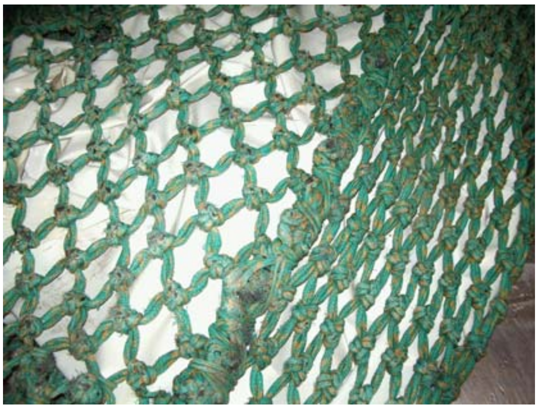
Effects of Trawling Subprogram: Maximising yields and reducing discards in the South East Trawl Fishery through gear development and evaluation.



Ian A. Knuckey and Crispian J.T. Ashby

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2.1 OBJECTIVES:

1. Develop and evaluate modifications of trawl gear to reduce the capture and subsequent discard of small fish by SEF trawl vessels.

2. Measure the effectiveness of gear modification in the reduction of discarding against bycatch targets and indicators in the SETF Bycatch Action Plan to be developed by the SETMAC bycatch action plan working group.

3. Quantify the economic implications of gear modifications to Industry. (Ensure appropriate data are collected to allow assessment of long-term economic outcomes).

4. Develop an extension strategy to ensure background and progress of project are adequately communicated to Industry, AFMA and the wider community.

1 NON-TECHNICAL SUMMARY

There is increasing worldwide concern about the ecological impacts of trawling. Reports of high levels of bycatch of fish and other species, habitat degradation, bad practices, stock depletion and perceptions of wastage and negative ecological impacts continue to fuel these concerns.

Australia's Commonwealth Trawl Sector (CTS) — previously known as the South East Trawl Fishery, or SETF — is a complex multi-species sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) operating across the shelf and upper slope waters in south eastern Australia. The SESSF caught approximately 22,000 t of fish during 2007 with a gross production valued at around $96 million during the 2006–07 financial year (Morison 2008).

More than 100 species of finfish and invertebrates are routinely taken in the SESSF, supplying most of the fresh fish for markets in NSW, Victoria, Tasmania and South Australia, and some product for the export market. Onboard monitoring programs have revealed that varying, but significant levels of the catch (up to 50% by weight) are caught and discarded in the fishery. Although some commercial species are discarded, many of the discards are comprised of small fish species with little or no commercial value. Like other trawl fisheries, there is increasing concern about the ecological impacts of this bycatch in the CTS. As a consequence, the Australian Fisheries Management Authority and fishery stakeholders have implemented a Bycatch Action Plan, which aims to reduce bycatch in the fishery and ensure ecological sustainability. An important component of this Plan is a project designed to modify the trawl gear to increase the proportion of small unwanted fish that escape. This report presents the results of that research and discusses the importance of disseminating this information to key industry stakeholders and the wider community.

The first phase of the project was to undertake covered codend experiments to determine the selectivity of standard trawl codends. There was a need to gain this type of information for stock assessment of CTS quota species (Cui *et al.* 2001). While conducting the selectivity research, we were also able to quantify the number and weight of organisms that escape from these trawls. Small-mesh codend covers were placed over standard commercial nets used in the CTS. The quantity and species composition of organisms caught in the cover were compared to those in the codend. About 70% of the organisms in the total catch escaped through the codend and were caught in the cover; this represented about 30% of the catch by weight. The codend catch consisted mainly of teleosts (79% by weight), elasmobranchs (15%), cephalopods (4%) and crustaceans (2%). In contrast, nearly all (96%) of the cover catch consisted of small teleosts, the most common of which were small non-commercial species. The implications of these results for management of the fishery and implementation of the Bycatch Action Plan are discussed.

In situ examination of the swimming behaviour of commercially important fish species was undertaken with underwater cameras positioned at various locations on demersal trawl gear employed in the CTS. Behavioural categories quantified included various swimming states and velocities within sections of the trawl net revealing differences among and within the species examined. Sources of variation in swimming behaviour included net position (mouth, body, extension and codend) and species. The ability to observe fishing gear and fish behaviour during the capture process was an essential requirement for the rapid development of selective fishing gears. Visual observations of the fishing gear can allow a quick assessment of its effectiveness during operation, while an understanding of fish behaviour during the capture process can stimulate ideas for the development of practical modifications designed to utilise behavioural differences between target and non-target species, thus increasing the selective properties of the gear.

Ways of reducing discards were investigated by testing codends constructed of different mesh sizes and/or shapes (90 mm square, 102 mm diamond/square, 110mm diamond/square) against the standard (control) 90 mm diamond mesh codend using trouser trawl experiments. Four different codends were trialled off Bermagui and off Portland, and the differences in the catch composition and size frequency quantified. Before experimental codends were trialled, the trouser trawl was extensively tested both in the flume tank and at sea reduce potential biases.

Increasing mesh size and/or using square mesh reduced catches of many species, particularly small non-commercial species but also reduced the discards of commercial species. There was also some degree of loss of commercial species that would normally be retained. Spatial variability in performance of modified codends was observed. Losses of commercial retained catch were particularly evident in deepwater off Bermagui, in particular of pink ling (*Genypterus blacoides*), Gould's squid (*Notodarus gouldi*) and offshore ocean perch (*Helicolenus barathri*), however modelling showed that catches (and catch value) of these species (except Gould's squid) recovered over time and improved to a level greater than the reference level. The greatest reduction in catches of non-commercial discard species was observed for blacktip cucumberfish (*Paraulopus nigripinnis*), threespined cardinalfish (*Apogonops anomalus*), common sawbelly (*Hoplostethus intermedius*) and various whiptail species (*Coelorinchus* spp).

Models were developed to investigate the impact of adopting modified codends in the east and west of the fishery with respect to stock biomass, retained yield, catch value and discard levels. In all cases, following implementation of test codends there was a significant reduction in discards but there was also an initial decrease in the yield and value of total catches ranging between 5-15% depending on the region and codend. These losses reduced over time and positive returns (compared to 90 mm diamond mesh) were generally achieved after a 4-6 year time horizon. Long term improvements in yield and catch were in the vicinity of about 5% overall, but varied considerably for different species and some species (eg. Goulds squid) did not regain a positive yield. In most cases, the value returned to, and bypassed the reference level, resulting in an overall long-term improvement in catch value. Off Bermagui, the greatest improvement in overall catch value was observed for 110 mm diamond codend which increased to about 4% above the reference level. This increase was largely due to an increase in the value of pink ling and tiger flathead (*Neoplatycephalus richardsoni*), and a comparatively small decrease in value of Gould's squid catches. Off Portland, both the 110 mm diamond and 102 mm square resulted in a 3% increase to catch value, both due to a large increase in the value of pink ling catches. The 110 mm square codend was the only test mesh that resulted in a long-term decrease in catch value. The critical question is whether the CTS can afford the short term losses in order benefit from the long term gains.

As a direct result of this project, and a further extension project FRDC 2001/006 – Promoting industry uptake of gear modifications to reduce bycatch in the South East Trawl Fishery – SETFIA promoted the use of larger and/or rotated mesh panels and they are now fitted into every trawl net in the SESSF.

At the time that the results of this project became available for industry, the CTS was in difficult financial times. Costs were increasing due primarily to increasing fuel prices and repairs and maintenance costs for the ageing fleet. In addition, operators faced stable or falling real prices of fish and reductions in TACs were being implemented. The cost of management levies, quota leasing costs and other non-fishing regulatory costs such as workers compensation and payroll tax exacerbate the situation. In 2001/02, the GVP of the fishery was about $70 million, but net returns to industry were only $0.5 million, yet it was under significant pressure to improve its ecological credentials.

Given the above, it was a very difficult time for industry to accept the need for codend modifications to reduce bycatch that would come at an initial cost in lost value of the catch, regardless of the fact that there were potential long-term gains in stock biomass, yield, and catch value. Immediate implementation of such measures would have had significant financial implications for many fishing businesses. It was acknowledged that there was a definite need for uptake, but a lot of work needed to be done with industry to facilitate this. As a result, FRDC supported a project 2001/006 – Promoting industry uptake of gear modifications to reduce bycatch in the South East Trawl Fishery. Through this project and ongoing work by SETFIA, larger and/or rotated mesh panels were introduced into most trawls in the SESSF and were ultimately mandated.

KEYWORDS: South East Trawl Fishery, bycatch reduction, gear modification.

1.1 ACKNOWLEDGMENTS

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2 BACKGROUND

2.1 PROJECT CONTEXT

On a worldwide basis, there is increasing concern about the ecological impacts of trawling (see review by Hall 1996). Reports of high levels of bycatch of fish and other species, habitat degradation, bad practices, stock depletion and perceptions of wastage and negative ecological impacts continue to fuel these concerns. At the 1996 World Fisheries Congress, there were numerous papers which highlighted these problems in fisheries around the world (e.g. Kennelly 1997; Suuronen, 1997; DeAlteris *et al*. 1997). In most cases, however, dedicated efforts to overcome such problems had been successful, particularly when they had involved cooperative teams of Industry members, fisheries managers, researchers and other interested community groups.

2.2 THE COMMONWEALTH TRAWL SECTOR

Australia's Southern and Eastern Scalefish and Shark Fishery (SESSF) is a complex multi-species fishery that provides most of the fresh fish for markets in south-eastern Australia and an export market to Asia and America. The Commonwealth Trawl Sector (CTS) is a sub-fishery of the SESSF previously known as the South East Trawl Fishery (SETF). Managed by the Australian Fisheries Management Authority (AFMA), the CTS is extends to the outer limit of the 200 mile Australian Fishing Zone (AFZ) off the states of South Australia, east from Kangaroo Island around Victoria and Tasmania to Barrenjoey Point near Sydney in New South Wales (Figure 2-1). The fishery operates in a variety of habitats in the shelf and upper slope waters over this wide geographical area. As such, a large range (>400) species are caught (Knuckey *et al.* 2000; 2001) from which over 100 species of fish and invertebrates are landed (Klaer and Tilzey 1994). Thirty-four of these species/groups are under quota management species groups comprise about 80% of the fisheries total catch (Morrison 2008). The CTS caught approximately 12,839 t of fish during 2008 with a gross production valued at around $46.4 million during the 2007–08 financial year (Morison *et al.* 2009)

2.3 BYCATCH IN THE CTS

In the CTS, like other trawl fisheries, issues such as high bycatch levels, habitat degradation, and perceptions of wastage need to be addressed.

Under Section 3 of the *Fisheries Management Act 1991 (Commonwealth)*, AFMA is required to ensure "that the exploitation of fisheries resources and the carrying on of any related activities are conducted in a manner consistent with the principles of ecologically sustainable development and the exercise of the precautionary principle, in particular the need to have regard to the impact of fishing activities on non-target species and the long term sustainability of the marine environment." An important part of achieving this objective was the establishment of the Integrated Scientific Monitoring Program (ISMP), which uses on-board field scientists to collect information on the quantity, size and age composition of the retained and discarded catch taken by board trawlers and Danish seine vessels working in the CTS (Knuckey *et al.* 1999; 2000; 2001). Although initially funded by AFMA and state and Commonwealth research agencies, industry now recognises the value of this information and there is now 75 % cost-recovery from the catching sector. The ISMP has a stratified sampling regime reflecting catch composition, fishing methods and area fished, provides estimates of quota and non-quota discard rates in the fishery (Smith *et al.* 1997; Knuckey and Gason 2001). Based on this information, we know that for a variety of reasons (Liggins and Knuckey 1999), considerable discarding takes place in some areas of the fishery (Liggins 1996; Knuckey and Liggins 1999). Generally, the lowest levels of discarding are in the target fisheries for spawning orange roughy (*Hoplostethus atlanticus*) and blue grenadier (*Macruronus novaezelandiae*), where more than 90% (by weight) of the total catch is usually retained, whereas in the mixed species "market" fisheries in western Bass Strait and off the east coast of New South Wales, up to 50% of the catch may be discarded (Knuckey and Liggins 1999; Knuckey *et al.* 1999; 2000; 2001). Some quota species may be discarded due to minimum legal lengths and influence of Total Allowable Catches (TACs) and Individual Transferable Quotas (ITQs), and both quota and commercial non-quota species are often discarded because of their low value due to various market and economic forces (Liggins and Knuckey 1999). A major component of the discarded catch, however, consists of small species of fish that are of no commercial value. An example of the catch composition from market fishing off the east coast of NSW is provided (Figure 2-2 adapted from Knuckey *et al.* 2000).

Australia's 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 AFMA and stakeholders is endeavouring to address bycatch in the CTS by developing and implementing a fishery-specific Bycatch Action Plan (AFMA 2001). This plan provides a framework to minimise the impacts of fishing in the CTF, reduce bycatch levels and increase community education and awareness of bycatch issues in the fishery. The work being undertaken in the present study is an important component of the Plan. In addition to the Bycatch Action Plan, the CTS has undergone Strategic Assessment under the Environment Protection and Biodiversity Conservation Act (EPBC Act 1999). Based on this Assessment the fishery was declared as an approved Wildlife Trade Operation (WTO) for a period of three years. Given the uncertainty associated with this fishery, however, and the need to progressively implement improved management arrangements, the declaration was subject to a number of conditions which included that:

1) AFMA, in consultation with industry and other stakeholders:

- develop and implement management arrangements to significantly reduce the current total level of quota and non-quota discards in the SESSF within 3 years; and
- within 12 months as part of the bycatch plan determine target reduction levels and baselines for future discarding in the fishery that are acceptable to Environment Australia.

2) Effective management requirements to use discard and other bycatch mitigation measures will be introduced at the conclusion of a trial and development period of up to three years. AFMA will monitor the extent of uptake of mitigation measures and introduce mandatory measures where voluntary uptake of measures is insufficient.

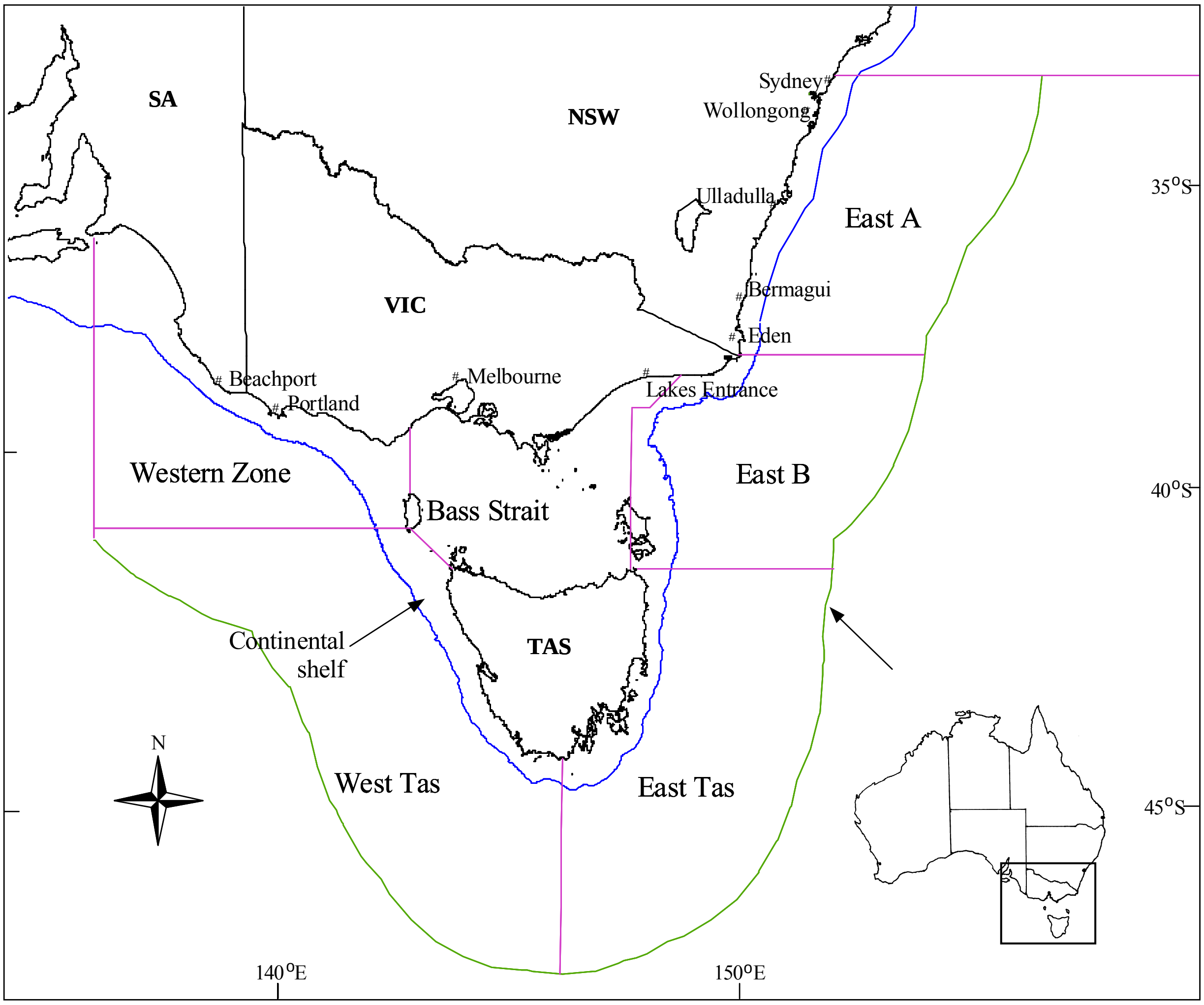


Figure 2-1 Spatial extent of the South East Trawl Fishery including the zones used to summarise the sub-fisheries (from Klaer and Tilzey 1994). The project was conducted off Bermagui in the east and Portland in the west.

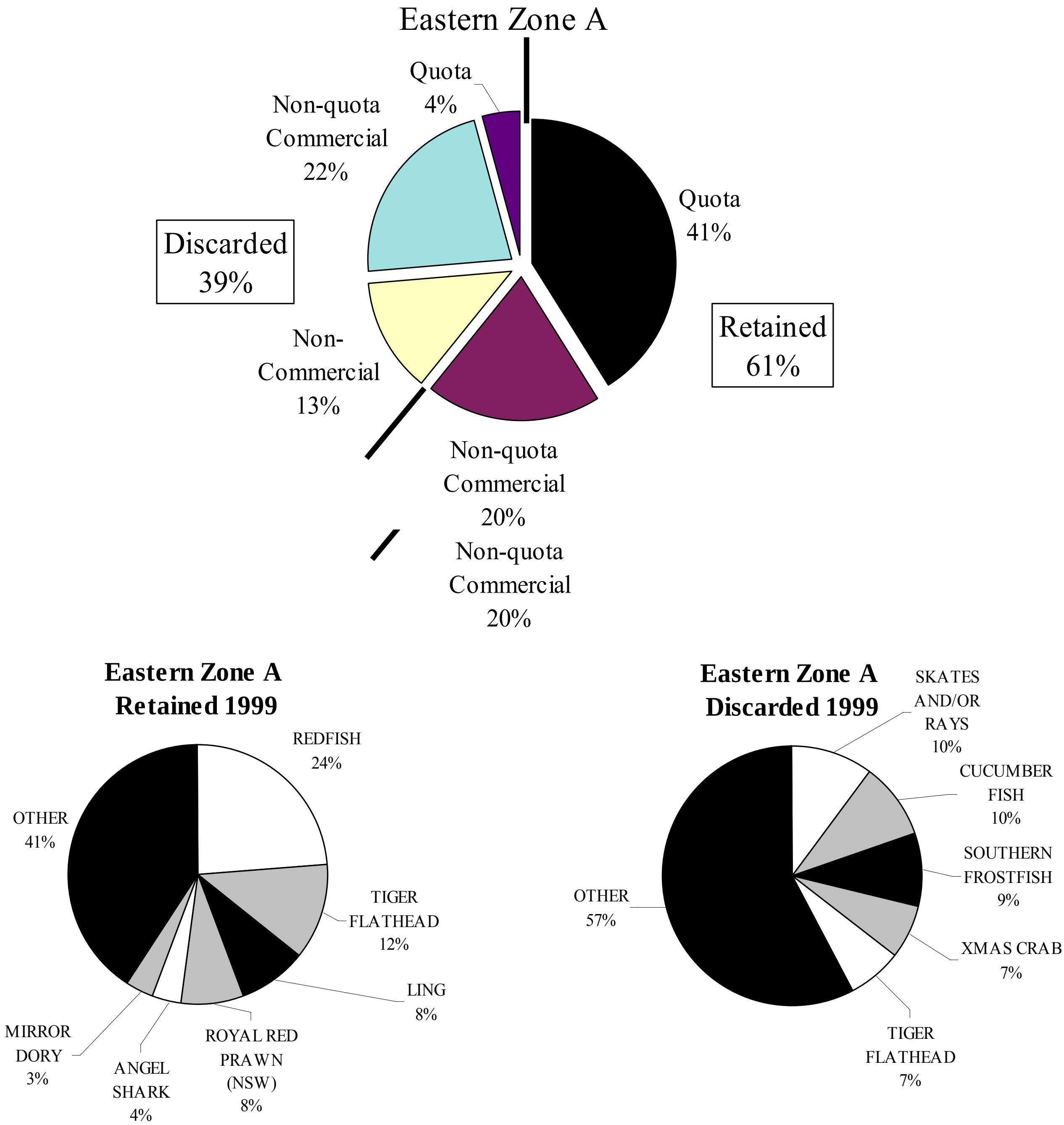


Figure 2-2 . An example of the composition of the retained and discarded catch in a typical "market fishing" shot off the east coast in the CTS (from Knuckey *et al.* 2000).

2.4 BYCATCH REDUCTION OPTIONS

Apart from its potential ecological concerns, discarding is considered unproductive and time consuming for fishers who have to sort through the catch and is also seen as a waste of a potentially valuable resource. Furthermore, whilst the effects of discarding have yet to be established at an ecosystem level, the practice attracts negative publicity for the Industry and is generally considered to be contrary to the principles of ecologically sustainable development.

Kennelly (1997) showed a number of examples in which genuine efforts to address bycatch had been successful. He highlighted that once bycatch issues were identified and quantified by observer programs, the success of the process depended on industry and scientists working together to determine and trial various ideas in order to find the best solution/s to the problem. This approach was initiated in the CTS in the form of a workshop held to begin addressing the bycatch and discarding issues of the fishery. Participants at the workshop included Industry members, fishery managers and people from various research agencies, government and non-government environment and conservation groups. At the workshop it was recognised that the bycatch of birds, turtles and dolphins was virtually non-existent in the fishery and the low capture rates of seals and benthos were not regarded as major issues (Knuckey and Liggins 1999) at that time. The level of discarding of small fish, however, was significant and was highlighted as the biggest bycatch issue in the CTS. The workshop concluded that there was potential for a variety of options to address the discarding problems in the CTF, including changes to management, improved utilisation and marketing of bycatch species, and changes to trawl gear selectivity. Participants supported the development of a project to investigate the potential of technological modification to CTS fishing gear to reduce the bycatch of small fish species. It was highlighted at the workshop that the success of the project would depend on a high level of industry involvement in developing and undertaking the project. As such, it was agreed that an industry member would be a co-investigator of the project and research would be conducted on industry vessels. A comprehensive extension and communication strategy —“letting the message get through”— was an important aspect of the project. To this end, the use of underwater video footage was considered a valuable tool, not only to monitor fish behaviour and observe characteristics of modified gear, but also as an effective means of getting the objectives and results of the project through to Industry and the wider community.

