Scalefish and Shark Fishery (SESSF) (Smith *et al.*, 1997), 2001 (Knuckey and Gason 2001) and 2009 (Bergh *et al.* 2009). As a result, there is already a good time-series of information on the bycatch composition of Danish seine vessels targeting both Eastern School Whiting and Tiger Flathead. Despite this, Danish seine discard information was not widely recognised because it was absorbed into summaries of the "East Victorian" region (for example, see page 38 of Koopman *et al.* 2007) which included data from otter board trawling. This was somewhat addressed by results from a one-year project of intensive onboard sampling of that sector which took place during 2006 (Koopman 2007).

Based on the above work we know that when targeting Tiger Flathead, the main species retained by Danish seiners are Tiger Flathead, Barracouta (*Thyrsites atun*), Southern Sawshark, Snapper (*Pagrus auratus*) and Jackass Morwong (*Nemadactylus macropterus*). The main discard species include species of Armour Gurnards (*Trigligae sp.* and *Peristediidae sp.*), Spikey Dogfish (*Squalus megalops*), Tiger Flathead, Barracouta and Common Stingaree (*Trygonoptera testacea*). When targeting Eastern School Whiting, the main retained species are Eastern School Whiting, Tiger Flathead, Barracouta, Snapper and Elephantfish; the main discard species are Armour Gurnards, Silverbelly, Sparsely Spotted Stingaree, Whitefin Swellshark (*Cephaloscyllium sp. A*) and Red Cod (*Pseudophycis bachus*).

There are a number of national and international acts, policies and plans that have been implemented which relate to bycatch issues in trawl fisheries and have the potential to impact significantly on the way trawl fisheries operate. Amendments to Schedule 4 of the *Wildlife Protection (Regulation of Exports and Imports) Act 1982* remove the blanket exemption for fish and require demonstration that fish being exported are not threatened as a result of their harvest. Historically, most of the Eastern School Whiting caught by the Danish seine fleet has been exported, so the implications of this component of the SESSF not meeting schedule 4 in the *Wildlife Protection Act (1982)* are of extreme concern. Further, the *Environment Protection and Biodiversity Conservation Act (1999)* (EPBC Act 1999) contains a range of regulations which include: strategic assessment of a fishery to ensure it is being carried out in an ecologically-sustainable manner; establishment of recovery plans; and reporting regimes for cetaceans, various threatened species and/or communities, migratory species and listed marine species. It also allows for the establishment of Marine Parks and Reserves to aid in the maintenance of community biodiversity in marine ecosystems. The Commonwealth Policy on Fisheries Bycatch requires the development of a strategic approach to addressing bycatch to ensure fisheries in Australian waters are ecologically sustainable. The Commonwealth, through the Australian Fisheries Management Authority (AFMA) and stakeholders, will address bycatch in accordance with the *Bycatch and Discards in Commonwealth Fisheries: Implementation Strategy* that was released by AMFA during 2008. This strategy aims to assist fisheries in addressing bycatch and discarding issues in a focussed and cost-effective way, and to work towards the Ministerial Directive of 2005 - to cease overfishing, recover overfished stocks, avoid further species becoming overfished, and to manage the broader environmental impacts of fishing including on protected species.

There has been extensive work on gear modifications to reduce the bycatch of small fish in otter board trawlers in the SESSF (Knuckey and Ashby 2009) and on the extension of the results to industry (Walker *et al*. 2010). Industry has subsequently continued to trial and implement gear modifications to reduce bycatch in otter board trawlers (e.g. Knuckey *et al.* 2008; SETFIA 2009). In contrast, very little bycatch reduction work has been undertaken in the Danish seine sector of the SESSF.

The fishing gear, methods, and targeting of the Danish seine fleet differ markedly to those of otter board trawlers. As such, gear modifications to reduce bycatch that are suitable for board trawling may not be suitable for the Danish seine gear. This is particularly the case for vessels targeting Eastern School Whiting, for which the minimum mesh size is 38 mm (compared to 90 mm for the otter board trawlers). This small Danish seine mesh size, however, can result in a high incidental capture of bycatch species of no market importance due to their small size or lack of commercial value. As it has done with the otter board trawlers, research aimed specifically at reducing bycatch would help provide the Danish seine fishery with the ability to meet the requirements of Ecologically Sustainable Development (ESD), and to meet AFMA's bycatch reduction targets.

Having a good understanding of the bycatch issues in the Danish seine sector of the SESSF, the next step is to determine the selectivity of Danish seine gear when targeting each of the main commercial species and trial appropriate modifications to reduce the level of discarded bycatch whilst maintaining current commercial yields. This was the goal of the current project.

Need

Discarding is a major problem facing commercial fisheries worldwide. The capture of fish that are later discarded is wasteful and may pose a threat to marine systems. It increases fishing costs through time spent sorting, reduces the quality of the retained fish, increases damage to gear, increases drag - causing increased fuel costs, and, ultimately, may affect the ecosystem on which target stocks rely. Moreover, there is a poor perception of fisheries with high discard levels. From various perspectives, therefore, there is a need to improve the selectivity of nets to reduce the capture of fish that are discarded. While work has been done to investigate improved selectivity of nets used by otter board trawlers, little work has been focused on Danish seine gear. There are no published studies on bycatch reduction in Danish seine gears in Australia, and few internationally. The Danish seine fleet operating out of Lakes Entrance, Victoria, targets Eastern School Whiting and Tiger Flathead. Different gears are used to target each of these species, and an understanding of the selectivity of these gears is required before trials of modified gears are conducted. Once these selectivities are determined, results can then be used, along with knowledge of the behaviour of fish in response to the gear, to develop trial gears that may reduce bycatch, while maintaining the profitability of the fishing operation.

This project aims to determine the selectivity of Danish seine gear and trial appropriate gear modifications that would maintain current commercial yields but reduce discarded bycatch.

Objectives

1. Determine optimum size and age-at-capture of Tiger Flathead and Eastern School Whiting by Danish seine gear.
2. To determine selectivities of Danish seine gear when targeting Tiger Flathead and Eastern School Whiting.
3. Construct and trial codends with mesh sizes to catch Tiger Flathead and Eastern School Whiting at their optimum sizes as determined by YPR analyses, and determine effect of changed mesh size on bycatch.

Methods

The methods section is separated into three sections to reflect the three aims of this project.

1. **Optimum size and age at first capture** describes the modelling technique developed and the data used to model yield- and value-per-recruit (YPR and VPR).
2. **Selectivity of Danish seine gear** describes covered codend and alternate haul experiments to estimate the selectivity of 65 mm and 75 mm Tiger Flathead codends, and 45 mm Eastern School Whiting codends. This section also describes the experiment to test the effect of (or lack of) masking by the codend cover on the escape of fish from the codend, and underwater video methods used to describe the behaviour of fish in response to the net.
3. **Gear modification** describes the construction and trial of the modified T90 net to estimate the selective properties, and compare catches with those of the 75 mm codend.

Optimum size and age-at-capture

Modelling yield-and value-per-recruit

Stochastic growth parameterisation with correction for selectivity and retention bias provide unbiased estimates of length-at-age distributions in fish population (Troynikov and Koopman 2009; Appendix 4). Given that many biological relationships can be related to, or represented by, length-based functions (length-weight, length-maturity, length-fecundity, etc.), the length-at-age distributions can be used to calculate different indices of reproduction and yield. The length selectivity of different fishing gears and retention functions can be used to calculate length-specific fishing mortality and retention. Also, if the length preferences of markets or social values are known, then gear efficiency for these values can be estimated.

Suppose $f(l)$ is some function of length which is mentioned above, and let $f(l) = w(l)$ be the length-weight relationship. Then, given

$$l(t) = L_{\infty}(1- \exp(-k(t-t_0))),$$

the double integral

$$I\,[f,R,S,T] = \int S(l(T))\, R(l(\mathrm{T})) f(l(T)) \exp(\int log(1- M(l(t)))\mathrm{d}t)\, g(k;\lambda)\,\mathrm{d}k,\ \ 0< t< T,\ \ 0< k \qquad \text{(Equation 1)}$$

provides the value of the retained catch-weight for the cohort at age T,

where $M(l(t)) = F(t)S(l(t)) + \mu(t)$ is total mortality, $F(t)$ is fishing mortality and $\mu(t)$ is natural mortality.

The control parameters $F(t)$ =const, $\mu(t)$ = const were used for simulation

Growth parameters L_{∞} and t_0, and the parameters of the probability distribution function $g(k;\lambda)$, should be estimated with correction for gear selectivity and retention biases.

Using the relationships $f(l(t))$, gear selectivity $S(l(t))$ and the retention functions $R(l(t))$ from Equation 1, we can calculate important biological characteristics of a fish cohort and estimate fishing gear efficiency for these biological characteristics and catch for different fishing gears.

Further, comparisons of yield and value per recruit that would be obtained using Danish seine gears with different selective properties can be modelled.

Simulation of changing mesh size was achieved by adjusting β_1 (equivalent to L_{50}). Values of β_1 modelled for each species are shown in Table 1. β_1 was increased by increments of 2.5 cm and 2 cm for Tiger Flathead and Eastern School Whiting respectively. Simulations were also run for fishing mortality rates ranging 0%–50%.

Data

Data for per-recruit analyses were collected from a number of sources (table 2). Size-price differential should be included in analysis of harvest strategies (Hilborn and Walters 1992), and these have been included in other studies to compare harvest strategies (e.g. Anderson 1989; Christensen and Vestergaard 1993; Gallagher *et al.* 2004). Market price was obtained from Melbourne Fish market records. Tiger Flathead are generally graded for sale into a number of size classes. For simplicity, two size classes are used in the modelling, large and small. Large fish are generally those greater than 42 cm in total length, and small fish are less than that size (Glen Richardson, pers. comm.). We allowed for some error in size grading: large fish were categorised as >40 cm, while small fish were categorised as <44 cm, and it was assumed that there was a linear distribution of fish between those sizes, with 50% of 42 cm fish being graded as small, and 50% as large.

Table 1. Values of β1 modelled to simulate changes in codend mesh size.

Tiger Flathead	Eastern School Whiting
25 cm	9 cm
27.5 cm	11 cm
30.5 cm	13 cm
32.5 cm	15 cm
35 cm	17 cm
37.5 cm	19 cm
40 cm	21 cm
	23 cm
	25 cm

Table 2. Parameters used in -per-recruit analyses.

Function	Parameter	Tiger Flathead	Eastern School Whiting
Selectivity	*B1*	30.57 cm [A]	17.1871 cm [B]
	B2	4.17821 [A]	3.22784 [B]
Retention	*B1*	24.4748 cm [A]	15.0358 cm [B]
	B2	1.18895 [A]	0.871935 [B]
	B3	1 [A]	1 [B]
	B4	0 [A]	0 [B]
	M	0.22 yr^{-1} [C]	0.5 yr^{-1} [B]
Maturity	T_m	30 cm [A]	16 cm [B]
	Slope	-0.25	
Length-weight	a	0.00588 [C]	0.013 [E]
	b	3.310 [C]	2.93 [E]
Market price		Large = $4.78/kg [F] Small $3.56/kg [F]	$2.89/kg [F]
Fecundity		Potential Fecundity/length relationship F=38000xLength-1091000 [D]	Potential Fecundity/length relationship F=10.0x$Length^{2.931}$ [D]

[A] Neil Klaer (CSIRO, pers. comm.)

[B] Jemery Day (CSIRO, pers. comm.)

[C] Klaer, N 2006.

[D] Wankowski, JWJ 1987.

[E] Klaer N, and Thomson, R. (2006).

[F] Melbourne Fish Market data (Catch and Effort, FV)

Selectivity of Danish seine gear

Different approaches to estimating selectivity were required for Tiger Flathead and Eastern School Whiting nets. Covered codend experiments rely on the construction and implementation of a codend cover that does not 'mask' or change the selectivity parameters of the codend. Data on the size frequency of fish caught in the cover compared to those caught in the codend easily allows calculation of the codend's selectivity.

Codends used to target Tiger Flathead are usually 65–75 mm stretched diameter. This was amenable to using a covered codend experiment, enabling direct quantification of within haul selectivity, reducing the between haul variation that can confound alternate haul results. This reduces uncertainty, as well as the number of replicate samples required. Eastern School Whiting are often targeted using 45 mm stretched diameter codend, meaning that a very fine cover would be required if that technique was to be used. This was not considered practical because the weight of the combined catch of the codend and cover, together with the weight of the gear, would put an unsafe workload on the vessel's lifting equipment and potentially upset the stability of the vessel during hauling. Instead, the alternate haul method was used to estimate selectivity of the Eastern School Whiting net. As the name implies, the alternate haul method relies on comparing the length frequency of fish caught in separate hauls with codends of different mesh size to estimate the selectivity of a larger mesh.

Vessel and fishing gear

The FV Nungurner was used for all fishing operations during this project. The FV Nungurner is a Danish seine vessel based in Lakes Entrance, Victoria. The vessel is 18.3 m long, the main engine has 195 horsepower, and total tonnage is 61 t.

The same commercial Danish seine net was also used throughout this project (Figure 1). The net had a footline 50 m long with chain and rubber discs. Eight coils of 250 m rode were deployed each side. Bar wings were constructed of 6 inch mesh, with 2 ¾ inch mesh in the shoulder and extension. Different codends were attached to this net during experiments.

The two Tiger Flathead codends were constructed of 65 mm and 75 mm twisted braid nylon mesh. The codend cover was constructed of 45 mm braid nylon mesh and used two polyethylene hoops to hold the cover open. The Eastern School Whiting codend was constructed of 45 mm braid nylon mesh. To measure the selectivity of the Eastern School Whiting net, a 25 mm knotless mesh codend was used as a control during alternate tows. Several stretched internal diameter measurements were made of each net to confirm codend mesh sizes.

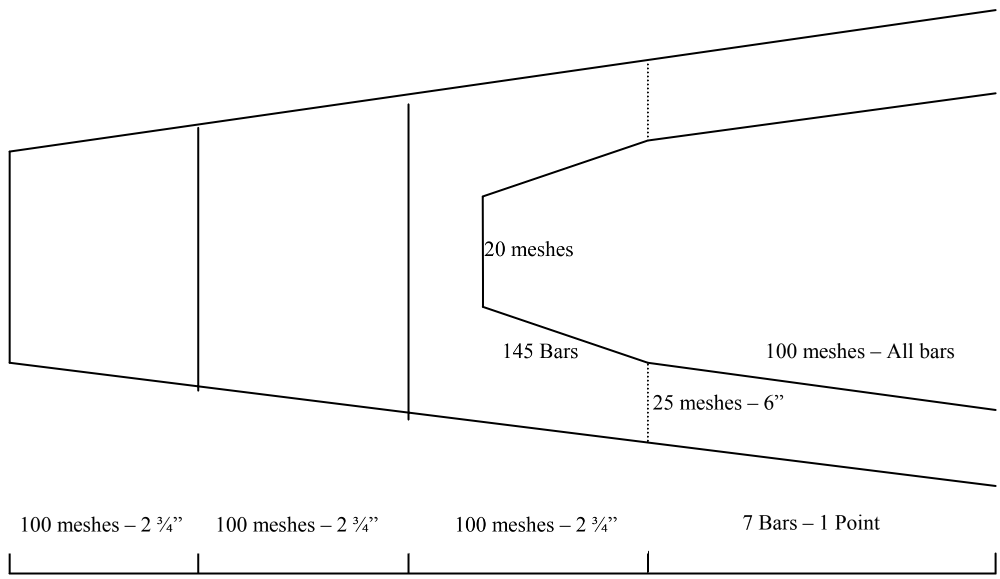


Figure 1. Net design that was used throughout the project. Different codends were attached for different experiments.

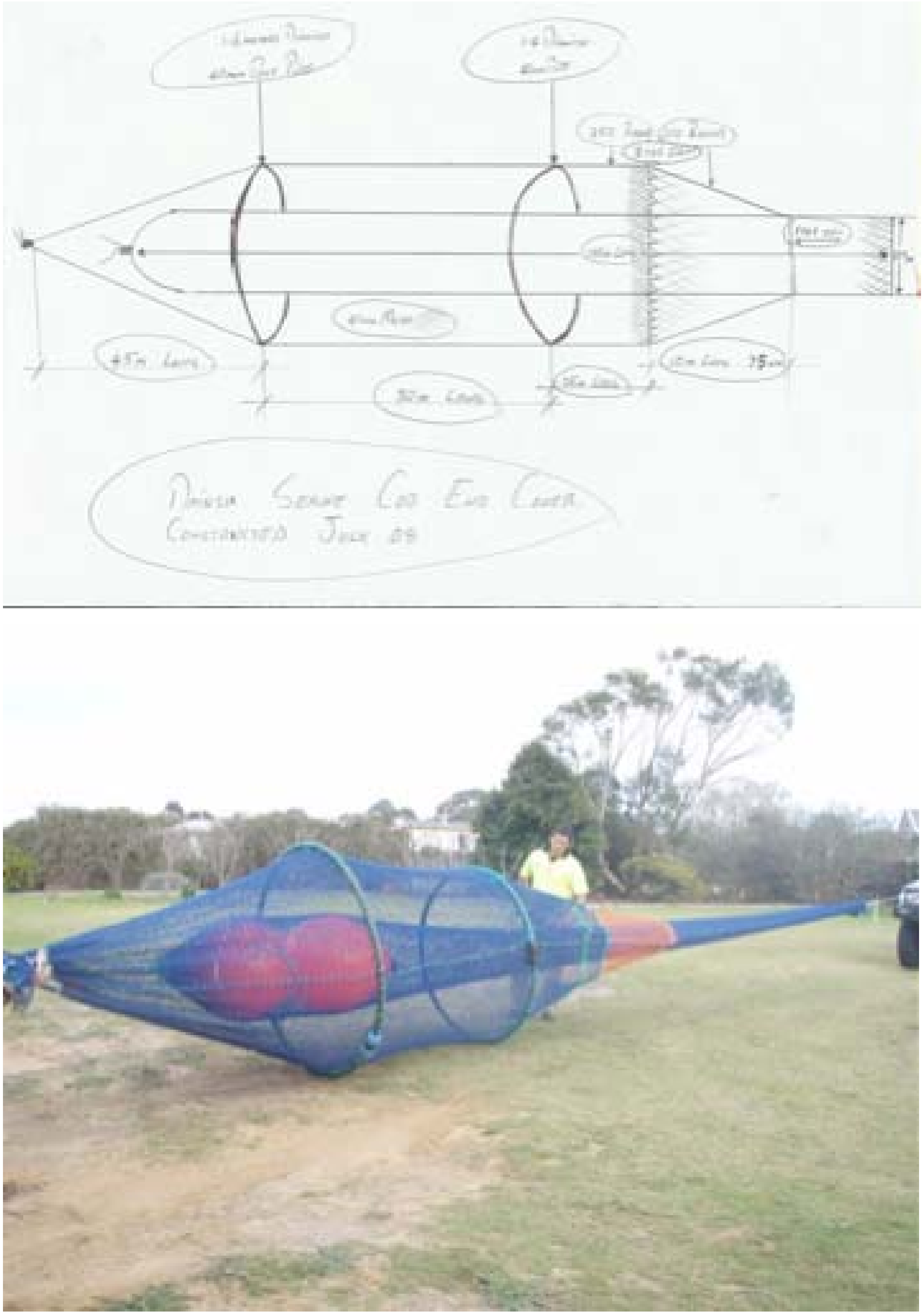


Figure 2. Design and image of codend cover showing hoops used to maintain gap between the codend and the cover.

Covered codend field methods

The covered codend experiment was carried out over five cruises between September 2008 – January 2009 (Appendix 3). Apart from the use of covered codends and the increased time between shots due to sampling of the catches, normal fishing procedures were followed. Covered codend experiments using the 75 mm codend were conducted during the first two cruises. A total of 17 shots were conducted, but one shot (shot 16) was omitted from analyses because the codend ripped, causing the catch in the codend to mix with the catch in the cover. Contact time (the time that the net is actually fishing) averaged 33 minutes and ranged 29–40 minutes. During cruise 2, an additional 5 shots were conducted using the 75 mm codend without the cover to enable testing of a masking effect of the cover. Footage from an underwater video camera positioned in between the codend and the cover was also used to determine if a masking effect was likely. This was done for each of the 65 mm, 75 mm and T90 codends on a total of 7 occasions (Table 4). Selectivity experiments using the 65 mm codend were conducted during December 2008. Fifteen shots were conducted, all with the cover on. Average tow duration was 35 minutes and ranged 30–37 minutes.

Alternate haul field methods

Because of the small diameter of standard Eastern School Whiting codends (45 mm), experiments using these gears necessitated the use of a very fine mesh to use as the control (25 mm). Concern was raised by the fishermen that the use of such fine mesh would result in the capture of a high volume of organisms, and may place an unsafe load on the vessel's lifting equipment. For this reason, alternate tows were used to estimate selectivity of Eastern School Whiting; however, even catches using single tows resulted in catches that were too heavy for the vessel. In the interest of safety, this experiment was abandoned after three shots with each of the 45 mm and 25 mm codends. These shots were conducted during January–February 2009 (Appendix 3). Average tow duration was 33 minutes and ranged 29–36 minutes.

Data collection

Operational and environmental data were collected for each shot. These included direction, speed, time and date of the shot. When the tow was completed, the net was hauled onboard and the catches from the codend and cover kept separate. Once separated into retained and discarded portions based on normal commercial practices, the weight of each species was recorded. Length measurements were collected for the main target species, and also for common bycatch species. Measurements taken for each species are shown in Table 3.

Table 3. Length measurement taken on fish species measured.

Species	Species name	Length measurement
Family Triglidae	*Family Triglidae*	Total length
Common Stinkfish	*Foetorepus calauropomus*	Total length
Blacktip Cucumberfish	*Paraulopus nigripinnis*	Total length
Eastern School Whiting	*Sillago flindersi*	Caudal fork length
Grooved Gurnard	*Lepidotrigla modesta*	Total length
Jackass Morwong	*Nemadactylus macropterus*	Caudal fork length
Roundsnout Gurnard	*Lepidotrigla mulhalli*	Total length
Tiger Flathead	*Neoplatycephalus richardsoni*	Total length

Underwater video analysis

The underwater video system was deployed during 17 day-time Danish seine tows throughout the study (Table 4). Night-time tows could not be filmed because the video system available did not have an illumination system. The shallow depth of Danish seining meant that there was sufficient ambient light during day-time shots. The video system worked well on most occasions; however, it became tangled in the nets during several tows, and failed to focus during one tow. It was placed at various locations in the net including on the wings, the shoulder, inside the codend and in between the codend and the cover. Some additional video footage was also obtained from an earlier Natural Heritage Trust funded project to document the behaviours of fish in response to Danish seine gear.

Behavioural analysis of fish behaviour was conducted in accordance with the methods of Piasente *et al.* (2004). Imagery was watched at slower than real time, and where species were identified, the reaction in response to the net was assigned to one of twelve behavioural categories (Table 5). The direction of successful escape attempts were also noted and recorded for each species.

Table 4. Description of shots filmed using underwater video set up.

Tape number	Shot number	Date	Net	Depth	Position in net	Comments
1	27	17/12/2008	65 mm	46 m	Inside cover on forward hops, facing rear	
2	29	17/12/2008	65 mm	46 m	Inside cover, forward of front hoop	
3	30	17/12/2008	65 mm	46 m	On rear hoop, inside cover facing forward	
4	32	17/12/2008	65 mm	46 m	Inside codend on seam, facing rear	
5	33	17/12/2008	65 mm	46 m	On headline	
6	35	17/12/2008	65 mm	45 m	Inside cover, at rear facing forward	
7	36	17/12/2008	65 mm	46 m	Inside cover, facing forward	
8	41	21/01/2009	25 mm	33 m	In codend facing forward	Dark video, not suitable for analysis
9	45	21/02/2009	T90	41 m	Rear hoop, facing forward	Fully zoomed in, unusable
10	46	21/02/2009	75 mm	39 m	Front of wing on the sparrow-tail, facing backwards	
11	47	21/02/2009	T90	39 m	Rear hoop inside cover, facing forward	
12	50	22/02/2009	T90	39 m	In between hoops, inside cover on seam pointing to the rear	
13	51	22/02/2009	75 mm	43 m	In shoulder of the net facing the rear	
14	52	22/02/2009	T90	41 m	Inside cover facing the rear, up from the second hoop	
15	57	24/03/2009	T90	76 m	In codend facing forward	
16	62	24/03/2009	T90	76 m	In codend facing rear	
17	63	24/03/2009	75 mm	76 m	In codend facing rear	

Table 5. Categories of fish behaviour used in examining the response of various fish species to the Danish seine net.

Behaviour	Behaviour category	Swimming speed[1]	Swimming direction[2]	Behavioural description	Code
Cruise swimming (Cs)	State	Faster (f)	Forward (F)	Fish swimming with a steady tail beat frequency faster than the trawl in the towing direction	Cs(f)F
Cruise swimming (Cs)	State	Slower (sl)	Forward (F)	Fish swimming with a steady tail beat frequency slower than the trawl in the towing direction	Cs(sl)F
Cruise swimming (Cs)	State	Same (sa)	Forward (F)	Fish swimming with a steady tail beat frequency at the same speed as the trawl in the towing direction	Cs(sa)F
Cruise swimming (Cs)	State	Unknown (un)	Aft (A)	Fish swimming with a steady tail beat frequency at an unknown speed opposite the towing direction	Cs(un)A
Cruise swimming (Cs)	State	Slower (sl) or same (sa)	Turn (T)	Fish performing a slow movement resulting in a change in orientation or direction after the response is performed	Cs(sl)T or Cs(sa)T
Rest (R)	State	None	None	Fish motionless, resting on panel of netting or observed drifting back towards the codend.	R
Impinged (I)	State	None	None	Fish impinged on panel of netting or against other fish in the codend.	I
Burst swim (Bs)	Event	Faster (f)	Forward (F) or aft (A)	Fish swimming with a high tail beat frequency, a vigorous, intense but brief high speed response	Bs(f)F or Bs(f)A
Burst swim (Bs)	Event	Faster (f)	Random, but strikes trawl netting (N)	Fish performing a burst swim resulting in contact with the netting.	Bs(f)N
Burst swim (Bs)	Event	Faster (f)	Turn (T)	Fish performing a burst swim resulting in a change in orientation or direction after the response is performed.	Bs(f)T

Analysis

To determine if the cover had a masking effect on the codend, length frequency distributions of main species measured during cruise 2 — during which the 75 mm codend was used with both the cover on and off (Appendix 3) — were compared using two-sample Kolmogorov-Smirnov tests (P=0.05).

Catch composition of the 75 mm and 65 mm commercial nets were compared to that of the codend covers, however statistical comparisons of commercial nets and their codend were not undertaken because samples are not independent. For summary, species identified were grouped into three categories: retained commercial, discarded commercial, and discarded non-commercial species. It was not within the aims of the project to quantitatively compare catch composition, or catch rates of different species between 75 mm and 65 mm nets. The temporal separation in sampling using these nets would introduce biases into such comparisons. For that reason, results of catches for each net are simply summarised.

Direct comparisons can be made between catches in the 45 mm Eastern School Whiting nets and the 25 mm net used as the control because they are independent observations. After testing for normality and homogeneity of variances using the Shapiro-Wilk test and Levene's test for heteroscedacity respectively, catch rates of main species were compared using paired t-tests. One-sided t-tests were used except for physically large animals such as Sparsely-spotted Stingaree and Starry Toad Fish for which two-sided t-tests were used. All analyses were conducted using the statistical package R (version 2.10.1).

Weighted length frequency data from each codend and the associated control (either the codend cover or 25 mm experimental codend) were combined across hauls for analysis. For species with sufficient data, logistic selection curves were fitted using the "trawlfunctions.R" package in statistical package R (version2.10.1). (http://www.stat.auckland.ac.nz/~millar/selectware/R/trawls/trawlfunctions.pdf).

Selection curves were fitted using the functions "ccfit" (for covered codend experiments) and "ttfit" (for alternate hauls experiment) using the SELECT methodology (Millar 1992; Millar *et al.* 2004). Analysis of alternate haul data using both the equal split and estimated-split models (Millar and Walsh 1992) were conducted but only results from the estimated-split model were retained because that model obtained a clearly superior fit. Overdispersion caused by between-haul variability and the weighting up of sub-sampled length frequency data (Macbeth *et al.* 2005) was REP corrected using methods described in Millar *et al.* (2004). In calculating REP, summation terms were restricted to terms for which the expected catches in the codend and the cover or control were greater than, or equal to 3 (Millar *et al.* 2004). Standard errors of estimated parameters were corrected by multiplying them by sqrt(REP). Estimates are presented for REP, L_{25}, L_{50}, L_{75} and SR (the selection range which equals the difference between L_{25} and L_{75}).

Gear modifications

Field methods

After examination of selectivity data and review of underwater video, it was decided that a T90 codend using 75 mm mesh (hereon in called the T90 net) was an appropriate codend to trial for bycatch reduction. Experiments using the T90 net were carried out over four cruises between February 2009 – May 2009 (Appendix 3). A total of 12 tows were conducted with each of the T90 and 75 mm control codends. The use of each net was alternated, and the codend cover was used on 5 of the T90 shots to enable estimation of selectivity. The range of tow durations was 31–36 minutes for both codends, and averaged 33 minutes and 34 minutes for 75 mm and T90 codends respectively.

Data collection and analysis was as for the previous section, except that the logistic curve did not provide an adequate fit to length frequency data from the T90 codend, and so the Richards curve was used (Wileman *et al.* 1996).

Results/Discussion

Optimum size and age-at-capture

An integrated bio-economic analysis of fish cohort dynamics was developed to model yield and value-per-recruit for Tiger Flathead and Eastern School Whiting. This approach was based on stochastic parameterisation of growth data developed by Troynikov (1998), Troynikov and Gorfine (1998), Troynikov *et al.* (1998), Troynikov and Walker (1999) and Punt *et al.* (2005). These stochastic growth models have been previously used in population dynamic models including rock lobster and abalone stock assessment models, and the numerical algorithms and software passed through extensive testing and debugging using a variety of growth data. This method has unique properties which makes it superior over other existing methods for growth analysis. For example, the programs include an original numerical algorithm for correction of gear selectivity bias in estimates of growth in a population. This algorithm was developed using Bayesian decomposition of size distribution in samples that allows for using joint data collected by different gear types (Troynikov 1999). The comprehensive growth modelling outputs include estimates of population growth parameters, likelihood ratio statistics for data comparison, selection of the best model using Kullback's informative integral, growth transition matrixes for population dynamic models, and a variety of graphical outputs.

The growth modelling outputs are used as input data to the software for bio-economic cohort analysis. The stochastic growth models allow addressing the interaction between fishing gear length-selectivity and length-at-age distributions in fish populations.

Stochastic cohort analysis allows for detailed modelling of cohort dynamics under fishing pressure, addressing all measurable biological relationships within a cohort. The outputs consist of a variety of information about fish cohort dynamics including sustainability indices, yield and discards when different fishing gears are deployed. The software provides quantitative comparison of the efficiency of the fishing gears with respect to commercial and social values as well as bio-sustainability in the form of simple quantitative indices.

The bio-economic model developed for this project has a number of advantages over standard deterministic models such as the Beverton-Holt model. Assumptions are not made that there is a steady-state stock structure nor that recruitment is independent of the size of the spawning stock. In addition, the model outputs include discard rates of the target species.

Adjusting age and growth for selectivity and retention

Most fisheries data are collected using size-selective fishing gear. These data contain information not only about growth of fish within the population, but also about selectivity of the gear. For instance, growth data collected using two different gears may produce two different sets of growth parameter estimates for the same population, which does not make biological sense. Therefore, when population parameters are estimated, gear selectivity should be accounted for by researchers. Despite most fisheries data being subject to gear-selectivity bias, the literature addressing effects of gear selectivity on estimating growth parameters is limited to only a few publications (eg Taylor *et al.* 2005).

To correct for bias, a maximum-likelihood estimator that incorporated gear selectivity, a size-dependent retention function and several stochastic growth models was developed (Troynikov and Koopman 2009; Appendix 4). The estimator allowed the use of samples collected by fishing gears with different selectivities, which increased sample size and data representativeness, and thus improved the accuracy of population parameter estimates. This correction was applied to both Tiger Flathead and Eastern School Whiting data before modelling YPR and VPR.

Optimum size-at-capture

YPR and VPR modelling were carried out using the integrated bio- economic model to examine the effects of changing length at 50% selection (L_{50}) as a way of simulating modifications to mesh size. A range of values for L_{50} that were greater and smaller than the current estimates were modelled (Table 1).

Current estimates of fishing mortality (F) for Tiger Flathead and Eastern School Whiting were obtained from the most current stock assessments for each species (Table 6), to assist with interpretation of YPR and VPR outputs. Estimates of F from 1999–2008 for Tiger Flathead ranged 0.079–0.128 yr^{-1} (Klaer 2009) and averaged 0.092 yr^{-1}, and for Eastern School Whiting ranged 0.135–0.476 yr^{-1} (Day 2009) and averaged 0.260 yr^{-1}. These mean instantaneous F values equate to mortality rates of 8.8% and 22.6% for Tiger Flathead and Eastern School Whiting respectively.

Table 6. Instantaneous fishing mortality rates for Tiger Flathead (Klaer 2009) and Eastern School Whiting (Day 2009) from the Danish seine fleet during 1999–2008.

Year	Tiger Flathead	Eastern School Whiting
1999	0.128	0.476
2000	0.090	0.366
2001	0.088	0.415
2002	0.084	0.332
2003	0.083	0.220
2004	0.087	0.150
2005	0.094	0.135
2006	0.079	0.150
2007	0.088	0.192
2008	0.096	0.169
Average	**0.092**	**0.260**

Tiger Flathead

YPR and VPR for Tiger Flathead over a range of F and L_{50} are shown in (Figure 3). The current estimate of length at 50% selectivity for Tiger Flathead by Danish seine gear at the time the analysis was conducted was 30.57 cm (Klaer, pers. comm.) and average F over the past 10 years has been 8.8% (or 0.092 yr^{-1}).

Modelling shows that the current fishery catches Tiger Flathead at a length that is close to, but greater than, the length that would provide the maximum yield and value-per-recruit. Increasing L_{50} would reduce both value and yield-per-recruit at current F, and the reduction would be at an even greater rate at lower rates of F. At current levels of F, increasing L_{50} to 32.5 cm would reduce VPR by about 3% and YPR by 5%. The relative stability of VPR and YPR to changes in L_{50} provides flexibility for experimenting with gear modifications, without large risk of significantly reducing the profitability of the catch. At about double the current level of F (~20%), VPR would be at its maximum observed for the current L_{50}, and YPR would be just slightly less than the yield that would be obtained with L_{50} of 27.5 cm. For L_{50} of 27.5 cm – 32.5 cm, maximum VPR and YPR are observed at a fishing mortality more than double the current estimate (Figure 4). At an F of 10%, VPR and YPR were 17% and 20% lower than for a F of 20% at current L_{50}. At low levels of F, YPR and in particular VPR, decrease rapidly. These results show that over a range of likely values of F, that both VPR and YPR are relatively insensitive to small changes in L_{50}.

Discard rates of Tiger Flathead are sensitive to both L_{50} and F (Figure 5). Because the minimum legal size of Tiger Flathead landed in Victoria is 28 cm, a selectivity profile that would catch a high proportion of fish under that size would obviously lead to an increase in discarding. However, even at L_{50} = 25 cm, discard rates are only 4% when F = 10%, but increase to about 12% when F = 40%. At L_{50} = 30.5 cm, discard rates are less than 2% for all levels of F, and fall below 0.5% at higher L_{50}. For a given L_{50}, discard rate increases proportionally to F, and the smaller the L_{50}, the greater the rate of increase. Discarding of Tiger Flathead by the Danish seine fleet is currently low, and at current levels of F, small reductions to L_{50} are unlikely to result in a large increase to discard rate of that species. Conversely, increases in L_{50} would not provide a large decrease in discard rate. This provides evidence that small modifications to selectivities of fishing gears to reduce bycatch are unlikely to significantly impact discarding of the target species.

Confidence in the integrated bio- economic model is gained from comparison of results with those of Chen *et al.* (1998). They modelled YPR of Tiger Flathead from the otter trawl fishery off NSW and found YPR values for a range of fishing mortalities between 60–160 g per recruit (for M = 0.2).

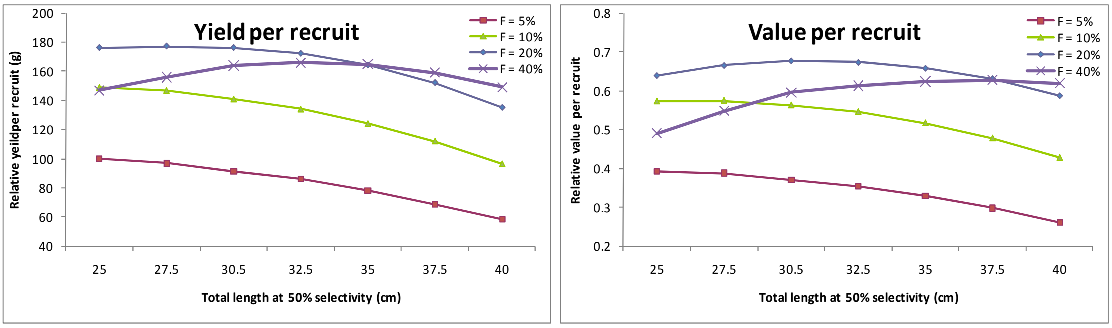


Figure 3. Value and yield-per-recruit of Tiger Flathead by length at 50% selectivity for three levels of fishing mortality.

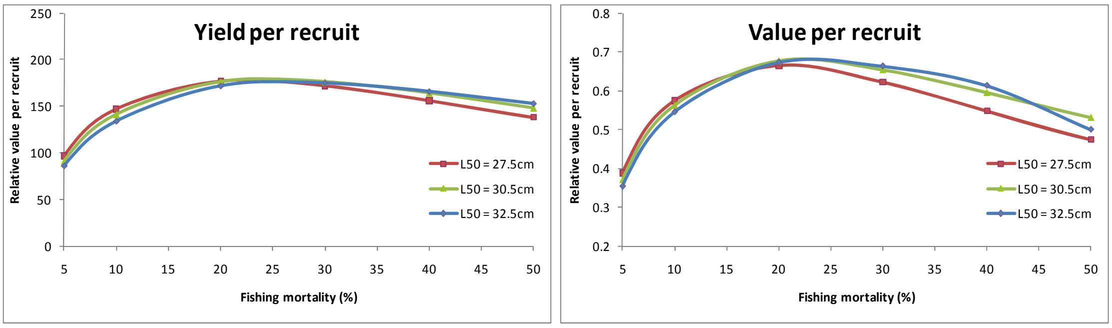


Figure 4. Value and yield-per-recruit of Tiger Flathead by fishing mortality for three different lengths at 50% selectivity.

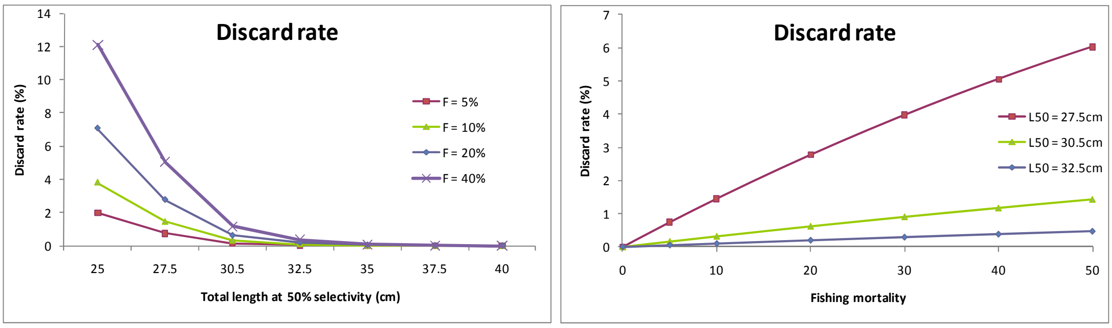


Figure 5. Discard rates of Tiger Flathead for different combinations of fishing mortality and lengths at 50% selectivity.

Eastern School Whiting

YPR and VPR for Eastern School Whiting over a range of F and L_{50} are shown in (Figure 6). The current estimate of length at 50% selectivity for Eastern School Whiting by Danish seine gear is 17.19 cm (Jemery Day, pers. comm.) and average F over the past 10 years has been 22.6% (or 0.260 yr^{-1}). Modelling shows that the current fishery catches Eastern School Whiting generally at a length greater than the length that would provide the maximum YPR (9 cm), but smaller than the length that would provide the greatest VPR (21 cm) (Figure 6). Increasing L_{50} to 19 cm would reduce the YPR by about 31%, but increase VPR by 14% at current F, while increasing F would increase YPR over the entire range of L_{50} modelled, and would increase VPR only at lengths greater than 17 cm. VPR is particularly low for F = 50% at L_{50} less than 17 cm.

YPR did not asymptote over the range of F modelled, but was consistently higher for smaller L_{50} (Figure 7). At L_{50} of 15 cm and 19 cm, YPR would be 32% and 57% greater at a fishing mortality of 50% than at a fishing mortality of 20%. For L_{50} of 15–17 cm, the current estimate of fishing mortality results in the largest VPR, while at L_{50} of 19 cm, the highest VPR is at a fishing mortality of 30%.

Discard rate at current F and L_{50} is about 4% and would increase to about 5% with a small reduction in selectivity to L_{50} of 15 cm (Figure 8). The difference in discard rates between different values of F is greatest at small L_{50}, when highest YPR are also observed. Discard rate is almost 0% at L_{50} of 25 cm. Discard rates increase at a similar rate to YPR with increasing F.

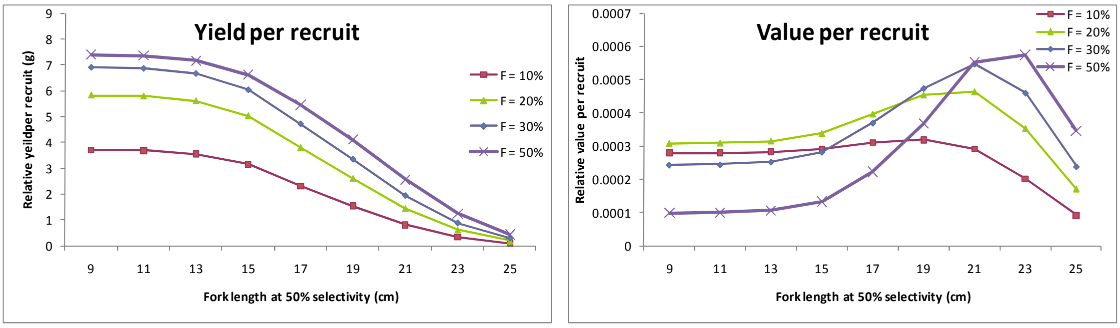


Figure 6. Value and yield-per-recruit of Eastern School Whiting by length at 50% selectivity for three levels of fishing mortality.

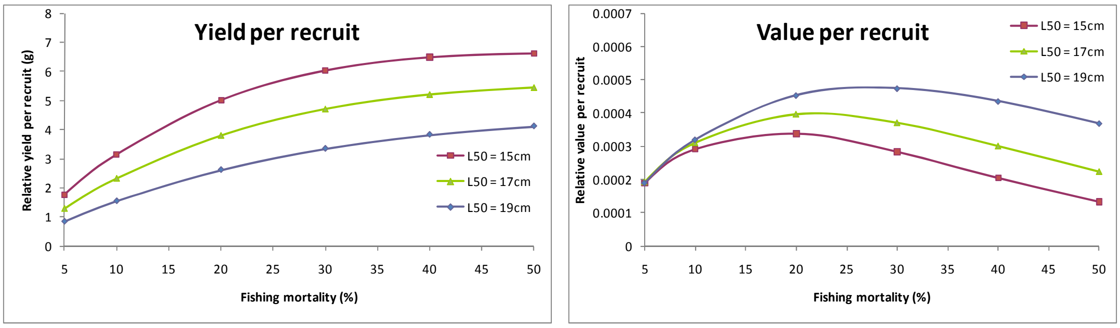


Figure 7. Value and yield-per-recruit of Eastern School Whiting by fishing mortality for three different lengths at 50% selectivity.

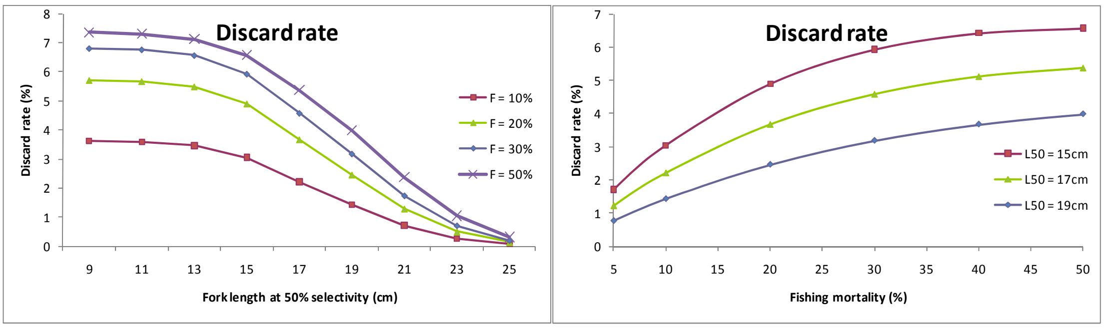


Figure 8. Discard rates of Eastern School Whiting for different combinations of fishing mortality and lengths at 50% selectivity.

Selectivity of Danish seine gear

Effect of the codend cover

It is well documented that a codend cover can mask the codend meshes, changing the selectivity of the gear (e.g. Main *et al.* 1992), and that hoops should be used to hold the cover clear of the codend to reduce potential masking (Main and Sangster 1998). Despite the use of hoops, it is still important to take measurements to determine if the cover is affecting the selectivity of the codend being tested. Such tests are often conducted in a laboratory flume tank; however, budget constraints confined testing to in situ observations using underwater video cameras and comparisons of the catch. During 10 – 11 October 2008, eleven shots were undertaken using the 75 mm Tiger Flathead net, six with the codend cover employed, and five without.

Examination of the video taken using a camera positioned between the codend and the codend cover showed that there was a large space between the cover and the codend, and that the cover did not appear to encumber the codend at all (Figure 9). The cover was constructed with hoops to maintain the open shape, which it did for the entirety of the shot, even during early stages of the tow when there was very little forward movement of the net. As the codend began to fill (Figure 9a), the gap between the codend and the cover started to close; but even near the end of the shot the codend remained unencumbered by the cover (Figure 9b).

Despite no apparent masking of the codend by the cover, one effect became obvious during video analysis. Tiger Flathead that were free swimming in the space between the cover and the codend were observed to swim back into the codend. This appeared to be infrequent; however, it may cause some bias in the data, which to our knowledge has never been accounted for. Without stereo imagery from which length measurements can be taken, it is difficult to account for this bias. It would be impossible to tell if these individuals again escaped from the codend.

Comparison of length frequency distributions of commonly caught species revealed no significant differences between shots with and without the cover (Figure 10). The length distribution appears to be larger for Tiger Flathead when the cover was on, and fish less than 28 cm were only observed in shots that did not use the cover. These differences in length frequency distribution were not statistically significant. There appeared to be more small Grooved Gurnard and Blacktip Cucumberfish in samples from catches that had the codend cover on; however, these differences were not statistically significant. The lack of difference in size frequency distributions is consistent with the presence of the cover having no effect on the efficiency of the codend.

a b

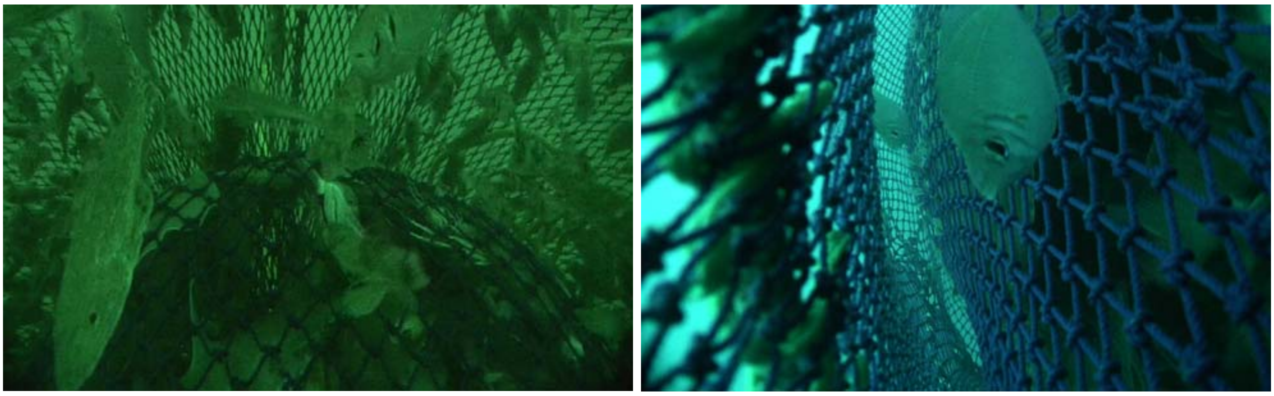


Figure 9. Freeze frames from video taken from in between the codend and the codend cover a) mid way through the shot, and b) near the end of the shot.

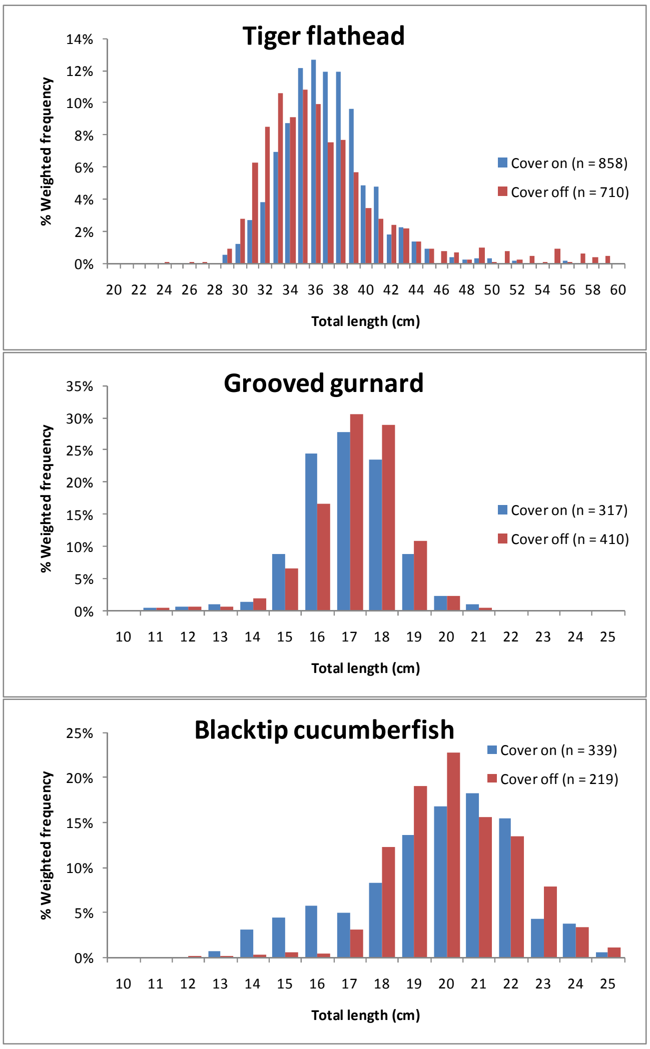


Figure 10. Comparison of length frequency of Tiger Flathead, Grooved Gurnard and Blacktip Cucumberfish in the codend with and without the codend cover using 75 mm Tiger Flathead codend. None of the distributions were significantly different (two-sample Kolmogorov-Smirnov tests *P*=0.05).

Tiger Flathead nets

Catch composition of the 75 mm net shot with and without the codend cover were combined for summaries. The total catch from the 75 mm Tiger Flathead codend was 11,626 kg (21 shots), while 3,072 kg (16 shots) was caught in the codend cover (Table 7). Retained fish made up 59.1% and 45.5% of the catch weight in the codend and cover respectively (Figure 11). The high proportion of fish retained from the cover demonstrates the 75 mm codend does allow marketable fish to escape. Some of this retained fish from the cover was Tiger Flathead, but the vast majority was Eastern School Whiting (included in the 'other finfish' category in Table 7), of which up to 250 kg per shot was caught. Tiger Flathead was the most commonly caught species in the 75 mm codend, comprising nearly 50% of the total catch weight (Figure 12). Southern Sawshark, Ocean Jacket, Latchet, Elephantfish and Red Gurnard were the other most commonly caught retained species. Discarded commercial species comprised only 0.7% and 1.0% of the total catches in the 75 mm codend and the cover, and the average catch rate of Tiger Flathead discarded in the 75 mm codend was 0.1 kg per shot. Discarded non-commercial species comprised 39.6 and 53.5% of the total catch in the codend and the cover, respectively. Most commonly caught non-commercial discards in the 75 mm codend were Sparsely-spotted Stingaree (8.5%), Blacktip Cucumberfish (5.3%), Grooved Gurnard (10.1%) and Family Triglidae (4.9%) (Figure 13). Species caught in the cover included Blacktip Cucumberfish (45.6%), Family Triglidae (1.6%), and Grooved Gurnard (1.3%). The very high proportion of Blacktip Cucumberfish was largely a result of one very large catch of 850 kg. One Spiny Pipehorse was caught in the 75 mm codend.

Total retained catch in the 65 mm codend and the cover were 70.7% and 0.8% respectively (Table 8 and Figure 14). Retained catch in the codend was overwhelmingly dominated by Tiger Flathead (62.9%), with smaller portions of Southern Sawshark (2.2%), Ocean Jacket (1.5%) and Red Gurnard (0.8%). Catch rate of Tiger Flathead in the codend was 400.3 kg per shot compared to 0.3 kg per shot in the cover (Figure 15). In comparison to the 75 mm codend, very little fish from marketable species escaped this codend during the experiment (keeping in mind that the results from the 75 mm codend cover contained very large catches of Eastern School Whiting which were not observed in the 65 mm codend cover catches). Discarded commercial species comprised only 0.3% and 0.8% of the total catches in the codend and cover, respectively. Highest catch rates of discarded commercial species in the codend were for Ocean Jacket and John Dory (*Zeus faber*) (both 0.4 kg per shot). Blacktip Cucumberfish comprised higher portions of the total catch in both the 65 mm codend (9.5%) and the cover (92.4%) than in the 75 mm codend, and was almost entirely due to one exceptionally large catch (tow number 25) of 900 kg and 1700 kg of Blacktip Cucumberfish in the codend and cover, respectively. Other main discarded non-commercial species were Sparsely-spotted Stingaree (8.9%), Roundsnout Gurnard (4.8%) and Grooved Gurnard (2.5%) (Figure 16). Other discarded non-commercial species in the cover were Roundsnout Gurnard (2.8%), Grooved Gurnard (0.5%) and Family Triglidae (0.3%). One Spiny Pipehorse was caught in the 65 mm codend, while three were caught in the cover.

A similar catch composition was reported in a previous study. During an intensified year of onboard observing during January 2006 – January 2007, Koopman (2007) reported a similar proportion of Tiger Flathead caught in Tiger Flathead nets (53.7%), and Armoured Gurnards (15.9%) (this group includes Family Triglidae and Grooved and Roundsnout Gurnards). They also reported that Spikey Dogfish (5.3%) and Barracouta (3.5%) were caught in relatively high quantities, and that Sparsely-spotted Stingaree (1.4%) and Blacktip Cucumberfish (0.9%) formed only a minor portion of the catch. Because the selectivity trials were conducted during September–December, and the intensive onboard sampling took place throughout the year, it is likely that differences in catch composition resulted from seasonal patterns of abundance. Further, the large captures of Barracouta in the 2006–2007 data were observed from a single trip, a large distance from the fishing grounds where the current selectivity trials were conducted.

The length distribution of Tiger Flathead shows that the majority of fish that escaped through the 75 mm codend were less than 33 cm, but some fish as large as 38 cm escaped (Figure 17). The smallest Tiger Flathead measured from the 75 mm codend was 28 cm, while the modal and greatest lengths were 36 cm and 60 cm, respectively. Selectivity parameters estimated for the combined hauls of Tiger Flathead using the 75 mm codend are shown in Table 9. L_{50} (30.08 cm) was only about 0.5 cm smaller than that estimated by SS2 for stock assessment (Klaer 2007), supporting the SS2 estimate. Standard errors of parameter estimates were multiplied by the square-root of REP to correct for overdispersion. Visually, the model fitted the data well, and the distribution of deviance residuals (the distance between the observed proportion of the catch in the 75mm codend and the expected proportion) appear to be evenly split between positive and negative values (Figure 18).

Tiger Flathead caught in the codend of the 65 mm Tiger Flathead net ranged 26–56 cm with a mode of 34 cm, and those caught in the codend cover ranged 23–31 cm with a mode of 26 cm (Figure 19). The sample size of fish (90 fish) from the codend cover is very low because few Tiger Flathead escaped through the 65 mm mesh. This lack of fish in the cover meant that the combined hauls size-selection model failed to converge. A logistic curve was instead plotted in Microsoft Excel using the Solver function with no estimates of error (Figure 19). Selection is nearly knife edge with SR = 0.22 cm. L_{50} (26.99 cm) was about 3 cm smaller than that from the 75 cm codend. The selection curve appeared to fit the data well.

Blacktip Cucumberfish caught in the 75 mm Tiger Flathead codend ranged 13–25 cm with a mode of 20.5 cm, and those in the cover ranged 11–24.5 cm with a mode of 19 cm (Figure 20). Despite a similar range and modal length, distributions were very different because subsampling of the very large catches in the cover greatly inflates the weighted frequency, compared with data from the codend. It appears that Blacktip Cucumberfish are not fully selected by the 75 mm codend at any of the sizes sampled (despite the 100% selectivity for the 25 cm length class which comprised of only one fish). The maximum length reported for Blacktip Cucumberfish is 28 cm (Gomon *et al*. 2008), so it is unlikely that any part of the population is fully selected for in 75 mm codends. Despite the limited selectivity of the size range sampled, a logistic curve was fitted (Figure 20 and Figure 21), with an L_{50} of 29.40 cm (Table 11). So at the maximum report length of 28 cm, less than 50% Blacktip Cucumberfish would be expected to be retained by the 75 mm codend. Because of the poor fit to the data and lack of confidence in the estimates, errors around parameter estimates are not reported.

The length frequency distributions for Blacktip Cucumberfish caught in 65 mm Tiger Flathead codend was almost identical to that caught in the cover (Figure 22). The largest fish in the cover and the codend were 23 cm and 22.5 cm respectively, while both the cover and the codend had minimum lengths of 15 cm and modal lengths of 19.5 cm. A poorly fitting logistic curve was estimated from the data over the range of lengths observed (Figure 22 and Figure 23). The curve was very flat with SR of 24.53 cm, and L_{50} of 26.67 cm (Table 11).

Blacktip Cucumberfish are a narrow, elongated species with a relatively soft body and no bony protrusions that would inhibit escape from a trawl net. Knuckey and Ashby (2010) also noted poor selectivity ogives in their analysis of covered codend experiments using otter trawl gear with 90 mm double braided codends. They postulated “the gear did not appear to select some species by size” and that the poor fits could be due to “these relatively small fish initially escaped into the cover at the start of the trawl, but then as the codend filled up during the trawl, the meshes close up and the same sized fish were unable to escape from the codend” or that “these smaller fish did not seem to actively swim or try to escape from the codend which may lead to poor selectivity”. L_{50} of 20.3 cm was reported for Blacktip Cucumberfish in the eastern region from that study.

The great majority of Eastern School Whiting escaped the 75 mm Tiger Flathead codend into the cover. The range of lengths sampled was almost identical, and modal lengths were 19 cm in both the codend and the cover (Figure 24). As for Blacktip Cucumberfish, the gear did not appear to select Eastern School Whiting by size. The logistic curve revealed L_{50} of 34.45 cm (Figure 24 and Table 12), nearly 1.5 cm greater than the maximum reported length of 33 cm (Gomon *et al.* 2008). Deviance residuals were strongly dominated by positive values, reinforcing the lack of fit to the data (Figure 25). Because of the lack of confidence in the estimates, errors around parameter estimates are not given.

The lengths of Grooved Gurnard caught in the 75 mm Tiger Flathead net ranged 11.5–21.5 cm in the codend and 12.5–19.25 cm in the cover (Figure 26). Modal lengths were 18 cm in the cover and 17.5 cm in the codend; the distributions of lengths in each of the nets appears similar. Consequently, the size selection model for combined hauls failed to converge and so a logistic curve was plotted in Microsoft Excel using the Solver function. The curve showed a knife-edge selection with L_{50} of 13.35 cm (Figure 26 and Table 13). This result should be treated with caution because of the lack of small fish in the sample, and because the lowest percent retention of the 75 mm codend observed was 74%.

Roundsnout Gurnard measured in samples from the codend cover of the 65 mm Tiger Flathead net ranged 11–19 cm with a mode of 16.5 cm, while fish measured from the codend ranged 14–20.5 cm with a mode of 17 cm (Figure 27). There is a clear bias in the length frequency distribution of fish measured from the cover towards smaller fish, compared to the codend, suggesting that the catch of this species was affected by selectivity in the size range sampled. This resulted in the successful fitting of a logistic curve with an L_{50} of 15.38 cm (Figure 27 and Table 14). The fit to the data appeared to be very good, and the deviance residuals were not biased in either direction (Figure 28). While Knuckey and Ashby (2010) did not get a useful fit of the selectivity ogive to the data collected during their otter trawl covered codend experiment, they estimated L_{50} to be 11.9 cm.

Despite using codend mesh 15–25 mm smaller than the otter trawl net used in Knuckey and Ashby (2010), this study has found that L_{50} was consistently larger for Danish seine gear than for otter trawl nets. This was observed for Tiger Flathead, Blacktip Cucumberfish and Roundsnout Gurnard. There are a number of possible reasons for the differences in selectivity. Trawl gear is in constant motion at speeds of 2.5–3.5 knots meaning there is constant pressure on the net, maintaining a narrow mesh opening and reducing opportunities for escape. The long duration of the otter trawl tow also means that the codends can become clogged with fish, and this may reduce the selectivity properties of the net over the 3–4 hours of the trawl. In comparison, the codend of a Danish seine net moves very little for the first ½ hour or so after deployment (as the wings are shot and pulled around to form the complete ring). During this time there is little or no pressure on the mesh in the codend and it remains open. Further, the fish spend the majority of the time outside of the codend where the mesh is of larger size, allowing more opportunity to escape, and because the bulk of the fish enter the Danish seine codend near the completion of the tow, most fish enter the net before the mesh becomes clogged, allowing more opportunity to escape.

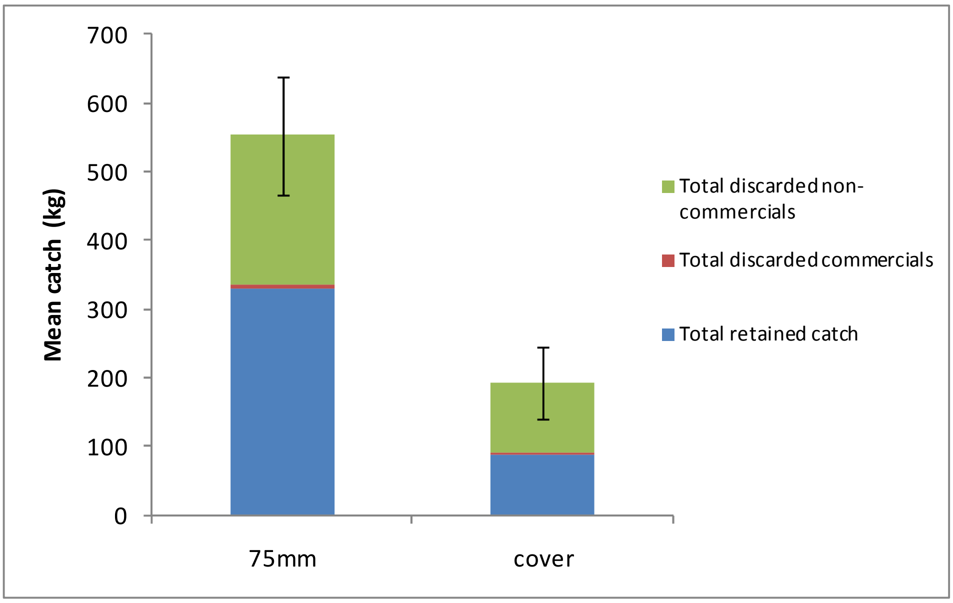


Figure 11. Mean total catch rates (+ SE) by the 75 mm codend and the cover.

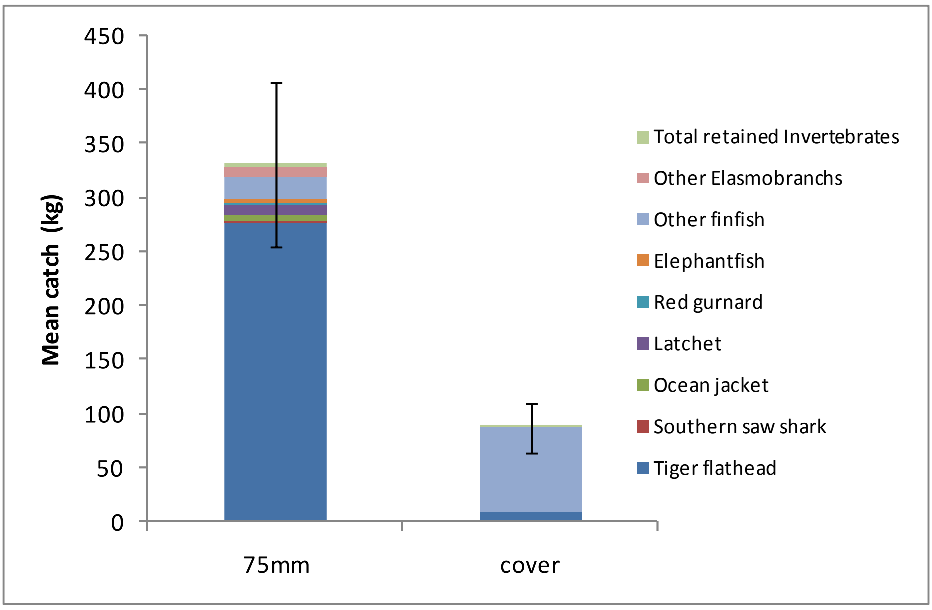


Figure 12. Mean retained catch rates (+ SE) by the 75 mm codend and the cover.

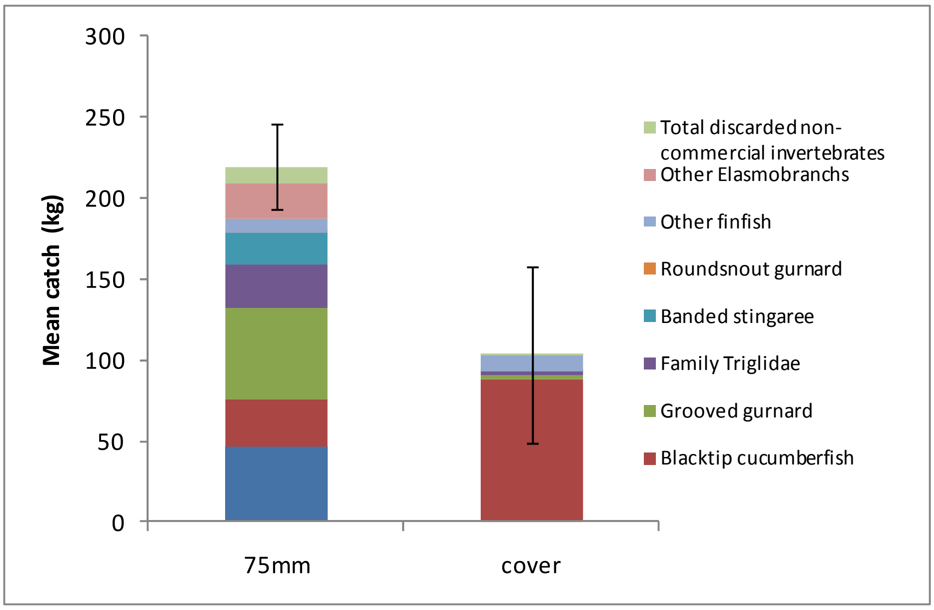


Figure 13. Mean discarded non-commercial species catch rates (+ SE) by the 75 mm codend and cover.

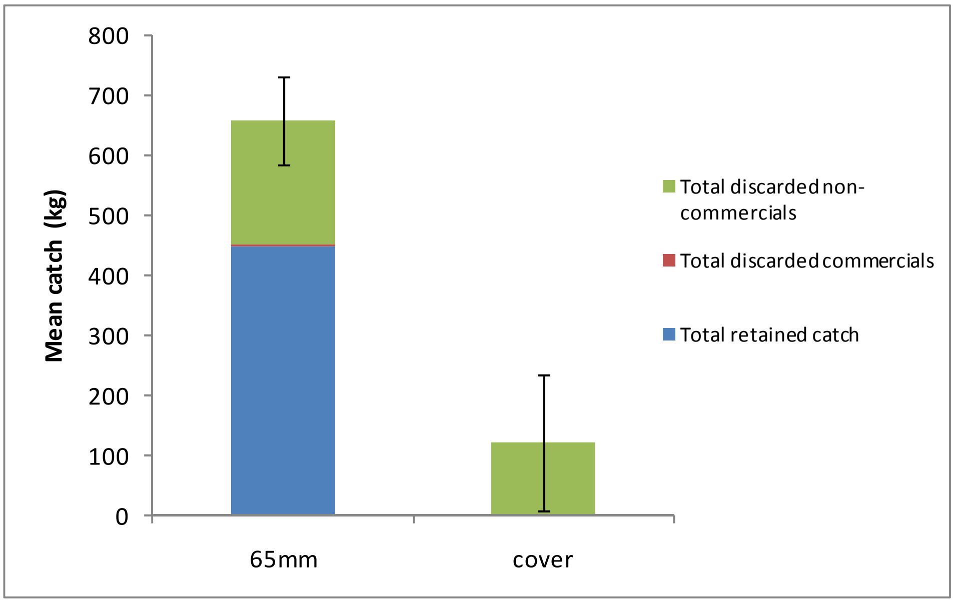


Figure 14. Mean total catch rates (+ SE) by the 65 mm codend and cover.

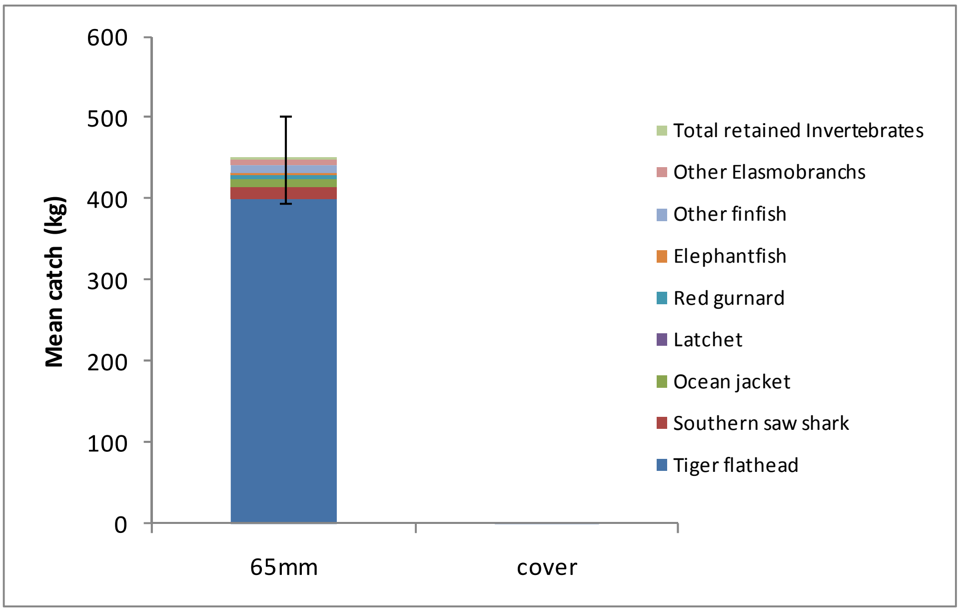


Figure 15. Mean retained catch rates (+ SE) by the 65 mm codend and the cover.