3 NEED

Discarding is unproductive and time consuming for fishers who have to sort through the catch and when commercial fish are discarded it is also seen as a waste of a potentially valuable resource. Furthermore, whilst the effects of discarding have yet to be established at an ecosystem level, the practice attracts negative publicity for the Industry and is considered by some to be contrary to the principles of ecologically sustainable development. For these reasons, it is necessary to consider ways of reducing the level of discarding in the CTS.

An understanding of gear selectivity is essential for the effective management of any fishery. Control of gear selectivity is a pre-requisite to regulating fishing mortalities associated with total catches (retained and discarded components). Like the majority of the world's fisheries, selectivities of trawls in the SESSF are regulated by means of legally defined minimum mesh sizes (currently 90 mm). There is a great potential however, to use the recent advancements in trawl technology such as different shapes and sizes of mesh panels and codends, exclusion devices and modified trawl rigging to help modify SESSF trawls and improve their selectivity towards targeted species and reduce the catch of small fish that are usually discarded. Thus, an extensive range of "tools" have been developed to improve trawl gear selectivity and overcome many of the perceived problems associated with trawling. With a sound knowledge of the use of such tools, they can be readily applied in the SESSF although they do need to be designed to meet the specific gear / species configurations that occur in this fishery.

There would be many benefits for CTS fishers if gear selectivity or fishing practices could be modified to maximise the yield of their catch whilst reducing the catch of unwanted fish. The problem is to develop practical solutions to the various selectivity-related problems in the CTS which will be willingly be adopted by the fishers.

It is important to note that in any fishery, the development and adoption of gear modifications to achieve certain goals, such as bycatch reduction, is a long and often tedious process. The current project is only a small step in this process. It will not solve, and is not expected to solve, all of the CTS bycatch problems. The results of the project will form one of the foundations upon which the CTS can exist under the principles of ecologically sustainable development.

4 OBJECTIVES

The project had four major objectives as outlined below:

1. Develop and evaluate modifications of trawl gear to reduce the capture and subsequent discard of small fish by SESSF trawl vessels.

2. Measure the effectiveness of gear modification in the reduction of discarding against bycatch targets and indicators in the CTS Bycatch Action Plan to be developed by the SETMAC bycatch action plan working group.

3. Quantify the economic implications of gear modifications to Industry. (Ensure appropriate data are collected to allow assessment of long-term economic outcomes).

4. Develop an extension strategy to ensure background and progress of project are adequately communicated to Industry, AFMA and the wider community.

5 TRAWL SELECTIVITY

5.1 INTRODUCTION

The use of industry vessels was considered a priority for this project for a number of reasons. This allows for gear trials to be conducted within normal fishing operations and provides access to local knowledge of current productive fishing grounds, meaning that direct observations of the effect of any modification type can be gauged against 'real' fishing operations where industry catch mixes and quantities will be represented. Industry acceptance is generally higher due to the fact that they have direct involvement in the project, and they can offer timely advice to associated gear problems. A further benefit is that one of the best ways to convey results is through industry word of mouth and direct contact with other fishers at the end of a day.

The project experiments were conducted on recognised trawl grounds in the eastern sector (Bermagui) and western sector (Portland) of the CTS. Industry vessels were invited to participate via a publicised tender process. Two vessels were chosen to provide the industry charter component of the project. For the eastern area, the FV 'Shelley H' was chosen. This vessel is a 17.3 metre, steel stern trawler powered by a 380 HP Cummins. The net used throughout the project was a Bollinger wing trawl. This net had a headline length of 18 fathoms with a headline height of 2.5 fathoms. Meshes around the mouth of the net were 45 ply, 4.5 inch mesh. In the western area, the FV 'Zeehaan' was used. The Zeehaan is a purpose built stern trawler with LOA of 22.5 metres and powered by a 425 HP Cummins. The net used was also a Bollinger wing trawl that was also used through the duration of the project. This net was slightly larger than that used in the east, having a headline length of 20 fathoms and a headline height of 2.5 fathoms. Meshes around the mouth were 60 ply, 4.5 inch.

Both vessels were 'typical' trawl vessels for their respective ports, and used the minimum specified mesh size of 90 mm inside knot length, constructed of 4 mm double braid mesh.

Trawl selectivity can be measured directly by the covered codend method, or indirectly by ‘paired-gear’ methods (Wileman *et al.* 1996). The covered codend method is frequently used to determine codend mesh selectivity (e.g. Dahm 1998; O’Neill and Kynoch 1996; Petrakis and Stergiou 1997) but effective use of this method can be operationally difficult, particularly on small vessels. The duration of test trawls are usually much shorter than commercial trawls because the accumulation of relatively large quantities of small fish in the cover may drag it down onto the codend and inhibit the escape of fish through the codend meshes (Cooper and Hickey 1988).

5.2 MATERIALS AND METHODS

The technique of using a “covered codend” was utilised to determine the selectivity of current trawl codends. The codend cover comprised two sections (Figure 5-1). The main body of the cover was of a four panel construction. Each panel consisted of 100 meshes by 100 meshes of 45 mm mesh, 60 ply polyethylene twine. A second section consisted of a large mesh skirt placed at the leading edge of the cover to assist water flow. The skirt was constructed of 10 meshes of 105 mm mesh length, 3 mm diameter polyethylene braid. The covered codend method has been noted as possibly affecting selectivity due to a phenomenon known as "masking" in which the cover meshes block the codend meshes, effectively inhibiting species from escaping through the codend. To alleviate this problem, two hoops were constructed and placed in two areas of the cover to keep it apart from the codend. The hoops were constructed of 14 mm diameter high density polyethylene irrigation pipe. The forward hoop had a diameter of 1.6 m and the aft hoop a diameter of 2.2 m.

The cover skirt was placed on the extension piece to allow the small mesh cover to totally surround the double braided codend meshes. The cover then extended beyond the end of the codend to allow escaping fish to be caught and retained behind the codend. To view whether "masking" was occurring, the full scale cover was placed in a flume tank and underwater video cameras were used during tows to observe the clearance between the codend and cover (Plate 5-1, Plate 5-2).

In normal commercial operations, tows are usually of 3 to 4 hours duration. For the covered-codend experiments, tow duration was reduced to between sixty and ninety minutes due to the potentially large quantities of small fish retained in the cover. Over a period of 8 months, 51 separate shots were conducted (28 off Bermagui and 23 off Portland) over 19 days.

5.2.1 Catch composition

Once a shot was completed the trawl was hauled to the vessel and both codend and cover were brought on board and sorted separately. The weights and numbers of each species caught in both the cover and codend were recorded. A random sub-sample of each species of fish was taken from the cover and codend for length frequency measurements. The caudal fork length (LCF) or total length (TL) was measured down to the nearest centimetre. Separate length frequency distributions for each species were plotted for fish from the cover and those from the codend.

5.2.2 Comparison of catch length frequency with and without the cover

There was some concern that the addition of the cover might alter the selective characteristics of the codend and therefore bias results of the covered-codend experiments. To test for this the length frequency distribution of a number of species caught in the codend with the cover on was compared with the length frequency distribution when they were caught with the cover off. Kolmogorov-Smirnov two sample tests were conducted on the distributions.

5.2.3 Selectivity of standard 90 mm double-braid codends

The selectivity ogive was established for 4 mm double-braid 90 mm diamond-mesh codends by plotting the number of fish within each one centimetre length class as a percentage of the total number of fish of that length-class. Data were pooled across regions because it was assumed that selectivity would not differ between regions although availability might. A logistic curve was fitted using a non–linear least squares procedure and the length at which 50% retention occurred was determined ($L_{50\%\ \mathrm{retained}}$). The fitting procedure was weighted with respect to the number of fish in each length-class to reduce the influence of low numbers of fish at the extremity of the selection ogive. The form of the logistic equation used was:

$$\%\ \mathrm{retained} = 100 / (1 + e^{a \times (b - c)})$$

Where *a* is a parameter indicating the rate of increase in retention;

b is a parameter representing 50% retention;

c is the 1 cm length–class.

5.3 RESULTS AND DISCUSSION

5.3.1 Catch composition

About 70% of the organisms in the total catch escaped through the codend and were caught in the cover; this represented about 30% of the catch by weight (Plate 5-3, Figure 5-2 Table 5-1). The codend catch consisted mainly of teleosts (79% by weight), elasmobranchs (15%), cephalopods (4%) and crustaceans (2%). In contrast, nearly all (96%) of the catch from the cover consisted of small teleosts (Figure 5-3). The most common teleosts in the cover were small non-commercial species including toothed whiptail (*Lepidorhynchus denticulatus*), grey whiptail (*Caelorinchus parvifasciatus*), threespine cardinalfish (*Apogonops anomalus*) and blacktip cucumberfish

(*Paraulopus nigripinnis*) (Figure 5-4). It is important to note that it is these species that form a large component of the catch that is usually discarded from the trawlers during standard commercial operations (Knuckey and Liggins 1999). Only low proportions of crustaceans (2%), cephalopods (1%) and elasmobranchs (1%) were in the cover. The large reduction in the percentage weight of elasmobranchs in the cover (1%) compared to the codend (15%) reflects the large number of draughtboard sharks (*Cephaloscyllium laticeps*), rays and stingarees, whose wide girths or shapes prevented escapement from the codend. In contrast, most of the elasmobranchs caught in the cover were various species of catshark and dogfish. There was no major difference in the crustacean and cephalopod species composition in the cover compared to the codend; except that those in the cover were generally smaller individuals.

Quota species only comprised 7% of the weight of fish caught in the cover, but this was evidence that small individuals of these species (ocean perch *Helicolenus spp*., gemfish *Rexea solandri*, flathead *Neoplatycephalus* and *Platycephalus spp*., pink ling *Genypterus blacodes* and redfish *Centroberyx affinis*) could escape through the codend.

Obviously, these finding have raised a lot of question about the survival of fish that escape through the codend. Video footage revealed that many of the fish that escape through the codend swam away, but it was also evident that some fish were damaged as they escaped through the codend. Quantification of the survival was unable to be ascertained during this project but is likely to vary significantly depending on the species.

Previously, a few covered codend experiments were carried out in the trawl and Danish seine fishery off New South Wales to determine selectivity of tiger flathead, redfish (Rowling 1979) and gemfish (Rowling 1986). Targeted specifically at selectivity, these experiments did not quantify the amounts of other “trash fish” escaping through the codend, but it was noted that large numbers of fish were caught in the cover. Industry has also held the view that significant numbers of fish are not retained by standard trawl codends. The present study has been the first to quantify escapement from SESSF trawls and the extent to which large numbers of small fish escaped from standard 90 mm codends was not expected. The findings were even a greater revelation to the various stakeholder groups not directly involved in the fishery, who had pre-conceived perceptions that virtually no fish escaped from within a trawl. In a newspaper article in Australia (Anon 2000) trawling was described “….where large nets are dragged through an area of the sea, catching all in their midst”. This highlighted the importance of getting the results of the initial fish escapement work through to Industry and wider stakeholder groups. Not only did the results of the present study provide baseline information against which future gear modifications could be compared, it laid the foundation of understanding upon which all stakeholders could work to better understand the issues and promote the value of bycatch reduction in the CTS.

Table 5-1. Number and weight of organisms caught in the codend and the cover summarised by species group.

Catch group	Codend		Cover		Total	
	Weight (kg)	Number	Weight (kg)	Number	Weight (kg)	Number
Cephalopods	826	2602	121	1108	947	3710
Crustaceans	296	4956	209	18310	505	23266
Elasmobranchs	2955	2136	54	362	3009	2498
Teleosts	15393	75161	8395	198156	23788	273317
Total	19470	84855	8780	217936	28249	302791

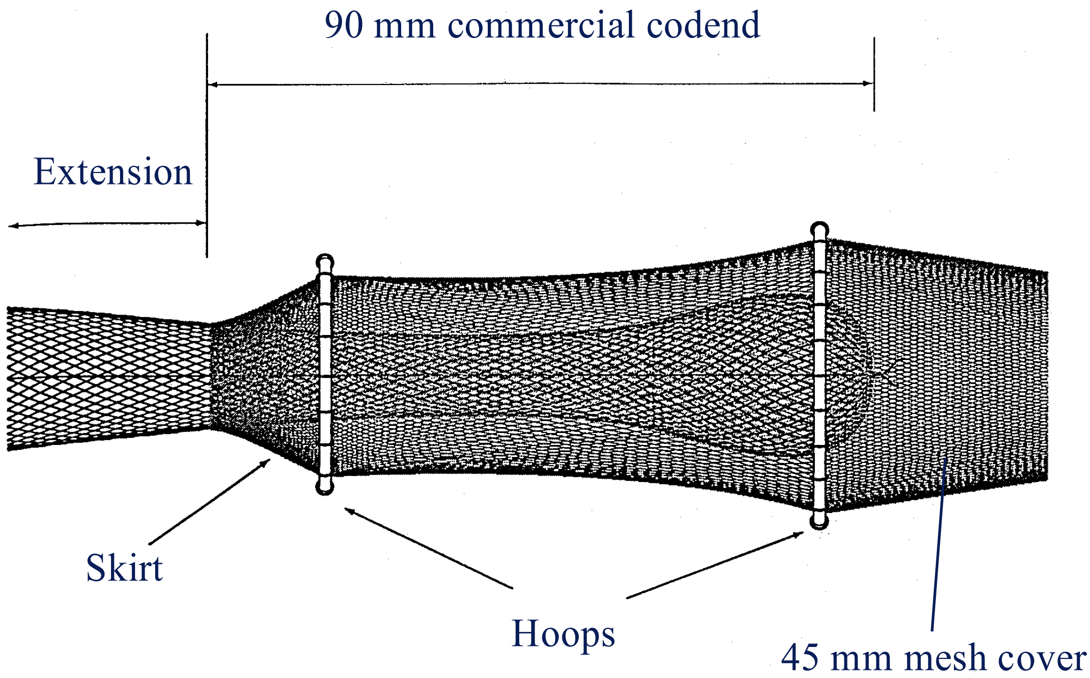


Figure 5-1. Diagram showing the small mesh cover placed around the standard 90 mm codend used in the CTS. Hoops supported the cover to ensure there was no masking of the codend. (Figure modified from Wileman *et al.* 1996).

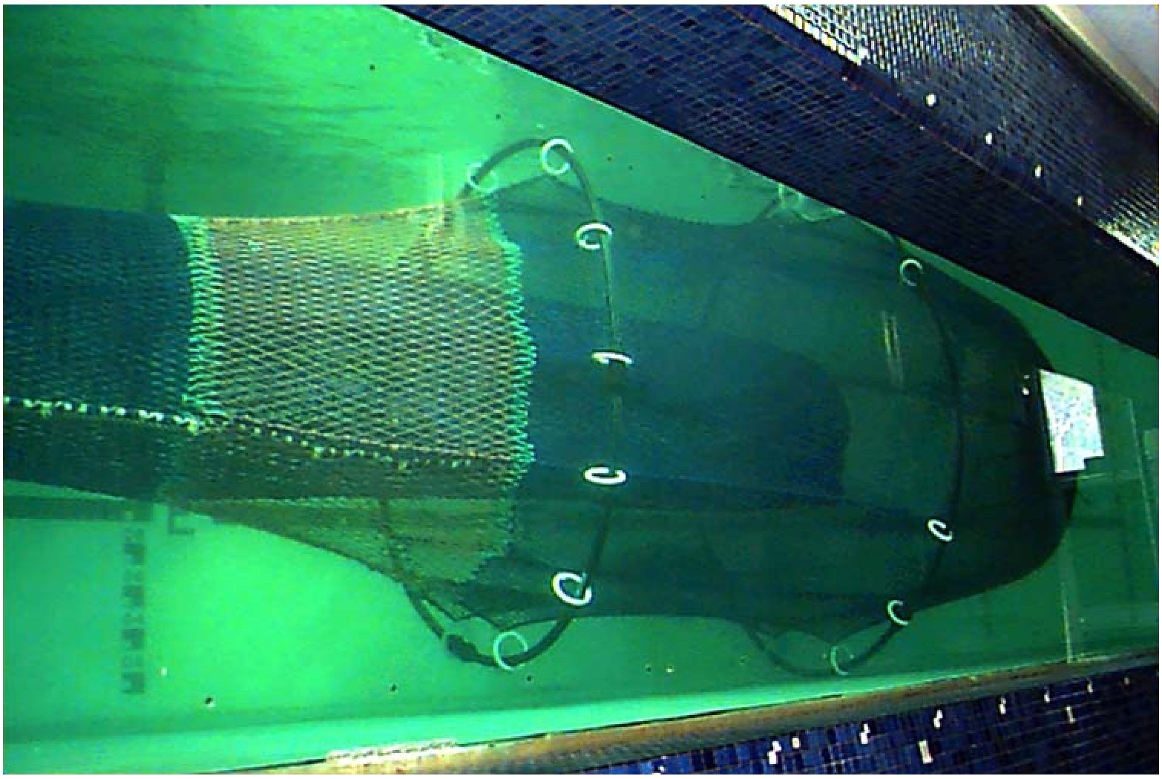


Plate 5-1. The covered codend trial in the Australian Maritime College flume tank.

Plate 5-2. Setting and deploying the covered codend on the Shelley H during project field trials.

Plate 5-3. Photographs of the catch from the codend (left) and the catch that escaped through the codend into the cover (right).

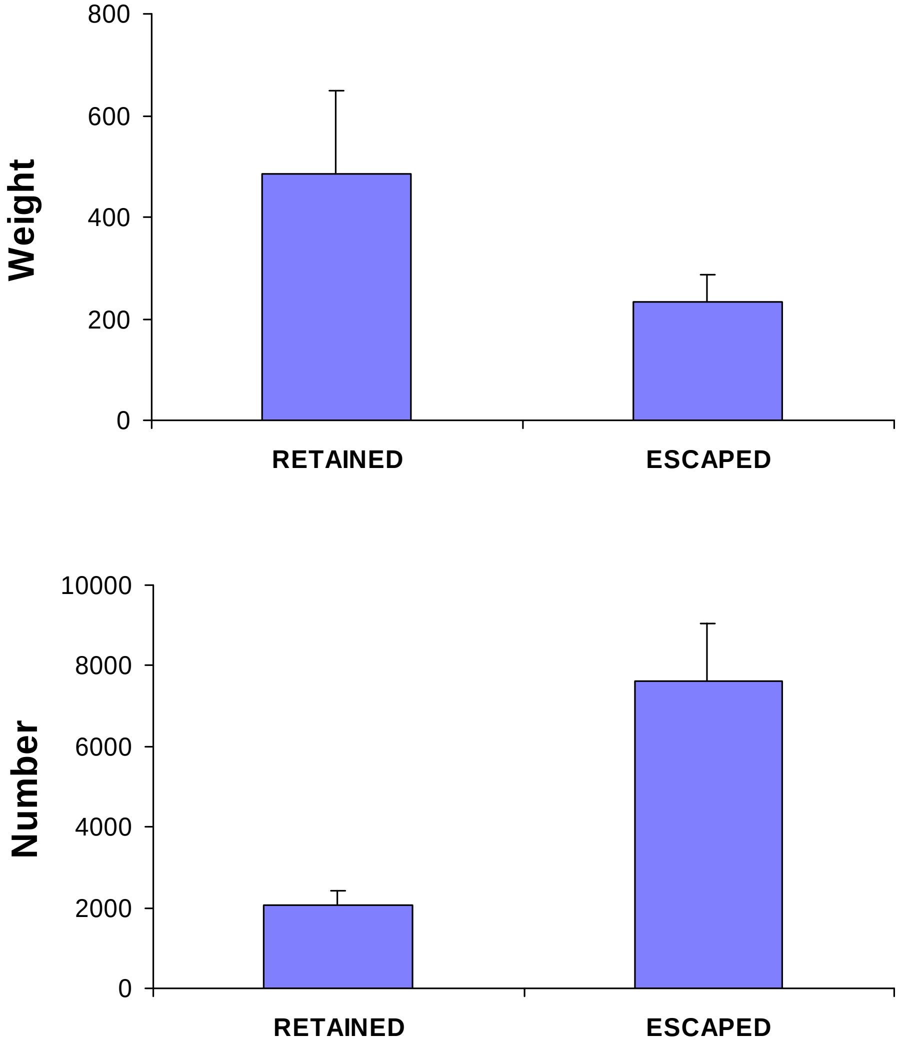
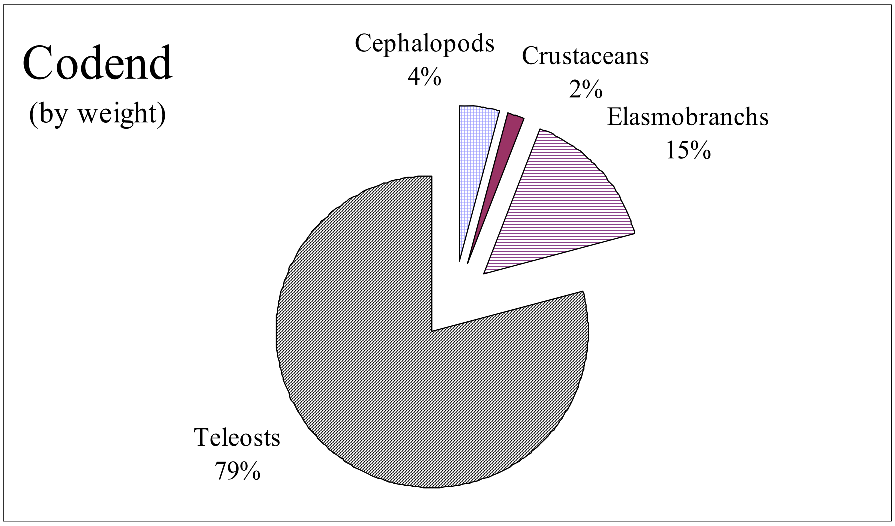


Figure 5-2. Histogram displaying the mean (±SE) of the weight (kg) and number of organisms that were retained in the codend or escaped into the cover.



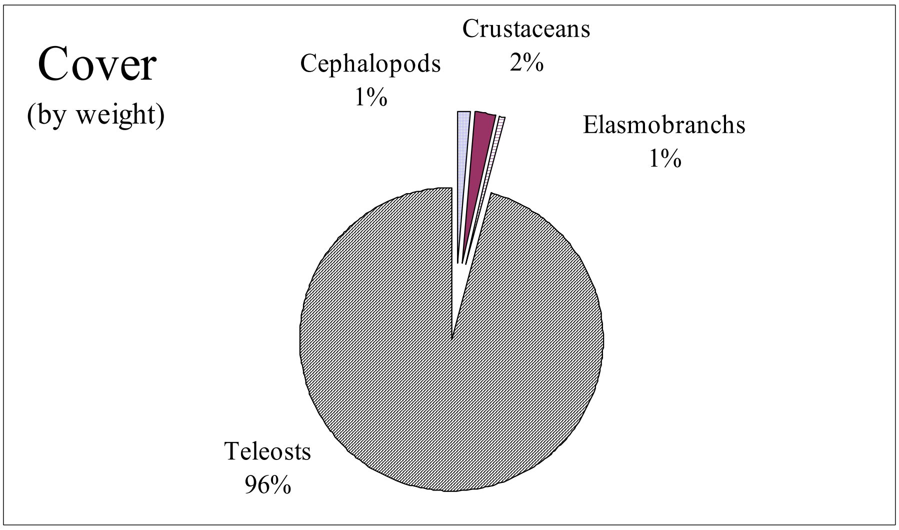


Figure 5-3. Pie charts of the species composition of the catches in the codend and cover.