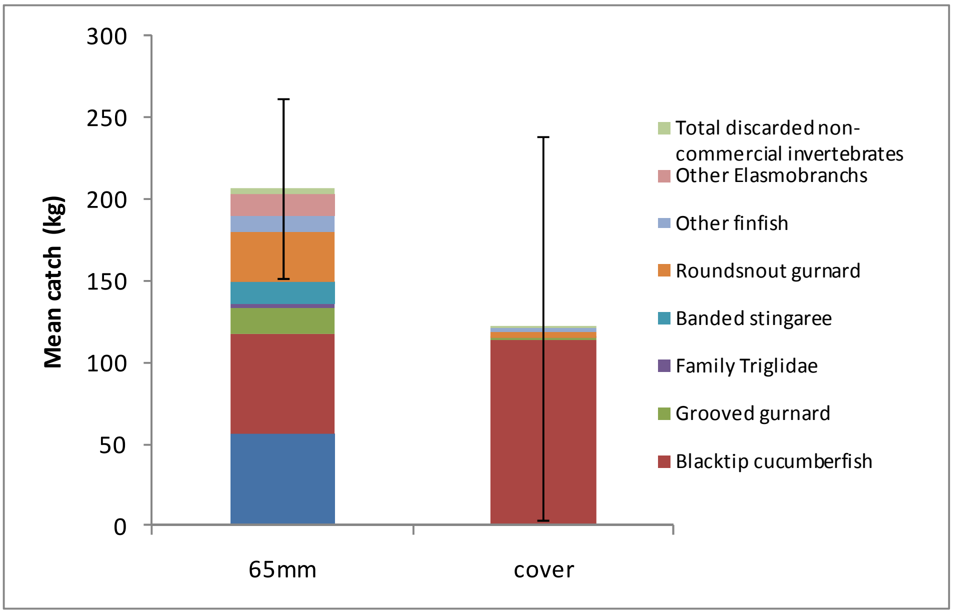


Figure 16. Mean discarded non-commercial species catch rates (+ SE) by the 65 mm codend and cover.

Table 7. Total catch weight (kg), mean catch (kg), standard error and % of total catch by 75 mm and the codend cover.

	75 mm codend (21 shots)				Codend cover (16 shots)			
	Total catch (kg)	Mean (kg)	SE	%	Total catch (kg)	Mean (kg)	SE	%
Retained commercial								
Tiger Flathead	5790	275.7	70.8	49.8	132	8.3	3.1	4.3
Southern Sawshark	71	3.4	0.9	0.6	0	0.0	0.0	0.0
Ocean Jacket	115	5.5	2.7	1.0	0	0.0	0.0	0.0
Latchet	162	7.7	3.0	1.4	0	0.0	0.0	0.0
Elephantfish	88	4.2	2.0	0.8	0	0.0	0.0	0.0
Red Gurnard	51	2.4	0.6	0.4	0	0.0	0.0	0.0
Other finfish	432	20.6	5.2	3.7	1264.5	79.0	23.2	41.2
Other Elasmobranchs	160	7.6	2.6	1.4	0	0.0	0.0	0.0
Total retained fish	**6869**	**327.1**	**76.4**	**59.1**	**1396.5**	**87.3**	**23.0**	**45.5**
Cephalopods	34	1.6	0.5	0.3	1	0.1	0.1	0.0
Other molluscs	0	0.0	0.0	0.0	0	0.0	0.0	0.0
Crustaceans	41	2.0	0.9	0.4	0	0.0	0.0	0.0
Total retained Invertebrates	**75**	**3.6**	**1.3**	**0.6**	**1**	**0.1**	**0.1**	**0.0**
Total retained catch	**6944**	**330.7**	**76.2**	**59.7**	**1397.5**	**87.3**	**23.0**	**45.5**
Discarded commercial								
Ocean Jacket	13	0.6	0.2	0.1	3.5	0.2	0.1	0.1
Gummy Shark	9	0.4	0.3	0.1	2	0.1	0.1	0.1
Draughtboard Shark	8	0.4	0.2	0.1	0	0.0	0.0	0.0
John Dory	1.5	0.1	0.1	0.0	0	0.0	0.0	0.0
Latchet	6	0.3	0.2	0.1	0	0.0	0.0	0.0
Tiger Flathead	2	0.1	0.1	0.0	12.5	0.8	0.2	0.4
Other finfish	16	0.8	0.2	0.1	12.5	0.8	0.2	0.4
Other Elasmobranchs	22	1.0	0.3	0.2	1	0.1	0.1	0.0
Total discarded commercial fish	**77.5**	**3.7**	**0.7**	**0.7**	**31.5**	**2.0**	**0.3**	**1.0**
Cephalopods	0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Total discarded commercial invertebrates	**0**	**0.0**	**0.0**	**0.0**	**0.5**	**0.0**	**0.0**	**0.0**
Total discarded commercials	**77.5**	**3.7**	**0.7**	**0.7**	**32**	**2.0**	**0.3**	**1.0**
Discarded non-commercial								
Sparsely-spotted Stingaree	984	46.9	11.6	8.5	0	0.0	0.0	0.0
Blacktip Cucumberfish	614	29.2	10.9	5.3	1400	87.5	53.3	45.6
Grooved Gurnard	1172	55.8	22.0	10.1	40	2.5	1.8	1.3
Family Triglidae	570	27.1	6.0	4.9	48	3.0	1.2	1.6
Banded Stingaree	402	19.1	4.9	3.5	2	0.1	0.1	0.1
Roundsnout Gurnard	10	0.5	0.2	0.1	2	0.1	0.1	0.1
Spiny Pipehorse	0.1	0.0	0.0	0.0	0	0.0	0.0	0.0
Other finfish	166	7.9	1.1	1.4	140.5	8.8	2.0	4.6
Other Elasmobranchs	461	22.0	6.7	4.0	7.5	0.5	0.2	0.2
Total discarded non-commercial fish	**4379.1**	**208.5**	**25.7**	**37.7**	**1640**	**102.5**	**54.3**	**53.4**
Other molluscs	19	0.9	0.7	0.2	0	0.0	0.0	0.0
Crustaceans	30	1.4	0.5	0.3	3	0.2	0.1	0.1
Corals	28	1.3	0.7	0.2	0	0.0	0.0	0.0
Starfish	1	0.0	0.0	0.0	0	0.0	0.0	0.0
Sponge	137	6.5	2.6	1.2	0	0.0	0.0	0.0
Total discarded non-commercial invertebrates	**225**	**10.7**	**3.6**	**1.9**	**3**	**0.2**	**0.1**	**0.1**
Total discarded non-commercials	**4604.1**	**219.2**	**26.2**	**39.6**	**1643**	**102.7**	**54.4**	**53.5**
Total discarded fish	**4456.6**	**212.2**	**26.1**	**38.3**	**1671.5**	**104.5**	**54.3**	**54.4**
Total discarded invertebrates	**225**	**10.7**	**3.6**	**1.9**	**3.5**	**0.2**	**0.1**	**0.1**
Total discards	**4681.6**	**222.9**	**26.6**	**40.3**	**1675**	**104.7**	**54.4**	**54.5**
Total catch	**11625.6**	**553.6**	**86.0**	**100**	**3072.5**	**192.0**	**52.6**	**100**

Table 8. Total catch weight (kg), mean catch (kg), standard error and % of total catch by 65 mm and the codend cover.

	65 mm codend (15 shots)				Codend cover (15 shots)			
	Total catch (kg)	Mean (kg)	SE	%	Total catch (kg)	Mean (kg)	SE	%
Retained commercial								
Tiger Flathead	6005	400.3	49.5	62.9	4.6	0.3	0.1	0.2
Southern Sawshark	211	14.1	5.1	2.2	0	0.0	0.0	0.0
Ocean Jacket	147	9.8	3.0	1.5	0	0.0	0.0	0.0
Latchet	4	0.3	0.2	0.0	0	0.0	0.0	0.0
Elephantfish	40	2.7	1.0	0.4	0	0.0	0.0	0.0
Red Gurnard	76	5.1	1.8	0.8	0	0.0	0.0	0.0
Other finfish	130.3	8.7	1.7	1.4	11	0.7	0.6	0.6
Other Elasmobranchs	107	7.1	2.4	1.1	0	0.0	0.0	0.0
Total retained fish	**6720.3**	**448.0**	**53.5**	**70.4**	**15.6**	**1.0**	**0.6**	**0.8**
Cephalopods	7.1	0.5	0.2	0.1	0	0.0	0.0	0.0
Other molluscs	0	0.0	0.0	0.0	0	0.0	0.0	0.0
Crustaceans	14	0.9	0.3	0.1	0	0.0	0.0	0.0
Total retained Invertebrates	**21.1**	**1.4**	**0.4**	**0.2**	**0**	**0.0**	**0.0**	**0.0**
Total retained catch	**6741.4**	**449.4**	**53.5**	**70.7**	**15.6**	**1.0**	**0.6**	**0.8**
Discarded commercial								
Ocean Jacket	5.7	0.4	0.2	0.1	0	0.0	0.0	0.0
Gummy Shark	2.7	0.2	0.1	0.0	0	0.0	0.0	0.0
Draughtboard Shark	3	0.2	0.2	0.0	0	0.0	0.0	0.0
John Dory	5.6	0.4	0.2	0.1	0	0.0	0.0	0.0
Latchet	0	0.0	0.0	0.0	0	0.0	0.0	0.0
Tiger Flathead	3	0.2	0.1	0.0	11.7	0.8	0.2	0.6
Other finfish	3.7	0.2	0.1	0.0	2.1	0.1	0.1	0.1
Other Elasmobranchs	0.3	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Total discarded commercial fish	**24**	**1.6**	**0.5**	**0.3**	**14.4**	**1.0**	**0.2**	**0.8**
Cephalopods	0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Total discarded commercial invertebrates	**0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**
Total discarded commercials	**24**	**1.6**	**0.5**	**0.3**	**14.5**	**1.0**	**0.2**	**0.8**
Discarded non-commercial								
Sparsely-spotted Stingaree	850	56.7	10.3	8.9	0	0.0	0.0	0.0
Blacktip Cucumberfish	903	60.2	62.1	9.5	1706.4	113.8	117	92.4
Grooved Gurnard	242	16.1	3.0	2.5	9.6	0.6	0.4	0.5
Family Triglidae	41	2.7	1.9	0.4	5	0.3	0.2	0.3
Banded Stingaree	192	12.8	3.4	2.0	0	0.0	0.0	0.0
Roundsnout Gurnard	460	30.7	8.1	4.8	52.1	3.5	1.8	2.8
Spiny Pipehorse	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Other finfish	143.7	9.6	2.2	1.5	41.2	2.7	0.8	2.2
Other Elasmobranchs	209.5	14.0	2.7	2.2	0	0.0	0.0	0.0
Total discarded non-commercial fish	**3041.3**	**202.8**	**54.6**	**31.9**	**1814.6**	**121.0**	**117**	**98.3**
Other molluscs	13	0.9	0.2	0.1	0	0.0	0.0	0.0
Crustaceans	24.7	1.6	0.3	0.3	1.9	0.1	0.1	0.1
Corals	0	0.0	0.0	0.0	0	0.0	0.0	0.0
Starfish	0	0.0	0.0	0.0	0	0.0	0.0	0.0
Sponge	15	1.0	0.5	0.2	0	0.0	0.0	0.0
Total discarded non-commercial invertebrates	**53.2**	**3.5**	**0.8**	**0.6**	**1.9**	**0.1**	**0.1**	**0.1**
Total discarded non-commercials	**3094.5**	**206.3**	**54.7**	**32.4**	**1816.5**	**121.1**	**117**	**98.4**
Total discarded fish	**3065.3**	**204.4**	**54.5**	**32.1**	**1829**	**121.9**	**117**	**99.0**
Total discarded invertebrates	**53.2**	**3.5**	**0.8**	**0.6**	**2**	**0.1**	**0.1**	**0.1**
Total discards	**3118.5**	**207.9**	**54.6**	**32.7**	**1831**	**122.1**	**117**	**99.2**
Total catch	**9859.9**	**657.3**	**74.3**	**100**	**1846.6**	**123.1**	**113**	**100**

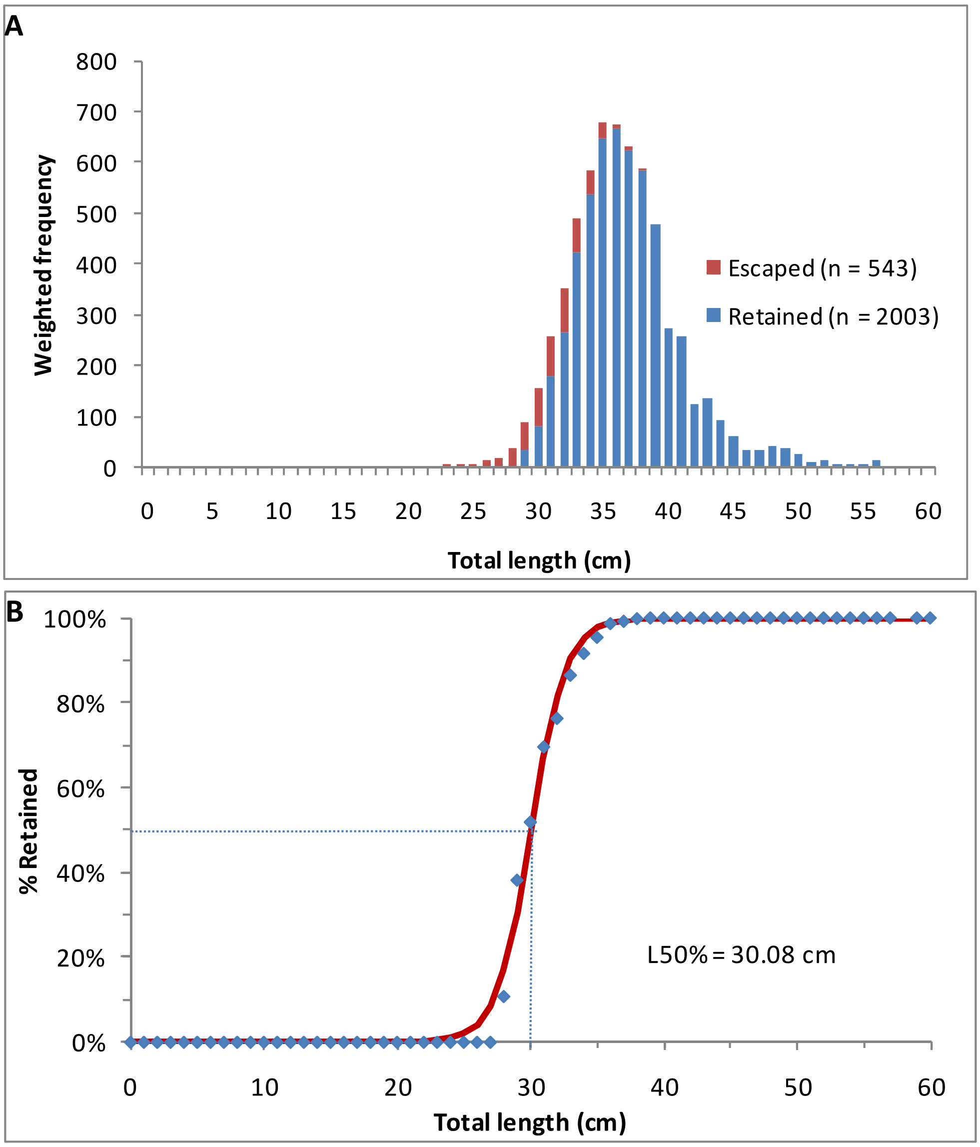


Figure 17. A. Length frequency distribution of Tiger Flathead that were retained in the 75 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 75 mm Tiger Flathead codend for Tiger Flathead. Each point (♦) marks the % retained at a given 1 cm length class and the line (—) represents the estimated logistic selectivity curve.

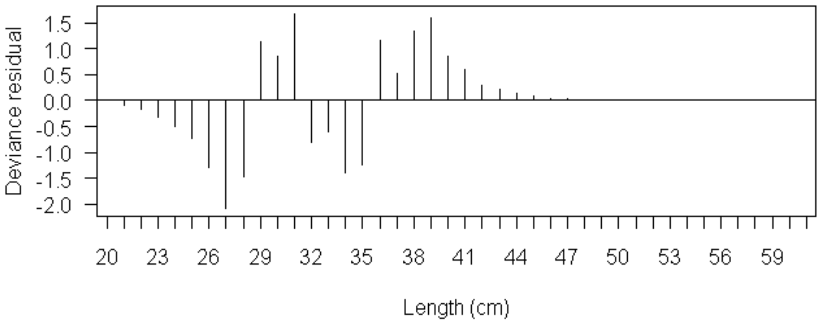


Figure 18. Plot of the deviance residuals from the selectivity ogive fit to Tiger Flathead length frequencies from the 75 mm covered codend.

Table 9. Combined hauls fits to Tiger Flathead data in the 75 mm covered codend catches.

Parameter	Estimate	S.E.
REP	3.94	
L_{25}	28.45 cm	0.33
L_{50}	30.08 cm	0.23
L_{75}	31.74 cm	0.17
SR	3.29 cm	0.25

Table 10. Combined hauls fits to Tiger Flathead data in the 65 mm covered codend catches. Logistic curve fitted using Solver function.

Parameter	Estimate
L_{25}	26.88 cm
L_{50}	26.99 cm
L_{75}	27.10 cm
SR	0.22 cm

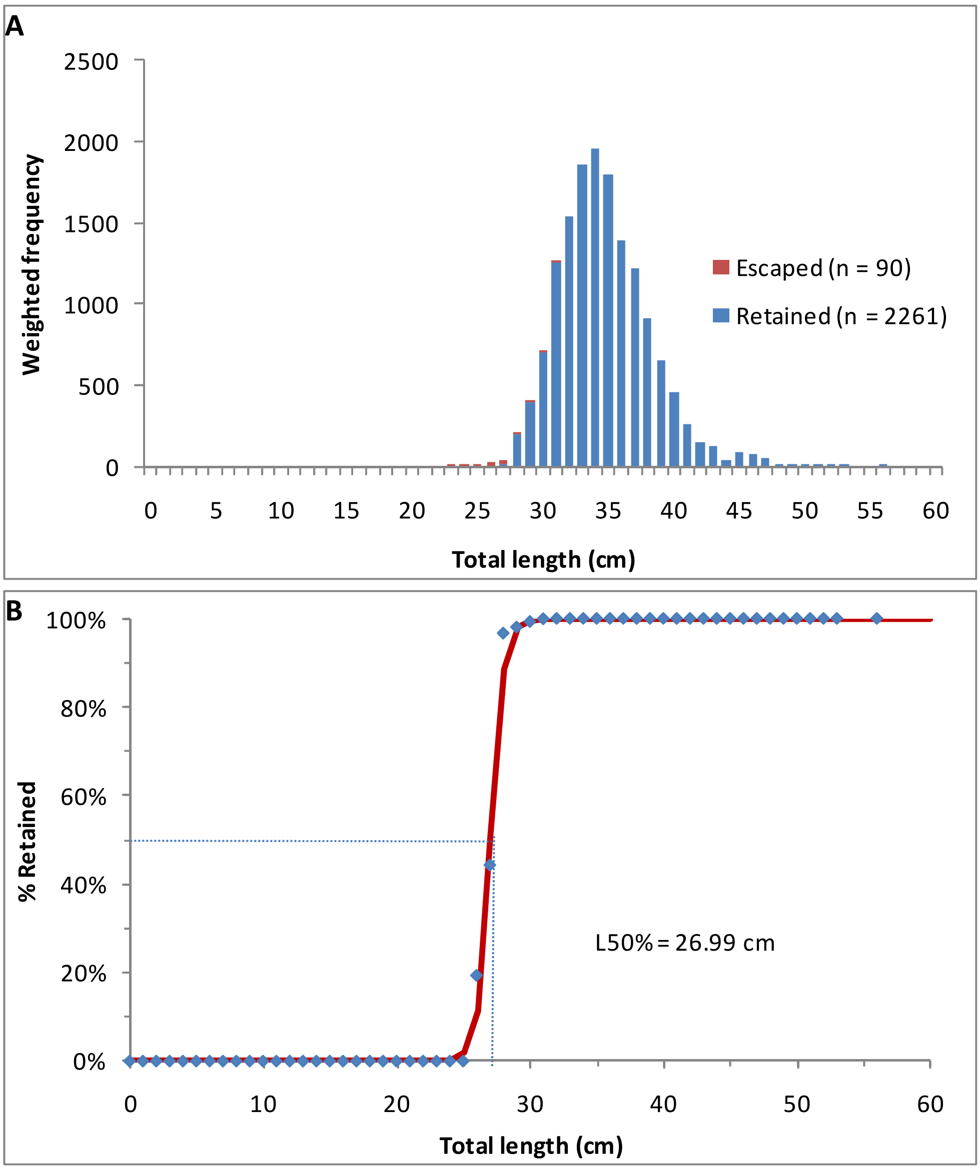


Figure 19. A. Length frequency distribution of Tiger Flathead that were retained in the 65 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 65 mm Tiger Flathead codend for Tiger Flathead. Each point (♦) marks the % retained at a given 1 cm length class and the line (—) represents the estimated logistic selectivity curve.

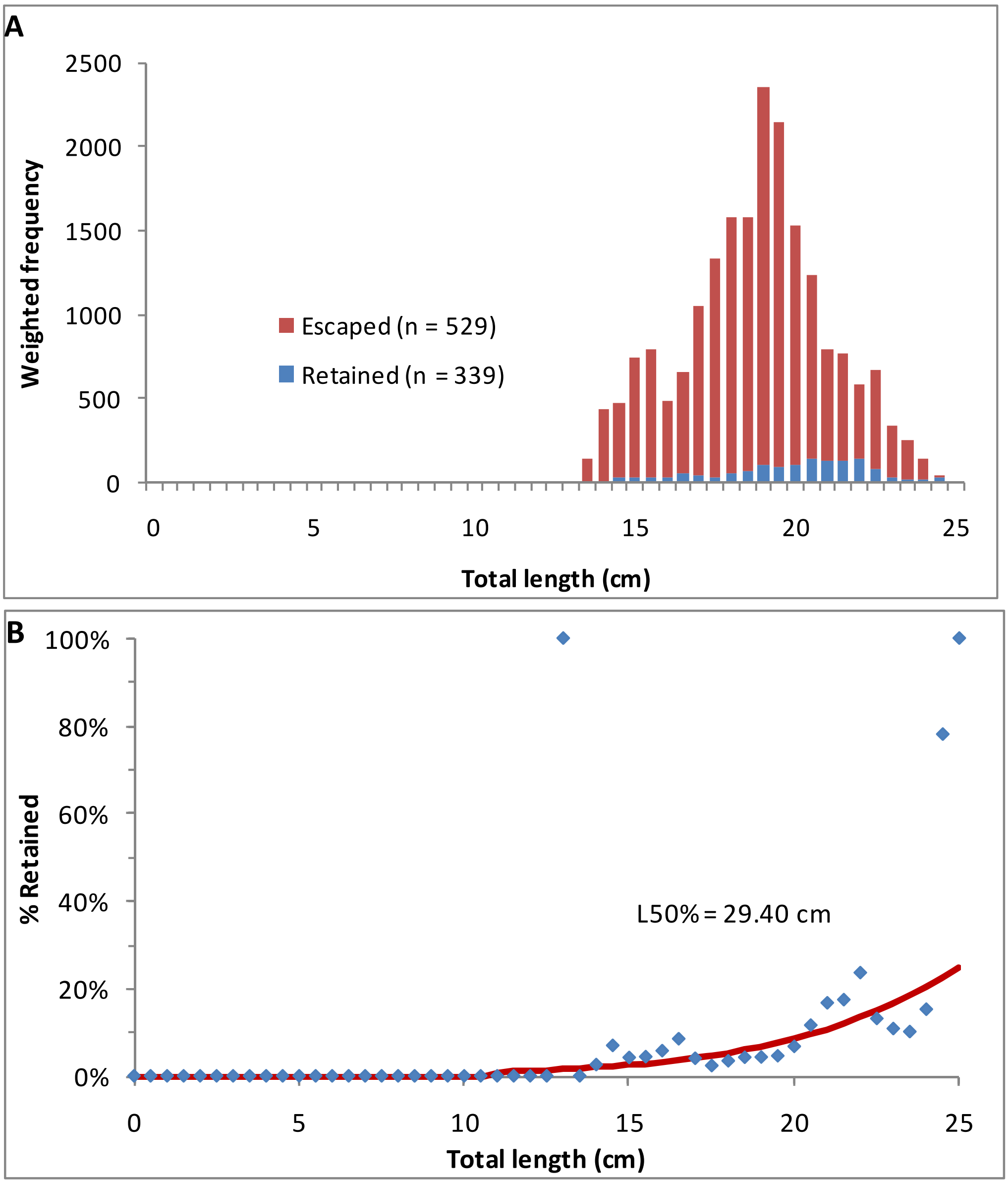


Figure 20. A. Length frequency distribution of Blacktip Cucumberfish that were retained in the 75 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 75 mm Tiger Flathead codend for blacktip cucumberfish. Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

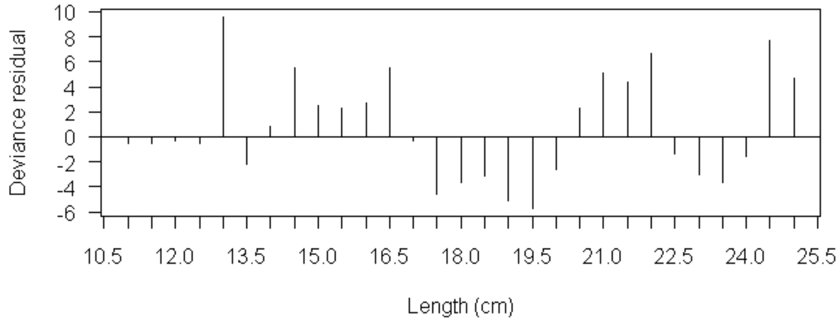


Figure 21. Plot of the deviance residuals from the selectivity ogive fit to Blacktip Cucumberfish length frequencies from the 75 mm covered codend.

Table 11. Combined hauls fits to Blacktip Cucumberfish data in the 75 mm and 65 mm covered codend catches.

Parameter	Estimate 75 mm	Estimate 65 mm
L_{25}	25.05 cm	14.40 cm
L_{50}	29.40 cm	26.67 cm
L_{75}	33.75 cm	38.94 cm
SR	8.71 cm	24.53 cm

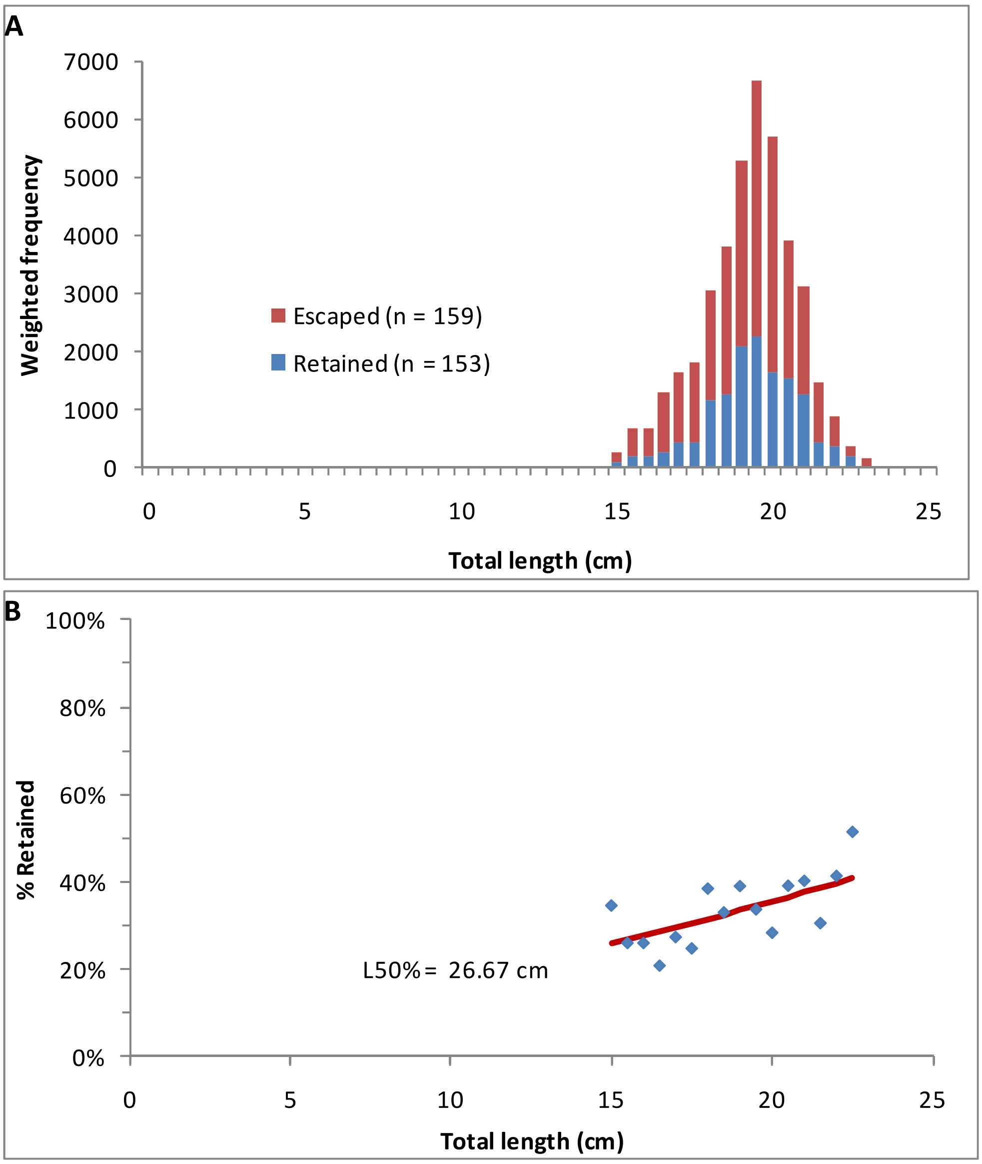


Figure 22. A. Length frequency distribution of Blacktip Cucumberfish that were retained in the 65 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 65 mm Tiger Flathead codend for blacktip cucumberfish. Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

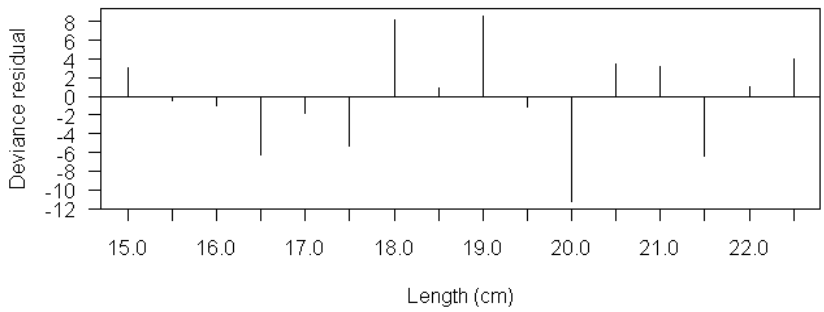


Figure 23. Plot of the deviance residuals from the selectivity ogive fit to Blacktip Cucumberfish length frequencies from the 65 mm covered codend.

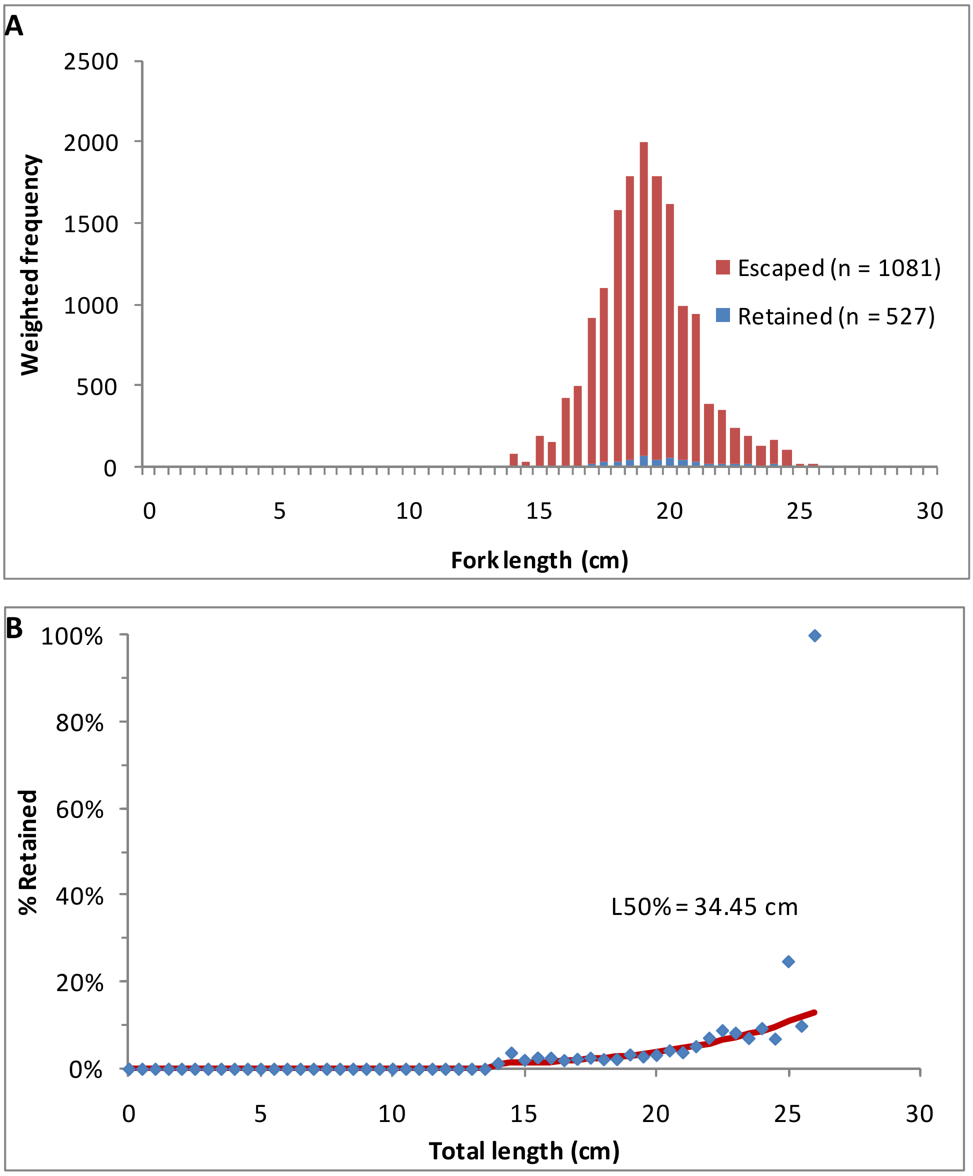


Figure 24. A. Length frequency distribution of Eastern School Whiting that were retained in the 75 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 75 mm Tiger Flathead codend for Eastern School Whiting. Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

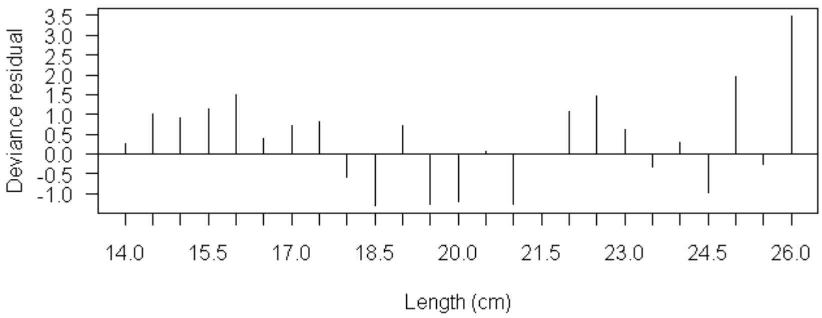


Figure 25. Plot of the deviance residuals from the selectivity ogive fit to Eastern School Whiting length frequencies from the 75 mm covered codend.