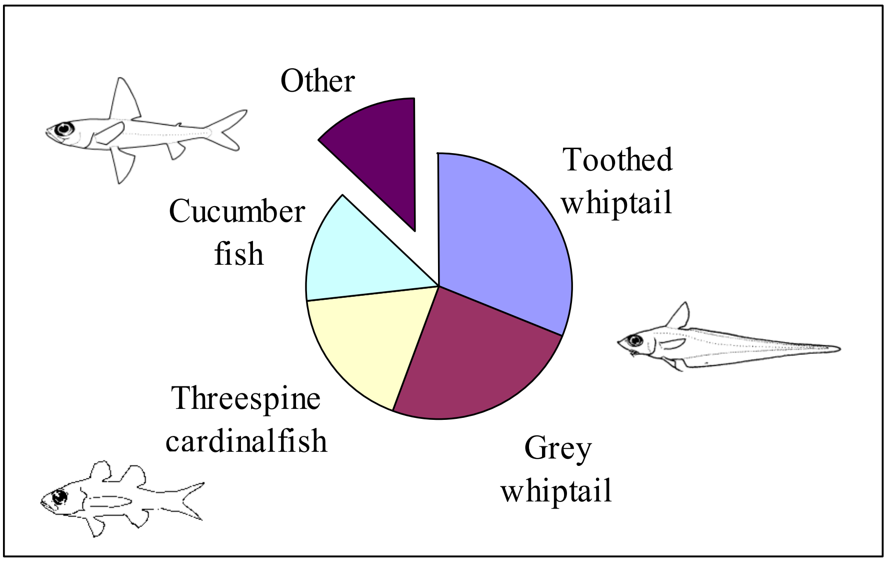


Figure 5-4. Teleost species caught in the cover (pictures from Gomon *et al.* 1994).

5.3.2 Comparison of catch length frequency with and without the cover

In conducting the covered codend experiments, the assumption is made that the addition of the cover does not significantly alter the selectivity of the net. Analysis of the length frequency of fish caught in the codend with and without the cover revealed that this assumption was sometimes true, but there were exceptions. No significant differences were noted for the most common bycatch species: toothed whiptail, banded whiptail (*Coelorinchus fasciatus*) and blacktip cucumberfish, or for John dory (*Zeus faber*) and offshore ocean perch (*Helicolenus barathri*) (Table 5-2). Significant differences were found for tiger flathead (*Neoplatycephalus richardsoni*), inshore ocean perch (*Helicolenus percoides*), grey whiptail, pink ling (*Genypterus blacodes*), roundsnout gurnard (*Lepidotrigla mulhalli*) and blue grenadier (*Macruronus novaezelandiae*). Plots of these length distributions are shown (Figure 5-5 to Figure 5-7) and reveal that a common difference is that a greater proportion of smaller fish were retained in the codend when the cover was on. It is not expected that this would have results from "masking" of the codend by the cover as the polyethylene hoops appeared to work very effectively. It may have arisen, however, due to the extra drag of the cover pulling on the extension, thereby closing the meshes forward of the cover and reducing escapement of smaller fish through the extension. This closure may have only been very slight as it appears to have only influenced size distributions of the generally larger fish species, not the small whiptails and blacktip cucumberfish. If this was the case, it implies the levels of escapement outlined in the previous section are possibly underestimated. It may also have slightly influenced the shape of the lower end of the selectivity curves shown in the next section.

Table 5-2. Kolmogorov-Smirnov two sample tests conducted on the length distributions of species in the codend with and without the cover.

Species	Chi-square	Pr.	Sig.
Offshore ocean perch	1.266911	.5<p<.7	non sig
Toothed whiptail	4.007568	.1<p<.2	non sig
Banded whiptail	3.667748	.1<p<.2	non sig
John Dory	5.231833	.05<p<.1	non sig
Cucumberfish	1.658312	.3<p<.5	non sig
Round snouted gurnard	6.868666	.02<p<.05	*
Blue grenadier	7.29959	.02<p<.05	*
Tiger flathead	17.19123	<.001	*
Inshore ocean perch	49.77026	<.001	*
Grey Whiptail	71.35855	<.001	*
Ling	17.46738	<.001	*

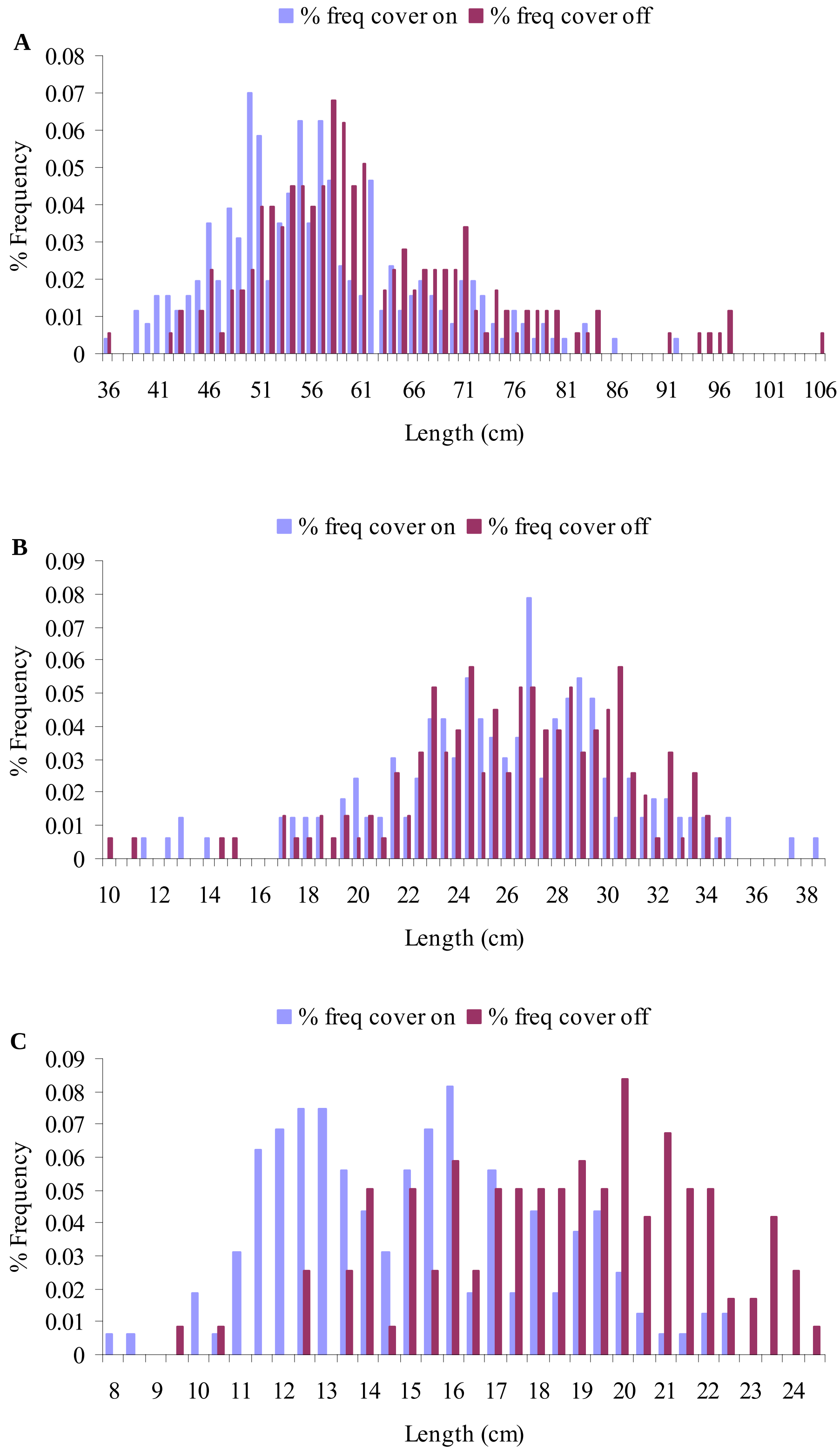


Figure 5-5. Comparison of catch length frequency in the codend with and without the cover. **A.** Pink ling (Sig.), **B.** Offshore ocean perch (N.S.), **C.** Inshore ocean perch (Sig.).

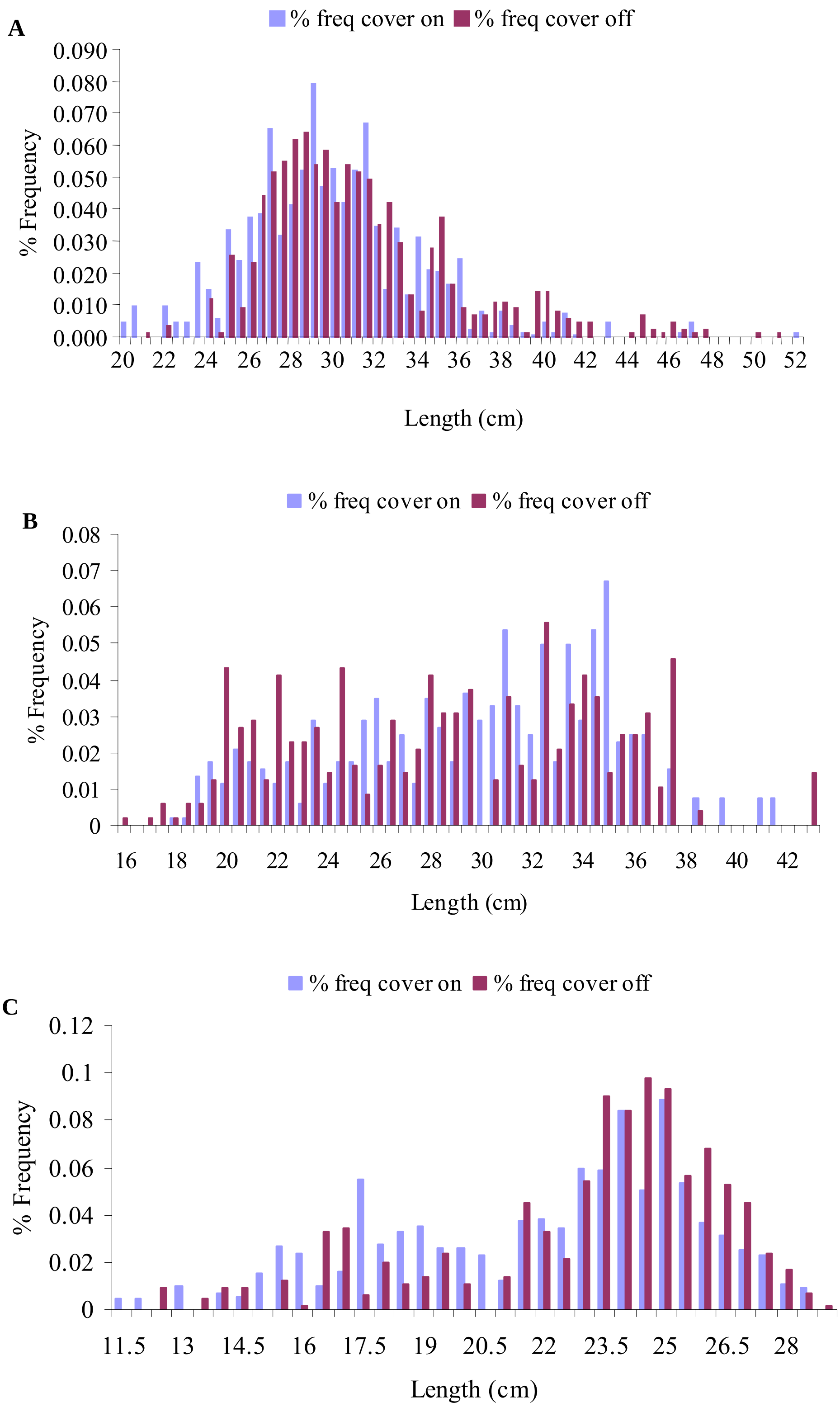


Figure 5-6. Comparison of catch length frequency in the codend with and without the cover. **A.** Tiger flathead (Sig.), **B.** Toothed whiptail (N.S), **C.** Grey whiptail (N.S).

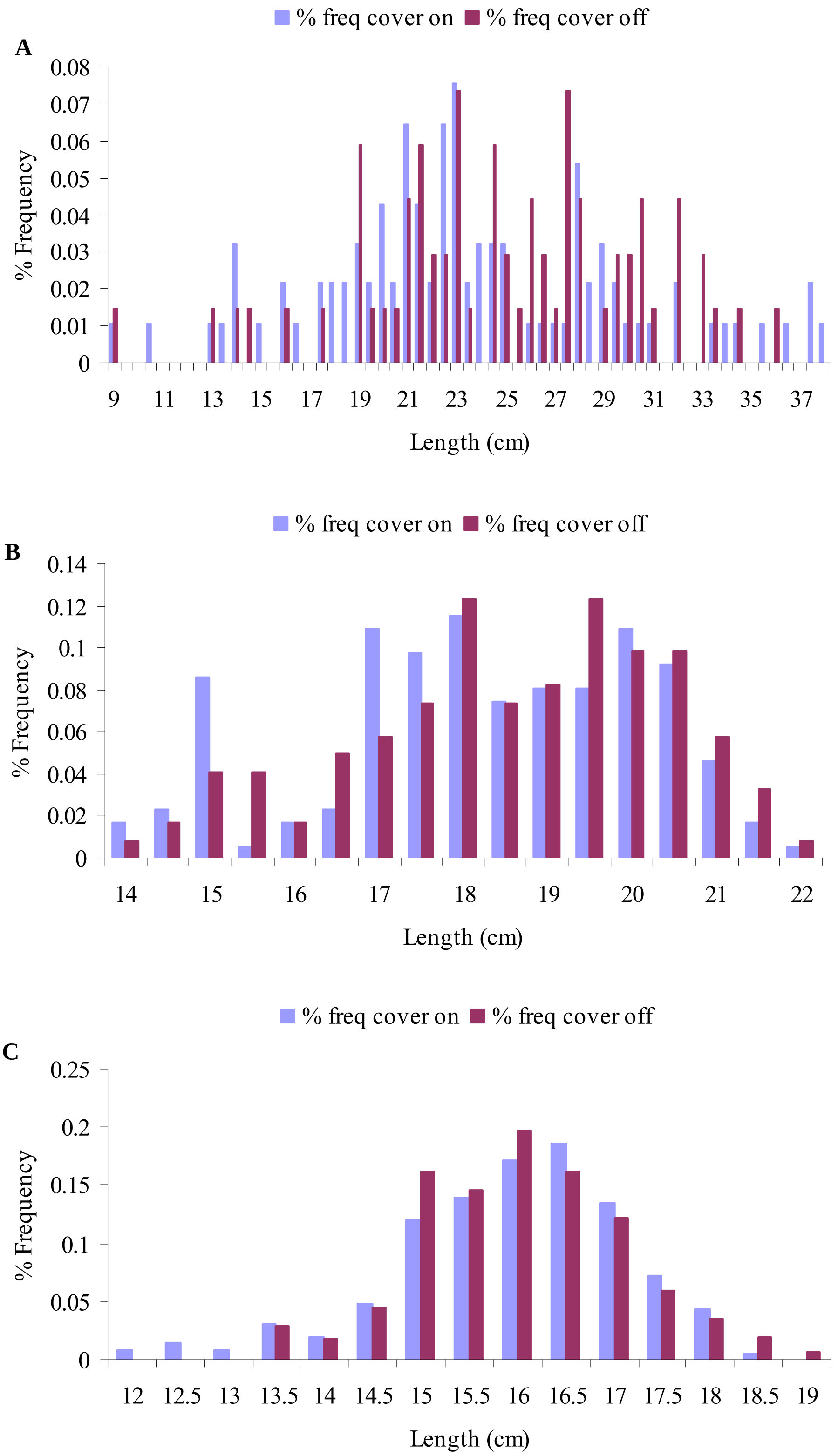


Figure 5-7. Comparison of catch length frequency in the codend with and without the cover. **A.** John dory (N.S.), **B.** Blacktip cucumberfish (N.S.) **C.** Roundsnout gurnard (Sig.).

5.3.3 Selectivity of standard 90 mm codend by species

Covered codend experiments yielded useful information on the selectivity of standard 90 mm diamond double braid codends for a number of common quota and bycatch species. In the East, selectivity ogives of quota species were produced for pink ling (Figure 5-8), gemfish (*Rexea solandri*) (Figure 5-9), inshore ocean perch (Figure 5-10), tiger flathead (Figure 5-11), and redfish (*Centroberyx affinis*) (Figure 5-12). Selectivity ogives were also produced for Gould's squid (Figure 5-13) and common bycatch species including toothed whiptail (Figure 5-14), banded whiptail (Figure 5-15) and grey whiptail (Figure 5-16). Less useful selectivity ogives were obtained for blacktip cucumberfish (Figure 5-17) and roundsnout gurnard (Figure 5-18).

In the west, selectivity ogives were achieved for the quota species blue grenadier (Figure 5-19), western gemfish (Figure 5-20), offshore ocean perch (Figure 5-21), and the non-quota commercial species deepwater flathead (*Neoplatycephalus conatus*) (Figure 5-22) and Gould's squid (Figure 5-23). Good selectivity ogives were also achieved for common bycatch species such as New Zealand dory (*Cyttus novaezealandiae*) (Figure 5-24), toothed whiptail (Figure 5-25), bigscale rubyfish (*Plagiogeneion macrolepis*) (Figure 5-26) and blacktip cucumberfish (Figure 5-27).

There were many species for which no selectivity data were not obtained. This was largely because the spatial and/or temporal distribution of the very small juveniles (relative to the mesh size) was such that they were simply not encountered during experiments. Quota species in this category included blue-eye trevalla (*Hyperoglyphe antarctica*), silver trevally (*Pseudocaranx dentex*), blue warehou (*Seriolella brama*), silver warehou (*Seriolella punctata*) and jackass morwong (*Nemadactylus macropterus*). Due to their shape, John dory and mirror dory also fell into this category as well.

Poor selectivity ogives were also observed because the gear did not appear to select some species by size (i.e. the same size range of fish were found in the codend and the cover). Examples of this are shown by blacktip cucumber fish and round-snouted gurnard. It is difficult to explain why this occurred. A possible explanation is that most of 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. Another possible explanation relates to the behaviour of the particular fish species. In the video footage, these smaller fish did not seem to actively swim or try to escape from the codend which may lead to poor selectivity.

5.3.3.1 Pink ling – East

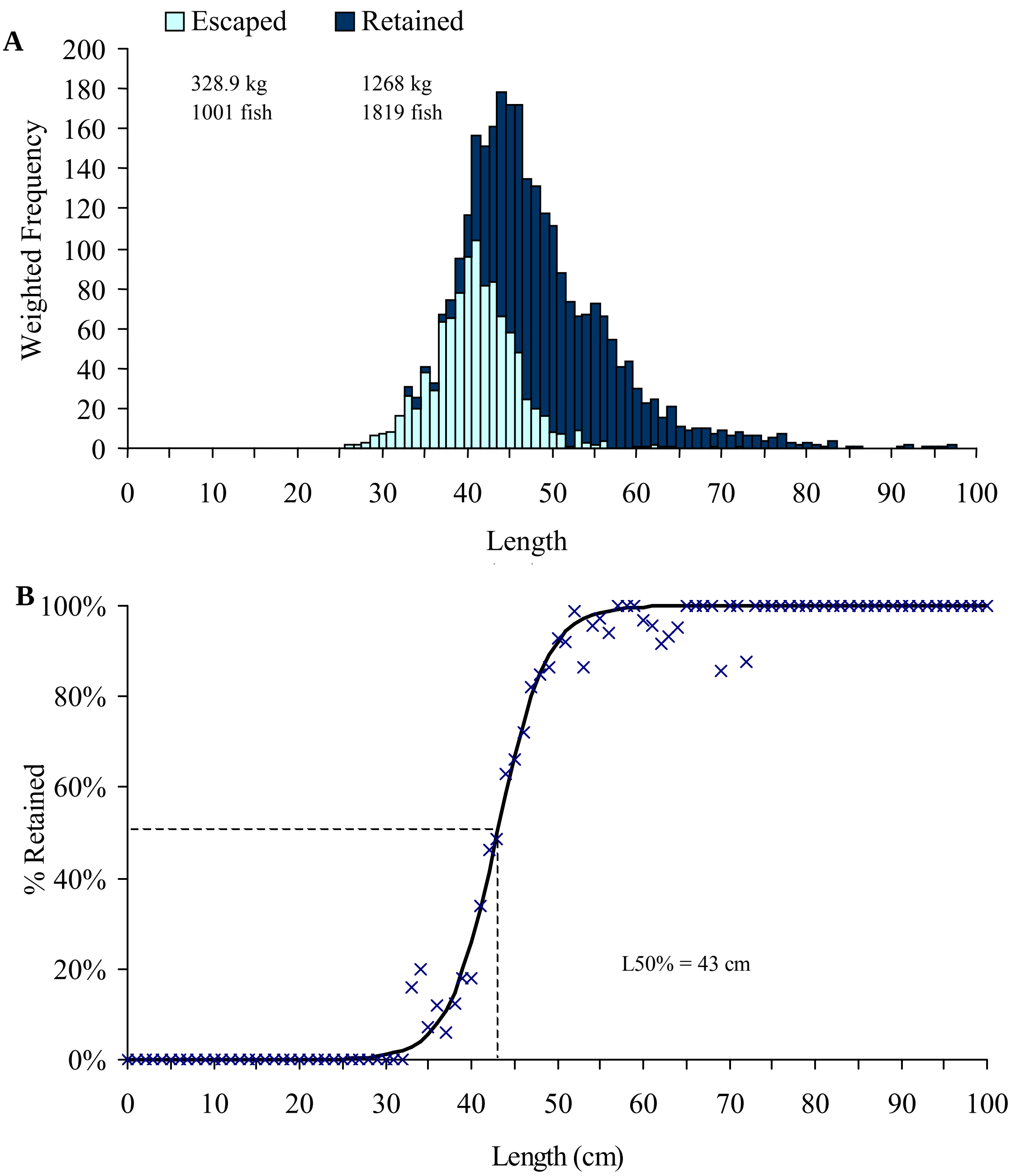


Figure 5-8. **A.** Length frequency distribution of pink ling (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for pink ling. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.2 Gemfish – East.

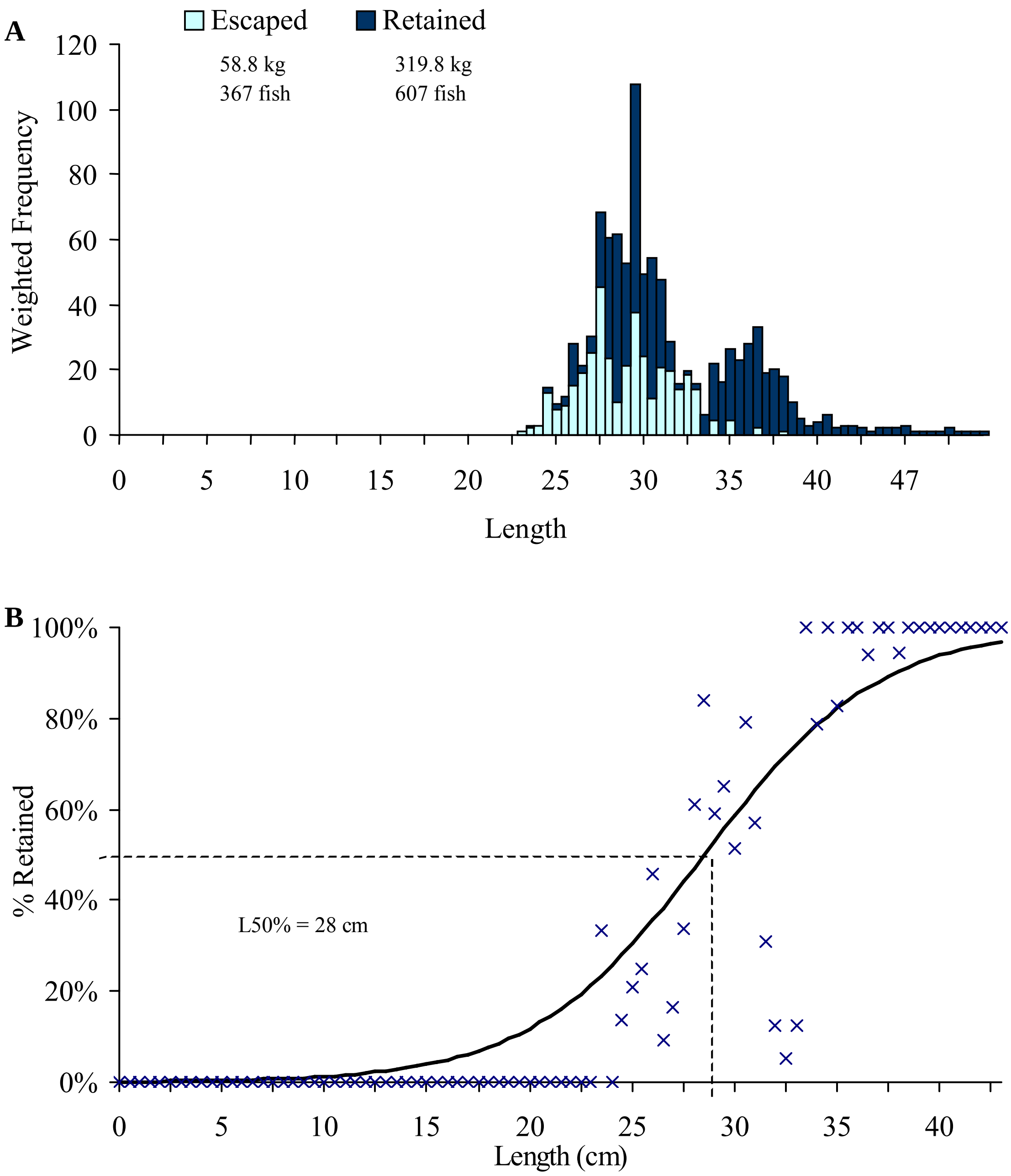


Figure 5-9. **A.** Length frequency distribution of gemfish (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for gemfish. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.3 Inshore ocean perch – East.

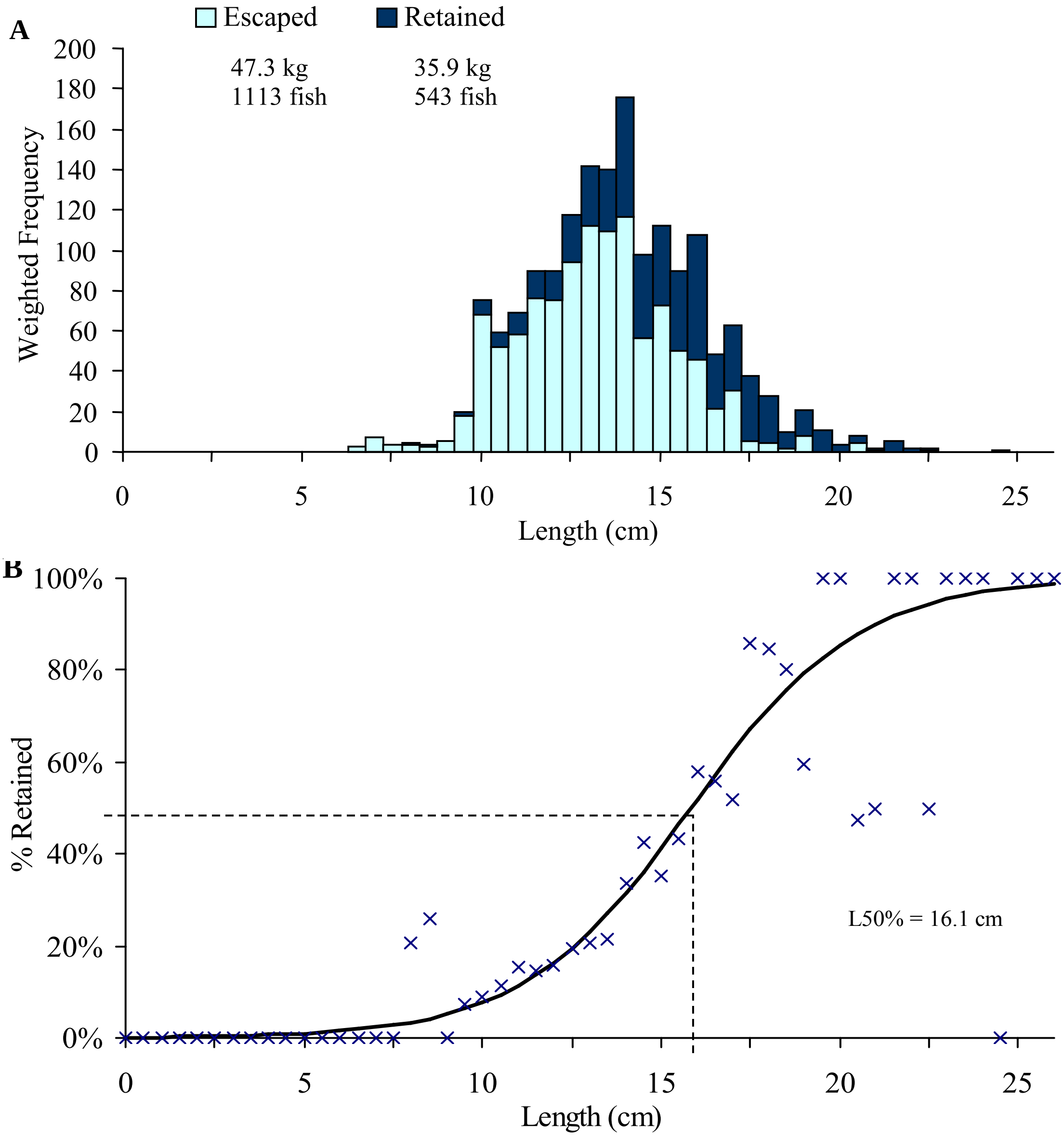


Figure 5-10. A. Length frequency distribution of inshore ocean perch (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for inshore ocean perch. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.4 Tiger flathead – East.

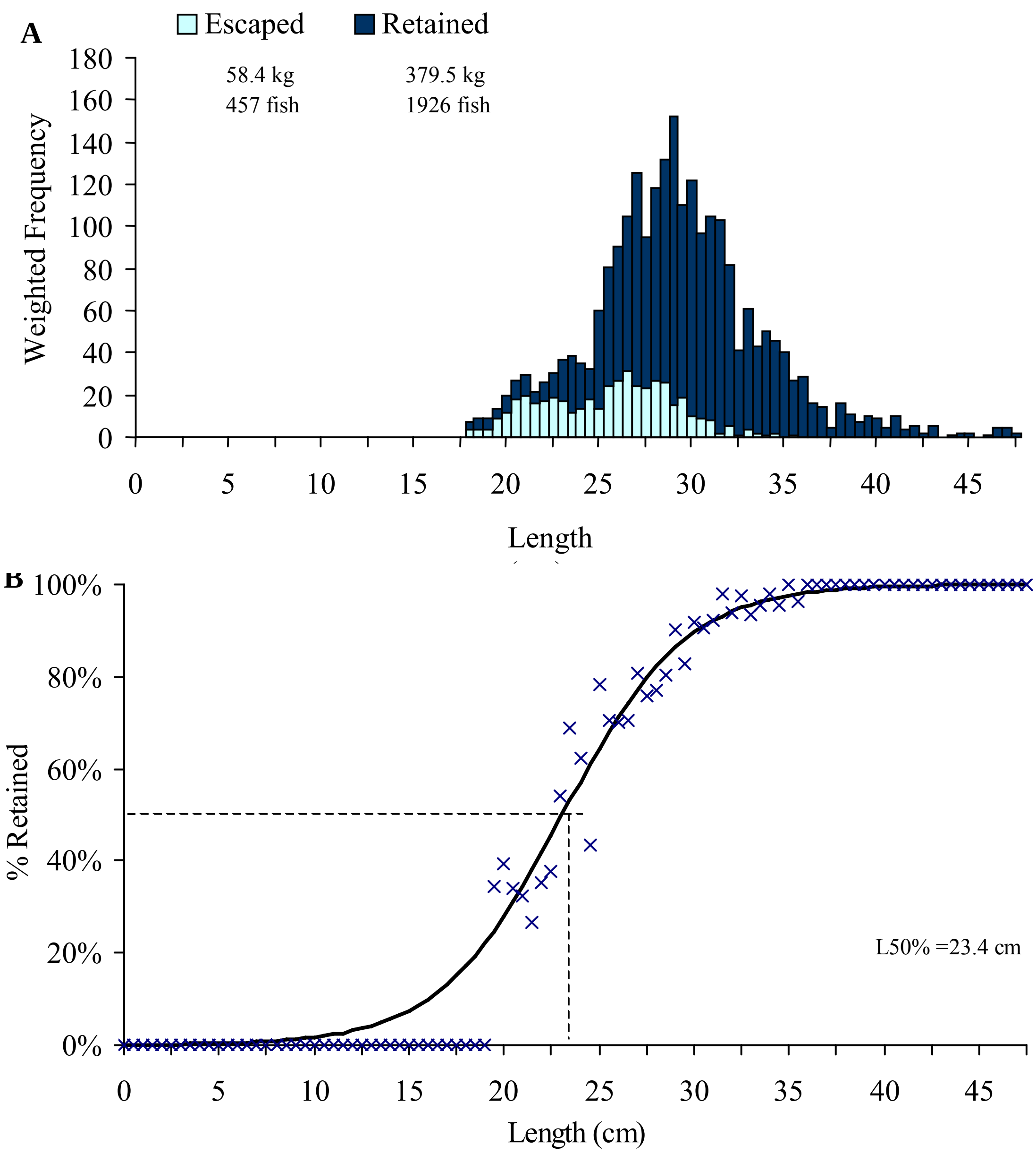


Figure 5-11. A. Length frequency distribution of tiger flathead (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for tiger flathead. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.5 Redfish – East.

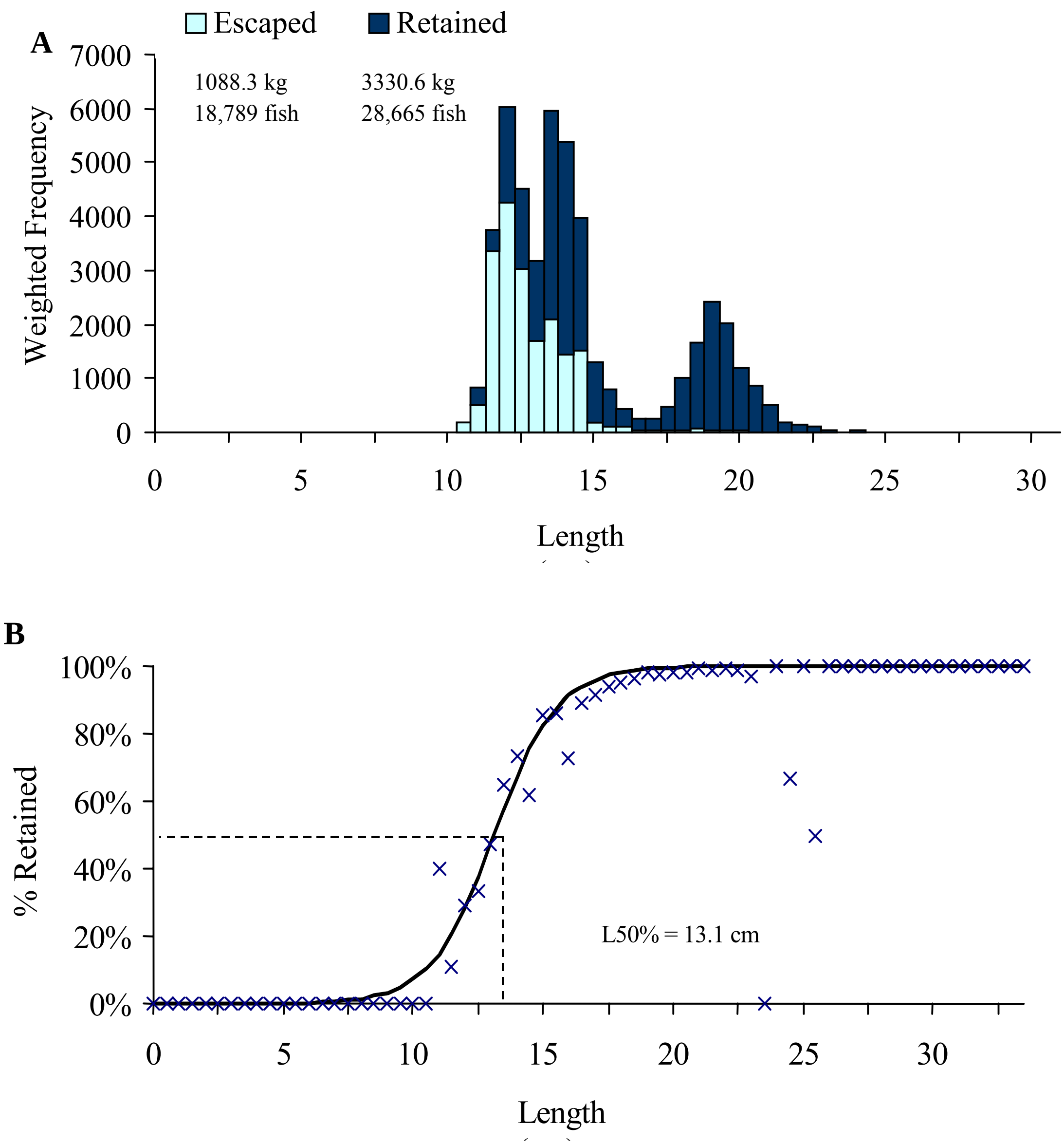
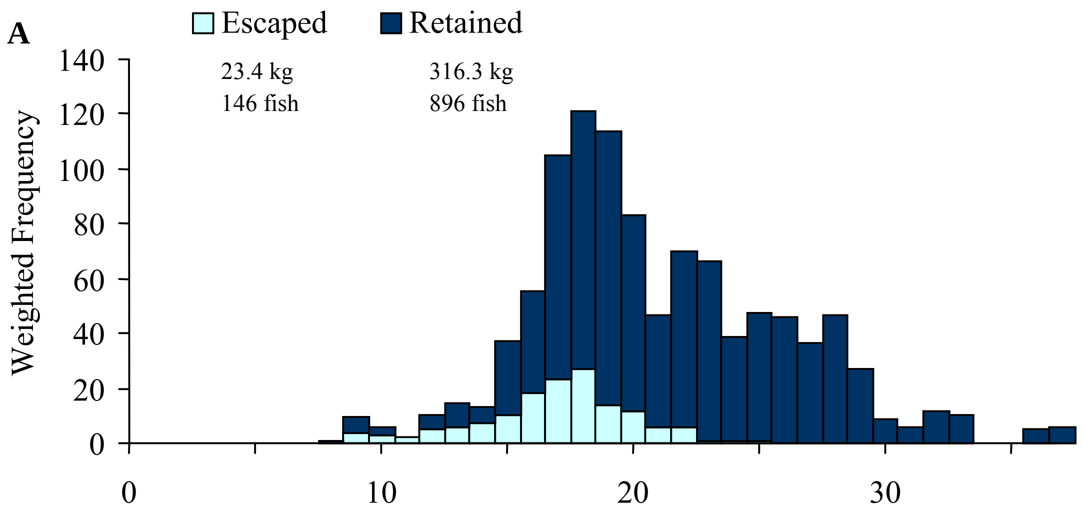


Figure 5-12. A. Length frequency distribution of redfish (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for redfish. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.6 Gould's squid – East.



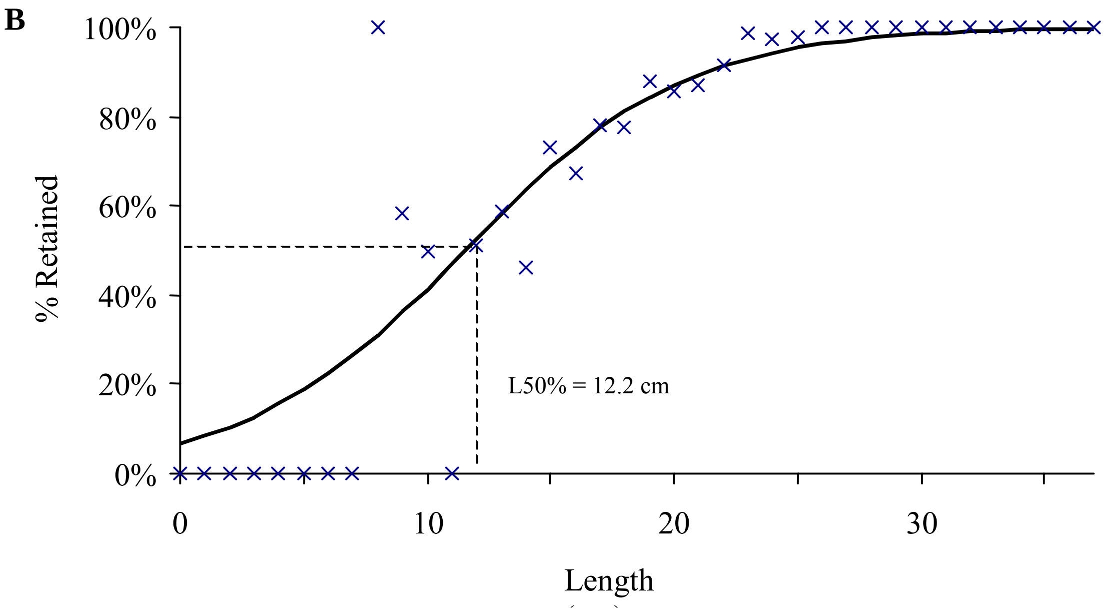
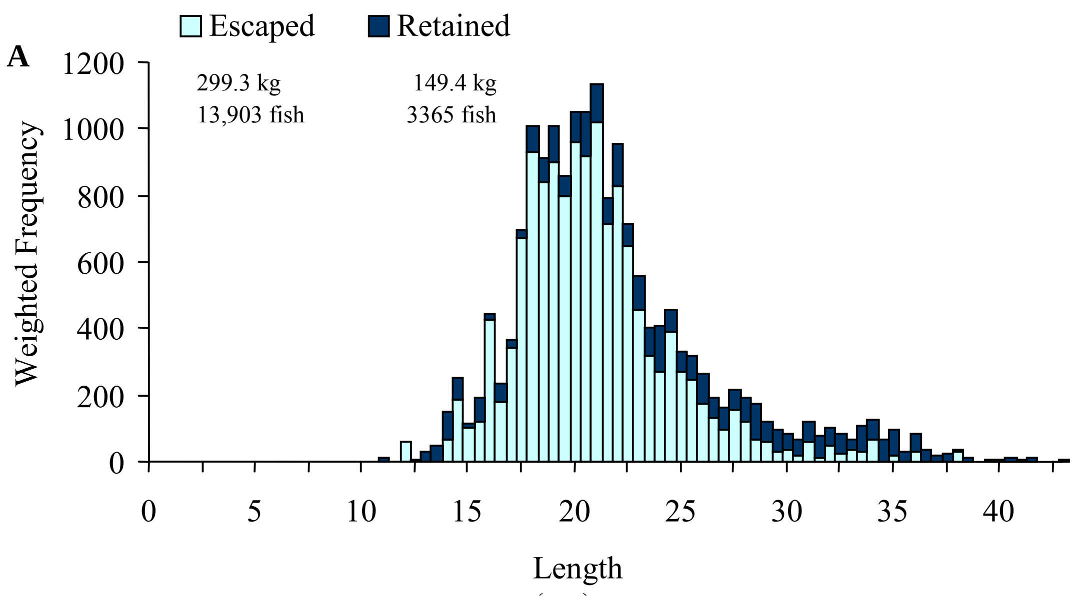


Figure 5-13. **A.** Length frequency distribution of Gould's squid (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for Gould's squid. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.7 Toothed whiptail – East.



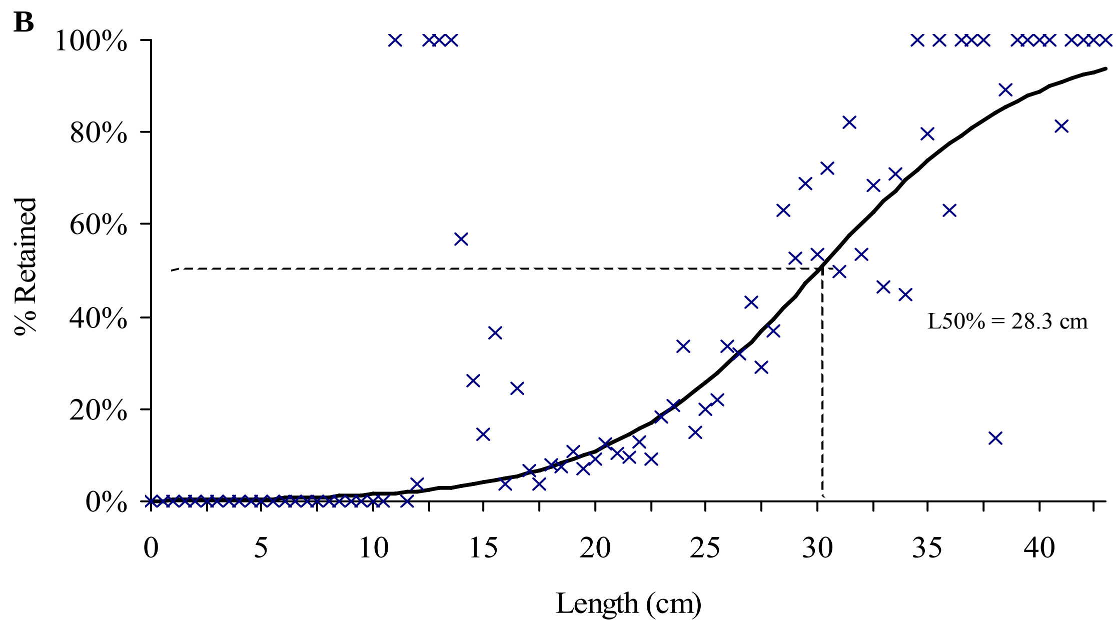


Figure 5-14. A. Length frequency distribution of toothed whiptail (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for toothed whiptail. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.8 *Banded whiptail – East.*