Table 12. Combined hauls fits to Eastern School Whiting data in the 75 mm covered codend catches.

Parameter	Estimate 75 mm
L_{25}	29.55 cm
L_{50}	34.45 cm
L_{75}	39.35 cm
SR	9.80 cm

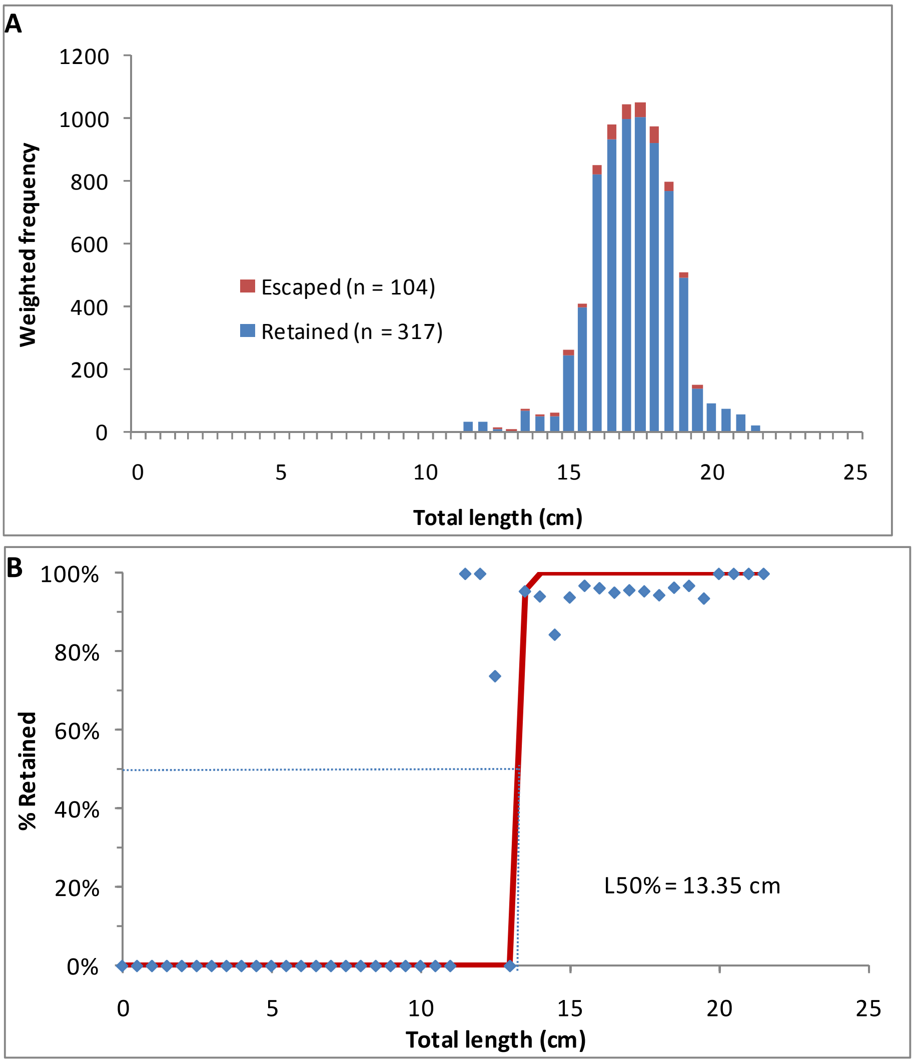


Figure 26. A. Length frequency distribution of Grooved Gurnard that were retained in the 75 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 75 mm Tiger Flathead codend for Grooved Gurnard . Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

Table 13. Combined hauls fits to Grooved Gurnard data in the 75 mm covered codend catches. Logistic curve fitted using Solver function.

Parameter	Estimate 75 mm
L_{25}	13.29 cm
L_{50}	13.35cm
L_{75}	13.40 cm
SR	0.11 cm

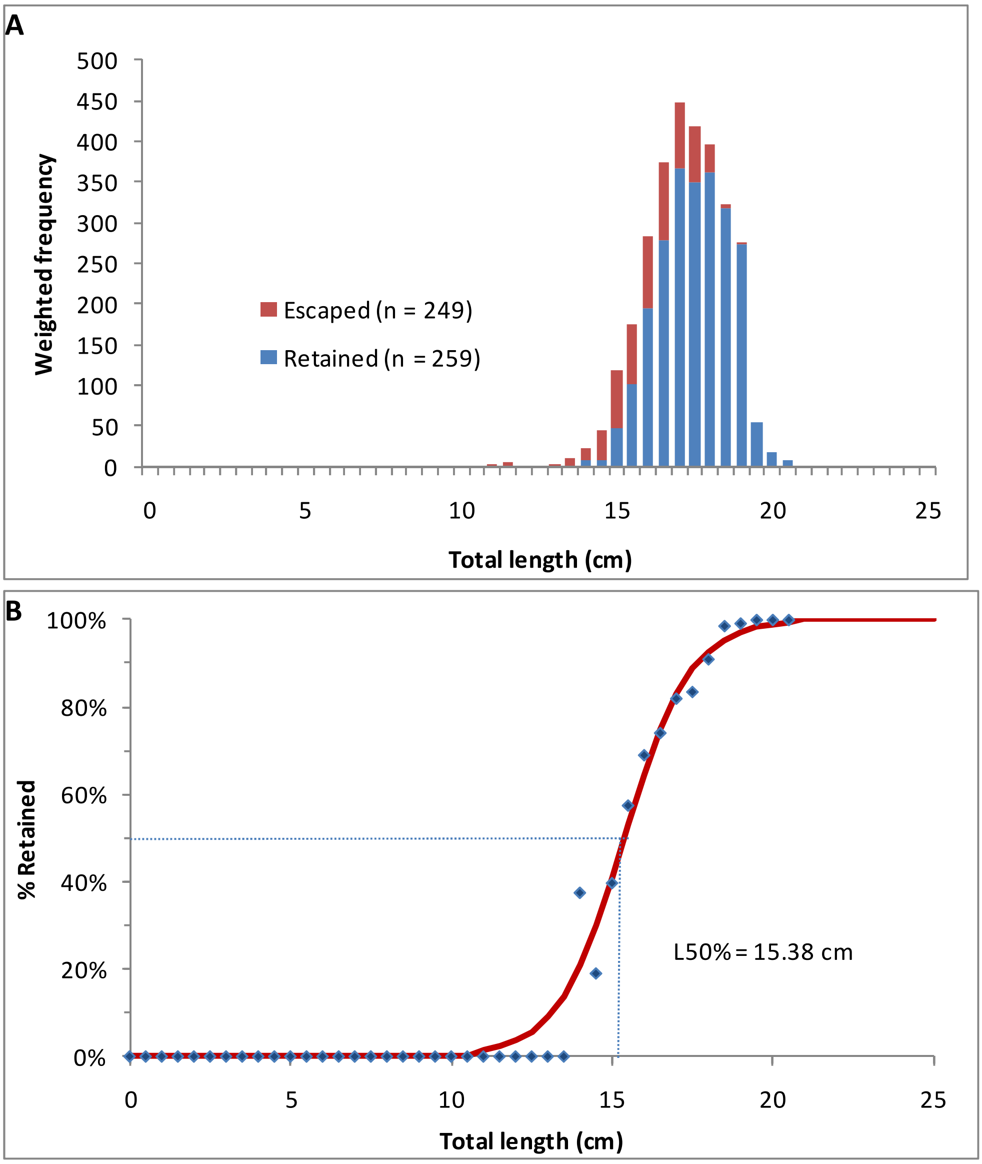


Figure 27. A. Length frequency distribution of Roundsnout Gurnard that were retained in the 65 mm Tiger Flathead codend and those that escaped into the 45 mm codend cover. B. Selectivity of the 65 mm Tiger Flathead codend for Roundsnout Gurnard . Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

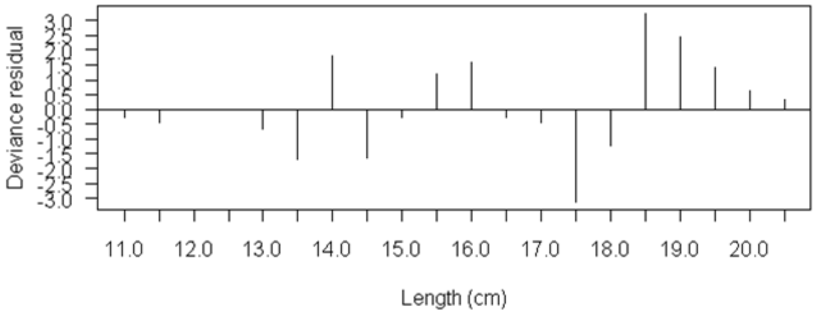


Figure 28. Plot of the deviance residuals from the selectivity ogive fit to Roundsnout Gurnard length frequencies from the 65 mm covered codend.

Table 14. Combined hauls fits to Roundsnout Gurnard data in the 65 mm covered codend catches. Logistic curve fitted using Solver function.

Parameter	Estimate 65 mm
L_{25}	14.24 cm
L_{50}	15.38cm
L_{75}	16.51 cm
SR	2.27 cm

Eastern School Whiting nets

The total catch in the 45 mm commercial Eastern School Whiting net and the 25 mm experimental net used for selectivity trials were 4,067 kg and 5,863 kg, respectively (Table 15), from an equal number of tows. Totals of 75.9% and 62.3% of catch weight from the 45 mm and 25 mm codends were retained (Figure 29). Eastern School Whiting, Tiger Flathead, Southern Bluespotted Flathead and Elephantfish comprised the greatest portions of the retained catch by both codends (Figure 30). While the 25 mm codend had a greater catch rate of Eastern School Whiting, they only comprised 50.1% of the catch from that codend compared to 64.9% of the catch by the 45 mm codend. Catch rate of discarded Tiger Flathead was significantly higher in the 25 mm codend (108.3 kg per shot) compared with the 45 mm codend (24.0 kg per shots). This suggests that a considerable quantity of small Tiger Flathead escape the 45 mm codend during normal fishing practices. Similarly, catch rates of discarded Barracouta, Southern Bluespotted Flathead and Sand Flathead (*Platycephalus bassensis*) were also much lower in the 45 mm codend (Figure 31). Overall, discarded commercial species comprised 3.0% of the catch weight in the 45 mm codend and 7.4% of the catch in the 25 mm codend. Nearly twice as much discarded catch were caught by the 25 mm codend as from the 45 mm codend (Figure 32**)**. This significant difference in discarded catch was due mostly to significantly larger catches of discarded Silverbelly, and larger (but non–significant) catches of Common Stinkfish and Roundsnout Gurnard by the 25 mm codend (Figure 33). There were no differences in catches of the physically larger main discard species (Sparsely-spotted Stingaree and Starry Toadfish [*Arothron firmamentum*]). This result suggests that differences in catch rates observed were not a result of differences in the efficiency of the two gears, but more probably due to the selective nature of the codends.

Koopman (2007) reported comparable quantities of Eastern School Whiting, Tiger Flathead and Sparsely-spotted Stingaree, but found a higher proportion of Barracouta and Silverbelly in the catches sampled throughout the year. Like the experiments using Tiger Flathead codends, shots using the Eastern School Whiting codend were conducted over a short time period (January–February), and did not capture the seasonal variability of the 2007 study.

Length distribution of Eastern School Whiting shows that the 25 mm codend caught more small (<16 cm) fish than the 45 mm codend (Figure 34). The small mesh codend also appeared to catch more fish

>20.5 cm; however, sample sizes at those lengths were very small. The most common length classes sampled in both nets were 16.0–17.5 cm. The logistic ogive estimated L_{50} of 15.63 cm (Figure 34 and Table 16). The curve fitted the data well at lengths less than 18 cm, after which the deviance residuals were quite high (Figure 35). The deviance however appears evenly distributed on both sides of the ogive.

L_{50} for Eastern School Whiting is about 1.5 cm smaller than that estimated by SS2 from stock assessments during 2007 (17.19 cm). Only limited sampling was conducted using the 25 mm codend because catches were so high, and created unsafe load on the vessels lifting equipment. These large catches in the 25 mm codend are likely to have affected the selective properties of the gear by helping fish avoid capture by assisting with a swimming escape caused by an increase in water pressure inside, and in front of the net (i.e. reduced flow through the net). The most recent estimate of L_{50} from the 2009 assessment (Day 2009) was even larger (17.5 cm for the Lakes Entrance fleet). It is clear that the length frequencies used in the SS2 model were different to those in the current study, with the modal length being about 2 cm greater in the observer data used in SS2. It is also recognised that the observer data did not include measurement of discarded fish. These two factors would have the effect of increasing L_{50} estimated by the model.

The 25 mm and 45 mm Eastern School Whiting codends both caught Tiger Flathead at a much smaller size than the 65 mm and 75 mm Tiger Flathead codends (Figure 36). Modal length in both of the Eastern School Whiting codends was 23 cm, and the bulk of the fish were less than 30 cm total length. In comparison, the 65 mm and 75 mm codends caught few fish less than 30 cm, and had modal lengths of 34 cm (Figure 19) and 36 cm (Figure 17) respectively. It is clear from the differences in length frequency distributions that the size of fish available for capture in the area where the Eastern School Whiting codends were used, were different to those where the Tiger Flathead codends were used. This difference is likely due to differences in depths fished when targeting the different species, and the size-dependent spatial distribution. More juvenile Tiger Flathead inhabit inshore areas, and they move into deeper offshore waters as they increase in size (Chen *et al.* 1998). Eastern School Whiting are usually targeted in depths <50 m, and nearly always in depths <100 m, while most Tiger Flathead are caught by Danish seine gear in depths ranging <50–200 m (Tilzey 1994). During this study, mean depths sampled using Eastern School Whiting and Tiger Flathead gears were 35 m and 71 m respectively. Length frequency distributions appeared similar between the 45 mm and 25 mm codends; however, the 25 mm codend caught considerably more fish across the size range observed. This difference in catch is highlighted by the efficiency parameters estimated for each haul as a part of the model fitting procedure. Efficiencies for the 45 mm codend ranged 0.31–0.43 (mean 0.37). The logistic selectivity curve fitted well to the data; however, the low efficiency of the 45 mm codend makes the logistic curve appear well above plotted data. The curve is relatively flat with SR of 10.99 cm and L_{50} of 24.51 cm (Figure 36 and Table 17). Deviance residuals are evenly distributed on either side of the curve, and are very tight for lengths less than 34 cm (Figure 37). Despite the apparent good fit, standard errors around the parameter estimates are high (Table 17), and so the estimates should be used with caution.

The length frequency distribution of Common Stinkfish was smaller in the 25 mm codend compared to the 45 mm codend (Figure 38). Samples from the smaller codend ranged 12.5–23.5 cm with a mode of 18 cm, and ranged 16.5 cm–26 cm with a modal length of 20.5 cm in the larger codend. It is unclear why the 25 cm codend did not catch Common Stinkfish greater than 23.5 cm. Sample sizes were small in that size range (2–3 fish per size class) from the 45 mm codend, and sampling of this species was restricted to one tow with each net. The logistic curve appeared to fit the data well (Figure 38 and Figure 39). Parameters of the logistic models are shown in Table 18. The efficiency parameter for Common Stinkfish of the 45 mm codend was 0.56.

Table 15. Total catch weight (kg), mean catch (kg), standard error and % of total catch by 45 mm and 25 mm codends.

	45 mm codend (3 shots)				25 mm codend (3 shots)			
	Total catch (kg)	Mean (kg)	SE	%	Total catch (kg)	Mean (kg)	SE	%
Retained commercial								
Eastern School Whiting	2640	880.0	176.9	64.9	2940	980.0	389.7	50.1
Tiger Flathead	165	55.0	30.1	4.1	265	88.3	39.2	4.5
Southern Bluespotted Flathead	120	40.0	15.0	3.0	205	68.3	31.9	3.5
Elephantfish	60	20.0	20.0	1.5	100	33.3	33.3	1.7
Sand Flathead	55	18.3	1.7	1.4	90	30.0	10.4	1.5
Longsnout Boarfish	12	4.0	3.1	0.3	15	5.0	5.0	0.3
Other finfish	8	2.7	1.2	0.2	16	5.3	2.8	0.3
Other Elasmobranchs	23	7.7	2.6	0.6	6	2.0	2.0	0.1
Total retained fish	**3083**	**1027.7**	131.1	**75.8**	**3637**	**1212.3**	438.2	**62.0**
Cephalopods	4	1.3	1.3	0.1	11	3.7	1.2	0.2
Crustaceans	1	0.3	0.3	0.0	2	0.7	0.7	0.0
Total retained Invertebrates	**5**	**1.7**	1.7	**0.1**	**13**	**4.3**	1.9	**0.2**
Total retained catch	**3088**	**1029.3**	130.5	**75.9**	**3650**	**1216.7**	440.0	**62.3**
Discarded commercial								
Tiger Flathead	72	24.0	8.3	1.8	325	108.3	20.9	5.5
Barracouta	26	8.7	8.2	0.6	30	10.0	10.0	0.5
Southern Bluespotted Flathead	11	3.7	1.7	0.3	37	12.3	8.9	0.6
Sand Flathead	11	3.7	1.2	0.3	27	9.0	5.6	0.5
Southern Sawshark	2	0.7	0.7	0.0	10	3.3	3.3	0.2
Greenback Flounder	0.5	0.2	0.2	0.0	4	1.3	0.3	0.1
Other Finfish	0.5	0.2	0.2	0.0	1.5	0.5	0.3	0.0
Other Elasmobranchs	0	0.0	0.0	0.0	2	0.7	0.7	0.0
Total discarded commercial fish	**123**	**41.0**	15.7	**3.0**	**436.5**	**145.5**	32.7	**7.4**
Cephalopods	1	0.3	0.3	0.0	0	0.0	0.0	0.0
Total discarded commercial invertebrates	**1**	**0.3**	0.3	**0.0**	**0**	**0.0**	0.0	**0.0**
Total discarded commercials	**124**	**41.3**	15.6	**3.0**	**436.5**	**145.5**	32.7	**7.4**
Discarded non-commercial								
Common Stinkfish	455	151.7	101.5	11.2	900	300.0	151.0	15.4
Roundsnout Gurnard	62	20.7	19.7	1.5	275	91.7	39.0	4.7
Sparsely-spotted Stingaree	155	51.7	20.9	3.8	135	45.0	17.6	2.3
Silverbelly	53	17.7	5.0	1.3	210	70.0	5.8	3.6
Starry Toadfish	31	10.3	7.4	0.8	40	13.3	8.4	0.7
Southern Fiddler Ray	12	4.0	2.0	0.3	41	13.7	1.3	0.7
Spiny Pipehorse	0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Other finfish	19.2	6.4	1.3	0.5	46	15.3	5.0	0.8
Other Elasmobranchs	49	16.3	0.7	1.2	80	26.7	12.3	1.4
Total discarded non-commercial fish	**836.2**	**278.7**	99.9	**20.6**	**1727.1**	**575.7**	222.3	**29.5**
Other molluscs	5	1.7	1.7	0.1	0	0.0	0.0	0.0
Crustaceans	7	2.3	1.9	0.2	0	0.0	0.0	0.0
Sponge	7	2.3	2.3	0.2	49	16.3	12.1	0.8
Total discarded non-commercial invertebrates	**19**	**6.3**	3.8	**0.5**	**49**	**16.3**	12.1	**0.8**
Total discarded non-commercials	**855.2**	**285.1**	99.0	**21.0**	**1776.1**	**592.0**	214.7	**30.3**
Total discarded fish	**959.2**	**319.7**	115.5	**23.6**	**2163.6**	**721.2**	221.6	**36.9**
Total discarded invertebrates	**20**	**6.7**	3.5	**0.5**	**49**	**16.3**	12.1	**0.8**
Total discards	**979.2**	**326.4**	114.4	**24.1**	**2212.6**	**737.5**	212.6	**37.7**
Total catch	**4067.2**	**1355.7**	121.8	**100**	**5862.6**	**1954.2**	641.1	**100**

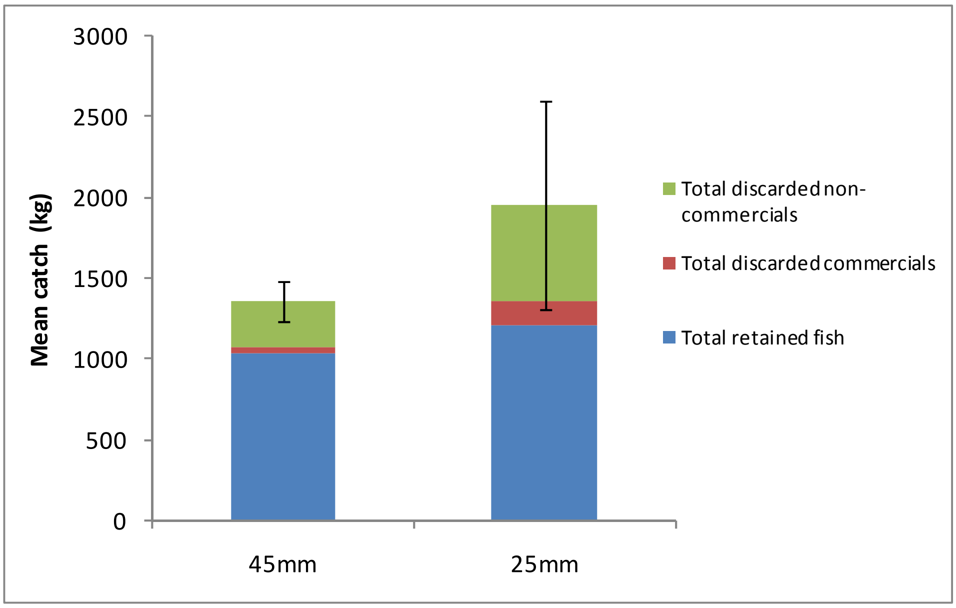


Figure 29. Mean total catch rates (+ SE) by the 45 mm and 25 mm codends.

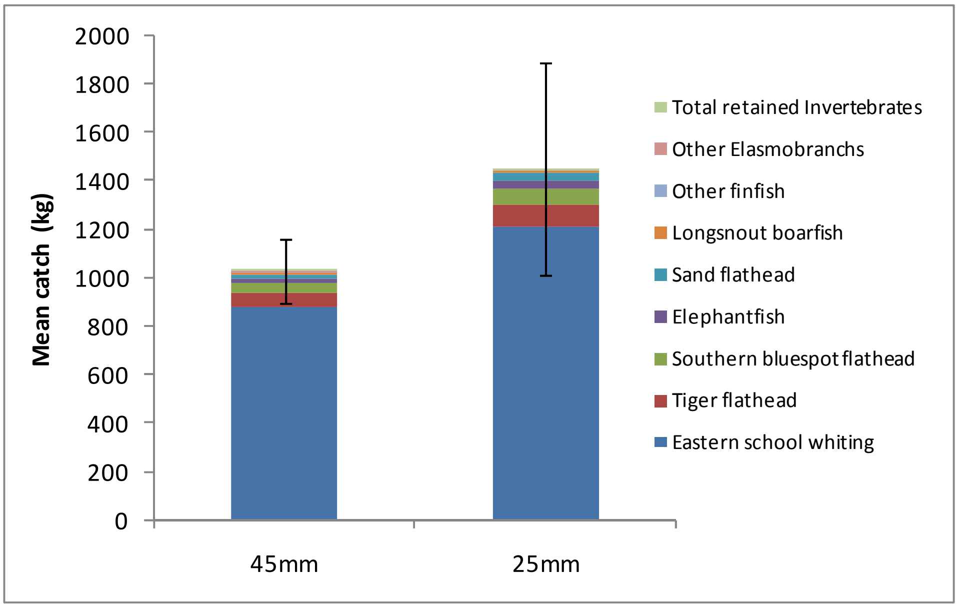


Figure 30. Mean retained catch rates (+ SE) by the 45 mm and 25 mm codends.

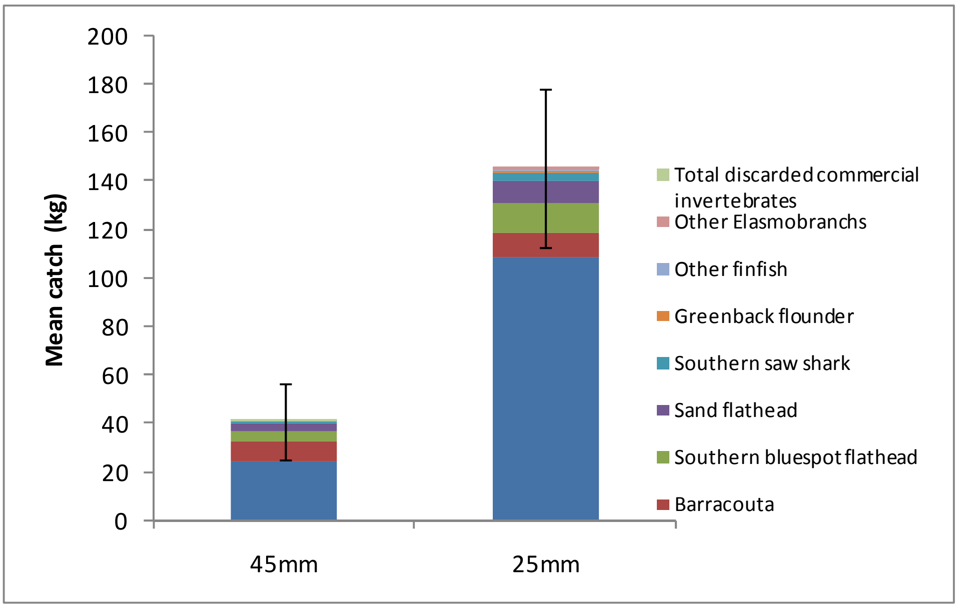


Figure 31. Mean discarded commercial species catch rates (+ SE) by the 45 mm and 25 mm codends.

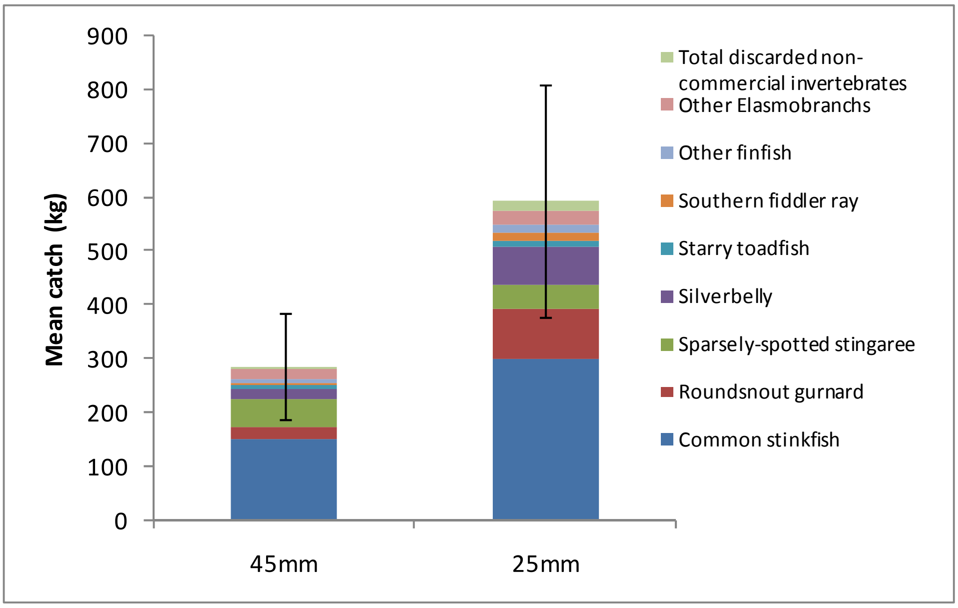


Figure 32. Mean discarded non-commercial species catch rates (+ SE) by the 45 mm and 25 mm codends.

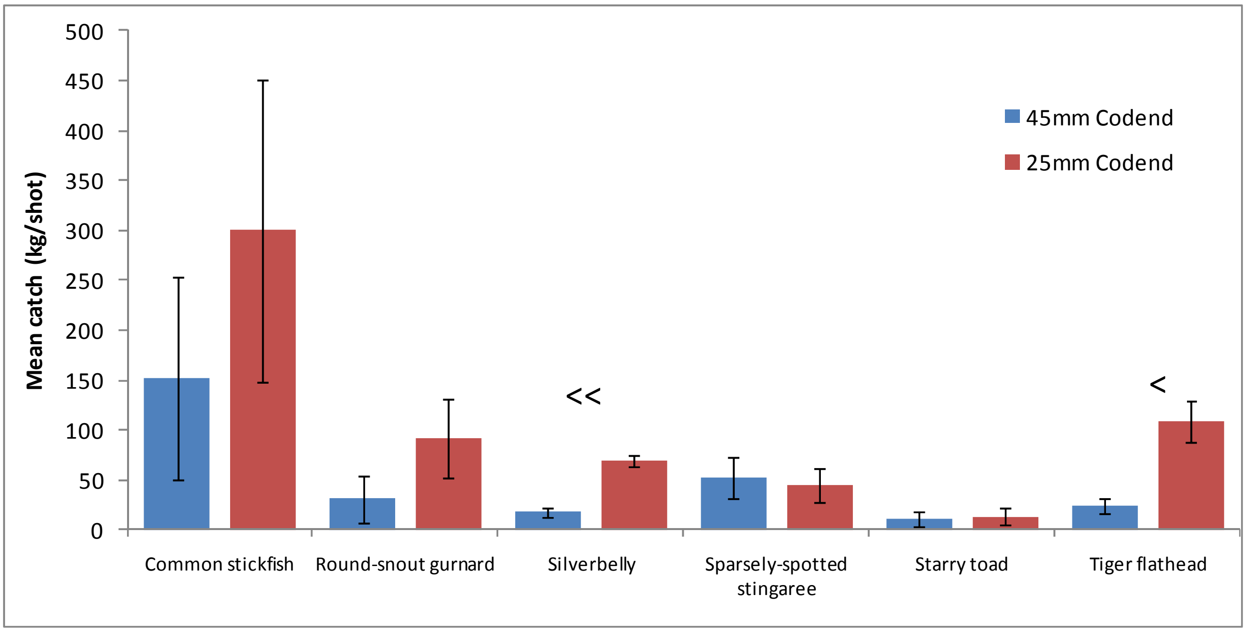


Figure 33. Comparison of mean catch weight per shot (kg/shot + SE) of main discard species between 45 mm and 25 mm Eastern School Whiting codends. Significance and direction of differences are indicated by < (significant at p<0.05) and << (significant at p<0.001).

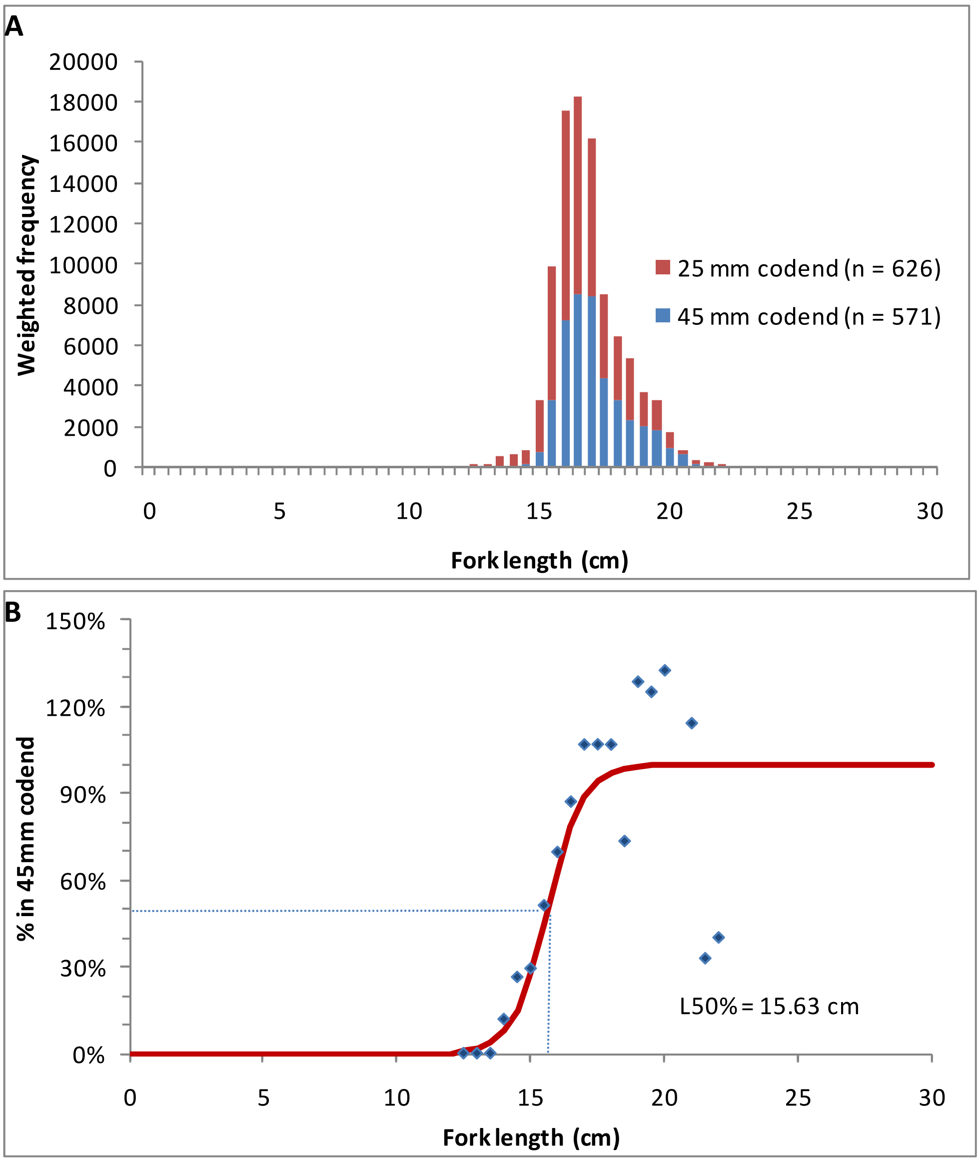


Figure 34. A. Length frequency distribution of Eastern School Whiting that were retained in the 45 mm and 25 mm Eastern School Whiting codends. B. Selectivity of the 45 mm Eastern School Whiting codend for Eastern School Whiting. Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

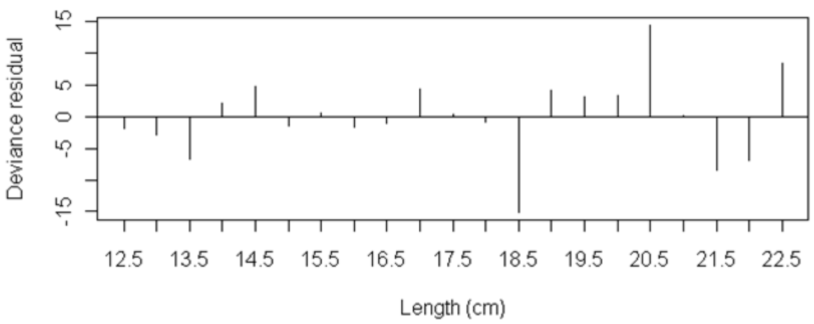


Figure 35. Plot of the deviance residuals from the selectivity ogive fit to Eastern School Whiting length frequencies from the 45 mm codend.

Table 16. Combined hauls fits to catches of Eastern School Whiting by the 45 mm codend.

Parameter	Estimate	S.E.
REP	126.95	
L_{25}	14.91 cm	0.27
L_{50}	15.63 cm	0.29
L_{75}	16.35 cm	0.45
SR	1.45 cm	0.47

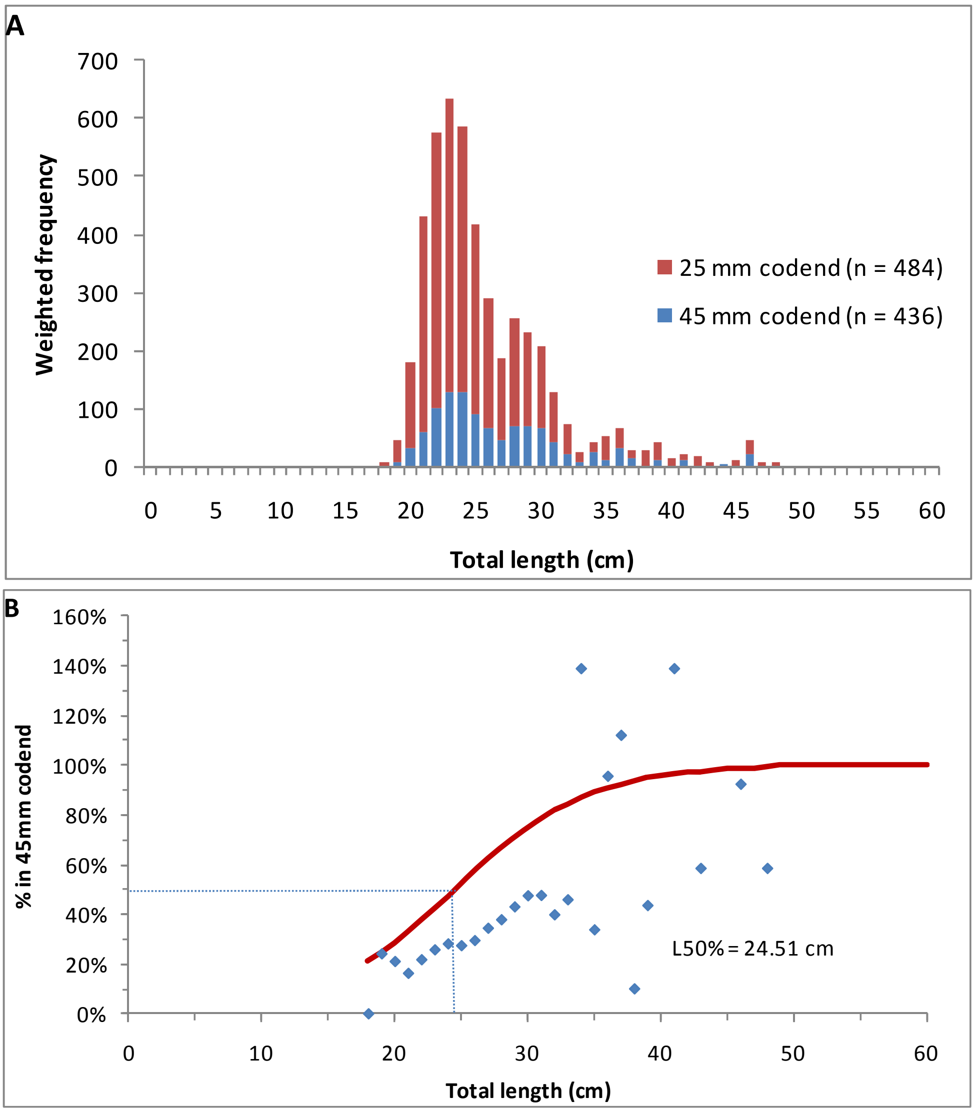


Figure 36. A. Length frequency distribution of Tiger Flathead that were retained in the 45 mm and 25 mm Eastern School Whiting codends. B. Selectivity of the 45 mm Eastern School Whiting codend for Tiger Flathead. Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

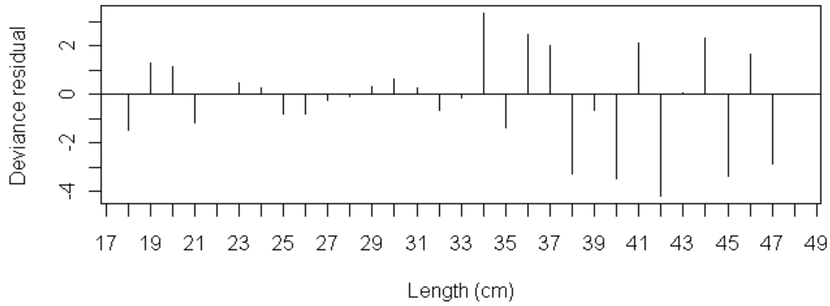


Figure 37. Plot of the deviance residuals from the selectivity ogive fit to Tiger Flathead length frequencies from the 45 mm codend.

Table 17. Combined hauls fits to catches of Tiger Flathead by the 45 mm codend.

Parameter	Estimate	S.E.
REP	6.427	
L_{25}	19.01 cm	2.32
L_{50}	24.51 cm	4.14
L_{75}	30.00 cm	7.16
SR	10.99 cm	6.68

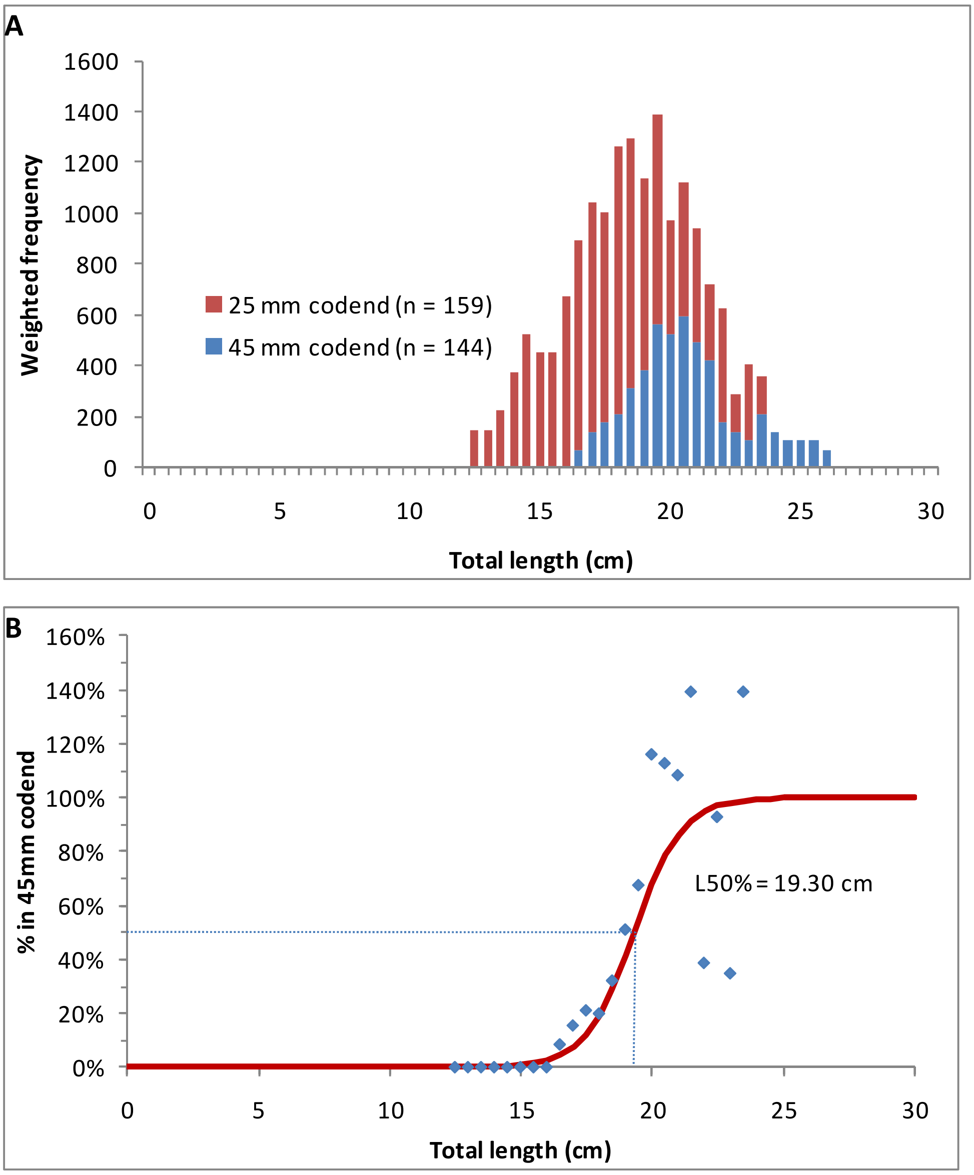


Figure 38. A. Length frequency distribution of Common Stinkfish that were retained in the 45 mm and 25 mm Eastern School Whiting codends. B. Selectivity of the 45 mm Eastern School Whiting codend for Common Stinkfish. Each point (♦) marks the % retained at a given 0.5 cm length class and the line (—) represents the estimated logistic selectivity curve.

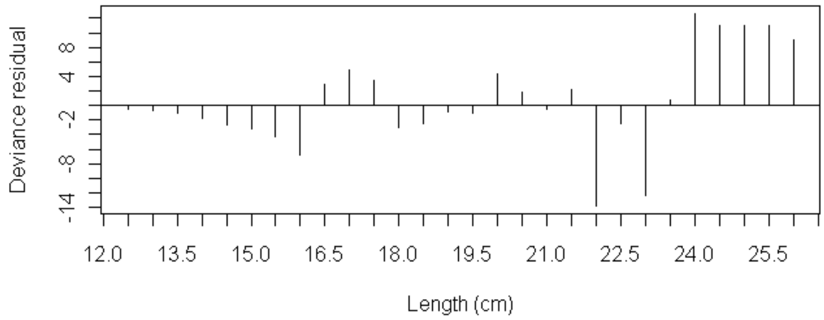


Figure 39. Plot of the deviance residuals from the selectivity ogive fit to Common Stinkfish length frequencies from the 45 mm codend.

Table 18. Combined hauls fits to catches of Common Stinkfish by the 45 mm codend.

Parameter	Estimate	S.E.
L_{25}	18.30 cm	0.07
L_{50}	19.30 cm	0.09
L_{75}	20.31 cm	0.12
SR	2.01 cm	0.07

Interactions with Threatented, Endangered or Protected Species

Six Spiny Pipehorse (Figure 40) were the only TEP species caught during these experiments. Of these, three were found in the codend cover, and one in each of the 75 mm, 65 mm and 25 mm codends. The presence of Spiny Pipehorse in the codend cover shows that they do escape through codends used during commercial fishing. The small numbers caught limit analysis and conclusions that can be made from these data, but mean catch rates over the entire project are presented and discussed in the Gear Modification section.

Figure 40. Spiny Pipehorse caught during selectivity experiments.

Observations of fish behaviour

Critical in planning gear modifications with the aim of reducing bycatch in trawl fisheries is obtaining information on the behaviour of fish in the net. The behaviour of fish in response to a trawl net can influence selection (Wardle 1989), and this information can be used to target specific areas of the net for modification, and assists in determining effective modification types. Video recorders housed in water proof casings are often used for *in situ* observations (e.g. Rose 1993; Walsh and William 1993; Glass and Wardle 1995, Bublitz 1996, Piasente *et al.* 2004; Krag *et al.* 2009). Imagery can then be reviewed and the behaviour of fish observed categorised and quantified (Castro *et al.* 1992; Thomsen 1993; Bublitz 1996).

General description of the Danish seine shot and behaviour of fish in the net

Danish seine shots are usually completed in 70 minutes from the time the net is deployed, to the time it is hauled back over the side of the vessel (Figure 41). This may be slightly shorter or longer depending on the depth of water fished. During this time, there are three distinct phases in the behaviour of the codend, and fish moving into it: 1) setting, 2) towing, and 3) retrieval.

The setting phase of the Danish seine trawl is of much longer duration than for an otter trawl. For the first ~45 minutes of the shot (including the net sinking to the sea floor), the codend moves very slowly through the water as the tow ropes and wings of the net are let out and begin to be drawn together. The shoulders and wings of the net are vertically flat for the first 15 minutes of the tow, before becoming concaved as the net starts to move. The codend remains quite limp during this time, with folds appearing along the length of the codend (Figure 42a). The meshes remain wide open during this phase, and very few fish enter the codend. The lack of fish moving into the net is caused by the lack of forward movement of the net and consequent lack of water flow. Species of Triglidae move into the codend during this phase in small numbers by either swimming slowly towards the codend, or drifting back at rest. They can be seen in the shoulder of the net swimming in the same direction as the net, or resting on the bottom meshes. Other small fish and sea jellies also begin to enter the codend. Fish in the codend behave calmly as there is little interaction between individuals due to the large space available.

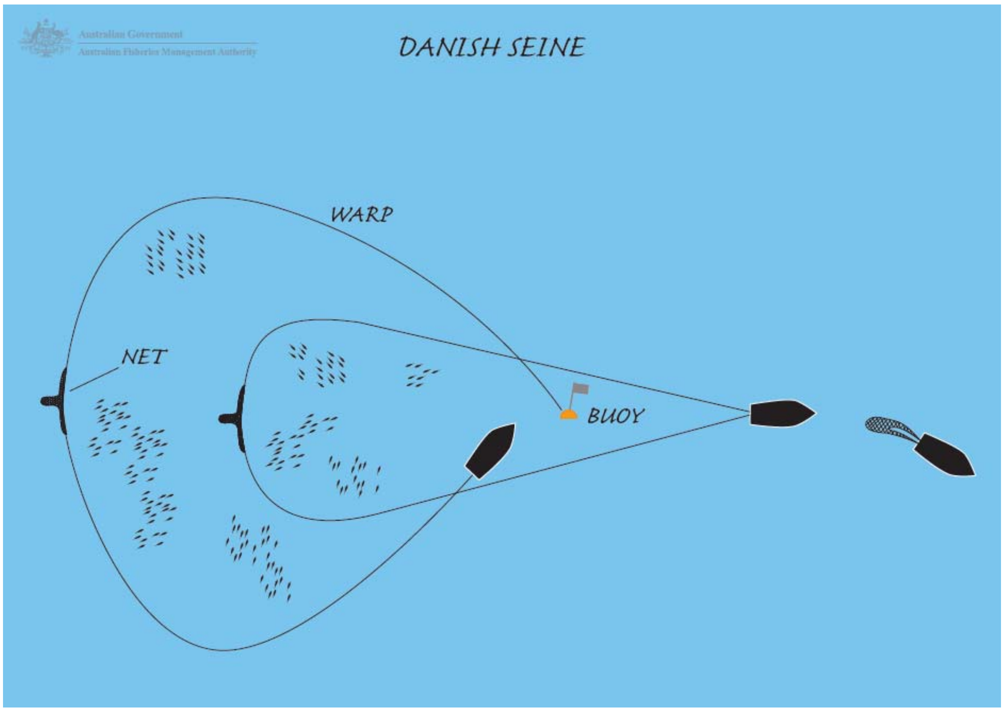


Figure 41. Operation of Danish seine gear from when the net is set to just before hauling. Reproduced from Australian Fisheries Management Authority website (http://www.afma.gov.au).

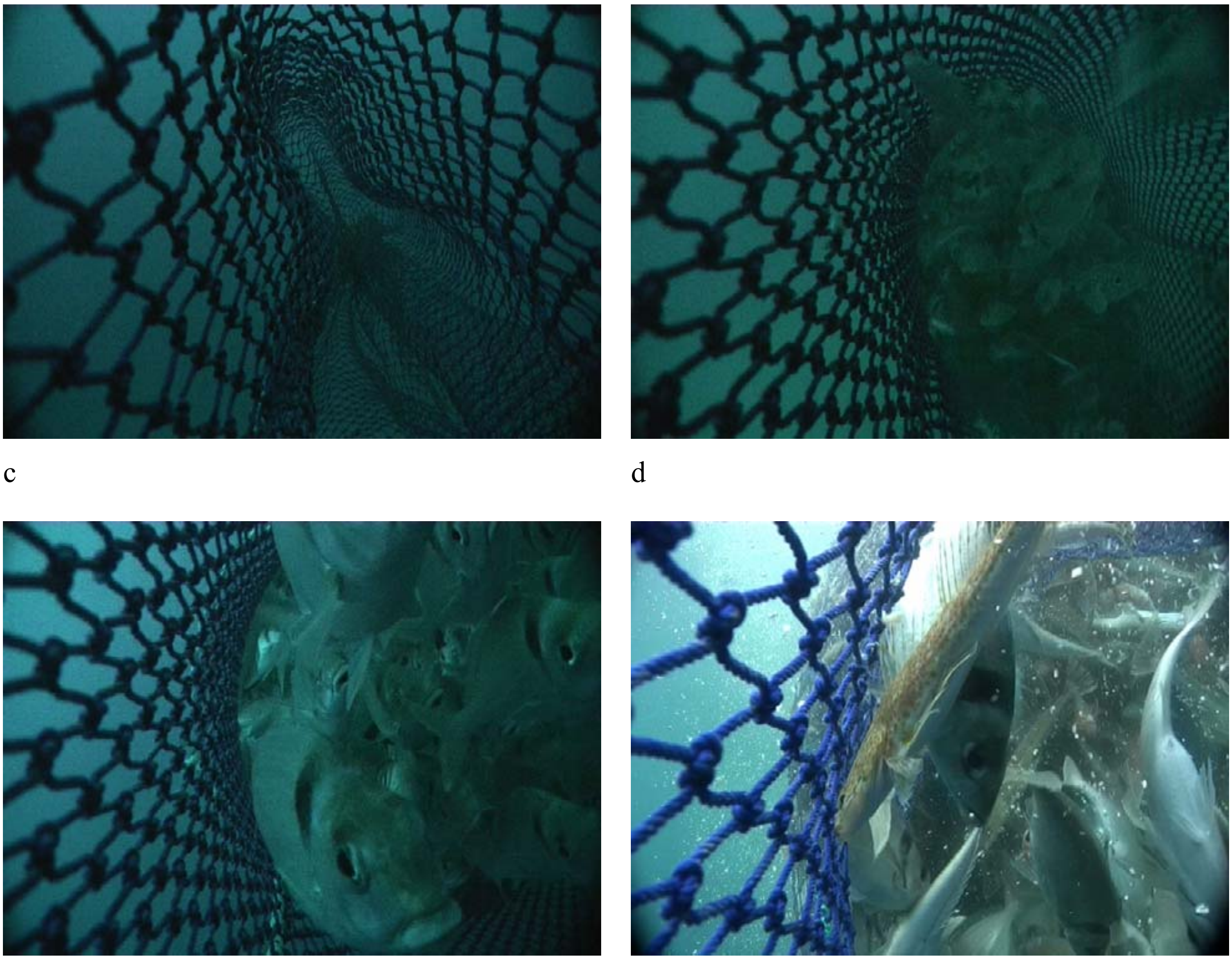
The towing phase begins about 45 minutes after the codend hits the water, and is characterised by an increase in water flow, and the regularity of fish entering the codend. During this stage the wings of the net are bowed over, and are being pulled forwards, but also towards the opposite wing. Not many fish were observed hitting the mesh in the wing, but rather they were herded back into the net. Most of the sponge encountered escaped under the foot rope. In the shoulder of the net, fish are seen resting on the bottom meshes, or swimming in the same direction as the net before being over-run. Demersal species swim within a metre of the sea floor in the shoulder, while pelagic species school at all levels. Fish entering the codend are often swimming in the same direction as the codend, being over-run by the net. Activity in the codend increases and as it fills up, the codend becomes tort with no folds in the net and stretched meshes (Figure 42b). Fish at the back of the codend become restricted in movement, and the amount of restriction increases as the codend fills.

As the retrieval phase begins, the wings begin to lift off the sea floor allowing more sponge to escape under the net. After about 65 minutes, fish have stopped entering the net apart from a few fish that were caught in higher sections of the net. The footline in the shoulder comes off the seafloor at about 67 minutes. The net is tight and meshes fully stretched because of the pressure of being hauled in, and the weight of the fish in the codend. If Jackass Morwong are present in the net, they school in front of the fish that are bunched in the codend, and often swim with the net right up until a minute or two before being hauled onboard (Figure 42c). After about 70 minutes, the codend is on the surface (Figure 42d), and usually hauled onboard within 2 or 3 minutes.

Tiger Flathead

Tiger Flathead observed in underwater footage from the wings were mostly swimming with a steady tail in the towing direction. In front of the wings they generally swam very close to the sea floor, and rarely touched the meshes. Tiger Flathead were observed to go under the foot line as they tired and were over-run while still swimming in the tow direction. They also swam steadily in the tow direction when in the shoulder of the net, and were also observed to rest on bottom meshes in that section. Movement towards the codend was usually a result of the fish swimming slower than the net. Physical interaction with other individuals was rare in the shoulder of the net and Tiger Flathead behaviour was generally steady as opposed to erratic.

a b



c d

Figure 42. Screen clips of a typical Danish seine shot after a) 35 minutes, b) 57 minutes, c) 68 minutes and d) 71 minutes.

A total of 546 Tiger Flathead were observed responding to the Danish seine codend. Tiger Flathead were mostly observed entering the codend swimming in the tow direction slower than the tow, swimming opposite to the tow direction, or while at rest drifting back towards the codend (Figure 43). In the codend, the most common behaviour (22%) observed was swimming in the tow direction at the same speed as the tow. The presence of a pressure wave forward of the codend possibly assists fish to maintain speed, and Tiger Flathead were commonly seen swimming in the tow direction quicker than the tow. In contrast, only about 5% of observations of Tiger Flathead behaviour recorded by Piasente *et al.* (2004) in the codend of otter trawl nets were cruise swimming in the same direction and speed as the tow. The different behaviours may be due to the faster speed and longer duration of an otter trawl tow. Both of these factors would reduce the ability to swim at the same speed as the net once in the codend. Early during the towing phase of the shot, Tiger Flathead were often observed resting on the bottom panel of the codend before being contacted by other individuals and reacting in a burst event. Similar behaviour was observed by Yanase *et al.* (2009) and Piasente *et al.* (2004) who also noted that after contact was made, the burst events usually resulted in contact with the side or upper panels. As the codend begins to fill, and physical contact with other individuals increase, behaviour becomes more erratic and burst events become more common. By far the most common burst event was random in direction, striking the net. This often resulted in escape through the mesh. Few Tiger Flathead were observed to become impinged in the mesh. However, as fish become tired and other fish begin to clutter the codend, Tiger Flathead at the rear of the codend become impinged against the net or between other individuals. Low numbers of Tiger Flathead were observed as impinged as these fish were usually obscured from view.

Of the 22 Tiger Flathead that were observed escaping, 61% escaped through side panels, 22% through the top panel and 17% through the bottom panel. These should not be treated as an indication of average direction of escape because the number of observations depends largely on the positioning of the video camera. Observation of escapement from all sides is an important qualitative result.

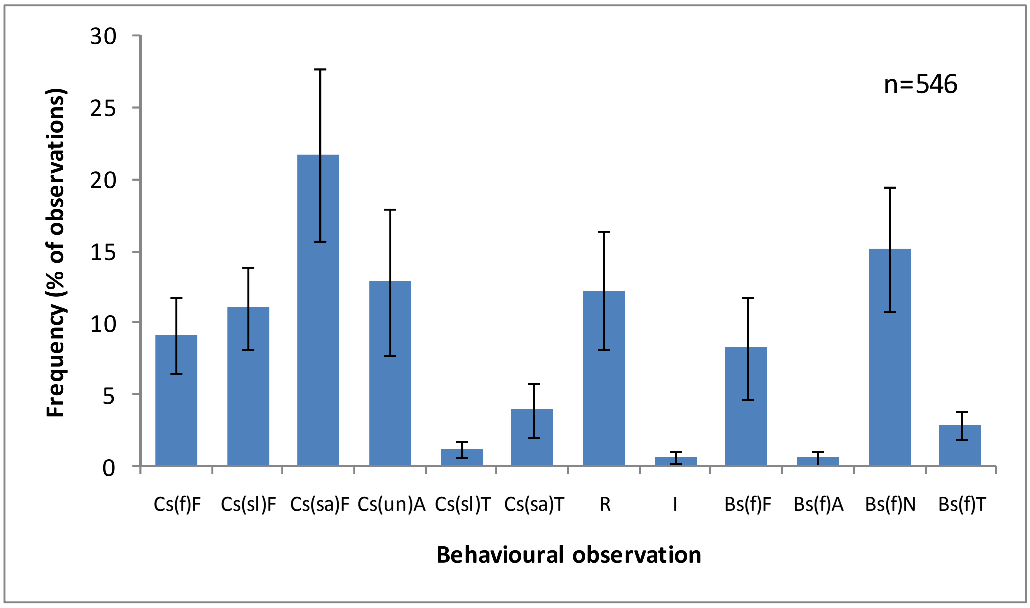


Figure 43. Summary of behavioural results from *in situ* camera observations of Tiger Flathead. Data are the proportions of the behavioural categories + S.E. See Table 5 for definition of behavioural categories.

Main bycatch species

Identification of Blacktip Cucumberfish was difficult because of their small size and their similar profile to other common species (e.g. Eastern School Whiting). Despite this, 47 observations of behaviour were recorded from the codend (Figure 44). Blacktip Cucumberfish usually entered the codend while swimming in the same direction, but at a slower speed than the codend, but also by swimming in the opposite direction to the net, or at rest drifting back towards the codend (Figure 45). All burst responses observed resulted in contact with the net. Of the 11 Blacktip Cucumberfish observed escaping the codend, 64% escaped through the side panel, while 36% escaped through the top panel. Because of their shape and small size, Blacktip Cucumberfish had very little trouble escaping the codend, especially while meshes were not stretched tight.

Jackass Morwong were easily identifiable because of their characteristic shape and black mark behind the head. A total of 97 behavioural observations were made for that species (Figure 46). Jackass Morwong usually entered the codend by swimming either in the same direction as, but slower than the tow, or by swimming directly into the codend. Once in the codend they were regularly observed swimming in the direction of, and at the same speed as the tow. This was particularly evident towards the end of the tow, when most of the other fish were 'consumed' by the accumulating catch at the back of the codend; Jackass Morwong schooled up in front of the mass of fish where they often remained until the net neared the surface. This was the dominant behaviour in the codend, and the same was observed in the codend of otter trawls by Piasente *et al.* (2004). Burst responses were occasionally observed after contact with another individual, and these sometimes resulted in contact with the net.

Silverbelly were easily identifiable in the codend because of their distinctive shape. They are a schooling species that were observed swimming within 0.5 m of the bottom in the shoulder of the net, in the same direction of the net. Loose schools formed in the shoulder about 50 minutes into the tow and lasted about 10 minutes (Figure 47) before the fish were overrun, and moved back towards the codend facing the same direction as the net. A total of 46 behavioural observations were recorded in the codend (Figure 48). Silverbelly most frequently entered the codend by swimming in the same direction as the net, but at a slower speed, or by swimming directly into the codend. Once in the codend they would often swim in the same direction as the net and at the same speed. Burst behaviours were frequently observed in the codend, and often resulted in escape. Most escapes occurred through the side panels, while some were observed through the top panels.

Species differentiation of the Family Triglidae was difficult from underwater video footage, and so they were grouped at the family level. Family Triglidae were usually the first species to enter the codend, and were also observed early in the shot swimming with, or resting on the shoulder of the net. They appeared to have little stamina and were quickly over-run either while swimming in the same direction as the net, or by turning and drifting or swimming back into the net. Family Triglidae entered the codend either by swimming in the same direction, but slower than the net, swimming directly into the codend, or drifting back into the codend while at rest. As was observed in the shoulder of the net, they were also observed resting on the bottom panel of the codend. Burst behaviours were commonly observed in the codend in response to contact with another individual, and these were mostly in the opposite direction to the net, and often resulted in contact with the net. Despite numerous records of behavioural observations, few escape events were observed for Family Triglidae. The shape of these fish and their numerous spiny protrusions, particularly those on the snout, inhibit escape. Their ability to escape is further reduced by three behavioural characteristics (Figure 49a). The first of these is the lack of speed when swimming in the direction of the net when they contact the net. They were frequently observed drifting or gliding into the net. With no speed, they were unlikely to make much penetration through the mesh, even if they avoided contact with the net by their rostral spines. Secondly, they usually approached the net at an angle that was far from perpendicular to the net. Combined with the relatively large head shape, this means that the head usually contacts the mesh before the snout is through the mesh. Thirdly, and this is probably related to the first point, they react to contact with the mesh by ceasing forward movement and turning away from the mesh. In comparison, Tiger Flathead often approach the mesh at an angle close to perpendicular, and once the snout is through the mesh, display burst swimming to push their body through the mesh. Family Triglidae were frequently observed contacting the top panels of the codend, but escapes were observed equally on the side and top panels (Figure 49b).

Stingarees (Family Urolophidae) were also grouped into Family level because of difficulty with identification to species level from the video footage. A total of 265 observations were made of stingaree behaviour in the codend (Figure 52). Stingarees were observed swimming in front of the wings close to the sea floor, apparently in response to the approaching nets. Movement was generally in the direction of the codend. Stingarees usually approached the codend either by being over-run, swimming in the same direction as the tow, but at a slower speed, or by swimming directly into the codend. Once in the codend, they were often observed swimming in the same direction and at the same speed as the codend. Stingarees often rested on the bottom panels of the net (Figure 51) where they attempted to use suction to maintain their position. This usually only lasted a minute of two, before water pressure caused them to lift off the net and fall back into the codend. Burst behaviours resulting in contact with the net were observed, but did not result in escape.

Eastern School Whiting were not identified in the codend, and so behaviours were not quantified for this species. Video from the mouth of the net shows Eastern School Whiting moving into the net in dispersed schools at a range of distances from the sea floor. Eastern School Whiting entered the net by swimming directly into it, or by being over-run while swimming in the same direction as, but slower than the net (Figure 53).

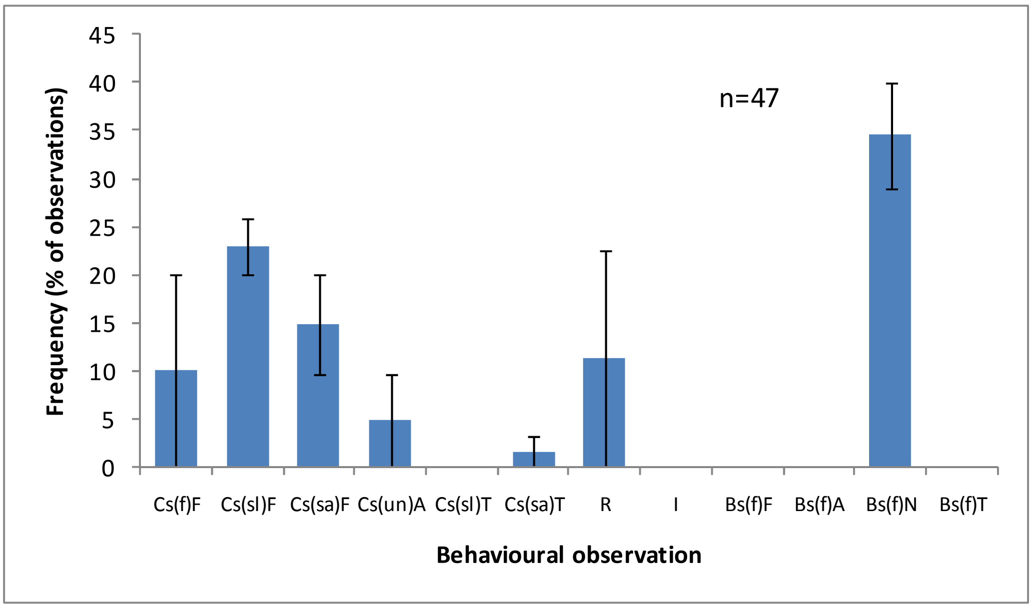


Figure 44. Summary of behavioural results from in situ camera observations of Blacktip Cucumberfish. Data are the proportions of the behavioural categories + S.E. See Table 5 for definition of behavioural categories.

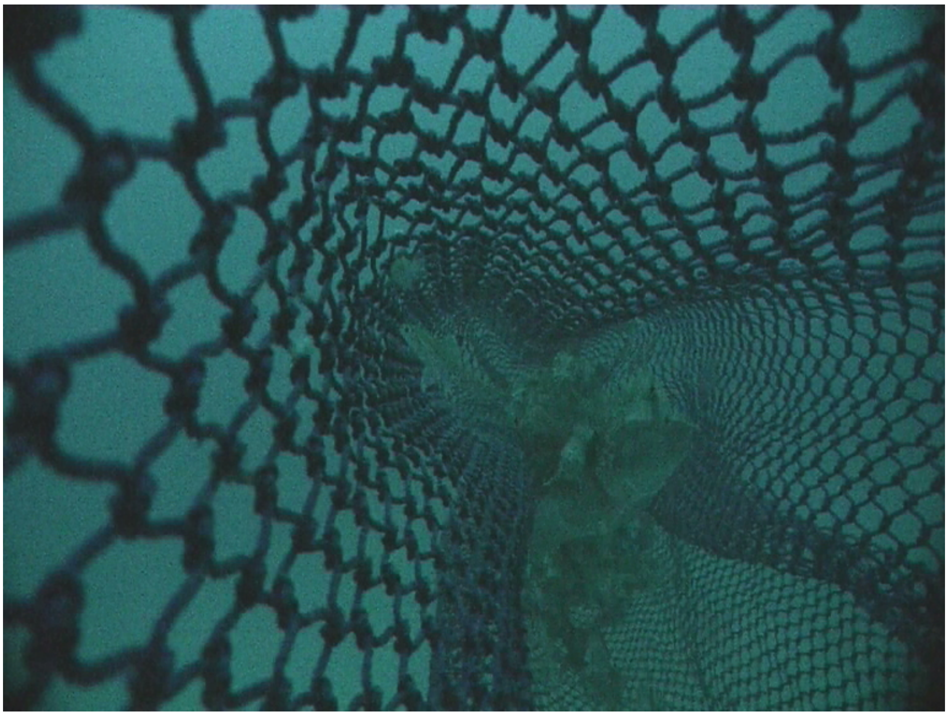


Figure 45. Blacktip Cucumberfish at rest drifting into the net just prior to escape through the side panel of the codend.

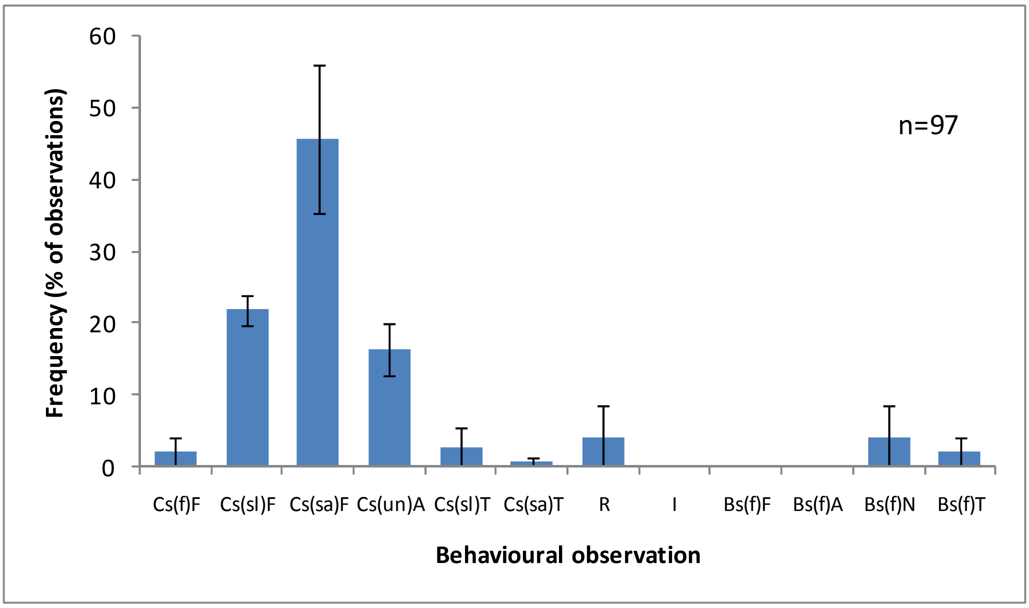


Figure 46. Summary of behavioural results from in situ camera observations of Jackass Morwong. Data are the proportions of the behavioural categories + S.E. See Table 5 for definition of behavioural categories.