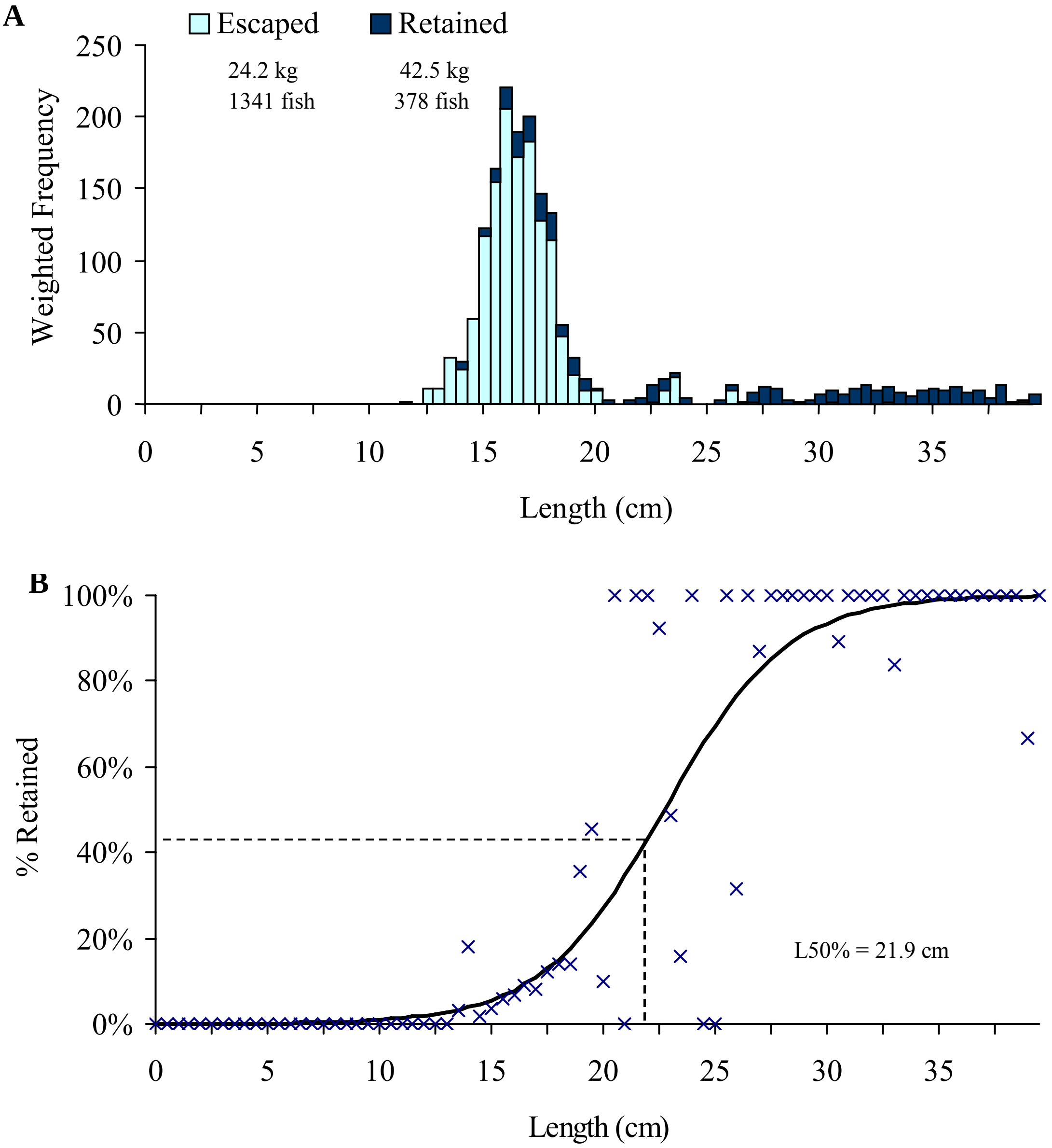


Figure 5-15. A. Length frequency distribution of banded whiptail (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for banded whiptail. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.9 Grey whiptail – East

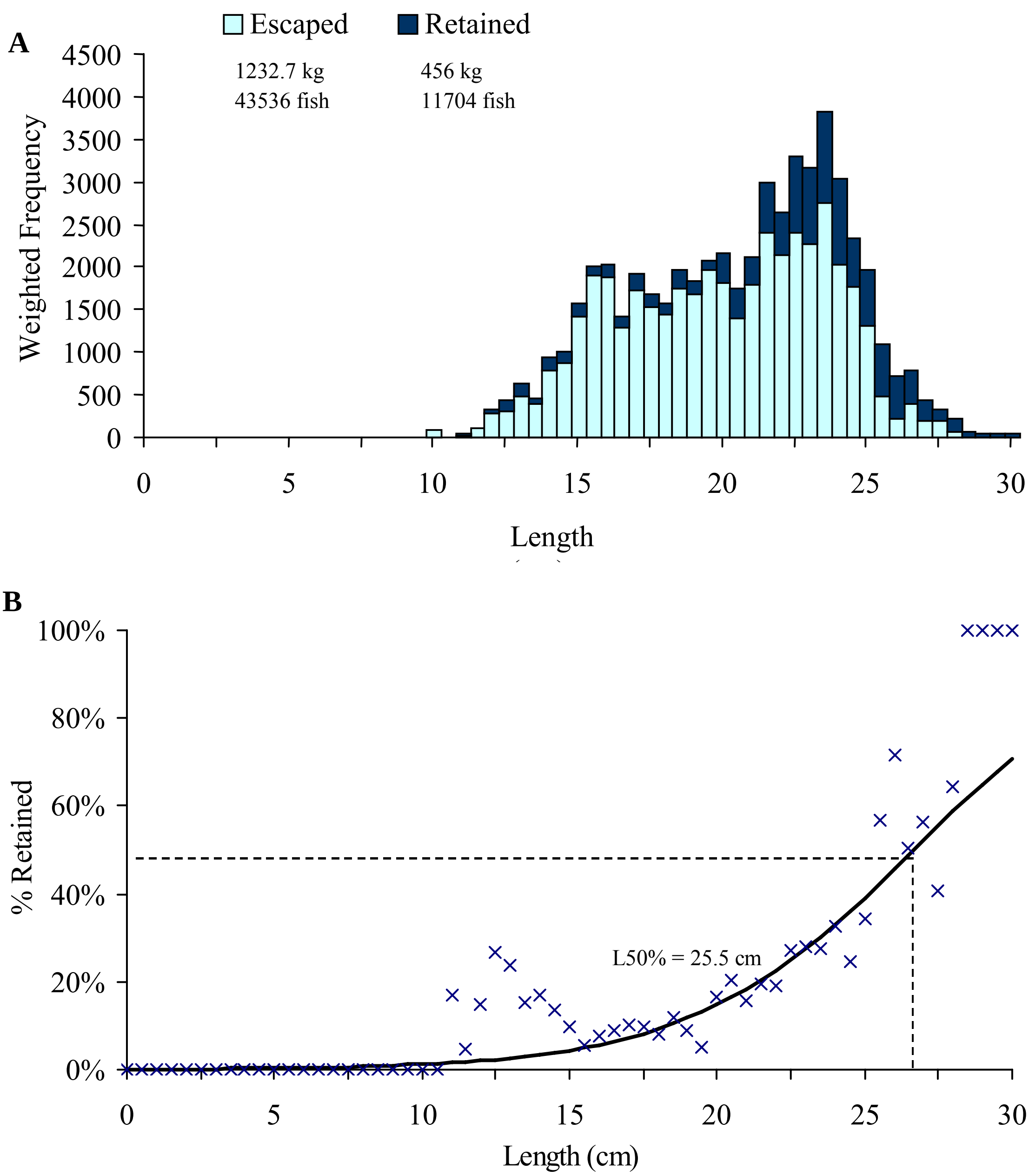


Figure 5-16. **A.** Length frequency distribution of grey whiptail (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for grey whiptail. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.10 Blacktip cucumberfish – East.

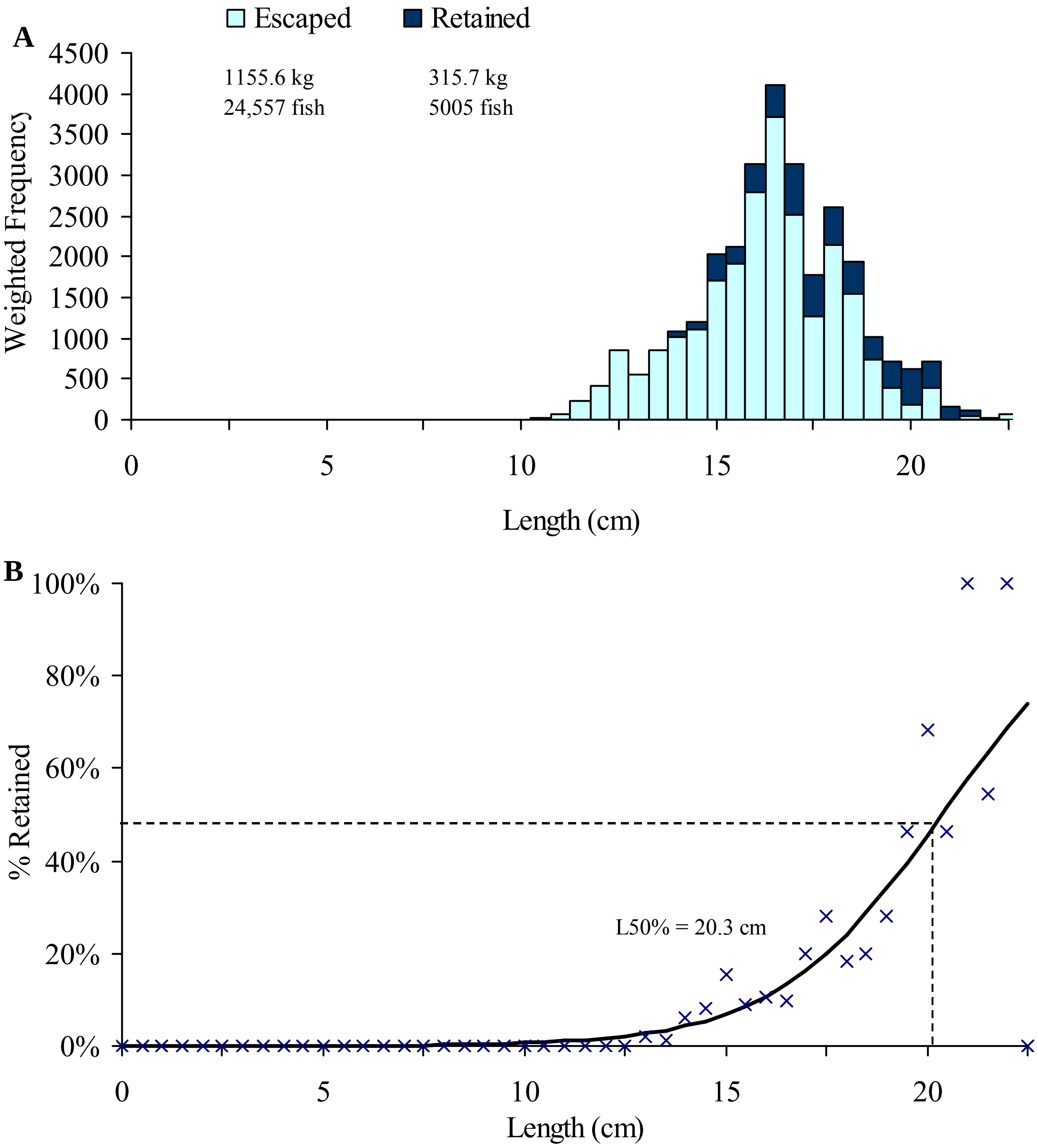
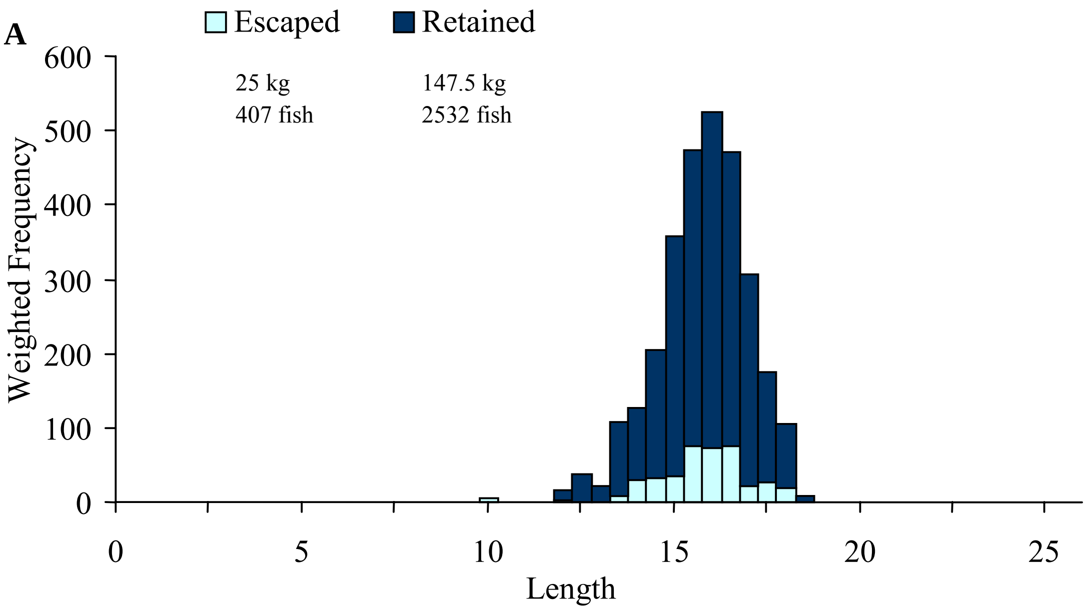


Figure 5-17. A. Length frequency distribution of blacktip cucumberfish (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for blacktip cucumberfish. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.11 Roundsnout gurnard – East.

A



B

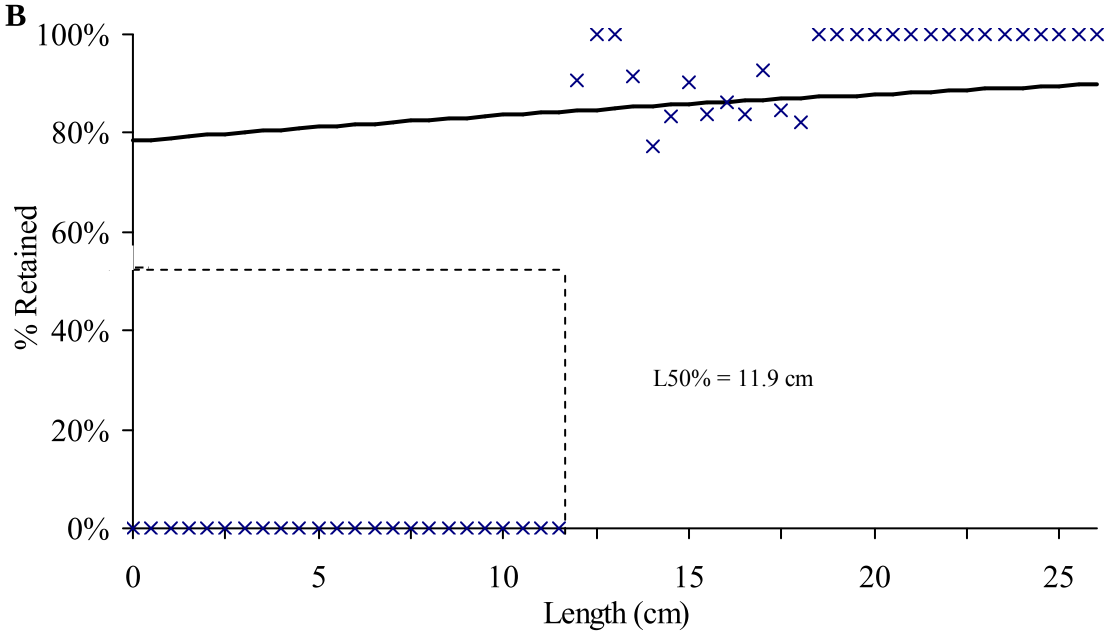


Figure 5-18. A. Length frequency distribution of roundsnout gurnard (east) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for roundsnout gurnard. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.12 Blue grenadier – West.

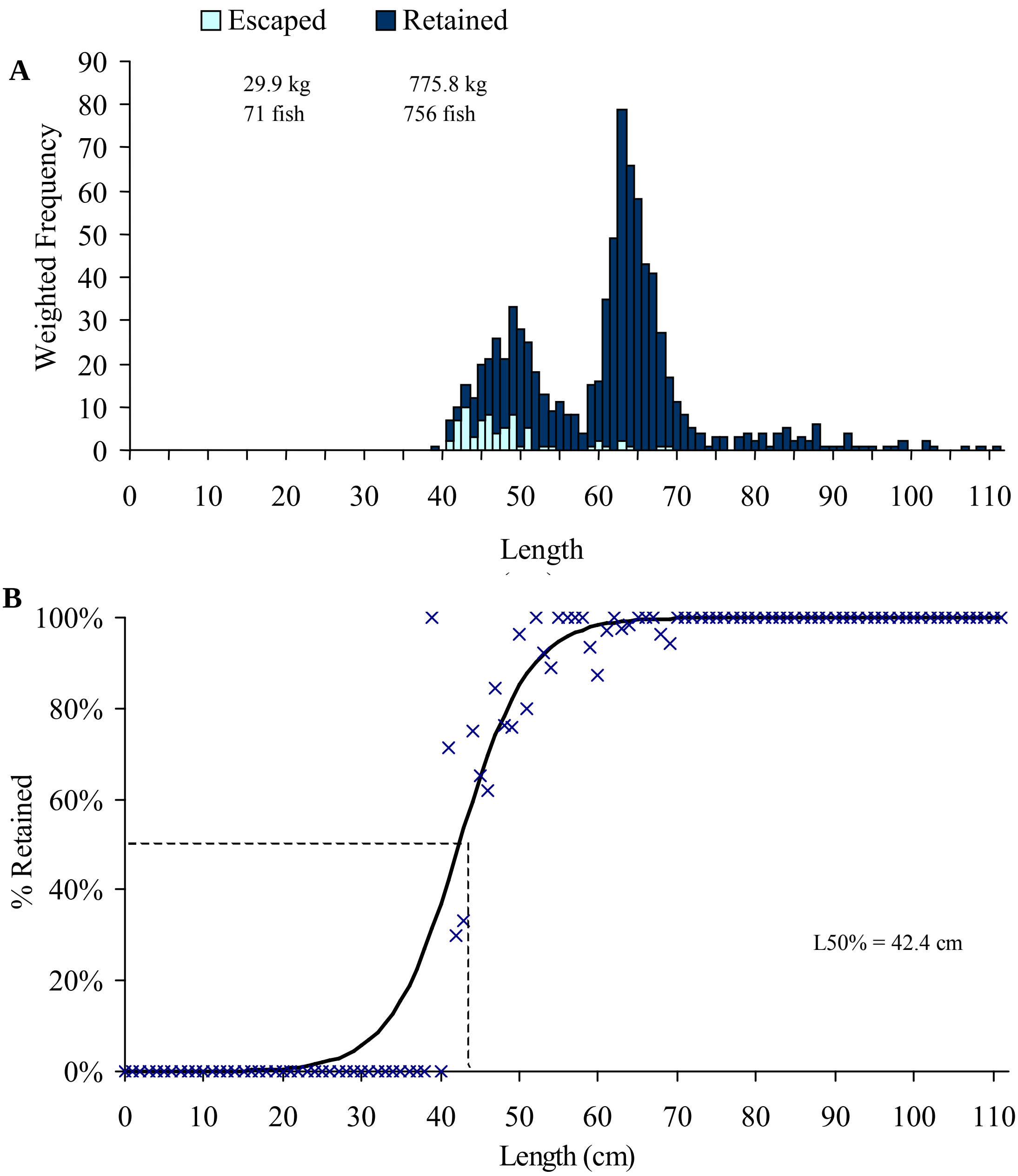
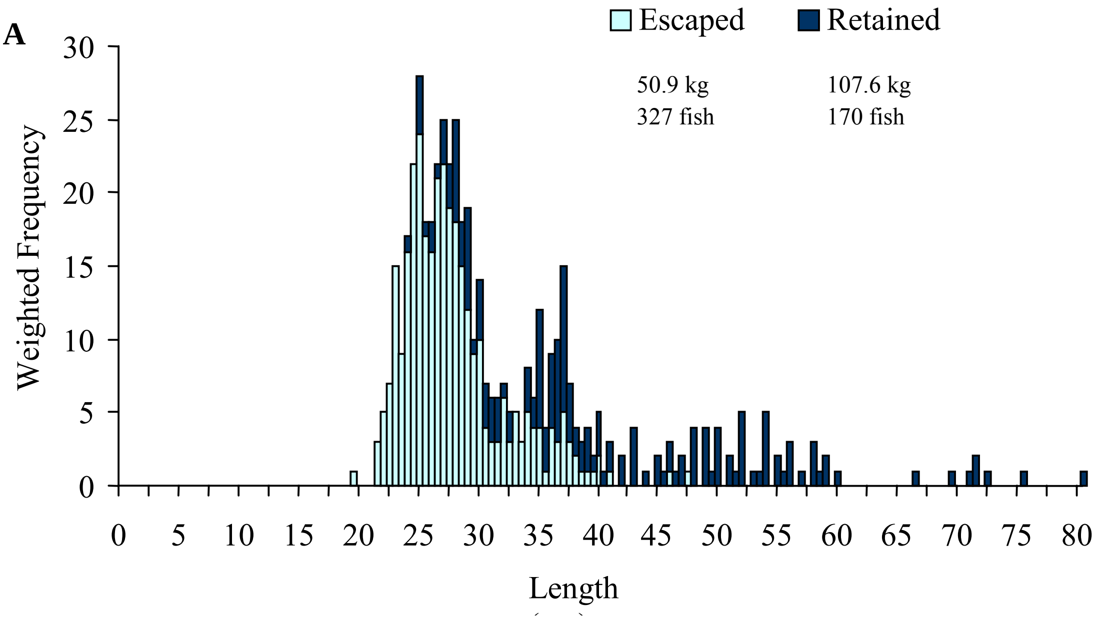


Figure 5-19. A. Length frequency distribution of blue grenadier (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for blue grenadier. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.13 Gemfish – West.