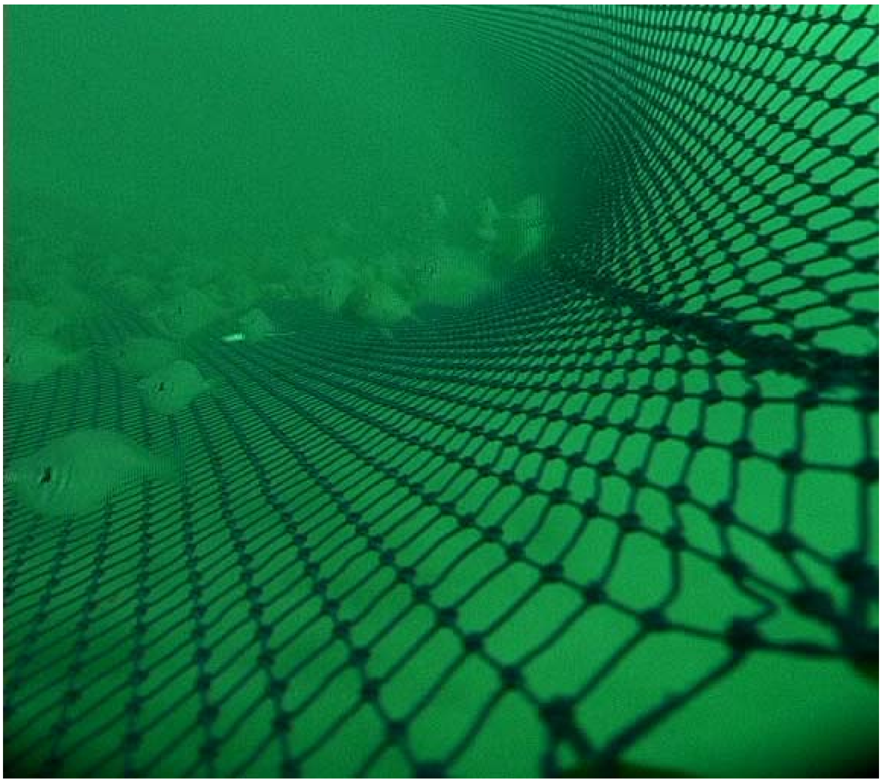


Figure 47. Silverbelly forming a loose school in the shoulder of the net.

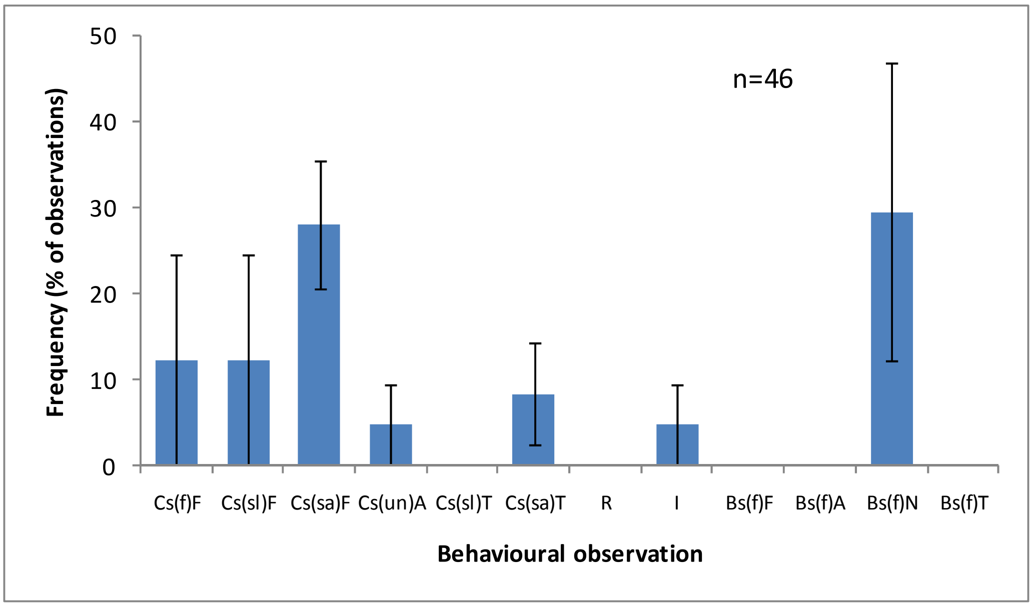


Figure 48. Summary of behavioural results from *in situ* camera observations of Silverbelly. Data are the proportions of the behavioural categories + S.E. See Table 5 for definition of behavioural categories.

a b

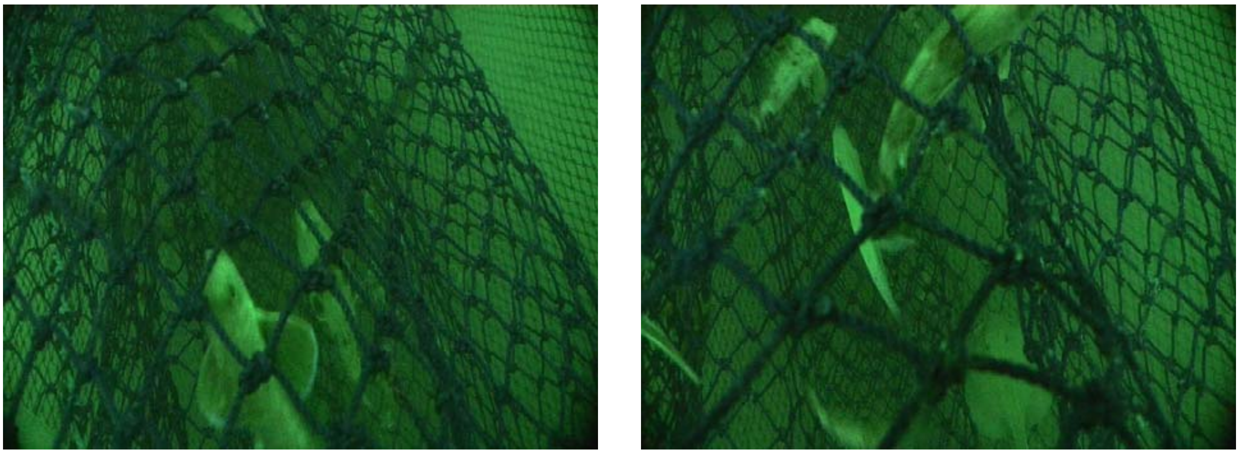


Figure 49. Family Triglidae showing a) a typical 'failed escape attempt' due to low angle of approach, lack of forward momentum, rostrum spines getting caught on mesh, and 'shying' away after contact with the mesh, and b) escaping from the codend.

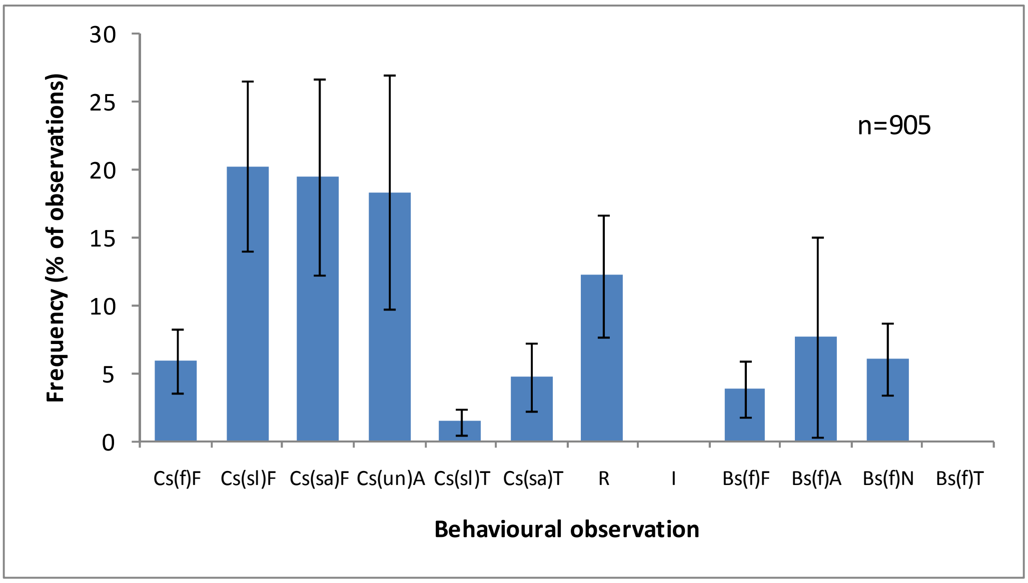


Figure 50. Summary of behavioural results from *in situ* camera observations of family Triglidae. Data are the proportions of the behavioural categories + S.E. See Table 5 for definition of behavioural categories.

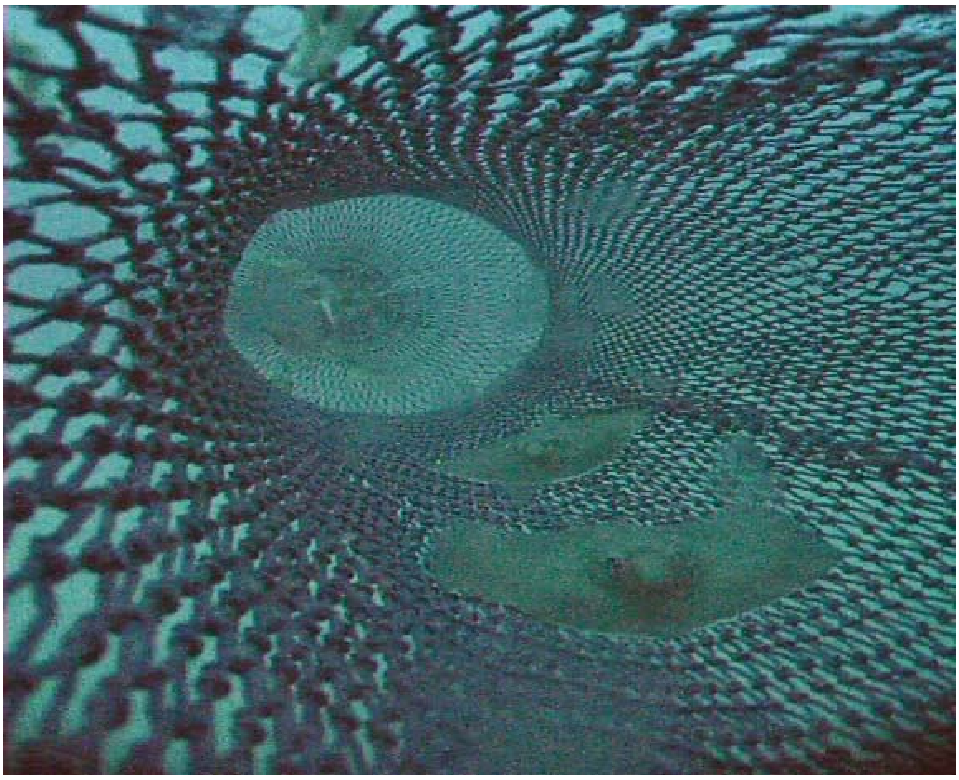


Figure 51. Two stingarees at rest on the bottom panels of the codend.

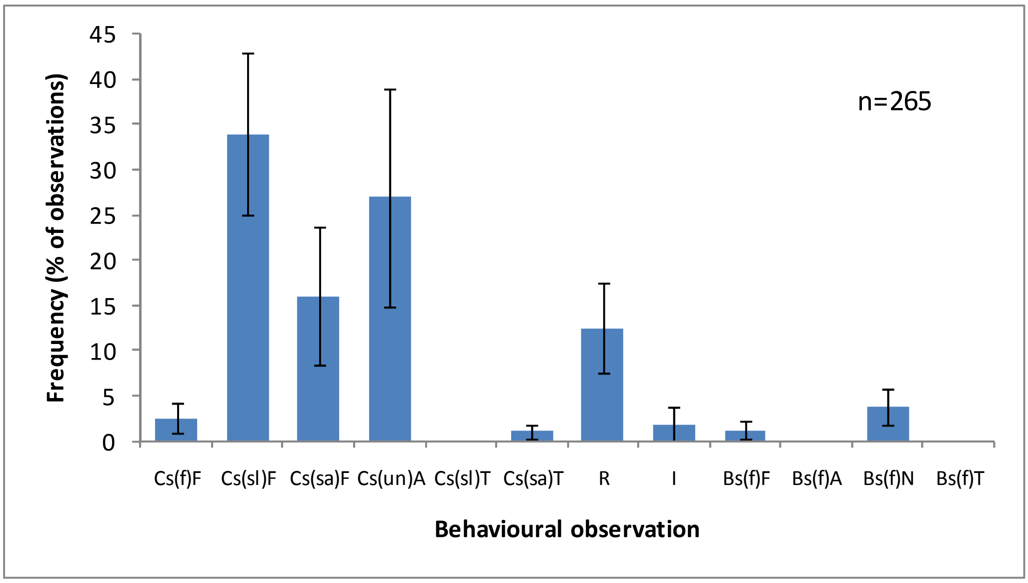


Figure 52. Summary of behavioural results from *in situ* camera observations of stingarees. Data are the proportions of the behavioural categories + S.E. See Table 5 for definition of behavioural categories.

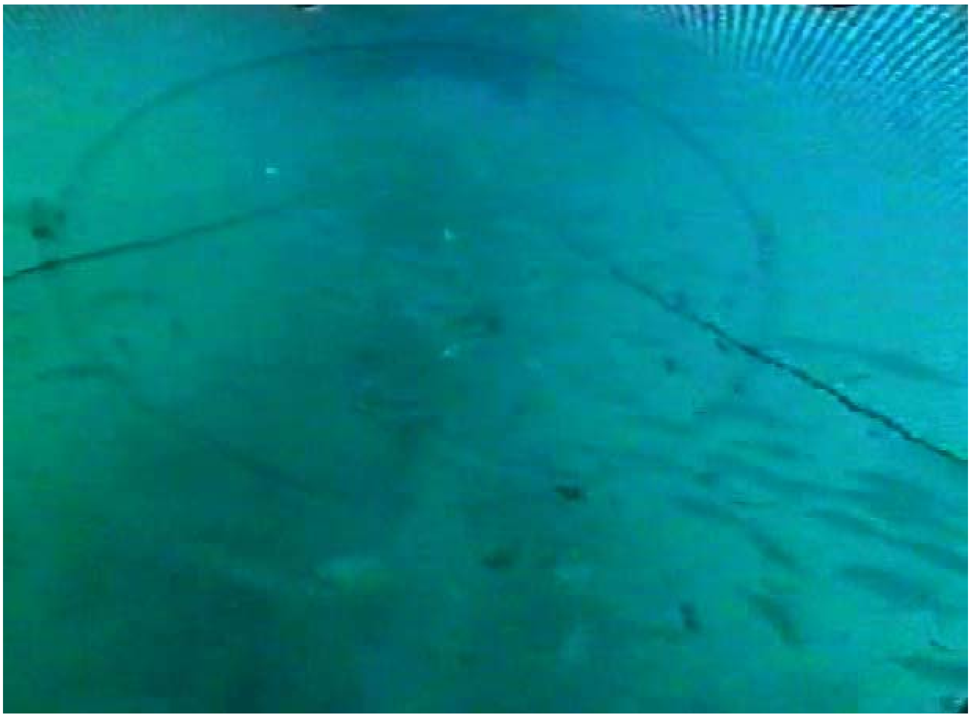


Figure 53. Eastern School Whiting entering the codend in a loose school. Most of the fish are facing into the codend (video by Crispian Ashby).

Gear modifications

The main bycatch species observed in Danish seine catches during selectivity trials in this study were stingarees and small non-commercial teleosts (Table 7, Table 8 and Table 15). Options for reducing bycatch of stingrays and stingarees usually involve the placement of a sorting grid inside the net to direct the large, unwanted species through bottom escape vents. Given the small size and flexibility of stingarees caught by Danish seine gear, it is unlikely that such grids would be successful. It appeared that the best option for reducing discards was to target small teleosts. Behavioural observation from the underwater video camera revealed that members of the Family Triglidae often make contact with the net in the codend; escape success was reduced by the rostral spines, or the head which is large in proportion to the rest of the body. One commonly caught member of this family, Grooved Gurnard, showed very little change in selectivity over the size range observed (Figure 26), while another, Roundsnout Gurnard, showed a very clear pattern of selectivity (Figure 27). Another major bycatch species, Blacktip Cucumberfish have little trouble escaping the codend, but still reveal some size selection (e.g. Figure 20), apparently as a result of mesh size. It is clear that increasing the size of mesh openings in the codend would benefit at least Blacktip Cucumberfish and Roundsnout Gurnard and may also benefit Grooved Gurnard. Other small non-commercial teleosts that might benefit from larger mesh openings include Barred Grubfish and Silverbelly.

Observations of the behaviour of the mesh in Danish seine gear showed that the vertical height of mesh openings reduced greatly under pressure (due to forward movement of the net and drag caused by the net and the catch in the net). Simply increasing mesh size to reduce bycatch did not seem appropriate for this fishery as it would likely reduce profitability. It has been shown that Tiger Flathead are caught at a size that is greater than that which would provide the maximum VPR, and any increase in L_{50} would lead to a lower VPR. The L_{50} is greater than the minimum legal length, and low discarding of Tiger Flathead is observed when targeting that species. Because Tiger Flathead are relatively dorso-ventrally flattened, any increases in stretched mesh diameter would directly affect L_{50} and may reduce profitability in the fishery. For example, it was shown that the difference in L_{50} between 65 mm and 75 mm mesh was more than 3 cm total length. In addition, such a change would still result in mesh that closes vertical height under pressure, still restricting escape of other species. One way of increasing the vertical height without increasing stretched mesh width is by rotating the mesh by 90 degrees (T90).

Published studies examining bycatch reduction in Danish seine fisheries are uncommon. Spingle (2001) tested increased mesh size, and square mesh codends to reduce catches of small Witch Flounder (*Glyptocephalus cynoglossus*) off Newfoundland. He found that using square mesh resulted in reduced catches of the less desirable, smaller fish; however, using diamond mesh of increased size, produced considerably smaller catches because it allowed small, but marketable fish to escape. In this case, diamond shaped mesh increased opportunities for escape because the target species is dorso-ventrally flattened. Roberton and Stewart (1988) also examined the effect of increasing mesh size and using square mesh in Danish seine gear to reduce the catch of small commercial species in the trawl fishery off Scotland. They found that selection ranges of haddock were narrower in square mesh codends than in diamond codends, but were similar for whiting. They also found that increasing mesh size of either square or diamond codends increased L_{50}.

T90 gear

An increasingly common trend in bycatch reduction in otter trawl fisheries is to use mesh that has been rotated 90 degrees, called T90. Rotating trawl mesh causes the knots to hold open the mesh wider (Figure 54), and was originally designed to stabilise the codend and improve the quality of the catch (Moderhak, 2000a; Digre *et al.* 2006). It was found, however, that it had the added benefit of allowing smaller fish to escape (Hansen 2006). Meshes turned 90 degrees have also been shown to have greater resistance to tensile force than standard mesh (Moderhak 2000b), which has clear implications for profitability. T90 nets have been trialled successfully in otter trawl gears internationally (e.g. Digre *et al.* 2006; Hansen 2006), and in Australia, in the Great Australian Bight (Knuckey *et al.* 2008). Knuckey *et al.* (2008) found that in comparison to the standard trawl net, the T90 net caught significantly less high discard species such as sponge, Barracouta, Spikey Dogfish, Australian Burrfish, Jack Mackerel, Rusty Carpetshark, and Sergeant Baker.

In the current project, T90 trials were carried out during February–May 2009. The first phase of sampling (February) examined the selectivity of the T90 net using covered codend experiments, while the second phase concentrated on comparing catch rates, catch composition and size composition between the 75 mm control codend, and the T90 codend using alternate hauls. Throughout the T90 trials, the use of the 75 mm control and T90 codends were alternated, so that data from all shots were used to compare catch rates, catch composition and size composition, but only data sampled during February was used for selectivity estimates.

Diamond mesh T90 mesh

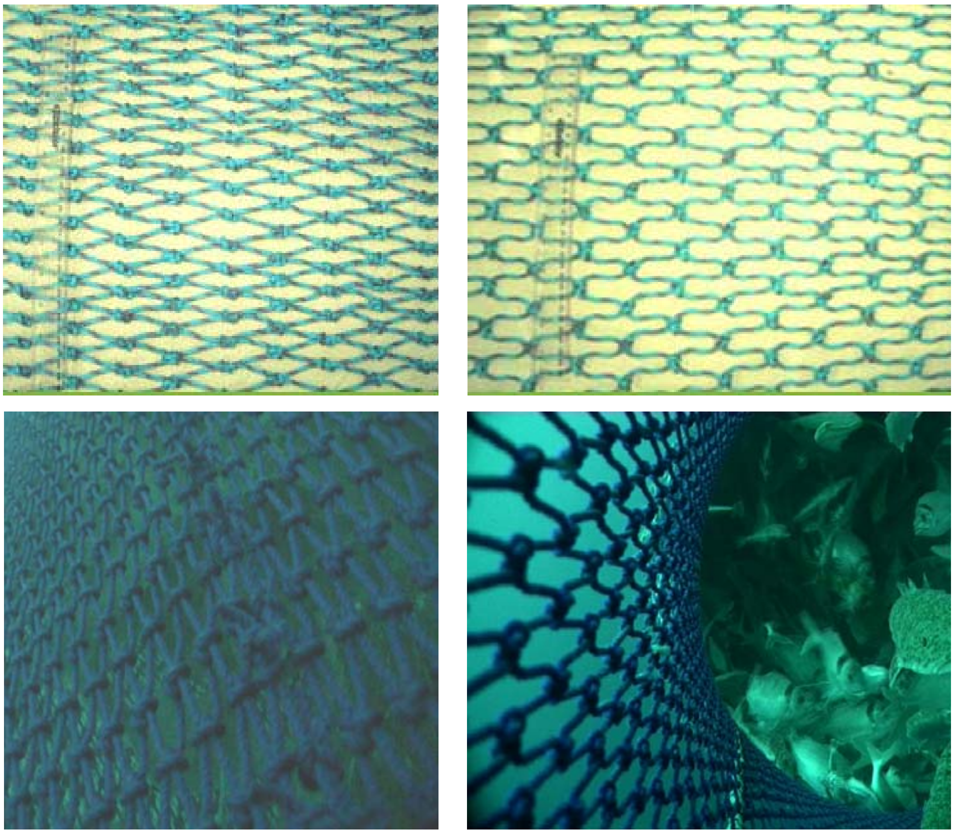


Figure 54. Comparison of diamond and T90 mesh in and out of the water. Out of water images supplied by OceanWatch Australia (http://www.oceanwatch.org.au/OWA-SeaNet-VIC-T90.htm).

Catch composition

Mean total catch per shot was significantly greater using the 75 mm control codend (701 kg) than using the T90 codend (591 kg), with the main difference being in the catch of discarded non-commercial species (Figure 55 and Table 19). Main components of the total catch were discarded non-commercial species and retained species, while discarded commercial species only made up a very small fraction of the total catch. The difference in total catches was due to significantly higher catch rates of discarded non-commercial species by the 75 mm control codend (387 kg) than the T90 codend (284 kg) (Figure 56). Catch rates of retained species were nearly identical (Figure 57), however the percentage of the total catch comprising retained weight was 52% for the T90 codend compared to 44% for the 75 mm control codend (Table 19). Catch rates of discarded commercial species were about twice as high (not significant) by the 75 mm codend (5.4 kg) as the T90 codend (2.6 kg) (Figure 58).

Catch rates of main retained species were similar between 75 mm control and T90 codends (Figure 59). Tiger Flathead catch rates were slightly higher (not significant) in the T90 codend. Catch of Jackass Morwong was higher (but not significantly) in the 75 mm control codend, while catch rates of Southern Sawshark and Common Sawshark were almost identical between codends.

Catch rates of commercial discard species were not analysed because of their small values. Highest mean catch rate was only 1.1 kg per shot for Tiger Flathead (Figure 58). Other main commercial discard species were Southern Sawshark, Ocean Jacket, Jackass Morwong, Red Gurnard, and Gummy Shark (*Mustelus antarcticus*).

Main discarded non-commercial species were Sparsely-spotted Stingaree (95.3 kg per shot in control codend and 73.0 kg per shot in T90 codend), Roundsnout Gurnard (85.4 kg per shot and 40.2 kg per shot) and Grooved Gurnard (69.7 kg per shot and 38.4 kg per shot). Difference in catch rates were not significant for Sparsely-spotted Stingaree, but were significantly greater in the control codend than the T90 codend for Roundsnout Gurnard and Grooved Gurnard (Figure 60). No difference was expected for Sparsely-spotted Stingaree because the large size and disc shape prohibits escape through codend meshes. Any escape by that species would need to occur before entry into the codend. The 53% and 45% reductions in captures of Roundsnout Gurnard and Grooved Gurnard were encouraging, and they were largely responsible for the 27% reduction in overall catch rates of discarded non-commercial species in the T90 codend. Only very small quantities of Blacktip Cucumberfish — one of the main discard species during selectivity trials (Table 9) — were caught during trials of the T90 net. It is likely that they too would have benefitted greatly from the increased mesh opening, and more readily escaped.

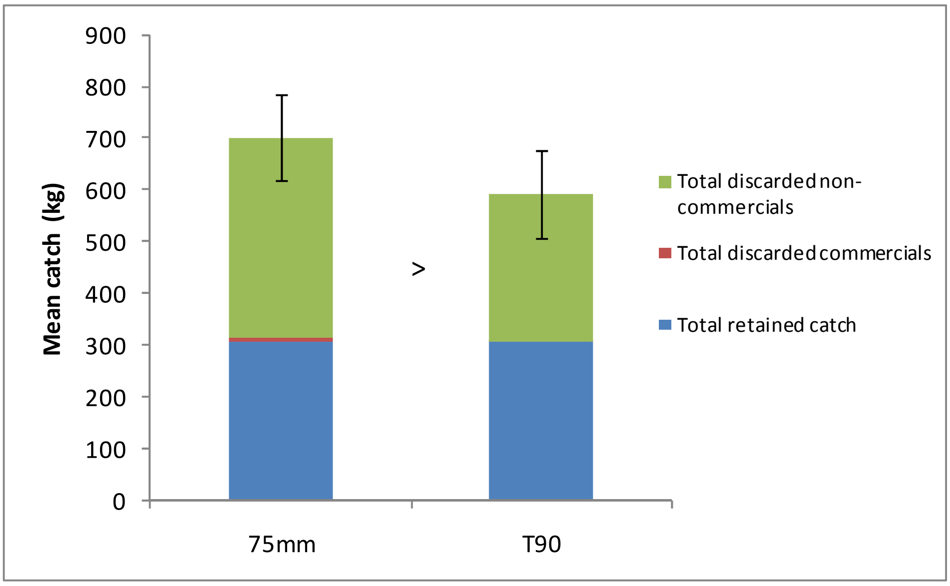


Figure 55. Mean total catch rates (+ SE) by the 75 mm control codend and the T90 codend. > indicates significant difference.

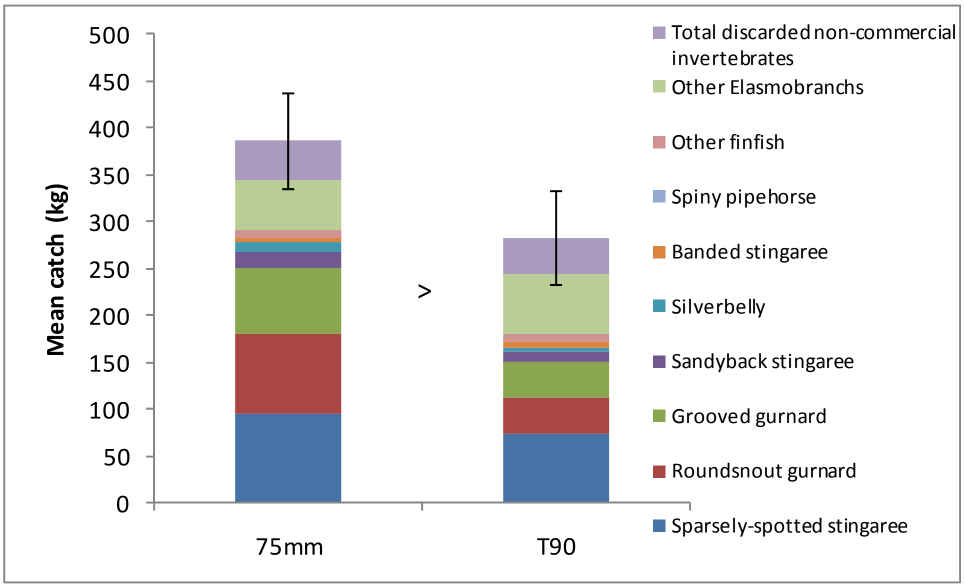


Figure 56. Mean discarded non-commercial species catch rates (+ SE) by the 75 mm control codend and the T90 codend. > indicates significant difference.

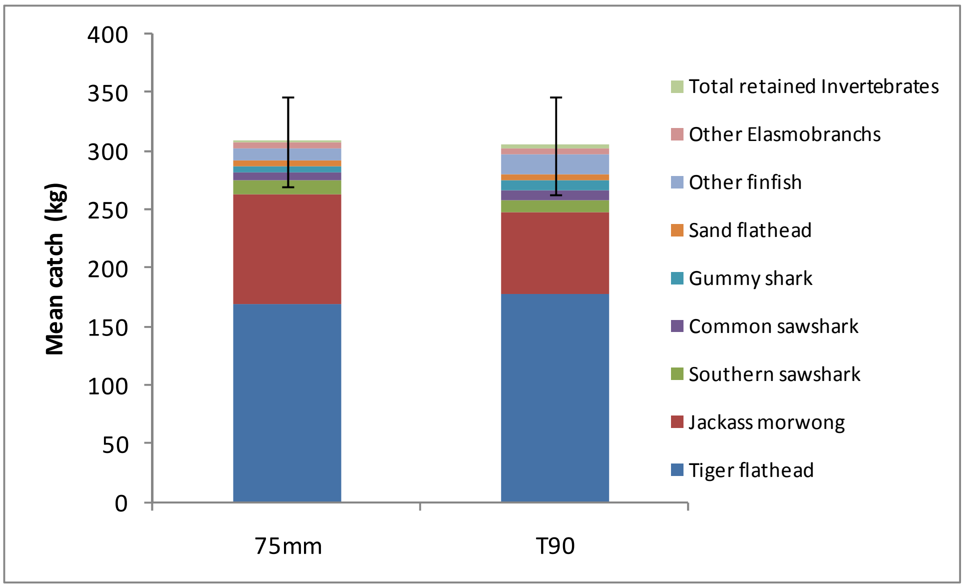


Figure 57. Mean retained catch rates (+ SE) by the 75 mm control codend and the T90 codend.

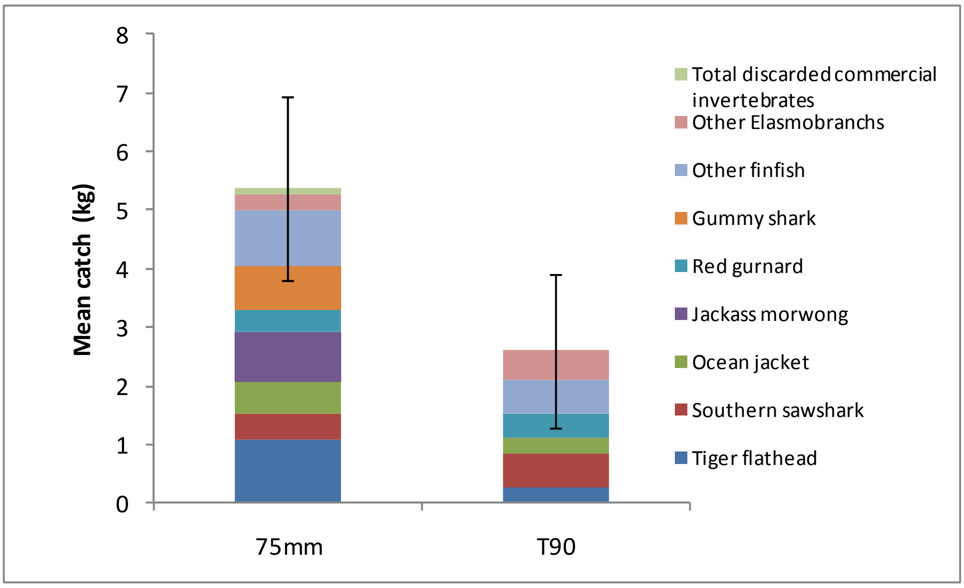


Figure 58. Mean discarded commercial species catch rates (+ SE) by the 75 mm control codend and the T90 codend.

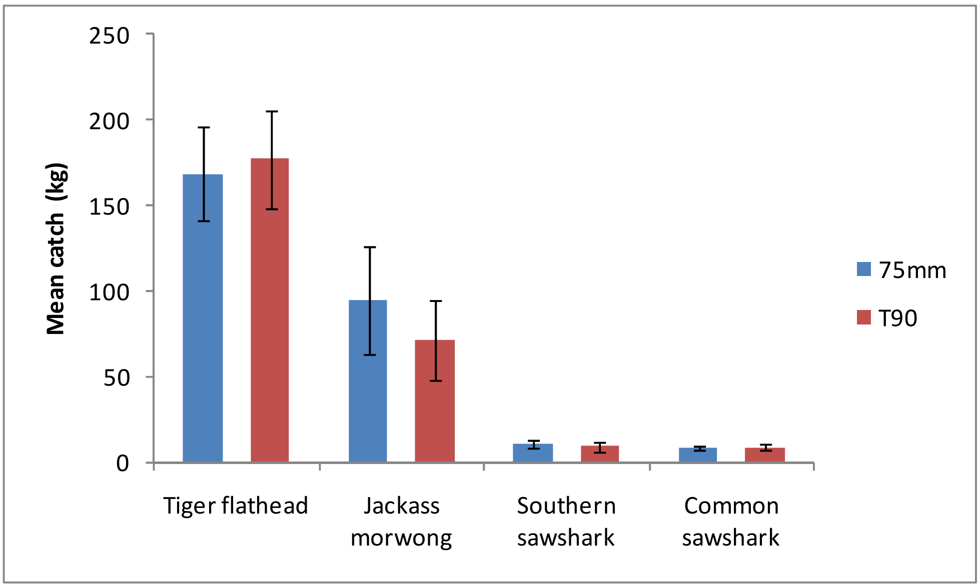


Figure 59. Mean catch rates (+ SE) of retained Tiger Flathead, Jackass Morwong, Southern Sawshark and Common Sawshark by the 75 mm control codend and the T90 codend.

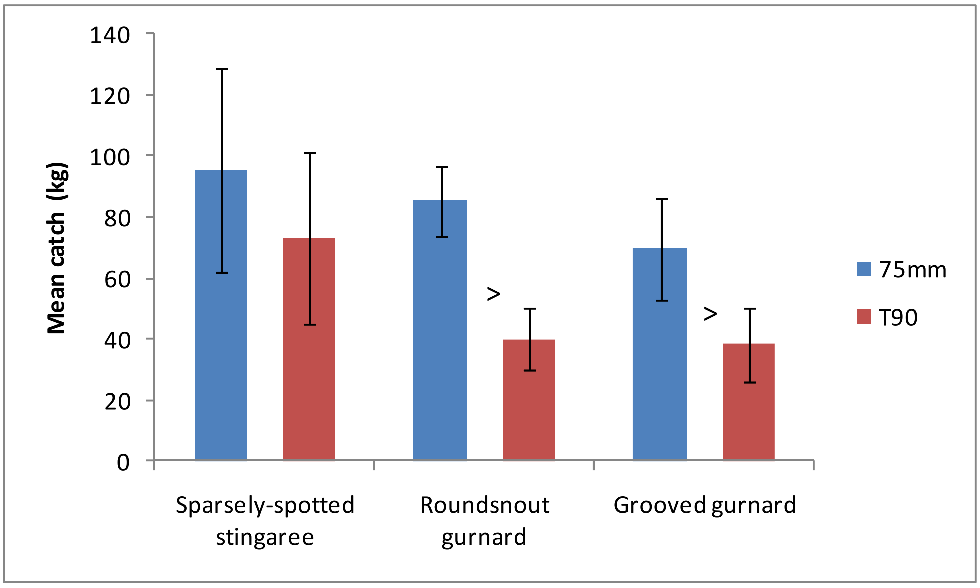


Figure 60. Mean catch rates (+ SE) of discarded Sparsely-spotted Stingaree, Roundsnout Gurnard and Grooved Gurnard by the 75 mm control codend and the T90 codend. > indicates significant difference.

Table 19. Total catch weight (kg), mean catch (kg), standard error and % of total catch by 75 mm and T90 codends.

	75mm			T90		
	Mean (kg)	**SE**	**%**	**Mean (kg)**	**SE**	**%**
Retained commercial						
Tiger Flathead	168.8	27.7	24.1	177.1	29.0	29.9
Jackass Morwong	94.6	31.1	13.5	71.2	23.7	12.0
Southern Sawshark	10.8	2.2	1.5	8.9	2.5	1.5
Common Sawshark	7.8	1.1	1.1	8.6	1.7	1.5
Gummy Shark	5.3	1.9	0.7	8.4	3.9	1.4
Sand Flathead	5.0	2.3	0.7	6.1	2.6	1.0
Other finfish	10.3	2.0	1.5	15.9	4.9	2.7
Other Elasmobranchs	5.0	2.1	0.7	6.4	2.0	1.1
Total retained fish	**307.5**	**38.7**	**43.9**	**302.6**	**42.6**	**51.2**
Cephalopods	0.7	0.3	0.1	2.2	1.2	0.4
Other molluscs	0.1	0.1	0.0	0.2	0.1	0.0
Crustaceans	0.1	0.1	0.0	0.1	0.0	0.0
Total retained Invertebrates	**0.9**	**0.3**	**0.1**	**2.5**	**1.2**	**0.4**
Total retained catch	**308.4**	**38.4**	**44.0**	**305.0**	**42.1**	**51.6**
Discarded commercial						
Tiger Flathead	1.1	0.6	0.2	0.3	0.3	0.0
Southern Sawshark	0.5	0.3	0.1	0.6	0.6	0.1
Ocean Jacket	0.5	0.3	0.1	0.3	0.2	0.0
Jackass Morwong	0.8	0.8	0.1	0.0	0.0	0.0
Red Gurnard	0.4	0.2	0.1	0.4	0.3	0.1
Gummy Shark	0.8	0.8	0.1	0.0	0.0	0.0
Other finfish	1.0	0.4	0.1	0.6	0.2	0.1
Other Elasmobranchs	0.3	0.2	0.0	0.5	0.4	0.1
Total discarded commercial fish	**5.3**	**1.5**	**0.8**	**2.6**	**1.3**	**0.4**
Cephalopods	0.1	0.1	0.0	0.0	0.0	0.0
Total discarded commercial invertebrates	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**
Total discarded commercials	**5.4**	**1.6**	**0.8**	**2.6**	**1.3**	**0.4**
Discarded non-commercial						
Sparsely-spotted Stingaree	95.3	33.2	13.6	73.1	28.3	12.4
Roundsnout Gurnard	85.4	11.2	12.2	40.2	9.9	6.8
Grooved Gurnard	69.7	16.9	9.9	38.4	12.2	6.5
Sandyback Stingaree	18.2	4.2	2.6	10.0	3.3	1.7
Silverbelly	9.3	5.4	1.3	3.3	2.2	0.6
Banded Stingaree	5.6	2.7	0.8	6.1	2.4	1.0
Spiny Pipehorse	0.0	0.0	0.0	0.0	0.0	0.0
Other finfish	8.0	1.9	1.1	10.3	4.4	1.7
Other Elasmobranchs	53.3	13.4	7.6	62.6	18.2	10.6
Total discarded non-commercial fish	**344.8**	**56.2**	**49.2**	**243.9**	**54.7**	**41.3**
Other molluscs	0.9	0.5	0.1	1.3	0.9	0.2
Crustaceans	0.9	0.5	0.1	0.5	0.3	0.1
Corals	0.3	0.3	0.0	0.0	0.0	0.0
Starfish	0.5	0.2	0.1	0.0	0.0	0.0
Sponge	39.8	24.5	5.7	38.0	18.9	6.4
Total discarded non-commercial invertebrates	**42.5**	**25.1**	**6.1**	**39.7**	**19.5**	**6.7**
Total discarded non-commercials	**387.2**	**51.5**	**55.2**	**283.7**	**49.4**	**48.0**
Total discarded fish	**350.0**	**55.5**	**49.9**	**246.5**	**54.1**	**41.7**
Total discarded invertebrates	**42.5**	**25.1**	**6.1**	**39.7**	**19.5**	**6.7**
Total discards	**392.6**	**51.0**	**56.0**	**286.3**	**49.2**	**48.4**
Total catch	**701.0**	**81.8**	**100.0**	**591.3**	**84.6**	**100.0**

Size composition

Compared to the 75 mm control codend, the T90 codend caught larger Tiger Flathead. The length frequency distributions sampled are significantly different; however, their shapes appear similar at intermediate lengths apart from the obvious increase in length in the T90 data (Figure 61). There are clear differences in the distributions at small lengths, with the T90 codend catching much less small (<33 cm) Tiger Flathead than the 75 mm codend. The modal lengths from the 75 mm control codend and T90 codend were 34 cm and 37 cm, respectively. There is very little difference in distributions at lengths greater than 45 cm.

Distributions of Jackass Morwong length frequencies were similar across the range of sizes sampled (Figure 61). Modal lengths were 29 cm and 30 cm for 75 mm control and T90 codends, respectively. While it is acknowledged that the sample size from the T90 codend (n=498) was smaller than that from the 75 mm control codend (n=636), the smallest fish measured from the T90 codend was 24 cm, compared to 19 cm from the 75 mm control codend, suggesting some difference in selectivity between nets at very small size. This is supported from SS2 outputs from the 2009 Jackass Morwong stock assessment which estimated L_{50} of 24.5 cm and a spread of 4.2 cm (spread is the difference between L_{50} and L_{95}) for the Danish seine fleet (Wayte 2010). Given this selectivity, only 50% of Jackass Morwong 24.5 cm in length, and only 5% of fish of 20.3 cm in length would be expected to be captured by the codend of standard Danish seine gear. The loss of fish <24 cm from the catch would have little effect on catch values as fish of that size caught in eastern Victoria are usually discarded (Koopman *et al.* 2006; Koopman *et al.* 2007).

Use of the T90 codend had a significant effect on the length structure of the catch of Roundsnout Gurnard (Figure 61). Maximum, minimum and modal lengths were nearly identical; however, the T90 net caught much less fish smaller than 15 cm. Similarities in the distributions at greater lengths suggest a clear effect of selectivity on the distributions of fish less than 17 cm.

Length frequency distributions of Grooved Gurnard were also significantly different between codends; however, the differences were not as great as for Roundsnout Gurnard (Figure 61). The 75 mm control codend caught much more fish smaller than 20 cm, after which the distributions appear similar. Modal lengths were 19.5 cm for the 75 mm control and 19.0 cm for the T90 codend.

Selectivity

The covered codend was only used on the T90 codend during cruise 7 and 8 (Appendix 3), and length frequency distributions presented in this section are also restricted to those two cruises. It is important to note that these two cruises were conducted at much shallower depths than the remainder of the cruises on which T90 gear was trialled, exposing the gear to a Tiger Flathead population containing a high proportion of small fish. Length frequencies of Tiger Flathead in the T90 codend and cover show a bimodal distribution with peaks at 29 cm and 39 cm (Figure 62). Range of lengths measured were 23–52 cm and 20–37 cm in the codend and cover, respectively. The proportion of fish in the cover was much higher than was observed in the selectivity experiment of the 75 mm and 65 mm codends, which caught few fish less than 30 cm in either the codends or the cover (Figure 17 and Figure 19). This is likely due to the differences in depths fished. About 68% of the Tiger Flathead caught in the cover during T90 experiments were retained by the fishers, suggesting that in areas where small Flathead are abundant, the T90 codend may result in the unacceptable loss of marketable fish. When Flathead quota is a limiting factor in fishing operations, which it has in recent years, this loss of small fish may not necessarily translate to a decrease in the value of the total catch and yet would reduce the likelihood of discarding small commercial species. This is even more likely for species that obtain much higher prices for larger specimens (see discussion below). Length frequency of fish caught by the 75 mm control codend during the two T90 covered codend experiment cruises was plotted over that from the T90 gear (Figure 62A). It shows a clear peak of fish of lengths 25–30 cm, and also much higher proportions of fish 30–32 cm. The availability of small Tiger Flathead also resulted in a long left-hand tail on the samples measured from the T90 codend.

Logistic curves fitted to the covered codend data resulted in long runs of large, positively biased residuals at small and large lengths. Consequently, a Richards curve was fitted which not only greatly improved the distribution of residuals, but also considerably reduced the model deviance (Figure 63). Selectivity parameter estimates and REP corrected standard errors are shown in Table 20. L_{50} for the T90 codend (33.59 cm) was significantly larger ($p<0.001$) than for the 75 mm codend (30.08 cm), while SR was similar. While L_{25} for the 75 mm codend (28.45 cm) was just larger than the minimum legal length, L_{25} for the T90 codend was well above the minimum legal length (31.77 cm). In other words, using the T90 codend results in the successful capture of only 25% of fish at length 31.77 cm. A change in L_{50} from 30.08 cm to 33.59 cm would likely result in a decrease in YPR and VPR of about 9% and 6% respectively. This decrease may be unacceptable to fishers.

Percent weighted frequency of Tiger Flathead were plotted for the 75 mm, 65 mm and T90 codends by size grade (size grades used in this analysis were #2 = <33 cm, #1 = 33–41 cm and XL = >41 cm) to compare potential value of catches (Figure 64). These experiments were not designed to make such comparisons; however it does reveal valuable information for the profitability of the Danish seine fishery. It should be highlighted that the only valid comparisons that can be made here are between the catch of the T90 codend and of the 75 mm codend used during the T90 experiment, and that during the T90 experiment, much of the fishing was conducted in an area containing large numbers of small fish. The 75 mm codend clearly caught a higher proportion of #1 and XL sized Tiger Flathead than the 65 mm codend. Only 10% of the Tiger Flathead from the 75 mm codend were graded #2, compared to 27% from the 65 mm codend. If 1 t of Tiger Flathead were landed from each of these size ranges, the catch from the 75 mm codend would be valued at $4,180, compared to only $3,808 from the 65 mm codend. Likewise, compared to the 75 mm codend used during the T90 experiment, the T90 codend caught much higher proportions of XL sized Tiger Flathead. The comparative catch values of 1 t of landed Tiger Flathead from these size ranges would be $3,428 and $4,272 for the 75 mm codend and T90 codend, respectively.

Threatened, Endangered and Protected (TEP) Species

Only one Spiny Pipehorse was observed during the T90 trials. It was caught in the 75 mm control codend. The number of Spiny Pipehorse observed is too low to draw any conclusions regarding the effect of codend type on their capture. No other TEP species were caught during this experiment.

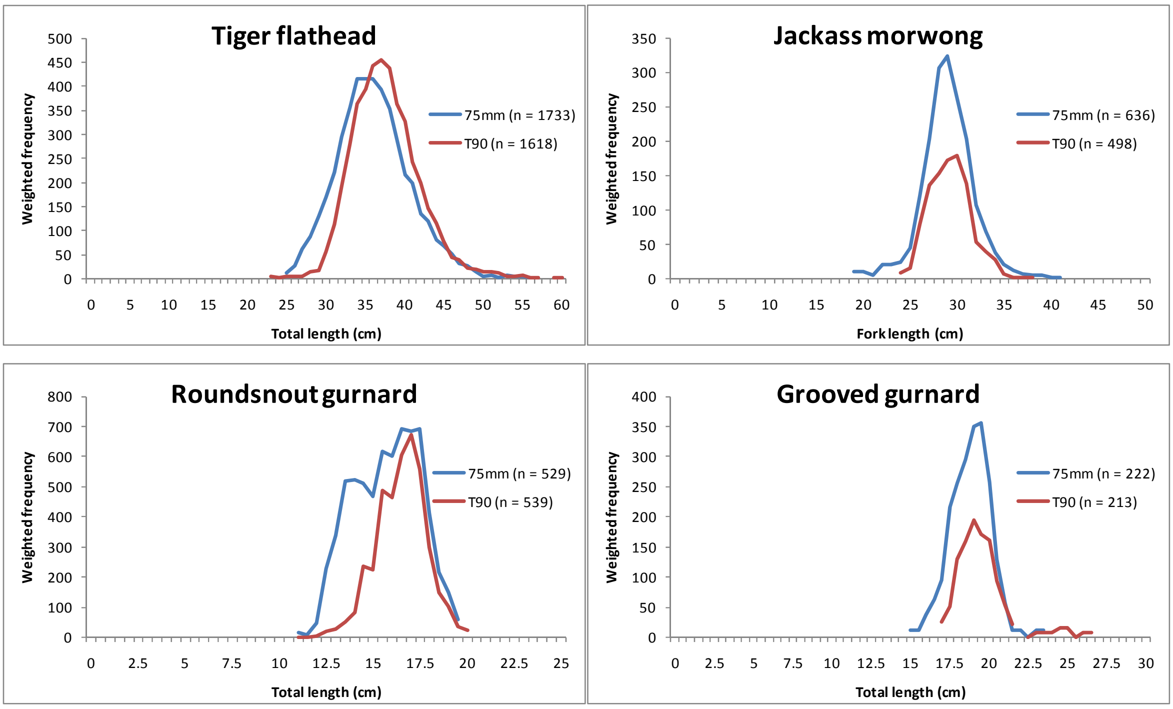
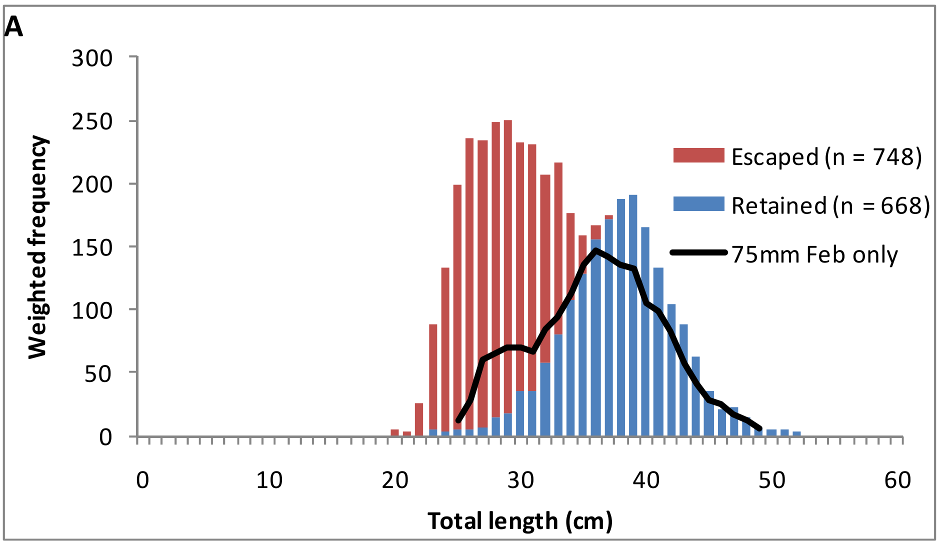


Figure 61. Comparison of length frequency of Tiger Flathead, Jackass Morwong, Roundsnout Gurnard and Grooved Gurnard between the 75 mm control codend and the T90 codend. Distributions of Tiger Flathead, Roundsnout Gurnard and Grooved Gurnard were significantly different (two-sample Kolmogorov-Smirnov tests P=0.05).



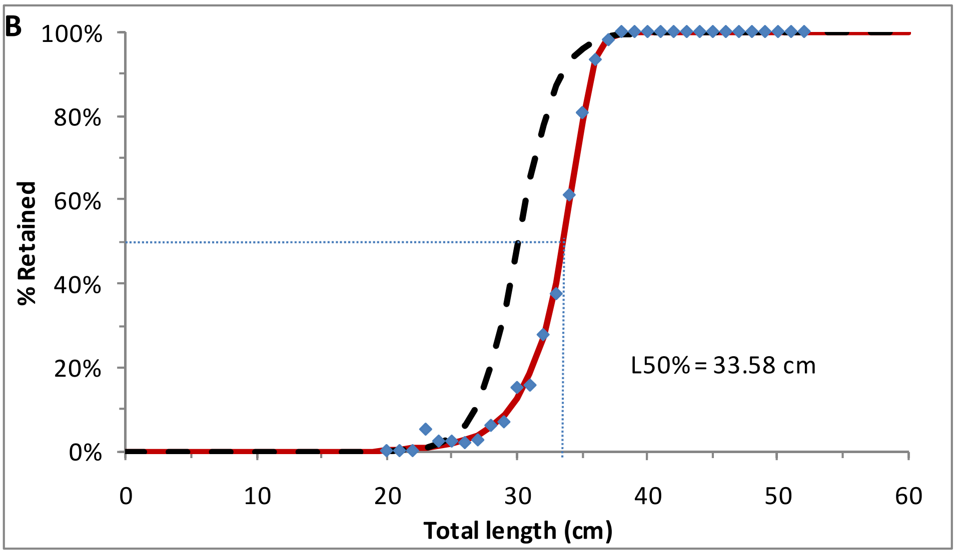


Figure 62. A. Length frequency distribution of Tiger Flathead that were retained in the T90 codend and those that escaped into the 45 mm codend cover. Solid dark line is the length frequency distribution of Tiger Flathead caught by the 75 mm control codend when fished during the same trips as the T90 covered codend experiment. B. Selectivity of the T90 codend for Tiger Flathead. Each point (♦) marks the % retained at a given 1 cm length class and the line (—) represents the estimated logistic selectivity curve. Dashed line is the selectivity curve estimated for the 75 mm control codend (Figure 17).

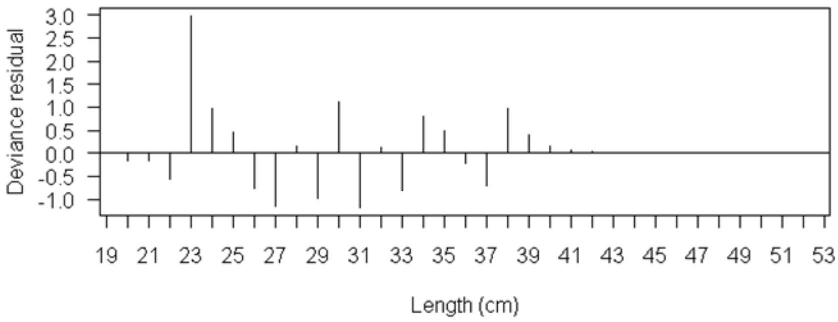


Figure 63. Plot of the deviance residuals from the selectivity ogive fit to Tiger Flathead length frequencies from the T90 covered codend.

Table 20. Combined hauls fits to Tiger Flathead data in T90 covered codend catches.

Parameter	Estimate	S.E.
REP	2.92	
L_{25}	31.77 cm	0.18
L_{50}	33.59 cm	0.18
L_{75}	34.79 cm	0.17
SR	3.03 cm	0.19

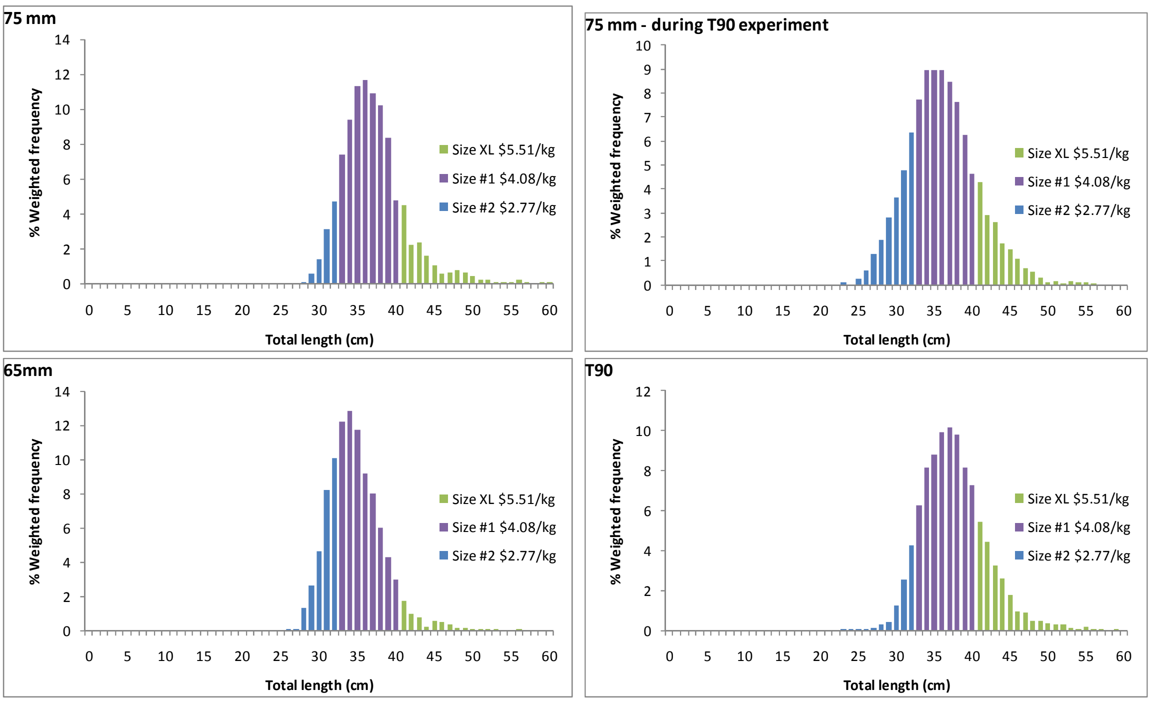


Figure 64. Percent weighted length frequency distributions of Tiger Flathead graded by size sampled from the 75 mm and 65 mm codends during selectivity experiments, and from the 75 mm control codend and T90 codend during the T90 experiment. Current (June, 2010) market price is shown in graphic key for each size class.

Discussion

Modelling YPR has shown that the Danish seine fishery is currently catching Tiger Flathead and Eastern School Whiting at lengths generally greater than those that would achieve maximum YPR. Tiger Flathead are also caught at a length larger than would achieve the maximum VPR. Eastern School Whiting however, are caught at generally smaller lengths than would achieve the maximum VPR. VPR for Tiger Flathead is relatively insensitive to small changes in L_{50} at the levels of fishing mortalities observed. Catching fish at a size above that which would provide the maximum VPR provides added protection to the target stock, and would limit the incidental catch of small, unwanted bycatch. The insensitivity of VPR for Tiger Flathead to small changes in L_{50} means that there is flexibility to change L_{50} through gear modification without impacting greatly on VPR.

The differences in L_{50} of Tiger Flathead caught by the 65 mm and 75 mm codends demonstrate the benefit of the recent increases in mesh size of codends by Industry members. The associated increase of L_{50} from 26.99 cm to 30.08 cm means that not only do much more fish under the minimum legal length escape through the codend, but small, legal sized fish also escape to contribute to the spawning population (length at maturity is 30 cm), and grow into larger more valuable fish. For example, recent data has shown that the difference in market price between the two smallest size grades is $1.31 (Simon Boag, pers. comm.). While it is obvious that a larger mesh size allows more small fish to escape and results in less bycatch, direct comparison between the catch composition of the 65 mm and 75 mm codends catch could not be made during the present study because the two gears were used during different cruises, thereby potentially confounding the results with spatial and temporal effects.

Underwater video footage revealed that many of the bycatch species observed show no preference in direction when attempting escape; similar to Tiger Flathead. This reduces the possibilities for modifications in which different mesh size panels are placed in some sections of the net. Instead, modifications should probably be made to the entire codend. Members of the Family Triglidae were found to be very poor at escaping from codends because of a combination of body shape and behaviour. They have a larger head, spiny protrusions from that head, and lack the speed and/or perseverance to attempt vigorous escape.

Despite a large increase in L_{50} for Tiger Flathead by the T90 net, it is not clear why there was no difference in catch rates of Tiger Flathead (and of retained catch overall) between the control and the T90 net (Figure 57). A masking effect of the codend cover was extensively examined during selectivity trials of the 75 mm codend and little evidence of masking was found. Several Tiger Flathead were observed by the underwater video camera moving from the cover, back into the codend, but this appeared a rare event. Video footage also showed a clear gap between the codend and the cover throughout the trawl (Figure 9). There was no difference in length frequency distributions between shots using the 75 mm codend with the cover on compared with those with the cover off (Figure 19). Further, length frequency data from the T90 net showed clear differences compared with samples from the cover, resulting from sorting of the catch (Figure 62). If there was significant masking or return of small fish from the cover into the codend, then an appreciable catch of 25–30 cm fish would be expected in the codend samples. In any case, the cover was only used on five of the twelve T90 shots.

T90 gears have been shown to result in an increased flow of water through the net which may somehow translate to an increase distance towed, or an increased catchability of larger fish, but no evidence for this was found in the data. There may have been some bias caused by the time of day the nets were used. While T90 and 75 mm control nets were alternated, the 75 mm control was more often used during the last shots of the day, and on some of those days, fishing was conducted later into the day. As a consequence, four of the 12 shots using the 75 mm control codend began after 15:00, while no shots were started that late using the T90 codend. Omitting these late tows may increase the mean catch of Tiger Flathead by the 75 mm codend; anecdotal evidence suggests that the effect of the time of day on fish size distribution would be minimal (Wayne Cheers, pers. comm.)

While it is not clear why there was no difference in catch of Tiger Flathead between codends, it is clear that the use of T90 codends significantly reduced the catch of discarded non-commercial species by about 27% (Figure 56), and showed potential to further reduce the small catches of discarded commercial species (Figure 58). Catches of large non-commercial species such as stingarees — which comprise a large portion of discarded bycatch in the Danish seine fishery and other fisheries (e.g. the Victorian Scallop Fishery [Coleman 2004], the Spencer Gulf Prawn Fishery [Dixon *et al.*, 2005], and the Queensland East Coast Trawl Fishery [Kyne, 2008]) — were not affected by the choice of codend. To reduce this class of bycatch would require the use of another device or technique, such as a sorting grid that separates them from the rest of the catch and funnels them out of the net. Stingarees are generally a small to medium ray, however, and those most commonly caught in the Danish seine fishery, Sparsely-spotted Stingaree and Banded Stingaree, reach maximum lengths of 44 cm and 50 cm, respectively (Last and Stevens 1994). Their small size and relatively flexible frame means that any sorting grid would need to be narrow in aperture, which increases susceptibility to clogging and could possibly lead to unacceptable losses of commercial species.

Based on the results of this study alone, it would appear that there is little downside to the adoption of 75 mm T90 mesh codends in the Danish seine fishery. Overall commercial catch rates appear to be maintained, including those for Tiger Flathead and there is a significant reduction in the bycatch of both non-commercial species and small commercial species. Nevertheless, at this stage it is unlikely that there would be wholesale adoption of such nets by Danish seine operators. The reasons behind this are complex. The current project was carried out over a fairly limited time period with a relatively small number of shots. As such, we have not been able to adequately encompass the full spatial and temporal coverage of the Danish seine fishery. The size range and availability of Tiger Flathead and other commercial species can vary considerably at relatively small spatial and temporal scales. There is a real and understandable concern amongst commercial fishers that T90 codends may not be suitable at certain times of the year or in certain areas of their fishery. Further commercial trials of T90 codends over extended spatial and temporal scales may help alleviate these concerns. Also, the use of T90 netting is a somewhat new and radical change to net making in a fishery that is known for its conservative and traditional approach to fishing techniques across many generations. This approach has served the fishery well over many years, so it is probably unrealistic to expect quick and extensive adoption over a small period of time. Nevertheless, a number of fishermen are interested in the potential of T90 and they may willingly keep trialling these types of codends while they are commercial fishing. This may give us a better understanding of the viability of introducing T90 codends into the fishery in the longer term. If this is to prove useful, it will be important that the commercial fishermen fill out their logbooks correctly indicating what type of codends are being used and the retained and discarded components of their catches.

The minimum mesh size allowed to be used by Danish seine fishers is 38 mm (Anon, 2010), and this small mesh is generally used to target Eastern School Whiting. No minimum mesh size is prescribed when targeting other species such as Tiger Flathead (although there are voluntary agreements in place) and as a result, a wide range of mesh sizes are used in the fishery. Obviously, using small mesh to target Tiger Flathead will result in high bycatch and discarding of small fish. Management changes aimed at reducing discards in the Danish seine fishery should focus on establishing appropriate mesh sizes when not targeting Eastern School Whiting. This may be difficult to enforce however, as it is not always clear which species is being targeted, and there is no facility for recording the target species in commercial logbooks.

Nevertheless, the current trials of the 75 mm T90 codend were useful in providing a reference point on what can be achieved in bycatch reduction in the Danish seine fishery. The progress of the fishery with respect to the uptake of gear to reduce bycatch should be reviewed once industry has had time to consider the results of this report and implement changes that they may think are appropriate.

Interactions with TEP species were rarely observed during this project. Only seven Spiny Pipehorse were recorded from the 67 shots conducted. Three were found in the codend cover showing that they do escape the commercial codends. Two were found in the 75 mm codend, one in the 65 mm codend and one in the 25 mm control codend. Excluding the three Spiny Pipehorse caught in the cover, this equates to a catch rate of about 0.04 fish per shot. In comparison, Koopman (2007) found catch rates of 0.12 fish per shot and 0.05 fish per shot when targeting Tiger Flathead and Eastern School Whiting respectively. While direct comparisons cannot be made between these results, Industry have taken measures to reduce bycatch of Spiny Pipehorse by avoiding known areas, and moving from point-wing nets to bar-wing nets (Wayne Cheers, pers. comm.). Bar-wing nets hold the mesh in the wings open more than point-wing nets, increasing the chance of escape. Australian fur seals were seen in the vicinity of the vessel during fishing operations, and sometimes fed from fish in the codend; however, no captures were observed.

Benefits

This report describes the results of escapement from standard Danish seine gear and has prompted experimentation of gear modification amongst the Lakes Entrance Danish seine fleet. This project was the first known trial conducted in Australia to reduce bycatch in the Danish seine fishery.

Robust fisheries stock assessments require the input of estimates of variables such as growth rates, fishing effort and selectivity. Selectivity estimates are generally estimated by the SS2 model during these stock assessments. This project has directly measured selectivity of Tiger Flathead and Eastern School Whiting, and these data were passed on to stock assessment scientists. The close agreement between selectivity parameters measured during this project with those estimated by SS2 models provides support for the validity of those models and their outputs.

Video observations of fish behaviour revealed that while different species behave differently in response to Danish seine gear, many species including Tiger Flathead attempted escape through side, top and bottom panels. This means that escape panels can not be efficiently used in Danish seine codends to reduce bycatch without loosing the target species, but that codend mesh size and orientation should be used that catch the target species at the optimum size, and increase the escape of bycatch. If escape panels were to be used in codends when targeting Tiger Flathead, they should be placed on the top or bottom panels were escape attempts by Tiger Flathead were less frequent.

The T90 net showed promise as a tool for reducing bycatch in the Danish seine fishery. Overall commercial catch rates appeared to be maintained, including those for Tiger Flathead, and there was a significant reduction in the bycatch of both non-commercial species and small commercial species. However the significant increase in L_{50} of Tiger Flathead could make the use of the net less profitable than current gears (a decrease in YPR and VPR of less than 10%), unless the benefit from catching more higher value, large fish outweighs the cost of the increased effort required to catch them. This is a possibility for the Danish seine fishery where Flathead quota has been a limiting factor in recent years. The increase in stock protection by allowing more fish to contribute to spawning should also be considered in management decisions regarding gear modifications. It is important to note that sampling during this project was carried out over a fairly limited time period with a relatively small number of shots. The size range and availability of Tiger Flathead and other commercial species can vary considerably at relatively small spatial and temporal scales, and as such, we have not been able to adequately encompass the full spatial and temporal coverage of the Danish seine fishery. Wider use of T90 nets would be required to get a more complete insight of the impact on catch of Tiger Flathead, bycatch and discards, and on the profitability of fishing operations.

Captures of TEP species were rare during this study. So much so that no recommendations could be made in terms of reducing their catch. This in itself might be a significant result, by demonstrating that the catch of these fish is a rare event. Industry members commented that catches of Spiny Pipehorse have been reduced significantly from the move to bar-wing nets from point-wing nets.

Further, this project facilitated ongoing cooperation between scientists and Industry to face future challenges in meeting management requirements, and to encourage Industry to be proactive in experimenting with gear modification to reduce bycatch. Industry members have shown interest in further experimentations, particularly aimed at demonstrating the effectiveness of bar-wing nets (as were used during this project) at reducing the capture of spiny pipehorse.

Further Development

Extension of these results to Industry members will be facilitated by a Seanet Officer during port visits. During these visits, the Officer will distribute the final report and DVD and discuss results.

Further examination of the behaviour of Eastern School Whiting in response to codends would be useful if gear trials to reduce bycatch in the Eastern School Whiting fishery are to be conducted. Because of their small size, we expect that any increase in mesh size when targeting Eastern School Whiting would not be commercially viable; however, the use of escape panels might be worth trialling.

Wider commercial use of T90 nets would be useful in determining effects on profitability of fishing operations. This would require accurate logbook recording of gear type used.

The capture of Spiny Pipehorse appears to have been one of the main issues facing the Danish seine fishery from a management perspective. Catch rates of Spiny Pipehorse were very low during this project, and Industry members believe that the move to bar-wing nets from point-wing nets has significantly reduced the catch of this species. They also expressed interest in demonstrating the effectiveness of these nets in reducing the incidental catch of Spiny Pipehorse using alternate hauls with each net.

Planned Outcomes

YPR and VPR modelling was completed for both Tiger Flathead and Eastern School Whiting. Results were presented to Industry members at a meeting held at LEFCOL (Lakes Entrance) on 23 April 2008. Experiments were also planned during that meeting, which resulted in excellent Industry co-operation during field work, and the safe completion of selectivity and gear modification trials.

This report not only quantifies the selectivity of current commercial gears for the Danish seine fishery, but also the discarded catch broken into commercial and non-commercial discards. While experimentation of modified gears was deemed unworkable for the Eastern School Whiting nets, comparisons between the 75 mm codend and an experimental T90 codend clearly demonstrated the differences in selectivity and catches of unwanted discards. It is unlikely that the uptake of 75 mm T90 mesh will be widespread because of uncertainty regarding the impact on economic profitability of fishing operations given the heterogeneity in size range and availability of Tiger Flathead and other commercial species over small temporal and spatial scales, and because of the industries typically conservative and traditional approach to fishing techniques. Nevertheless, results of this project have set a benchmark from which further experimentation can be planned.

Video observations of fish behaviour in response to the net were quantified and summarised in accordance with established methods. These observations were useful in identifying areas of attempted escape by target and bycatch species. Results obtained will be important considerations for future gear modification trials.

A short (10 minute) DVD was produced to summarise and promote the results of this project. The DVD and the report will be distributed amongst Danish seine fishermen in person by a Seanet Officer to ensure understanding of results.

One paper has already been published in an international peer reviewed journal (Appendix 4) and it is anticipated that at least one more will be submitted.

Conclusion

- Modelling YPR and VPR has shown that the Danish seine fishery is currently catching Tiger Flathead at a length greater than would achieve maximum VPR, but that VPR is relatively insensitive to small changes in L_{50} at the levels of fishing mortalities observed.
- Catching fish at a size above that which would provide the maximum VPR provides added protection to the target stock, and limits the incidental catch of small, unwanted bycatch.
- The insensitivity to small changes in L_{50} means that there is flexibility to change L_{50} through gear modification without impacting greatly on VPR.