A



B

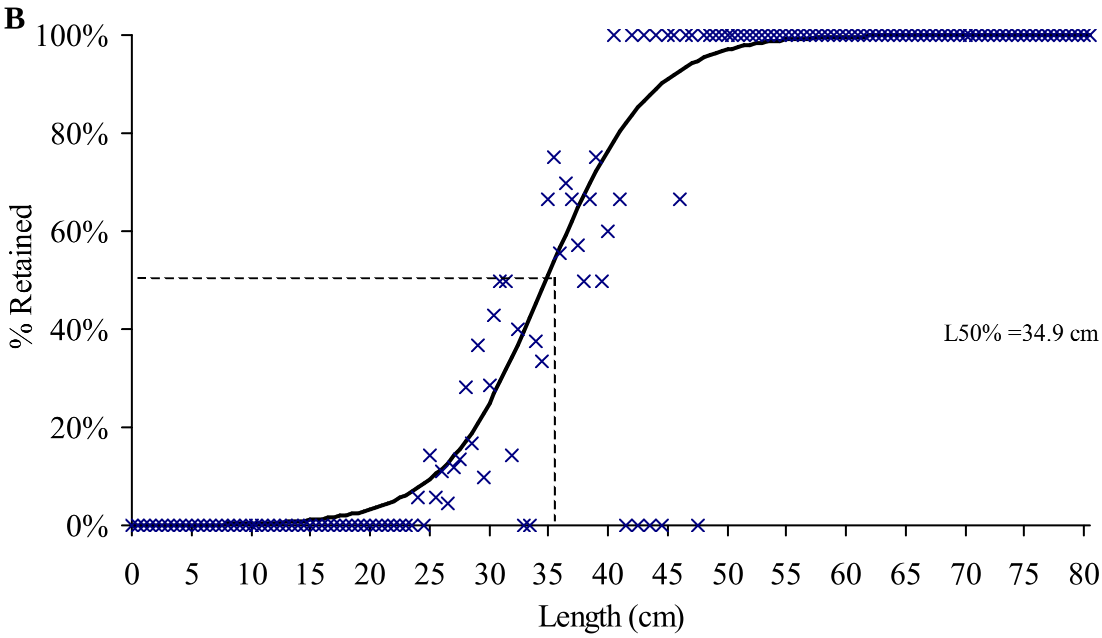
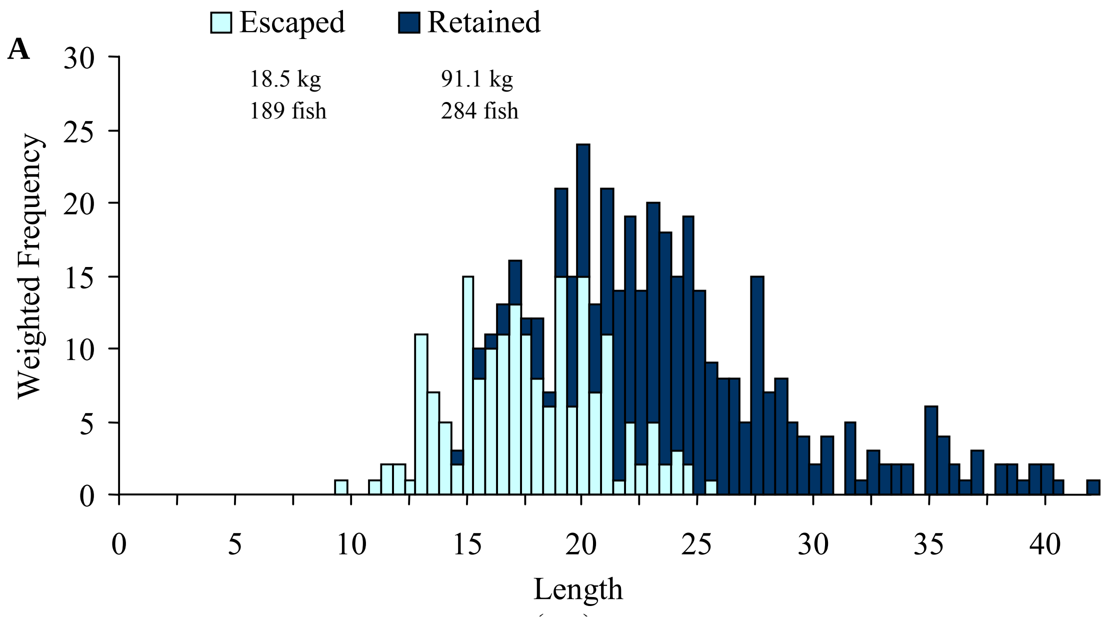


Figure 5-20. **A.** Length frequency distribution of gemfish (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for gemfsh. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.14 Offshore ocean perch - west



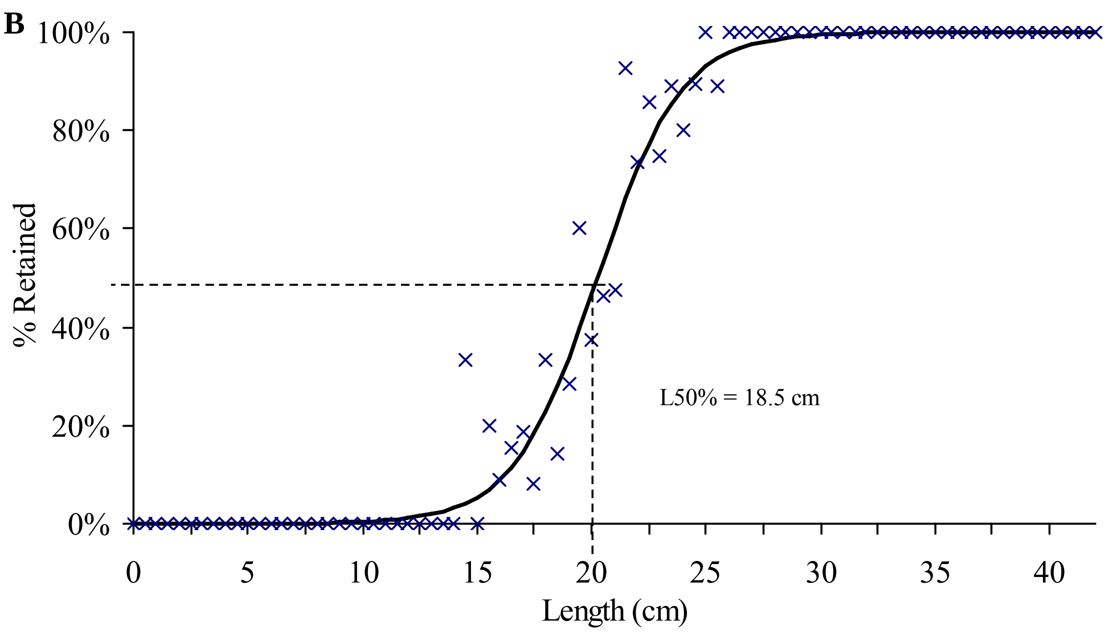


Figure 5-21. A. Length frequency distribution of offshore ocean perch (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for offshore ocean perch. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.15 Deepwater flathead - West

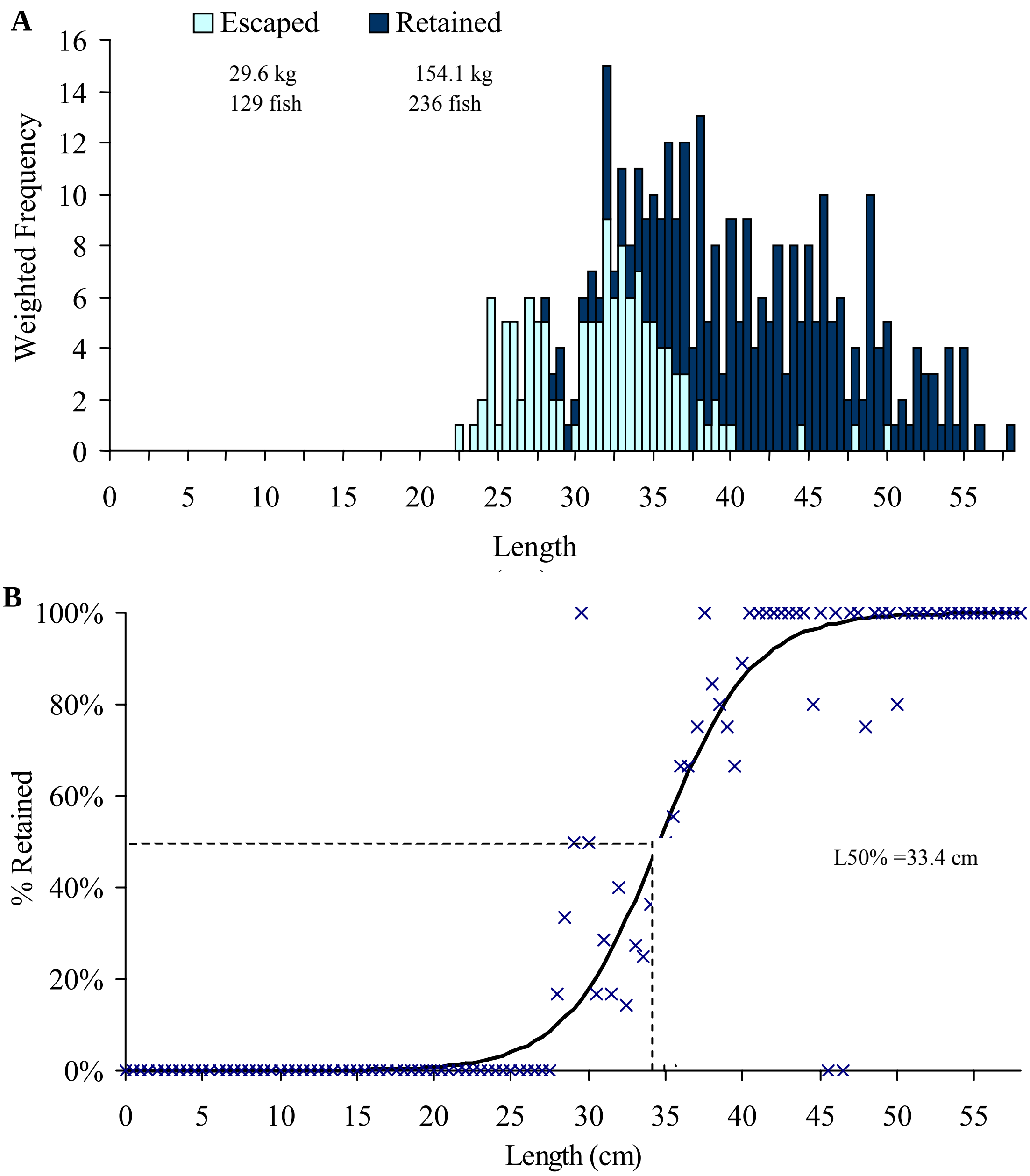
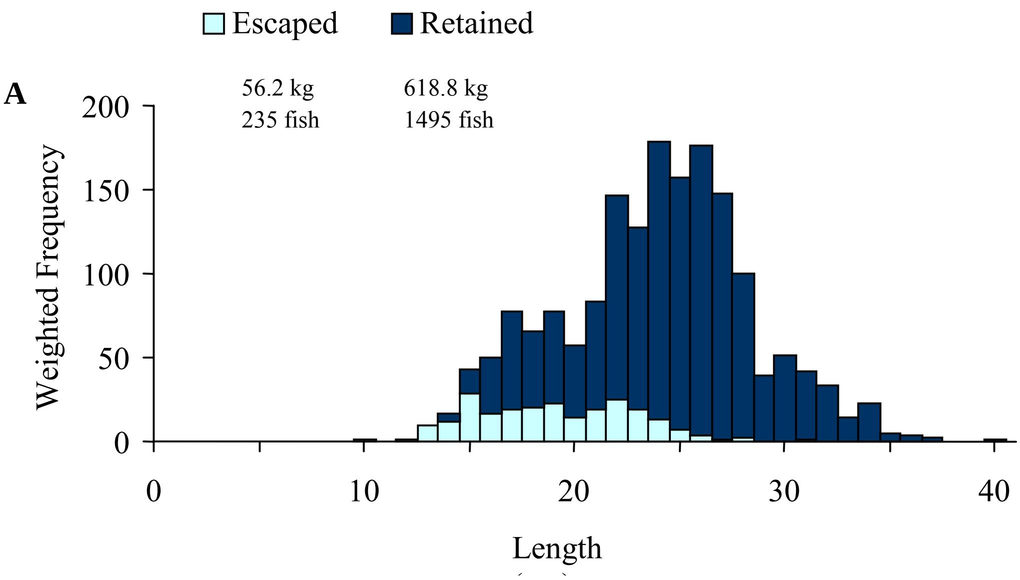


Figure 5-22. A. Length frequency distribution of deepwater flathead (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for deepwater flathead. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.16 Gould's squid - West.



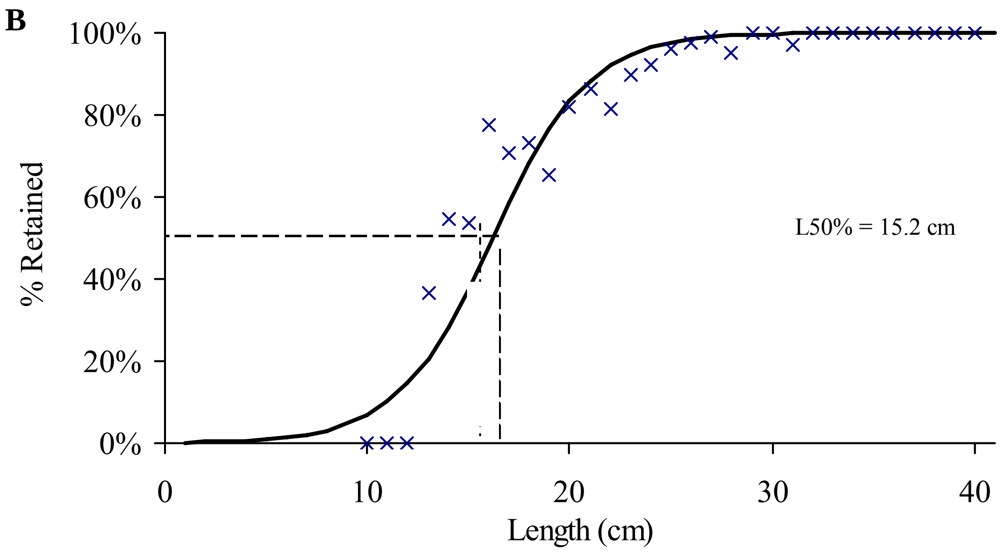
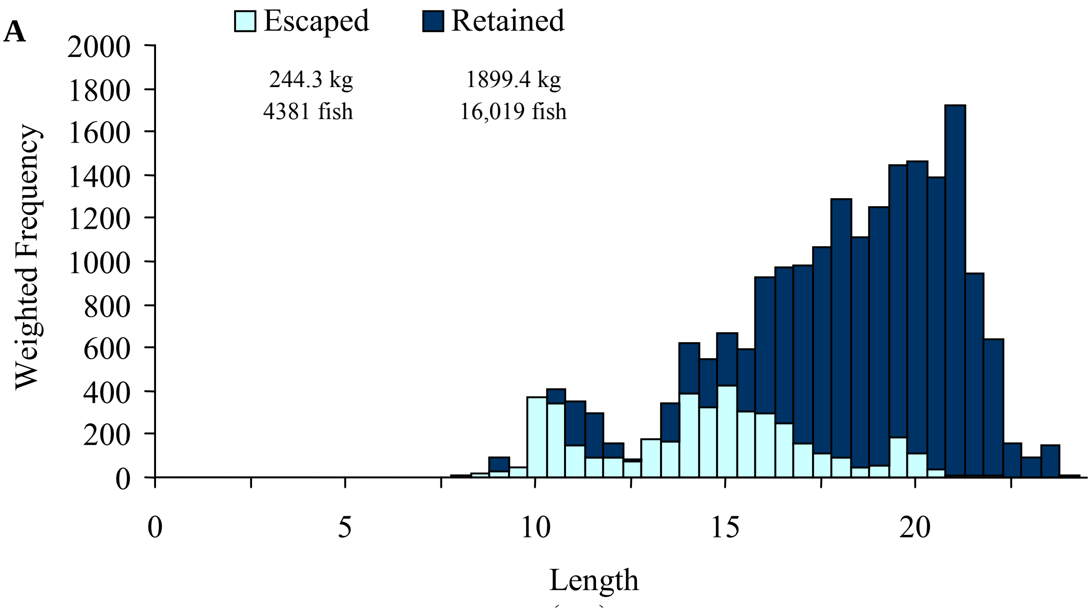


Figure 5-23. **A.** Length frequency distribution of Gould's squid (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for Gould's squid. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.17 New Zealand dory - West



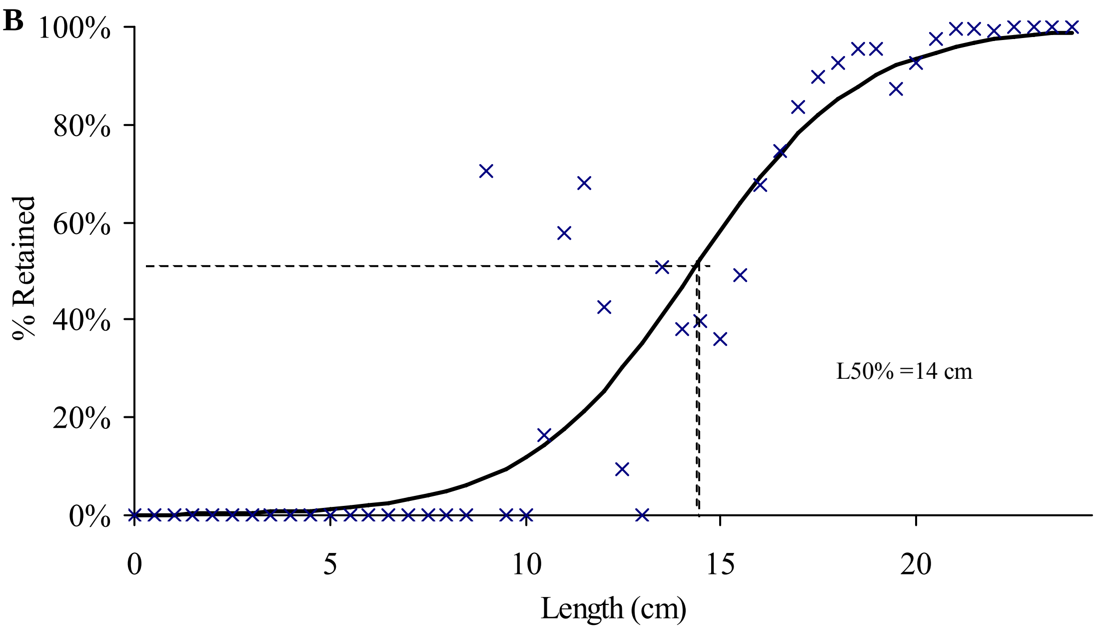


Figure 5-24. A. Length frequency distribution of New Zealand dory (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for New Zealand dory. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.18 Toothed whiptail - West

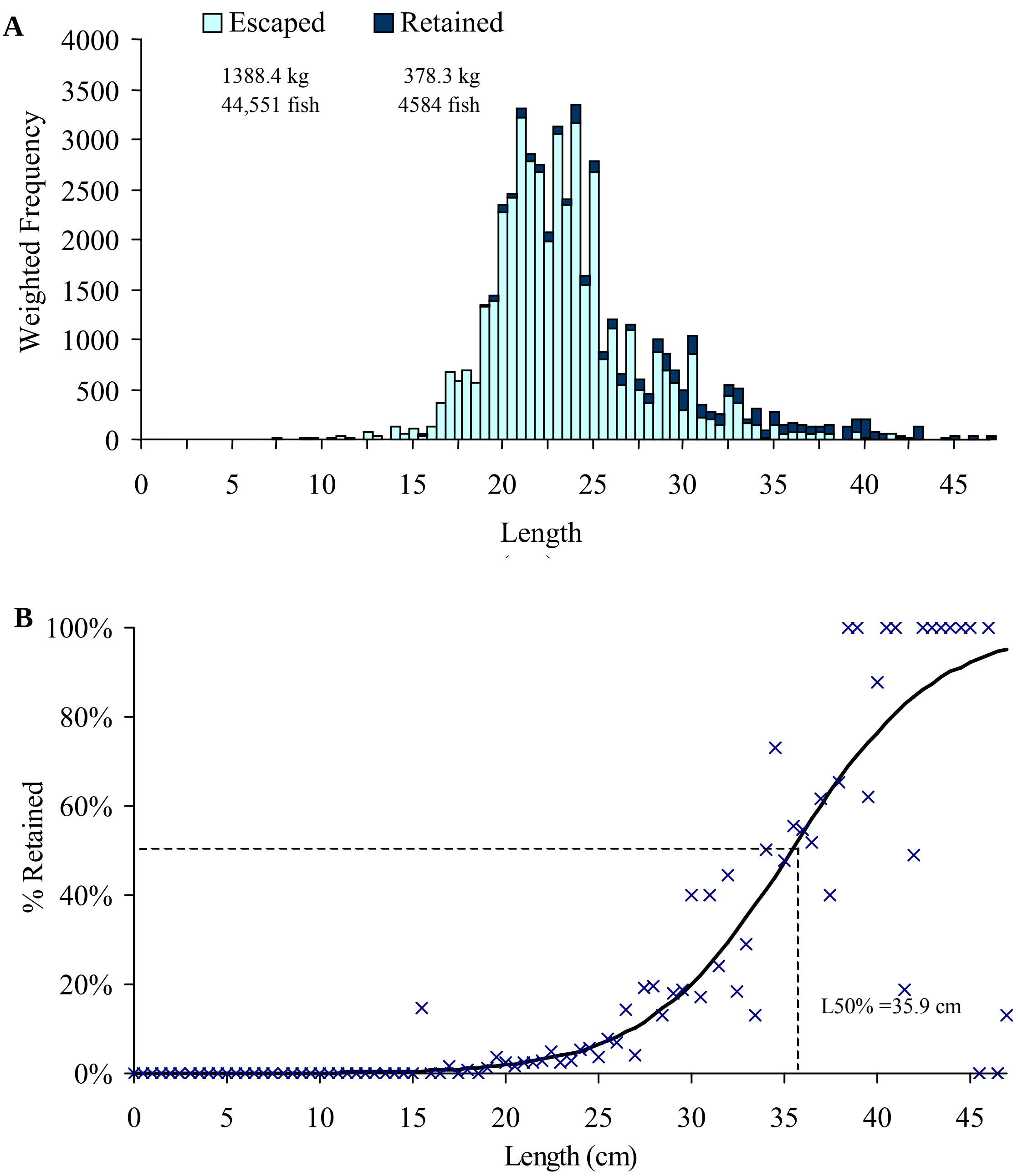


Figure 5-25. A. Length frequency distribution of toothed whiptail (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). B. Selectivity of a standard 90 mm double braided codend for toothed whiptail. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.19 Bigscale rubyfish - West

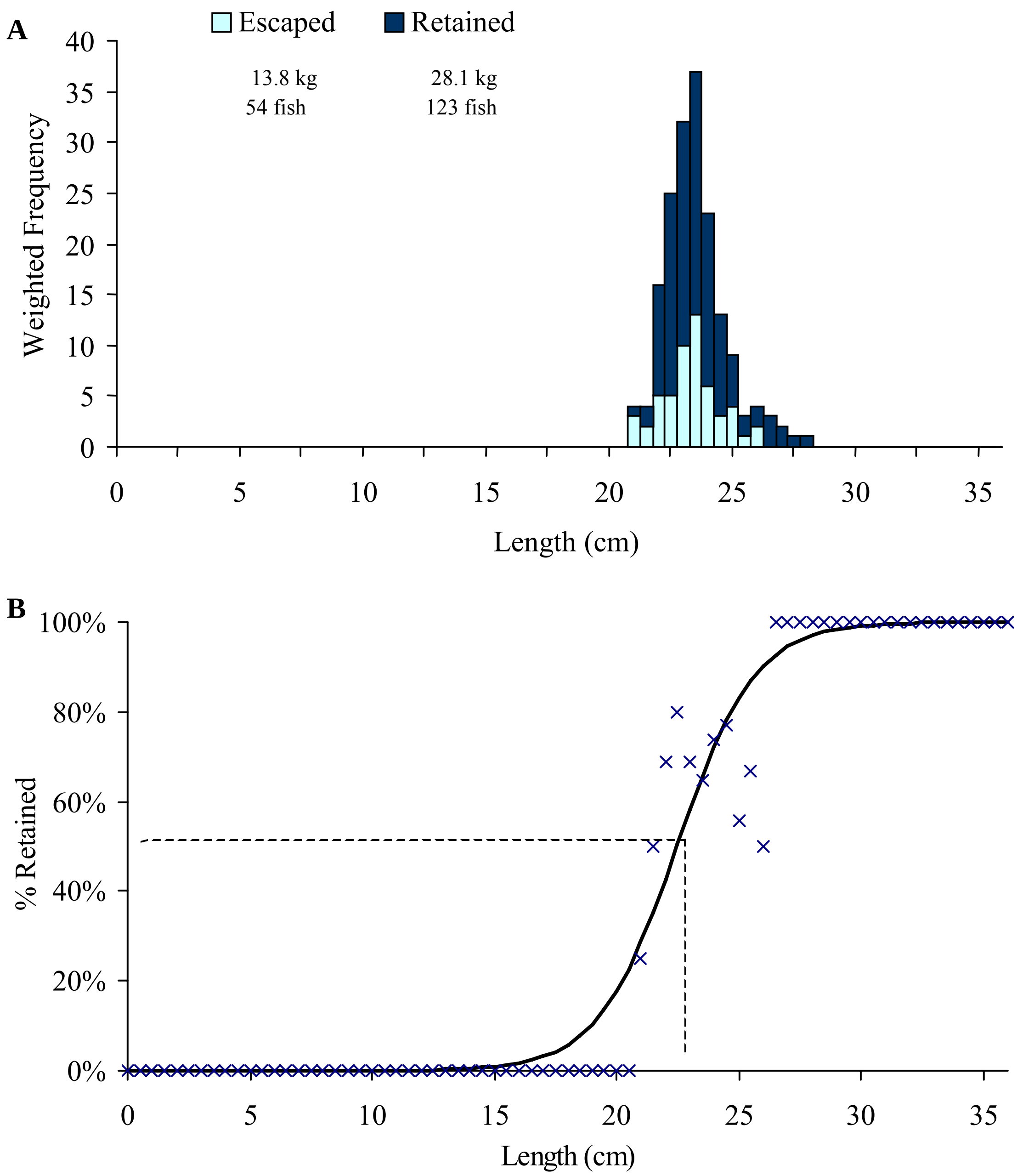
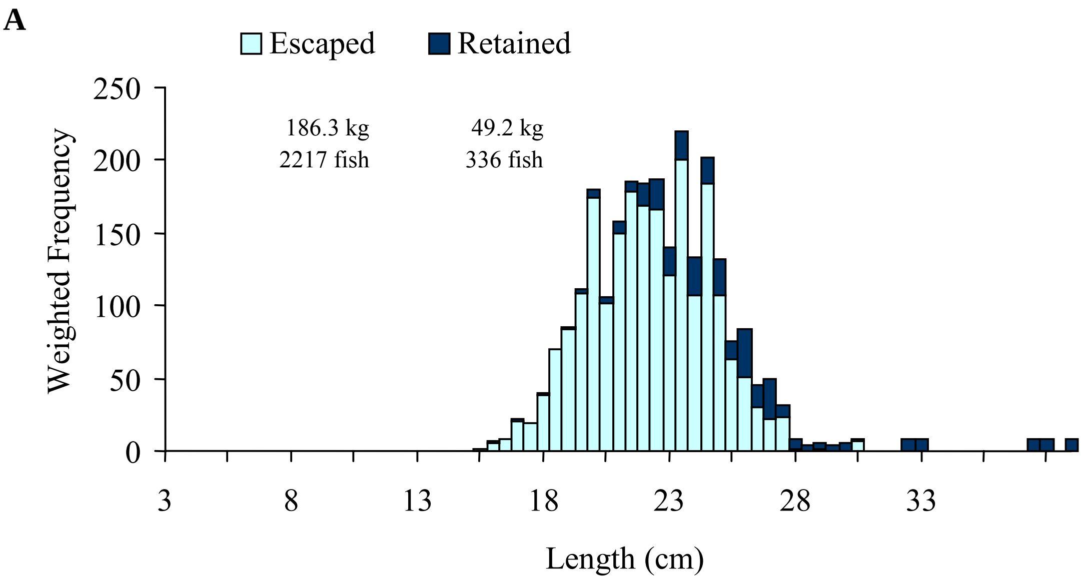