- Modelling YPR and VPR has shown that the Danish seine fishery is currently catching Eastern School Whiting at a length greater than would achieve maximum YPR, but smaller than would achieve the maximum VPR.
- L_{50} of Tiger Flathead for mesh sizes 65 mm and 75 mm were estimated to be 26.99 cm and 30.08 cm respectively.
- Main bycatch species caught by the 75 mm codend were Sparsely-spotted Stingaree, Blacktip Cucumberfish, Grooved Gurnard, other members of Family Triglidae and Banded Stingaree.
- Main bycatch species caught by the 65 mm codend were Sparsely-spotted Stingaree, Blacktip Cucumberfish, Roundsnout Gurnard, and Banded Stingaree.
- L_{50} of Eastern School Whiting by the 45 mm codend was estimated to be 15.63 cm.
- Main bycatch species caught by the 45 mm codend were Common Stinkfish, Sparsely-spotted Stingaree, Tiger Flathead, Roundsnout Gurnard, and Silverbelly.
- Tiger Flathead attempted escape from the codend through the top, side and bottom panels. This means that selective panels of increased mesh (or rotated mesh) can not be used in the codend to reduce bycatch without some loss of the target species. However, this does inform future work aimed at reducing bycatch or small Tiger Flathead from 45 mm Eastern School Whiting codends. The behaviour of Eastern School Whiting in the codends was not adequately quantified here because the footage taken during Eastern School Whiting fishing was too dark for analysis, and further opportunities for filming underwater video using the 45 mm net were lost because of operational concerns .
- The T90 codend caught similar quantities of commercial species (including Tiger Flathead) to the 75 mm control codend, but caught about 27% less discarded non-commercial species.
- Selectivity of the T90 net for Tiger Flathead was significantly larger than for the 75 mm codends (33.59 cm compared to 30.08 cm).
- It is unclear why the large increase in L_{50} of the T90 net did not lead to reduced catch rates in that net, but may have resulted from an increase in the catchability of large fish due to increased water flow through the T90 net.
- Main bycatch species reduced by the T90 codend were Roundsnout Gurnard, Grooved Gurnard and Silverbelly.
- The T90 experiment was conducted over relatively small temporal and spatial scales. Because the size range and availability of Tiger Flathead and other commercial species can vary considerably at relatively small spatial and temporal scales, there is concern that the T90 mesh might not be suitable at certain times of the year or in certain areas of the fishery.
- Wider Industry experimentation with the T90 codend is required before the economic impacts of its use can be fully understood.
- The only TEP species caught during these trials were seven Spiny Pipehorse, and three of those were found in the codend cover. This demonstrates that Spiny Pipehorse do escape the commercial codends. Insufficient observations of these species were made to enable interpretation of the effect of gear type on the catch of that species; however, catch rate was lower compared to an earlier study. This reduced catch rate appears to be related to the move by Industry from point-wing nets to bar-wing nets that hold the mesh in the wings open more, increasing the chance of escape.

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Appendix 1: Intellectual Property

No intellectual property has arisen during this project.

Appendix 2: Staff

Principle Investigator:	James Andrews, Victorian DPI
Field Scientist:	Paul McCoy, Victorian DPI
Scientist:	Juan Matias Braccini, Victorian DPI
Modeller:	Vladimir Troynikov, Victorian DPI
Scientist:	Matt Koopman, Fishwell Consulting Pty Ltd

Appendix 3: Tow data for all shots conducted during project

							Start position		End position		Tow		Depth				Wind		
Cruise number	Tow number	Shot date	Codend *= underwater video deployed with net	Target species	Start time	Tow duration (mins)	Latitude	Longitude	Latitude	Longitude	Direction (deg)	Speed (knts)	(fm)	(m)	Swell height (m)	Sea height (m)	Speed (knts)	Direction (deg)	Total catch (kg)
1	1	18/09/2008	75 mm + cover	FLT	06:49	35	37°54'	148°41'	37°54'	148°41'	40	1.9	25-27	46-49	0.5	0	5	30	297
1	2	18/09/2008	75 mm + cover	FLT	09:00	33	37°54'	148°40'	37°54'	148°41'	51	2	25-26	46-48	0.5	0	5	30	360
1	3	18/09/2008	75 mm + cover	FLT	11:01	29	37°56'	148°40'	37°54'	148°39'	260	1.9	25-26	46-48	0.5	0	5	30	316
1	4	18/09/2008	75 mm + cover	FLT	12:57	35	37°56'	148°39'	37°56'	148°38'	60	1.9	25-26	46-48	0.5	0	5	30	369
1	5	18/09/2008	75 mm + cover	FLT	14:45	32	37°55'	148°38'	37°55'	148°39'	60	1.9	25-26	46-48	0.5	0	5	30	392
1	6	18/09/2008	75 mm + cover	FLT	16:44	29	37°54'	148°39'	37°54'	148°40'	45	2.1	25-26	46-48	0.5	0	5	30	355
1	7	19/09/2008	75 mm + cover	FLT	06:22	33	37°56'	148°44'	37°56'	148°44'	48	2	26-27	48-49	0.5	0	5	355	452
1	8	19/09/2008	75 mm + cover	FLT	08:16	31	37°54'	148°42'	37°53'	148°43'	51	2	26-27	48-49	0.5	0	5	355	394
1	9	19/09/2008	75 mm + cover	FLT	10:29	33	37°55'	148°37'	37°55'	148°36'	225	1.7	25-26	46-48	0.5	0	5	355	308
1	10	19/09/2008	75 mm + cover	FLT	12:34	32	37°57'	148°40'	37°58'	148°39'	230	1.6	28-29	51-53	0.5	0	5	340	619
2	11	10/10/2008	75 mm + cover	FLT	09:45	34	38°05'	149°09'	38°05'	149°09'	225	1.9	68-70	124-128	1	0	6	30	253.5
2	12	10/10/2008	75 mm + cover	FLT	11:55	38	38°10'	149°04'	38°10'	149°04'	20	1.8	75-76	137-139	1	0	6	30	207
2	13	10/10/2008	75 mm + cover	FLT	14:08	33	38°11'	149°00'	38°12'	149°00'	160	1.9	76-77	139-141	1	0	5	30	287.5
2	14	10/10/2008	75 mm	FLT	15:51	34	38°11'	148°57'	38°11'	148°56'	240	1.8	74-75	135-137	1	0	5	30	242
2	15	10/10/2008	75 mm + cover	FLT	17:40	36	38°10'	149°0'	38°10'	148°59'	252	1.6	72-82	132-150	1	0	5	30	256
2	16	11/10/2008	75 mm + cover	FLT	06:11	34	37°54'	149°18'	37°54'	149°17'	270	1.8	62-63	113-115	1	0	5	355	2208
2	17	11/10/2008	75 mm	FLT	08:05	30	37°54'	149°18'	37°54'	149°17'	250	1.8	62-63	113-115	1	0	5	355	1753.6
2	18	11/10/2008	75 mm + cover	FLT	09:45	30	37°54'	149°19'	37°54'	149°18'	250	1.9	62-63	113-115	1	0	5	355	1116.5
2	19	11/10/2008	75 mm	FLT	12:15	40	37°54'	149°19'	37°54'	149°18'	350	1.8	62-63	113-115	1	0	5	350	925.5
2	20	11/10/2008	75 mm + cover	FLT	13:55	31	37°53'	149°19'	37°54'	149°20'	98	1.8	62-63	113-115	1	0	5	350	942
2	21	11/10/2008	75 mm	FLT	15:50	34	37°53'	149°20'	37°53'	149°19'	250	1.6	62-63	113-115	1	0	5	350	927
2	22	11/10/2008	75 mm	FLT	17:35	32	37°53'	149°21'	37°54'	149°20'	230	2	62-63	113-115	1	0	7	355	852
3	23	9/12/2008	65 mm + cover	FLT	06:55	37	38°15'	148°35'	38°16'	148°35'	170	1.6	65-67	119-123	1	0.2	7	350	318
3	24	9/12/2008	65 mm + cover	FLT	08:41	32	38°15'	148°35'	38°16'	148°35'	175	1.7	76-80	139-146	1	0.2	7	350	329.8
3	25	9/12/2008	65 mm + cover	FLT	10:10	36	38°16'	148°36'	38°17'	148°36'	165	1.7	75-105	137-192	1	0.2	7	350	1234
4	26	17/12/2008	65 mm + cover	FLT	07:31	36	37°54'	148°39'	37°56'	148°39'	224		25-26	46-48	1	0	5	235	396
4	27	17/12/2008	65 mm + cover*	FLT	09:04	30	37°55'	148°40'	37°55'	148°41'	75	1.9	25-26	46-48	1	0	5	225	552
4	28	17/12/2008	65 mm + cover	FLT	10:32	36	37°55'	148°41'	37°54'	148°42'	75	1.9	25-26	46-48	1	0	5	225	739
4	29	17/12/2008	65 mm + cover*	FLT	12:12	36	37°54'	148°42'	37°54'	148°43'	35	1.8	25-26	46-48	1	0	5	220	722.6
4	30	17/12/2008	65 mm + cover*	FLT	13:49	35	37°55'	148°41'	37°54'	148°42'	210	1.8	25-26	46-48	1	0	5	210	582.2
4	31	17/12/2008	65 mm + cover	FLT	15:42	34	37°56'	148°40'	37°54'	148°42'	40	1.8	25-26	46-48	1	0	5	210	634.8
4	32	17/12/2008	65 mm + cover*	FLT	17:10	34	37°54'	148°42'	37°54'	148°43'	45	1.8	25-26	46-48	1	0	5	210	713
4	33	17/12/2008	65 mm + cover*	FLT	18:40	36	37°54'	148°43'	37°53'	148°44'	48	1.8	25-26	46-48	1	0	5	190	1228.9
4	34	18/12/2008	65 mm + cover	FLT	06:11	37	37°53'	148°43'	37°54'	148°42'	225	1.7	25-26	46-48	1	0.3	10	45	514.3
4	35	18/12/2008	65 mm + cover*	FLT	07:49	36	37°54'	148°43'	37°54'	148°42'	45	1.8	24-26	44-48	1	0.2	8	35	591.2
4	36	18/12/2008	65 mm + cover*	FLT	09:25	35	37°54'	148°42'	37°54'	148°43'	45	1.8	25-26	46-48	1	0.1	7	30	375.2
4	37	18/12/2008	65 mm + cover	FLT	11:15	34	37°54'	148°42'	37°54'	148°43'	110	1.8	25-26	46-48	1	0.1	7	110	928.9
5	38	21/01/2009	45 mm whiting	ESW	02:11	34	38°22'	147°25'	38°23'	147°24'	205	2	17-18	31-33	1	0.5	10	205	1461.5
5	39	21/01/2009	25 mm whiting	ESW	04:15	34	38°23'	147°22'	38°24'	147°21'	210	2.2	17-18	31-33	1	0.3	8	200	1543
5	40	21/01/2009	45 mm whiting	ESW	05:51	36	38°25'	147°22'	38°24'	147°22'	30	1.9	17-18	31-33	1	0.3	8	200	1112.8
5	41	21/01/2009	25 mm whiting*	ESW	07:44	33	38°23'	147°24'	38°22'	147°25'	45	1.9	18-19	33-35	1	0.2	8	210	1108
6	42	6/02/2009	25 mm whiting	ESW	21:35	32	38°23'	147°24'	38°22'	147°25'	65	1.9	18-19	33-35	1	0.5	12	60	3211.6
6	43	6/02/2009	45 mm whiting	ESW	23:02	29	38°22'	147°25'	38°21'	147°26'	45	1.8	18-19	33-35	1.5	0.8	15	60	1492.9
7	44	21/02/2009	T90 + cover	FLT	07:34	33	38°10'	147°42'	38°10'	147°44'	65	1.8	22-23	40-42	2	0.5	10	220	726
7	45	21/02/2009	T90 + cover*	FLT	09:36	31	38°10'	147°43'	38°09'	147°44'	220	1.8	22-23	40-42	2	0.5	10	220	341.7
7	46	21/02/2009	75 mm*	FLT	11:43	32	38°11'	147°40'	38°10'	147°41'	160	1.8	21-22	38-40	2	0	5	160	720.3
7	47	21/02/2009	T90 + cover*	FLT	13:25	33	38°09'	147°42'	38°08'	147°43'	55	1.8	21-22	38-40	2	0	5	160	553.3
7	48	21/02/2009	75 mm	FLT	15:47	35	38°08'	147°44'	38°08'	147°43'	330	1.8	21-22	38-40	2	0.2	10	150	493
8	49	22/02/2009	75 mm	FLT	07:36	31	38°09'	147°41'	38°08'	147°42'	45	1.8	21-22	38-40	1.5	0.2	10	50	516.8
8	50	22/02/2009	T90 + cover*	FLT	09:41	32	38°10'	147°41'	38°09'	147°41'	40	1.8	21-22	38-40	1.5	0.2	10	40	221
8	51	22/02/2009	75 mm*	FLT	11:55	34	38°07'	147°48'	38°07'	147°47'	245	1.8	23-24	42-44	1.5	0.2	10	40	502.6
8	52	22/02/2009	T90 + cover*	FLT	13:39	34	38°04'	147°48'	38°04'	147°48'	40	1.8	22-23	40-42	1.5	0.4	12	60	405.5

Cruise number	Tow number	Shot date	Codend *= underwater video deployed with net	Target species	Start time	Tow duration (mins)	Start position Latitude	Start position Longitude	End position Latitude	End position Longitude	Tow Direction (deg)	Tow Speed (knts)	Depth (fm)	Depth (m)	Swell height (m)	Sea height (m)	Wind Speed (knts)	Wind Direction (deg)	Total catch (kg)
9	53	24/03/2009	T90	FLT	07:32	34	38°41'	148°09'	38°41'	148°07'	290	1.8	42-43	77-79	1	0	5	60	974.3
9	54	24/03/2009	75 mm	FLT	09:26	33	38°42'	148°08'	38°41'	148°07'	260	1.7	41-42	75-77	1	0	5	60	1063
9	55	24/03/2009	T90	FLT	11:00	35	38°42'	148°07'	38°42'	148°06'	310	1.7	41-42	75-77	1	0	5	60	1073.2
9	56	24/03/2009	75 mm	FLT	13:06	31	38°41'	148°07'	38°42'	148°06'	222	1.8	40-41	73-75	1	0	5	60	1106
9	57	24/03/2009	T90*	FLT	14:45	34	38°42'	148°07'	38°42'	148°08'	120	1.7	41-42	75-77	1	0	5	60	1033.7
9	58	24/03/2009	75 mm	FLT	16:22	34	38°41'	148°08'	38°41'	148°10'	94	1.7	41-42	75-77	1	0	5	60	1185.8
9	59	24/03/2009	75 mm	FLT	18:01	32	38°40'	148°09'	38°41'	148°10'	112	1.6	41-42	75-77	1	0	5	60	850.7
9	60	25/03/2009	T90	FLT	06:12	36	38°40'	148°08'	38°40'	148°09'	70	1.7	41-42	75-77	1	0	5	70	380
9	61	25/03/2009	75 mm	FLT	07:56	36	38°42'	148°08'	38°43'	148°07'	251	1.8	41-42	75-77	1	0	5	60	559.8
9	62	25/03/2009	T90*	FLT	09:26	33	38°43'	148°08'	38°43'	148°07'	225	1.7	41-42	75-77	1	0	5	60	547
9	63	25/03/2009	75 mm*	FLT	12:17	34	38°44'	148°09'	38°44'	148°07'	210	1.8	41-42	75-77	1	0	5	35	560.5
10	64	19/05/2009	T90	FLT	07:46	33	38°32'	148°09'	38°32'	148°07'	245	1.6	39-40	71-73	1	0.5	8	40	493.2
10	65	19/05/2009	75 mm	FLT	11:03	35	38°45'	148°10'	38°46'	148°10'	172	1.8	42-43	77-79	1.5	0.5	10	40	536.3
10	66	19/05/2009	T90	FLT	13:42	34	38°45'	148°11'	38°45'	148°12'	120	1.7	45-44	82-81	1.5	0.5	10	40	346.8
10	67	19/05/2009	75 mm	FLT	17:21	33	38°32'	148°07'	38°32'	148°08'	275	1.8	39-40	71-73	1.5	0.5	12	40	317.4

Appendix 4: Paper published in Fisheries Science Volume 75

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ORIGINAL ARTICLE

Fisheries

The effect of Danish seine selectivity and retention on growth estimates of tiger flathead *Platycephalus richardsoni*

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Abstract This work demonstrates the correction of gear-selectivity and retention effects in estimation of growth in fish populations. The selectivity bias can be removed from length-at-age and length increment data. To correct for bias, a maximum-likelihood estimator that incorporates gear selectivity, a size-dependent retention function and several stochastic growth models are provided. The estimator allows the use of joint samples collected by fishing gears with different selectivity, which increases sample size and data representativeness, and thus improves accuracy of population parameter estimates. Data collected from retained tiger flathead caught by Danish seine gear were used for numerical analysis of the selectivity bias. Stock assessment implications of bias in growth estimation are discussed.

Keywords Bayes theorem · Gear selectivity · Retention · Stochastic growth model

Introduction

Most fisheries data are collected using size-selective fishing gear. These data contain information not only about growth of fish within the population, but also about selectivity of the gear. For instance, growth data collected using two different gears may produce two different sets of growth parameter estimates for the same population. That is biological nonsense, because population parameters are not determined by the gear type used for data collection. Therefore when population parameters are estimated, gear selectivity should be accounted for by researchers. Despite most fisheries data being subject to gear-selectivity bias, the literature addressing effects of gear selectivity on estimating growth parameters is limited to only a few publications [1–5].

In our work we used data collected from retained tiger flathead *Platycephalus richardsoni* caught by Danish seine gear off southeast Australia. Length-at-age data for tiger flathead subsampled from Danish seine catch have two main selectivity components: gear selectivity bias, which is largely a function of mesh size and configuration of the net, and size-specific retention bias, which is produced by judgement of the fisher and can be dependent on a combination of market influences, size limits and quota availability.

For correcting bias in growth data we used a maximum-likelihood estimator that included selectivity and retention functions [6] for tiger flathead (N. Klaer, personal communication, 2007). For parameterisation of size-at-age data, stochastic growth models were used so that interactions between length-at-age distributions in a population with length-specific selectivity of sampling methods could be properly addressed.

Methods

Growth data sampling

Sagittal otolith samples were collected between October 1998 and November 2005 from the retained catch of the Danish seine tiger flathead fishery operating out of Lakes Entrance, Victoria, Australia, as a part of routine sampling

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by the Integrated Scientific Monitoring Program [7]. Age estimates were obtained from 1,760 otoliths processed by the Central Ageing Facility [8], Fisheries Research Branch, Fisheries Victoria, Australia. Age data were converted to decimal age calculated as:

$$\text{Age} = \text{CR} + M/12,$$

where CR is the number of complete rings and M is the number of months after January during the year that the sample was collected. It has been shown that decimal ages do not produce growth estimates significantly different from those estimated from integer age estimates; however, one advantage is that error around the estimates is reduced using decimal ages [9].

The likelihood estimator

Bayesian decomposition of the length l distribution in a sample was used to obtain unbiased growth parameter estimates. Length-at-age distribution in a sample $P(l|$ "selected") was considered as a posterior distribution, and length-at-age distribution in a population as a *prior* distribution [3]. By definition [10], the selectivity function is proportional to the conditional probability $P($"selected"$|\, l)$—individuals with size l to be caught by the fishing gear, and the retention function is the proportion of individuals at size l which are retained from the catch.

Let $f(l;\, t,\, a)$ be the probability density function (pdf) of length l at age t in a population, where a is the parameter set to be estimated, $S(l) \sim P($"selected"$|\, l)$ is the selectivity function and $R(l) \sim P($"retained"$|\, l)$ is the retention function. Using Bayes theorem, the pdf of length l at age t in the catch is [3]

$$p_1(l;\ t,\ a) = f(l;\ t,\ a)S(l)/\mathrm{I}_1[t,\ a], \tag{1}$$

where

$$\mathrm{I}_1[t,\ a] = \int f(x;\ t,\ a)S(x)\mathrm{d}x, \quad 0 < x.$$

From Eq. 1 it is clear that the size distribution in a population is different from the size distribution in the catch, given $S(l)$ is not a constant.

Furthermore, using size-specific subsampling with retention $R(l)$ from the catch, the pdf of length-at-age in a sample of growth data is

$$p(l;\ t,\ a) = p_1(l;\ t,\ a)R(l)/\mathrm{I}[t,\ a], \tag{2}$$

where

$$\mathrm{I}[t,\ a] = \int p_1(x;\ t,\ a)R(x)\mathrm{d}x, \quad 0 < x.$$

For biological reasons, pdfs of length-at-age $f(l;\, t,\, a)$ and $p_1(l;\ t,\ a)$ have a positive domain, therefore the area of integration for $\mathrm{I}_1[t,\, a]$ and $\mathrm{I}[t,\, a]$ is positive $(0 < x)$. Note, if subsampling from the catch is not size specific, i.e., $R(l) = \text{const.}$, then from Eq. 2 we have

$$p(l;\ t,\ a) = p_1(l;\ t,\ a).$$

Finally, from Eqs. 1 and 2 we have

$$p(l;\ t,\ a) = f(l;\ t,\ a)S(l)R(l)/\mathrm{I}[t,\ a], \tag{3}$$

where

$$\mathrm{I}[t,\ a] = \int f(x;\ t,\ a)S(x)R(x)\mathrm{d}x, \quad 0 < x.$$

From Eq. 3 the maximum-likelihood estimator for population growth parameters a is

$$\mathrm{lik}[\hat{a}] = \max \Pi\ p(l_i; t_i, a) \quad i = 1, \ldots, n, \tag{4}$$

where n is sample size.

When $S(l) = \text{const.}$ (nonselective gear) and retention $R(l) = \text{const.}$, then the likelihood estimator Eq. 4 is reduced to the form

$$\mathrm{lik}[\hat{a}] = \max \Pi\ f(l_i; t_i, a), \quad i = 1, \ldots, n. \tag{5}$$

In common practice, instead of the Eq. 4 estimator, Eq. 5 is used, potentially resulting in bias among estimates of population growth parameters if fishing gear is length selective and/or retention is length specific.

Growth parameterisation

For parameterisation of length-at-age data we used a stochastic version [11]

$$f(l;\ t,\ L_\infty,\ t_0,\ \lambda) = g(k; \lambda)J_l(t), \tag{6}$$

of the deterministic von Bertalanffy growth model [12]

$$l = L_\infty(1 - \exp(-k(t - t_0))),$$

where $g(k;\, \lambda)$ is a pdf of the von Bertalanffy parameter k, which is assumed to be random, λ is the parameter set, and

$$J_l(t) = 1/((t - t_0)(L_\infty - l))$$

is the Jacobian of the transformation,

$$k = -\log(1 - l/L_\infty)/(t - t_0).$$

The pdf (6) of length l at age t is dependent on the parameter set λ and the growth parameters L_∞ and t_0.

In the numerical example three versions of the stochastic growth model Eq. 6 were used, where $g(k;\, \lambda)$ represents the positive distributions: Weibull, gamma and log-normal. The number of parameters to be estimated was the same in all three stochastic models. To discriminate between the models with respect to data fitting, we use the Kullback–Leibler divergence (K–L divergence), [13].

All three stochastic growth models are devoid of negative tails in length distributions. Note that deterministic

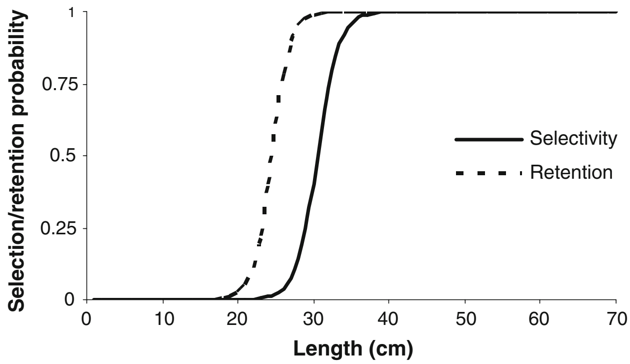

Fig. 1 Selectivity ($\beta_1 = 30.570$, $\beta_2 = 4.178$) and retention ($\gamma_1 = 24.475$, $\gamma_2 = 1.189$) functions for tiger flathead caught by Danish seine gear (N. Klaer, personal communication, 2007)

growth models represent only mean length-at-age, providing insufficient information for properly describing interactions between populations and size-selective fishing gear.

Selectivity and retention functions

A logistic curve [6] was adapted for the tiger flathead length-selectivity function of the Danish seine gear:

$$S(l) = \left(1 + e^{-\ln(19)(l-\beta_1)/\beta_2}\right)^{-1}, \quad (7)$$

where β_1 is the length at 50% selectivity and β_2 is the difference between the length at 95% selectivity and the length at 50% selectivity (Fig. 1). The fraction of the tiger flathead catch retained in length bin l is calculated as [6]

$$R(l) = \left(1 + e^{-(l-\gamma_1)/\gamma_2}\right)^{-1}, \quad (8)$$

where γ_1 is the length at the point of inflection in the retention function, and γ_2 is the parameter determining the slope at the point of inflection. The estimates of selectivity and retention parameters were supplied by Neil Klaer, CSIRO, Hobart.

Results

Substituting Eqs. 6, 7 and 8 into the general form Eq. 4 of the estimator, we obtained the likelihood function for estimating population parameters with corrections for size selectivity and retention biases in tiger flathead growth data. The simplex method [14] was used to approximate the maximum-likelihood estimates by minimisation of the negative log-likelihood function. K-L divergence indicated that the model with a gamma $g(k; \lambda) = \gamma(k; \mathrm{E}[k], \mathrm{Var}[k])$ distributed von Bertalanffy growth parameter k provided the best fit to the data. Note that K-L divergence is not a statistical test of a hypothesis; however, in practice it helps avoid inappropriate assumptions about distributions of random parameters. Table 1 shows parameter estimates with and without correction for selectivity and retention bias.

Table 1 Parameter estimates of stochastic growth model (6) with gamma-random parameter k; E[k] and Var[k] are mathematical expectation and variance of random parameter k (%) is standard error, sample size is $n = 1{,}760$

Parameter	Uncorrected (Eq. 5)	Corrected (Eq. 4)
t_0	–11.92 (<1%)	–3.96 (<1%)
L_∞	806.53 (<1%)	58.00 (<1%)
E[k]	0.0026 (<1%)	0.1047 (<1%)
Var[k]	0.00056 (2%)	0.24860 (2%)

Since the sample size ($n = 1{,}760$) is relatively large and the growth model has only four parameters to estimate, most estimates in Table 1 have standard errors less than 1%.

Figure 2 provides an illustration for data fitting using direct estimation (Eq. 5) and corrected using the estimator from Eq. 4, which removed selectivity bias from the data. Uncorrected 5% and 95% percentiles (Fig. 2) show where

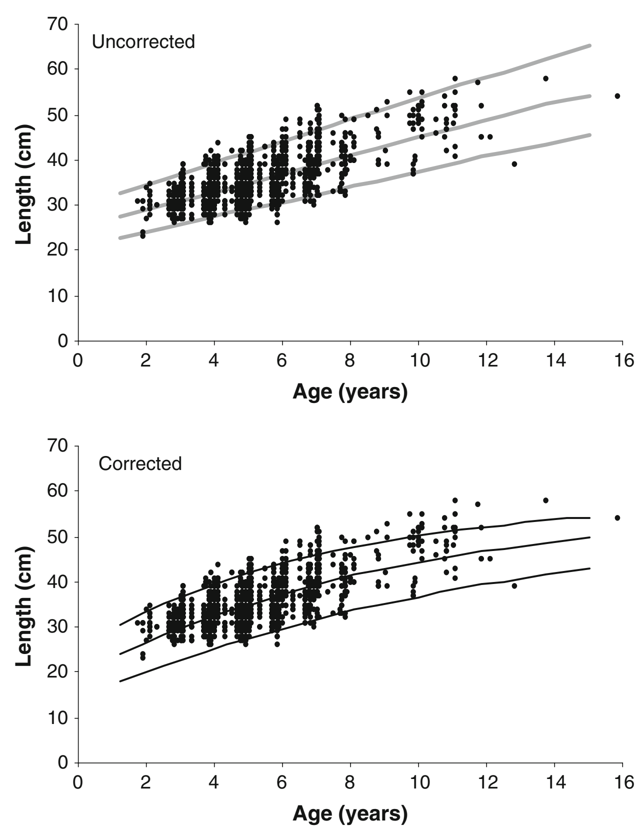

Fig. 2 Raw length-at-age data (*dots*) and $Q_p[t]$, $p \times 100 = 5\%$, 50% and 95% percentiles of length-at-age uncorrected using estimator Eq. 5 and corrected for selectivity and retention using estimator Eq. 4

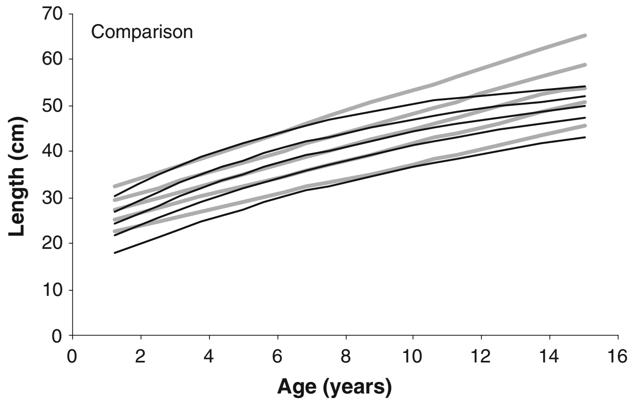

Fig. 3 Percentiles $Q_p[t]$, $p \times 100 = 5\%$, 25%, 50%, 75% and 95% of length-at-age uncorrected (*grey*, estimator Eq. 5 and corrected for selectivity and retention (*black*, estimator Eq. 4)

90% of the affected data is located; however, corrected percentiles show the limits where 90% of data should be—*given sampling is not size selective*.

Shapes of length-at-age percentiles for uncorrected growth estimates were linear over the lifetime of tiger flathead compared with the familiar shape of length-at-age percentiles seen in the corrected growth estimates that appear to approach an asymptote (Fig. 3). Corrected length-at-age percentiles also better reflect reality by showing nonlinear growth among the earliest age groups.

The greatest differences in medians of length-at-age are among the earliest and oldest age groups, for which medians are smaller when accounting for selectivity and retention bias. From ages 5 to 8 years, medians of length-at-age are slightly larger when taking selectivity and retention bias into account (Table 2). Detailed quantitative interpretation of these differences is not straightforward because the data biases in the earliest and oldest age groups will affect the results in a complex way when uncorrected growth estimation is conducted.

Differences between corrected and uncorrected medians of length at ages 1, 3, 7 and 12 years old were −3.5, −1.1, 0.3 and –2.0 cm, respectively.

The percentiles $Q_p[t]$ (Figs. 2, 3; Table 2) were obtained by numerically solving the equation;

$$p = \int_0^{Q_p[t]} f(x; t, L_\infty, t_0, \mathrm{E}[k], \mathrm{Var}[k])\mathrm{d}x$$

for $p = 0.05$, 0.25, 0.50, 0.75 and 0.95.

Note that percentiles $Q_p[t]$ are the characteristics of the distributions of length-at-age in fish populations, *not statistical errors* of the median growth estimates.

A more explicit comparison of the effects of selectivity and retention on the estimates of length distributions for some chosen ages 1, 3, 7 and 12 years old fish are shown in Fig. 4.

Table 2 Median $Q_{0.5}[t]$ of length-at-age of tiger flathead uncorrected (estimator Eq. 5) and corrected (estimator Eq. 4) for selectivity and retention bias

Age (years)	Length (cm)	
	Uncorrected	Corrected
1	26.8	23.3
2	28.9	26.7
3	30.9	29.8
4	32.9	32.5
5	34.9	35.0
6	37.0	37.3
7	39.0	39.3
8	41.0	41.2
9	43.0	42.8
10	45.0	44.3
11	47.0	45.7
12	48.9	46.9
13	50.9	48.0
14	52.4	49.0
15	53.9	49.9

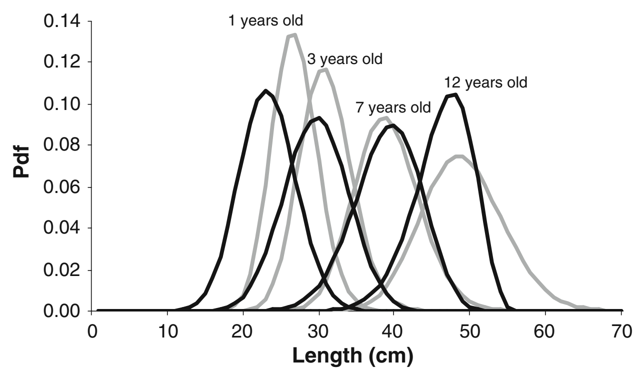

Fig. 4 Pdf $f(l; t, L_\infty, t_0, \mathrm{E}[k], \mathrm{Var}[k])$ of length l for ages $t = 1$, 3, 7 and 12 years old fish: uncorrected (*grey*, estimator Eq. 5) and corrected (*black*, estimator Eq. 4)

Figures 2 and 3 and Table 1 provide general, and Fig. 4 and Table 2 detailed, results of corrected and biased growth estimates in a population that allow for comprehensive analysis of selectivity and retention effects on growth estimation.

Discussion

Bias is inherent in any fisheries data collected. One of the most common sources is size-selectivity bias. This means that the sample collected may not be directly representative of the population from which it was taken. This bias should be removed from population parameter estimates where possible. We used a likelihood estimator that applied gear length-selectivity and size-dependent retention functions for selectivity bias correction. Numerical results for tiger flathead caught by Danish seine gear explicitly demonstrate the difference between growth estimates obtained directly using the estimator in Eq. 5 and corrected estimates that are independent of gear selectivity and retention obtained from estimator in Eq. 4.

In this example, we used length-at-age data to demonstrate the need to account for selectivity and retention bias. Similarly, this approach can be used for growth data obtained from tag-recapture experiments [3, 5]. The general form of the estimator in Eq. 4 can be applied to tagging data by using conditional pdf for length at recapture $f(l_2| l_1;\, \Delta t,\, \alpha)$ in Eq. 1, [11];

$$p(l_2|l_1;\, \Delta t,\, a) = f(l_2|l_1;\, \Delta t,\, \alpha)S(l_2)/\mathrm{I}[\Delta t, \alpha], \tag{9}$$

where l_1 and l_2 are length at release and length at recapture, Δt is time at liberty and $S(l_2)$ is selectivity function of the gear that was used for recapture.

In estimator Eq. 5, data collected by different gear types *cannot be used in one sample*, because results from the estimation are biologically invalid. Estimators obtained using Eq. 1, 3 or 9 can be readily applied to growth estimation using a joint sample collected by several gear types with different selectivity functions $S_j(l)$, $j = 1,\ldots,m$;

$$\mathrm{lik}[\hat{a}] = \max \Pi\Pi p\left(l_{i,j}; t_{i,j}, a\right), \quad i = 1, \ldots, n, j = 1, \ldots, m,$$

where the index i, j denotes the individual i caught by gear j. Combining data from different gear types reduces dependency on 'fishing luck', better represent a population, increase sample size and thus improve accuracy in population parameter estimates.

Unbiased growth estimation can be obtained when gear selectivity is known; alternatively, gear selectivity can be estimated when real growth parameters are known. Formally, joint likelihood estimation of selectivity and growth parameters can also be conducted. However, the joint estimation implies statistical correlation between the estimates of biological parameters and nonbiological selectivity parameters of the gears. Thus, the results of joint estimation can be questionable for both growth and selectivity parameters. The methods for independent gear selectivity estimation are well known from the literature [15–18], enabling the estimator Eq. 4 or 9 to be used to estimate unbiased growth parameters in many fish stocks.

Length distribution and growth data provide the fundamental information which addresses most biological relationships within fish populations. Therefore, in length-based fish stock management, biased growth estimates can lead to biased management decisions about legal minimum lengths for fishing and gear types or both. Biased growth estimates may also have important implications in the inclusion of data from the discarded portion of the catch in quantitative stock assessments. Inappropriate management strategies can adversely affect reproductive capacity of a population. Unbiased estimation of growth allows for more accurate estimation of future commercial revenue for fisheries, particular where there is size-based discarding due to disparity in market price between small and large fish, or there is a legal minimum length.

Length selectivity and discarding are characteristics of most fishing methods. Results obtained for tiger flathead fishery data in this study suggest that these biases should be accounted for when estimating growth of fish for fishery-dependent samples.

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