Figure 5-26. **A.** Length frequency distribution of bigscale rubyfish (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for bigscale rubyfish. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

5.3.3.20 Blacktip cucumberfish – West



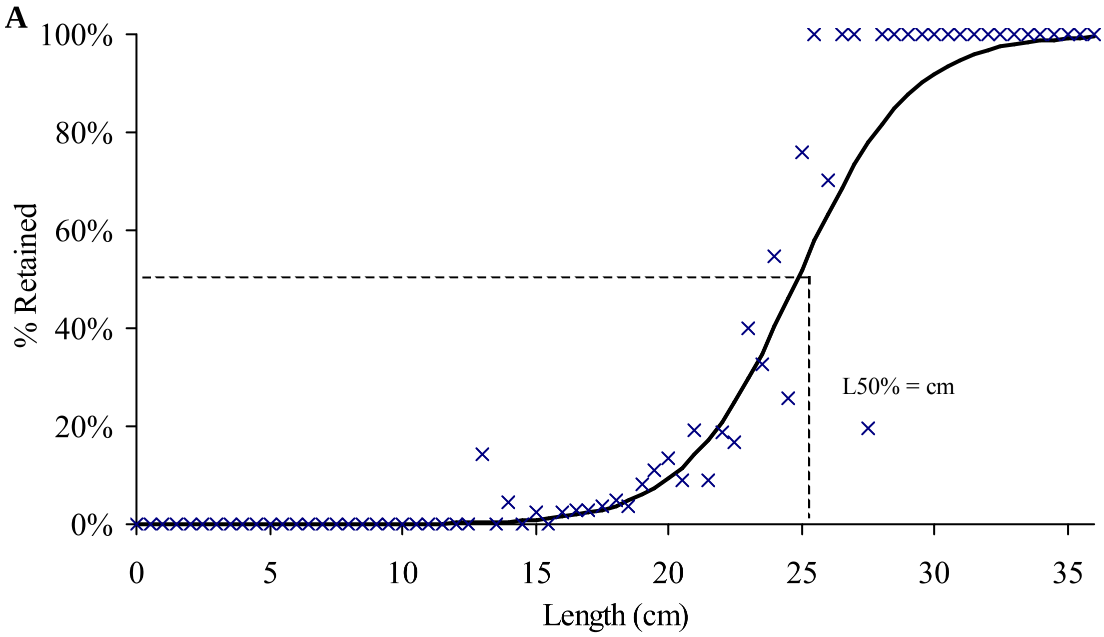


Figure 5-27. **A.** Length frequency distribution of blacktip cucumberfish (west) that were retained in a standard 90 mm double braided codend (■) and those that escaped into the 45 mm codend cover (■). **B.** Selectivity of a standard 90 mm double braided codend for blacktip cucumberfish. Each point (x) marks the % retained at a given 1cm length class and the line (—) represents the estimated logistic selectivity curve.

6 FISH BEHAVIOUR

6.1 INTRODUCTION

Observing fishing gear performance and fish behaviour during both commercial and scientific operations have been achieved through the use of a variety of techniques over the past 50 years (see Urquhart and Stewart (1993) for review). Observations collected during a commercial fishing operation are essential in that they provide added information on what factors are likely to affect the selective properties of the gear employed and how these factors may change, thus altering the selective properties under a variety of environmental conditions (Watson 1989). Both still and video cameras have been used to obtain observations within and around towed fishing gears with two main approaches used; either attached to a ROV (Remotely Operated Vehicle) and towed separately behind the vessel (e.g. Main and Sangster 1981; Wardle 1993) or attached onto the fishing gear itself (e.g. Glass and Wardle 1989; Walsh and Hickey 1993; Rose 1995). These studies have been able to describe the general behaviour observed and the differences between fish species at particular regions during the capture process. More importantly they have shown how the general behaviour of fish can be altered by changes in ambient light levels revealing that a fishes reaction towards the gear is induced primarily by the visual stimulus produced by the different components of the trawl system. Other stimuli produced during the fishing operation thought to interplay with the visual stimuli and cause fish to respond include tactile stimuli (contact with other individuals and the gear itself) and auditory stimuli (sound produced by the vessel and the gear as well as changes in water flow within the trawl net) (Watson 1989).

The swimming capability of a species is also understood to be a major factor affecting the behaviour of an individual fish that will ultimately have an affect on the efficiency and selectivity of the towed fishing gear. The swimming capability including its maximum swimming speed, endurance and manoeuvrability is suggested to be a function of its size, age and physiological condition that are again affected by extrinsic factors such as ambient light intensity and ocean–bottom temperature (He 1991; 1993; Winger *et al*. 1999). A classical description of the differences in the observed behaviour of demersal fish species within the trawl mouth, is given by Main and Sangster (1981). They were able to show that bottom fish species, such as cod, haddock and whiting, all with similar morphologies behave differently at the same region during the capture process. For example, cod entering the trawl remain close to the seabed, haddock rise and enter the trawl in the upper half, whereas whiting enter the trawl in between cod and haddock.

Understanding these behavioural differences, Main and Sangster (1982) modified the standard trawl design in the form of a three-level separator trawl leading to three separate codends in attempt to utilise the observed behavioural differences. Results obtained revealed the majority of haddock and whiting were recorded in the middle and top levels while the majority of cod, flatfish and skates were located in the bottom codend. Suggested benefits of this gear design include increased quality of fish, reduced sorting times and each level could lead to a codend mesh size and configuration that holds selective properties to the larger marketable fish that are dependant upon consumer demand and stock management requirements.

Wardle and He (1988) stated that the escape of fish from otter trawls occurs mainly in three areas: ahead of the otter boards and during herding by the sweeps and bridles; within the area of the trawl mouth by swimming over the headline or under the footgear; and within the codend by swimming through the meshes. Observations of diamond mesh codends by Robertson and Ferro (1988) revealed that the meshes have their maximum opening just in front of the accumulated catch in a narrow band of meshes (0.5-1.5m) in the lengthwise direction. Further observations collected were able to show that the majority of fish escaping were recorded passing through meshes located in the side and top panels of this region (Engas *et al*. 1989). The behaviour of fish within the codend is therefore noted to be a major factor affecting the selective properties of the gear (Wardle 1989; Watson 1989). Other factors include mesh size and shape (Robertson 1989; Broadhurst and Kennelly 1995a) towing speed, catch rate and volume (Robertson and Ferro 1988).

Current approaches towards improving the selectivity of trawl gear include changes to current net designs such as altering mesh shape and increases in mesh size. Such designs aim to provide increased areas of open meshes through which fish can escape (Glass *et al*. 1993). Information on how fish species are observed to escape capture and more importantly determining what behaviours may result in escape and what triggers these particular behaviours, is therefore essential for the rapid development of practical solutions to further improve the selectivity of the current fishing gear used.

Ferno (1993) stated that more research has been devoted to determine the limits of achievements of sense organs and muscles than to find out what fish actually do in a catch situation. The majority of studies using underwater cameras to observe gear performance and fish behaviour have been assessed in a qualitative manner. However attempts have been made to extract quantitative information from such data. For example Castro *et al.* (1992) categorised fish behaviour and generated species-specific ethograms to describe differences in behaviour in the extension section of a trawl net. This type of research is yet to be performed on Southern Hemisphere trawl fisheries therefore our knowledge of fish behaviour during the capture process of our species is limited.

6.2 OBJECTIVES

Video cameras were used in this project to achieve a number of objectives. They were a useful tool to observe the geometry and performance of standard and modified demersal trawl nets. Based on video footage we were able to determine quickly whether nets were setting correctly and how well modified gear such as codend covers, twin codends (trouser trawl), square-mesh panels and lastridge rope systems were performing.

In addition, video footage was used specifically to:

- To observe and describe the observed swimming behaviour of selected target and non-target fish species at various locations within a standard demersal trawl; and,
- To quantify and compare the observed swimming behaviour of selected fish species within the codend of a trawl and in response to the various trawl modifications.

This chapter provides written descriptions of the behaviour observed by selected fish species within trawl nets as well as discussing the observations obtained when assessing the effectiveness of the various gears designs used throughout the project. This study also uses defined behavioural units at attempts to determine differences in the swimming states and events observed by selected fish species within the codend and extension sections of demersal trawl nets.

6.3 MATERIALS AND METHODS

6.3.1 Camera Systems

Staff from the Faculty of Fisheries and Marine Environment at the Australian Maritime College (AMC) designed and constructed two camera systems for use in this project to observe trawl geometry and the behaviour of various fish species during the capture process. The initial camera system (camera system A) consisted of a Javelin monochrome camera (model no. OS45D CCD) with a 6 mm auto-iris lens capable of operation at illumination levels to 0.01 lux and a recorder pod. Housed within the recorder pod were a Sony Hi-8 analogue camcorder (model no. CCD-TRV66E), a 12 volt sealed lead-acid rechargeable battery, a 20 watt halogen lamp and a controller box. The halogen lamp was used to illuminate ahead of the camera while the controller box contained a variable time delay so that filming occurred after a pre-selected time interval following deployment of the trawl. Battery life was sufficient to record visual images for a total of 90 minutes. Surrounding the camera system was an aluminium frame designed to protect the system from impacts with the deck of the boat or the catch. The frame was tied to the trawl netting prior to deployment and four 200 mm diameter plastic floats were attached to the frame to counter the weight of the camera system. Camera system A was used predominantly in the extension section and codend of the trawl.

The second camera system (camera system B) consisted of two major components; a recorder pod and a small, lightweight camera pod (Plate 6-1). This system was designed to allow location of the camera pod at the trawl mouth or wingends without impacting negatively on trawl geometry or fish behaviour; this being a limitation of the heavier camera system A.

Plate 6-1. Camera system B, with the recorder pod on the left and the camera pod on the right. The camcorder and batteries are housed together and inserted into the recorder pod, and the low-light camera is inserted into the camera pod. A light is attached adjacent to the camera, and the umbilical cable provides power to the camera and video signals to the camcorder.

Within the camera pod were housed a Remote Ocean Systems 'Navigator' low-light monochrome camera and a single 20-watt halogen lamp. Fitted to the camera was a 3.8 mm auto-iris lens capable of operation at illumination levels to 3.4 x 10^{-4} lux. The recorder pod housed the Sony Hi-8 camcorder, a controller box and two 12 volt sealed lead-acid rechargeable batteries to record visual images for a total of 240 minutes. Both pods were housed in aluminium frames for protection and to facilitate attachment to the trawl. An umbilical cable measuring 15 m in length extended between the pods to provide power to the camera and transmit the video signal from the camera to the camcorder. The camera pod was designed with manual pan and tilt capability to allow rapid adjustment of the camera's field of view, as well as to obtain useful images along the entire length of the trawl. Three 200 mm diameter plastic floats were attached to the recorder housing and another was attached to the camera housing. A feature of this camera system was the ability to connect the two housings together if required, thus enabling more rapid attachment of the camera system to the trawl and reduced delays in fishing time. This camera system was used in all locations of the trawl, from the wingends to the codend.

All camera operations were performed onboard the commercial vessels, FV *Shelley H* and FV *Zeehaan*, operating out of Bermagui (NSW) and Portland (VIC) respectively. Water depths in which the camera systems were used ranged from 90–420 m at Bermagui and 200–660 m at Portland.

6.3.2 Fishing gear observations; camera location & orientation

The camera systems were used to observe the geometry of the demersal fish trawls as well as the various codend modifications used to improve trawl selectivity. This section describes the specific location and orientation of the camera systems when attached to the trawls.

6.3.2.1 Demersal fish trawls

Fishing operations observed for trawl geometry on the *Shelley H* and *Zeehaan* towed similar gear in overall design, but with different sized ground gear and mesh sizes throughout the length of the trawl (we need to confirm this detail).

The cameras were used to observe all sections of the trawl, from the wingends to the codend (Figure 6-1). Using camera system B, the camera pod was attached to the headline and wings of the trawl. Directed forward, this allowed the geometry of the trawl wingends to be observed, while directed aft, the camera allowed the trawl mouth to be observed, and in particular the rubber discs of the ground gear and adjacent trawl meshes. By observing this section of the trawl it was possible to assess the degree of seabed impact by the ground gear.

Both camera systems A and B were used in the extension section and codend of each trawl. This allowed the geometry of these regions of the trawl to be observed as well as the impact of catch loading on mesh geometry and opening.

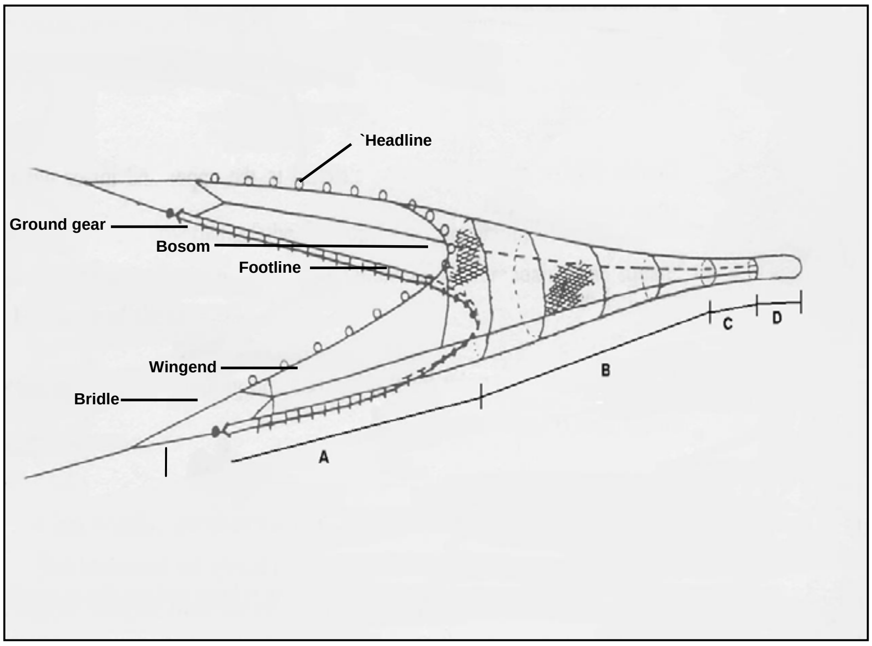


Figure 6-1. A demersal trawl with the four main locations for trawl attachment indicated: (A) wingends and mouth, (B) body, (C) extension and (D) codend.

6.3.2.2 *Codend cover*

Video cameras were used in the codend cover experiments to confirm that adequate clearance between the codend and the cover was maintained under commercial operating conditions. Camera system A was used to make this observation as well as assess the ability of fish to escape through the meshes of the codend. The camera system was attached directly to the small mesh cover immediately before the first PVC hoop, and positioned at the centre of the top panel of the codend. The camera faced aft towards the codend drawstring.

6.3.2.3 *Trouser trawl*

The trouser trawl, or twin codend trawl, was used to obtain direct comparisons between catches obtained in the standard and modified codends. To help assess the design and geometry of the trouser trawl and associated fish behaviour, the camera was attached directly to the top panel of the trawl immediately before the separation point of the trawl into the two extension pieces or trouser 'legs'. The camera was directed aft towards the codend and angled slightly down.

6.3.2.4 Codend modifications

Several codend modifications were tested during this project to reduce the capture of discard species. These modifications included lastridge ropes attached to a standard 90 mm diamond mesh codend, a 110 mm diamond mesh codend, a 102 mm square-mesh codend and a 90 mm square-mesh panel. Technical details of these modifications with specifications is provided in Section 7. The effectiveness of each modification was compared against the standard 90 mm diamond mesh codend using the trouser trawl during trials off both Bermagui and Portland.

Camera system A was used in the early stages of the project to collect observations of the lastridge rope system and square mesh panel. The camera was located immediately ahead of the lastridge ropes and square mesh panel in the top panel of the net facing aft. Camera system B was used to obtain observations of the 110 mm diamond mesh codend and the 102 mm square-mesh codend. These observations were achieved by attaching the camera pod to the top panel of the extension piece with the recorder pod attached to the top panel ahead of the separation point between the two 'legs' of the trouser (Plate 6-2).

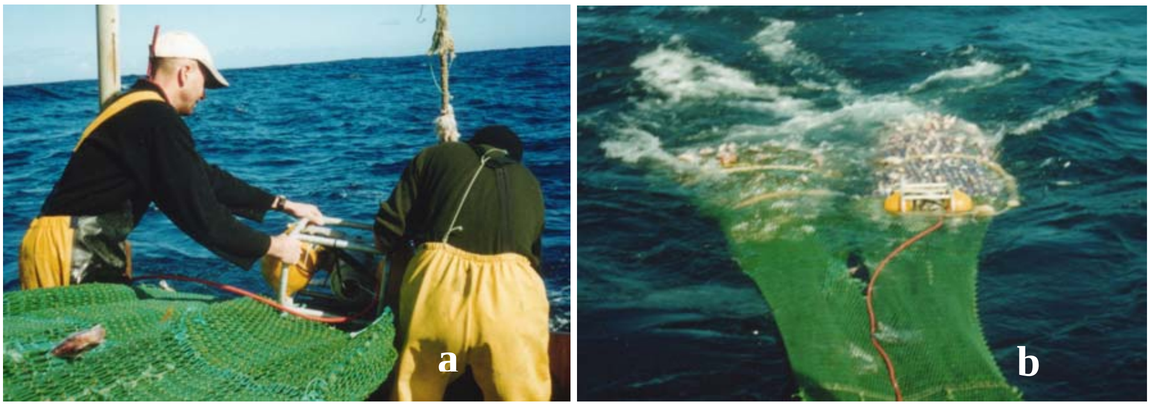


Plate 6-2. Attaching the camera pod to the top panel of the extension section before the 110 mm square mesh codend.

6.3.3 Observations of fish behaviour

The camera systems were used to gain a greater understanding of how various fish species behave in response to the trawl gear and during different stages of the capture process. This was achieved by locating the cameras at various locations within the trawl nets, including the trawl wingends and mouth, wingends, trawl body, extension and codend. Both camera systems A and B were used to observe fish behaviour, however, the design of the latter camera system allowed the lightweight camera pod to be mounted on either wingend or the bosom of the headline with minimal influence on trawl geometry. In these positions, the camera was facing forward to observe fish as the trawl approached or angled downwards towards the ground gear to observe fish either in the trawl mouth or responding to the ground gear. Observations of fish in the trawl body were achieved using camera system B attached to the top panel of the trawl, with the camera facing aft and angled downwards towards the bottom panel of the trawl. Observations of fish behaviour in the extension piece and within the standard 90 mm diamond mesh codend were made with both camera systems. The cameras were directed either forward or aft, again being attached to the top panel of the codend.

6.3.3.1 Video analysis of fish behaviour

To quantify the behaviour of fish during the capture process, the video footage was analysed and descriptive categories of observed behaviour were developed. These categories include a description of swimming behaviour, and the direction and speed of the fish relative to the direction and speed of the trawl (Table 6-1). The duration and frequency of each category was recorded so that behavioural differences between locations in the trawl for a particular species or between species could be assessed. Each behavioural category was recorded as either an 'event' or a 'state'. An event is defined as a discrete, instantaneous action such as a burst swim or turn, while a continuous action of longer duration such as cruise swimming is defined as a state (Lehner 1979; Martin and Bateson 1986).

Table 6-1. Categories of fish behaviour during the capture process.

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

1. Relative to towing speed
2. Relative to towing direction

It is important to note that for each species reported in this study, the number of observations does not necessarily equate to the total number of individuals of that species that passed into the trawl. In the trawl mouth, for example, the cameras were only able to view a small section of the trawl, being limited by ambient light levels, the capabilities of the cameras to film under such conditions and the physical constraints associated with cameras fixed to a trawl. Some individuals may therefore have entered the trawl and escaped without having been observed, while others may have been observed responding to the trawl in such numbers that it was not possible to follow the behaviour of all individual fish. The number of observations reported in this study therefore relates to the total number of individuals observed performing the various behavioural categories during an observation period, and includes individual fish that may have performed several distinct behavioural categories.

The fish species selected for observation and detailed analysis were commercial and non-commercial species that typically dominate the catch at the Bermagui and Portland fishing grounds (Table 6-2). All behavioural observations for each species were recorded in response to a standard demersal fish trawl. Several other important species were also encountered in this study, however, as they were only observed in one section of the trawl, only brief descriptions of their behaviour are provided (Table 6-3). Those species observed responding to the trawl modifications, such as the trouser trawl, are also briefly described.

Table 6-2. The major commercial and non-commercial fish species selected for behavioural observation and detailed analysis.

Common name	Scientific name	Code
Commercial species		
Blue grenadier	*Macruronus novaezelandiae*	BG
Silver warehou	*Seriolella punctata*	SW
Pink ling	*Genypterus blacodes*	PL
Gemfish	*Rexea solandri*	G
Ocean perch	*Helicolenus* spp.	OP
Jackass morwong	*Nemadactylus macropterus*	JM
Tiger flathead	*Neoplatycephalus richardsoni*	TF
Non-commercial species		
New Zealand dory	*Cyttus novaezelandiae*	NZD
Whiptail	*Coelorinchus* spp.	W

Table 6-3. Other important species observed.

Common name	Scientific name	Code
Commercial species		
Blue-eye trevalla	*Hyperoglyphe antarctica*	BE
Gould's squid	*Notodarus gouldi*	SQ
Redfish	*Centroberyx affinis*	RF
Blue warehou	*Seriolella brama*	BW
Non-commercial species		
Bellows fish	*Macroramphosus sp.*	BF
Blacktip cucumberfish	*Paraulopus nigripinnis*	C
Toothed whiptail	*Lepidorhynchus denticulatus*	TW
Threespine cardinalfish	*Apogonops anomalus*	CF
Gurnard species*	*Pterygotrigla spp.*	G
Jack mackerel*	*Trachurus declivis*	JMK

* Occasionally of commercial value.

To further aid behavioural comparisons between species and identify potential strategies to facilitate the exclusion of discards from the codend (whilst retaining the commercial species), the observed behaviour of each species in this section of the trawl is described in greater detail. Three categories were used to describe this behaviour, each providing a description of the swimming activity of each species and thereby providing a broad means of indicating which species is more likely to be capable of actively swimming through the meshes of the codend (Table 6-4).

Table 6-4. Descriptions of fish activity in the codend.

Activity level	Behaviour
High activity	All burst swim and burst turn events.
Medium activity	All cruising swimming states including slow turn events.
No activity	Both rest and impinged states.

6.4 RESULTS

6.4.1 Fishing gear observations

This section describes the results of fishing gear observations, including the standard demersal trawl and the codend modifications to reduce the capture of non-commercial species. Also included are descriptions of fish behaviour in response to these modifications.

6.4.1.1 Demersal trawl

The demersal trawl gear used in the East and West regions during this study were not identical, with differences between their overall size, design and construction. Variation in mesh size was the most obvious observed difference between the trawls, however, the observations indicated that the overall geometry and appearance of both was essentially similar.

With the cameras placed on the headline and upper wings of the trawls and directed forward, it was possible to observe the behaviour of fish as the trawl approached. Many species did not respond to the gear until immediately prior to or upon contact by the trawl. These species were typically solitary individuals either resting on the seabed or in the water column, such as blue grenadier or pink ling. In contrast, schooling species such as silver trevally, Gould's squid and jack mackerel, were observed entering the trawl mouth en masse cruise swimming in the towing direction. Silver trevally, for example, were observed at the Bermagui fishing grounds cruise swimming in the trawl mouth at the same speed as the trawl. Individuals were located immediately ahead of the ground gear and close to the seabed (<2 m), where they maintained station for some time (>5 mins). Eventually, these individuals rose upwards, turned, and swam towards the codend. On another occasion, a school of silver trevally cruise swimming in the trawl mouth were suddenly startled and observed using a burst swimming manoeuvre to escape from of the trawl path. The reason for this sudden behaviour is not known. Schools of Gould's squid were observed on several occasions off Portland keeping station in the trawl mouth and body for short periods (<30 secs) before slowly being overtaken by the trawl. These individuals were typically located close to the top panel of the trawl several metres above the seabed (Plate 6-3).

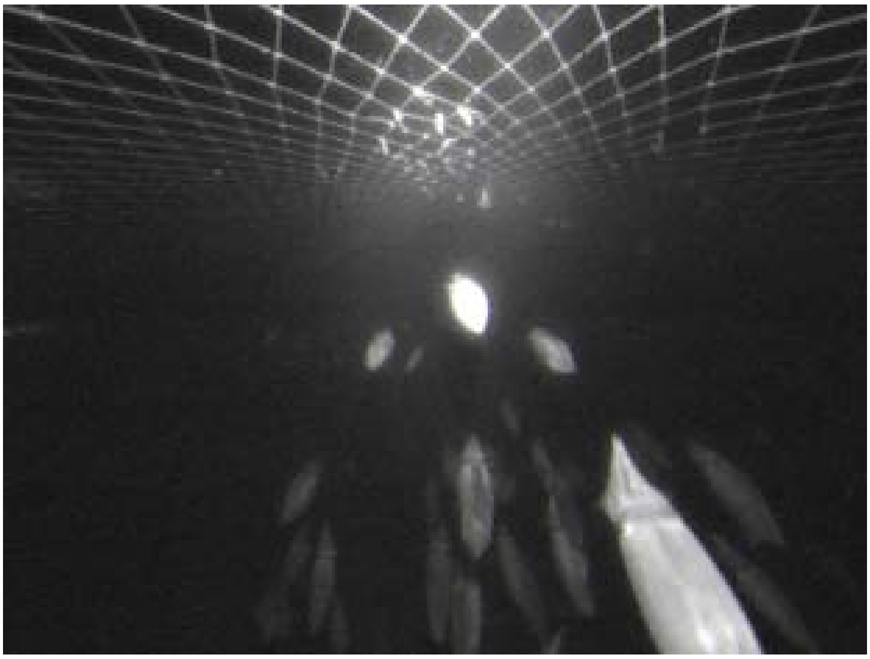


Plate 6-3. A school of Gould's squid entering the trawl near the top panel.

One schooling species that did not appear to have been herded by the trawl was redfish. Schools of this species (>200 individuals) were observed off Bermagui remaining motionless in the water column as the trawl approached. They did not appear to have been herded by the sweeps or wingends of the trawl, and no burst swimming to avoid the trawl was observed. Instead, they simply turned and faced the approaching trawl before passing out of view into the trawl body (Plate 6-4). Larger schools of redfish appeared to have a greater vertical distribution (seabed to headline height) than smaller schools, which remained closer to the seabed.

Other notable observations in this region of the trawl included a blue-eye trevalla swimming from outside the trawl path, through a wingend mesh and into the trawl mouth (Plate 6-5 a – d). On another occasion a seal was observed freely entering and leaving the trawl mouth during deployment of the gear, remaining inside the trawl for up to 20 seconds at a time, whilst on another occasion a seal was observed during retrieval of the gear swimming outside the trawl and feeding on fish caught in the wingend meshes.

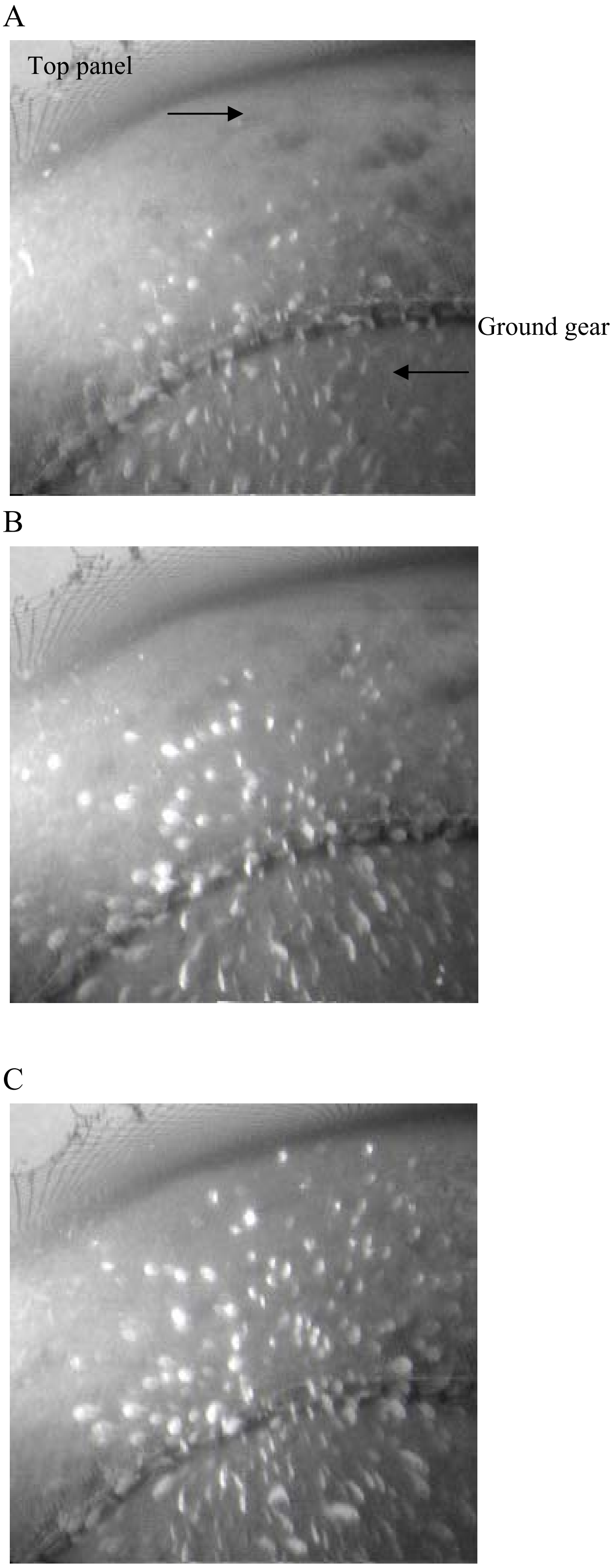


Plate 6-4. School of redfish entering the trawl. (Change in orientation suggest some response to trawl)

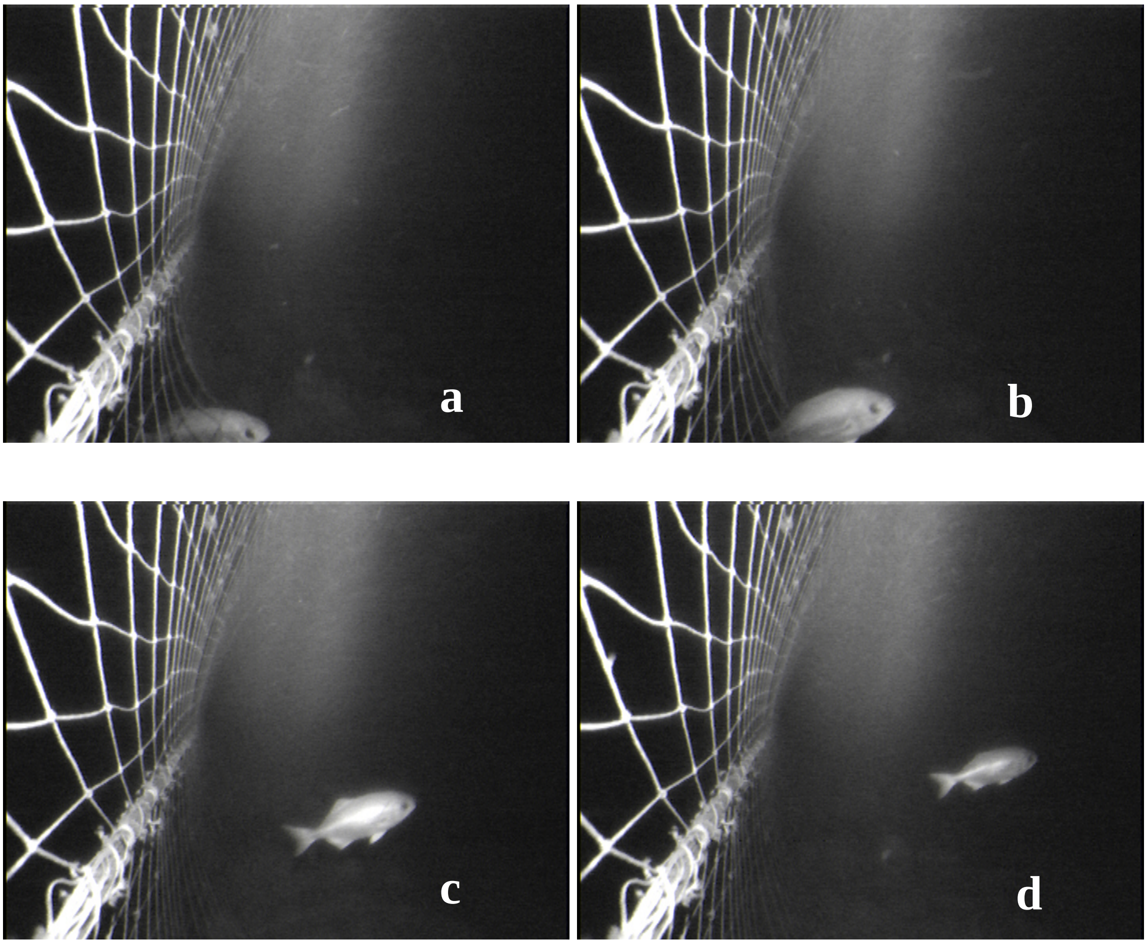


Plate 6-5. Camera attached to the seam of the port (left) wingend directed aft shows an individual blue-eye trevalla outside the trawl path penetrating (a) and swimming through a wingend mesh (b) and entering the trawl mouth (c & d).

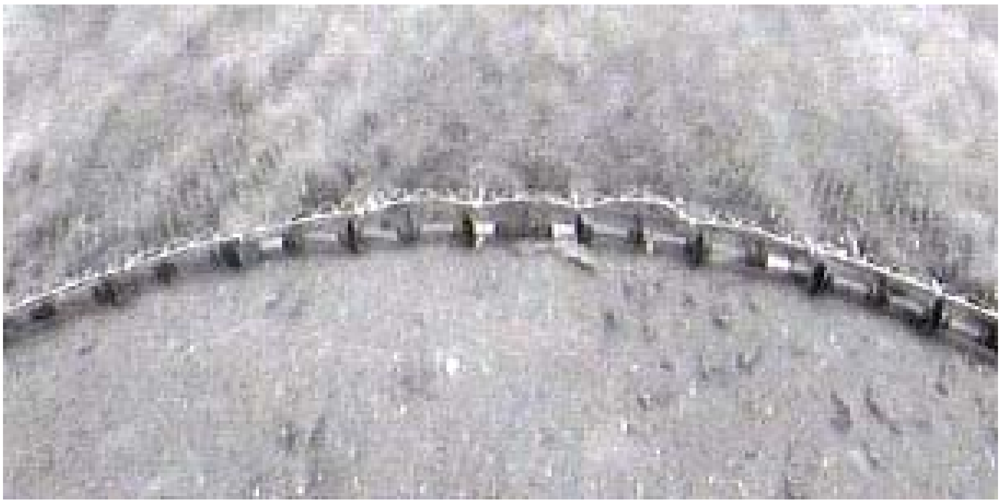


Plate 6-6. Camera attached to the headline directed aft towards the ground gear, with sand clouds clearly visible. Fish ahead of the ground gear are attempting to swim in the towing direction and avoid the trawl.

With the cameras placed on the headline and upper wings of the trawls, it was possible to observe the rubber discs of the ground gear and adjacent trawl meshes. The rubber discs were observed to be in continuous contact with the seabed, extending along the entire observable length of the ground gear. The seabed was flat and smooth, and was generally characterised by sand and mud sediments void of benthic animals. Contact with the seabed by the rubber discs caused disturbance of the substrate and visible plumes of sand to be raised in the water column (Table 6-6). On one occasion, the trawl was observed passing over long, narrow grooves in the substrate measuring approximately 30 mm deep. These grooves were presumably caused by the otter boards of another trawl.

The meshes in the trawl immediately adjacent the ground gear were open, and were well clear of the seabed. At the wingends, these meshes extended vertically above the ground gear, with the overall wingend shape being curved by hydrodynamic forces acting on the trawl (Plate 6-7). Interestingly, trawl geometry and the size of the sand plume often varied simultaneously during the tow. On numerous occasions the sand plume was observed to increase dramatically in size, followed immediately by reduced headline height and increased wingend curvature. Then, as the plume was reduced in size, headline height increase and wingend curvature was reduced. Presumably, this phenomena was linked to the ground gear encountering seabed sediments of varying softness. In soft sediments, for example, the ploughing action of the ground gear is likely to increase, resulting in increased lateral tension in the ground gear (with respect to the towing direction). This can result in increased trawl spread and reduced headline height, and hence alter the geometry of the trawl . Observations of the trawl mouth and body indicated that the meshes were open wide, and the trawl netting taught. With the camera located in the codend (directed forward), the meshes of the extension section became extended longitudinally and mesh opening was decreased. The geometry of these meshes was consistent around the entire circumference of the extension section.

With the camera either located in the extension section (directed aft) or in the codend itself, numerous folds were observed in the codend netting (Plate 6-8 and Plate 6-9). These folds extended longitudinally along the codend and were particularly apparent at the beginning of each tow, when catch volume was low and the codend meshes were not widely open. As the catch accumulated, the folds became less obvious and codend meshes near the extension section were further closed. The codend developed a bulbous shape as the catch increased and only meshes immediately ahead of and adjacent the catch were widely open.

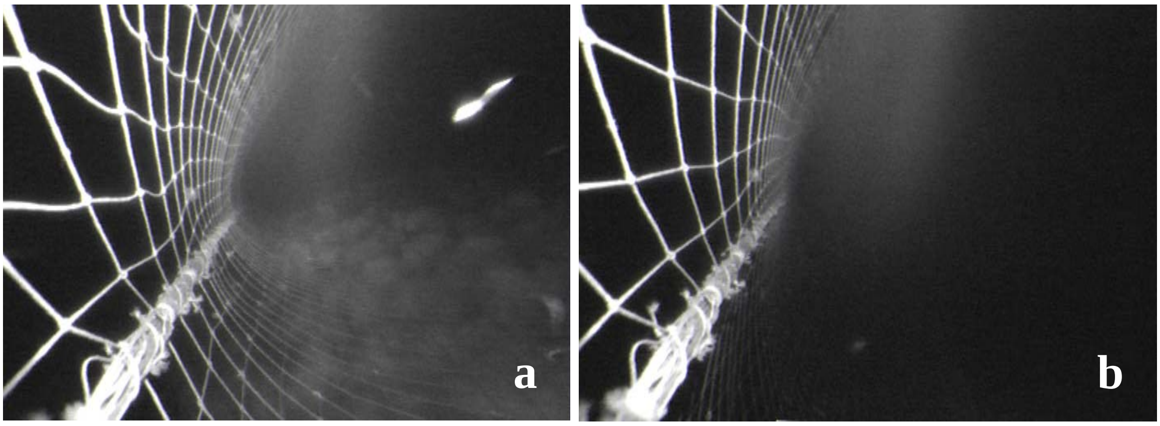


Plate 6-7. Differences in wing geometry over soft (a) and hard (b) substrates.

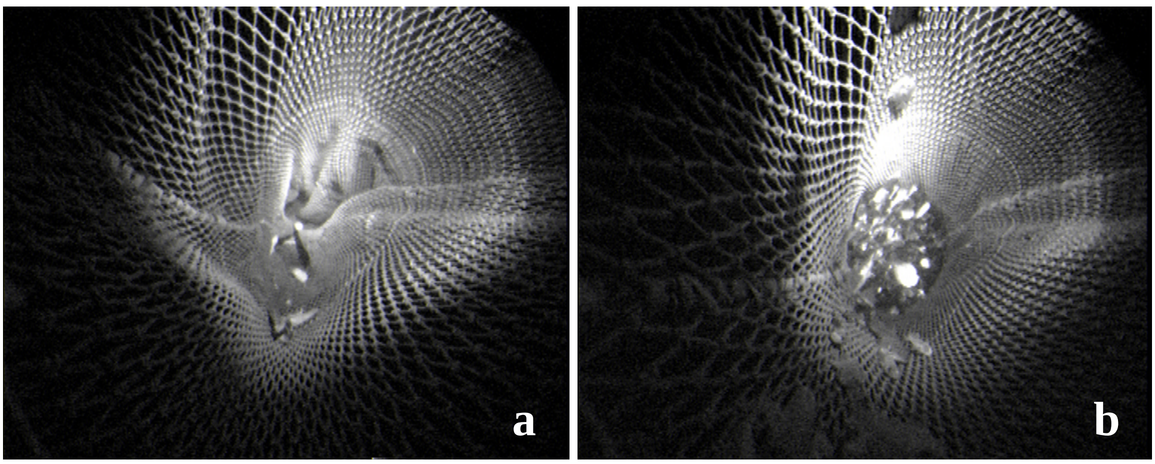


Plate 6-8. Camera attached to 90 mm codend directed aft. Note the longitudinal folds in the empty codend (a) are removed by catch-induced tension on codend (b).

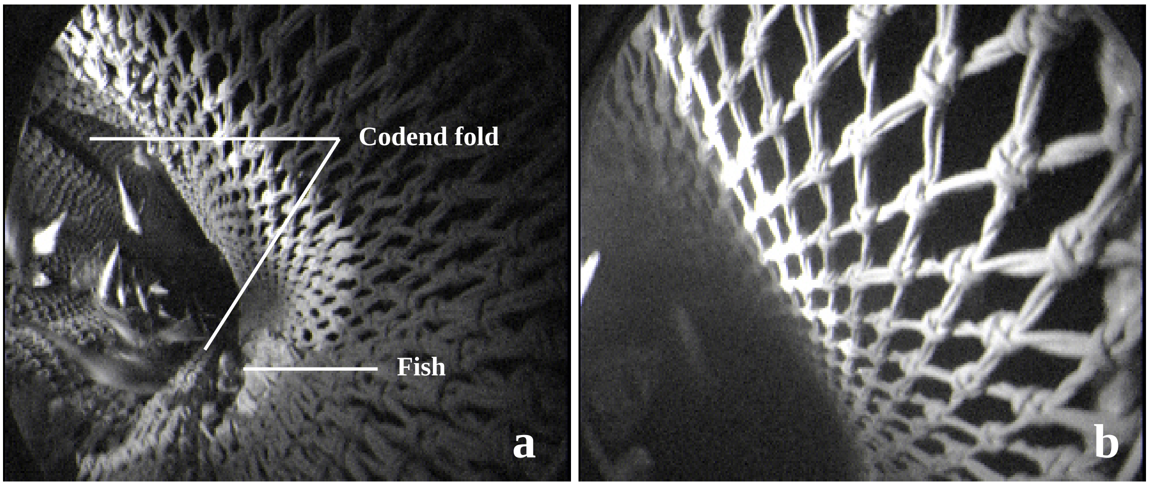


Plate 6-9. Comparison of mesh opening at the beginning (left) and end of a tow (right). The camera is attached to the top panel of the codend directed forward. Note the codend folds and the fish resting on the folded netting.

6.4.1.2 Codend cover

The camera observations of the codend cover confirmed the earlier flume tank observations by revealing a clearance of approximately 300 mm between the codend and codend cover. The geometry of the codend meshes appeared to be unaffected by the codend cover (see previous section for description of codend geometry) and at no time was the cover observed to come into contact with the codend.

During these observations numerous small fish were observed escaping from the codend, suggesting that the codend cover had no negative influence on fish escape rates. In the deep-water tow (~400 m) small whiptails dominated the catch in the cover, and video observations showed the relative ease with which this species escaped from the codend (Plate 6-10 a–c). Once initial penetration of the mesh occurred, the escape of this species was typically achieved by means of a singular movement involving burst swimming and rapid twisting of the body. On numerous occasions the escape of this species was facilitated by catch surging forward in the codend causing a temporary reduction in mesh tension. This allowed the mesh openings to briefly increase in width and easier passage of fish into the cover.

Catch results during these trials indicated that a small number of large gemfish and blue grenadier were consistently being recorded in the catch collected by the codend cover. These fish were too large to physically pass through the codend meshes, and it was presumed they had escaped through a hole at the end of the codend were the drawstrings pull the codend mesh together (Plate 6-11). To observe if this was the case, the camera system was attached of the top panel of the codend cover near the drawstrings, facing forward in the direction of tow. The resulting observations showed that during the initial stages of the tow, when catch levels were low, the mesh in the codend was sufficiently open to allow their escape and whiptail were observed escaping through this opening. The escape of fish continued until larger fish were pressed against the opening of the codend and effectively blocked the opening for the remainder of the tow.

During a shallow-water tow (~100 m), the codend cover was also well clear of the codend and large numbers of bellows fish were observed escaping from the codend. The escape response of bellows fish typically involved a single burst swim through an open codend mesh, although some larger individuals were observed wedged in the meshes for a short time before their 2nd and 3rd burst swim attempts allowed them to pass into the cover.

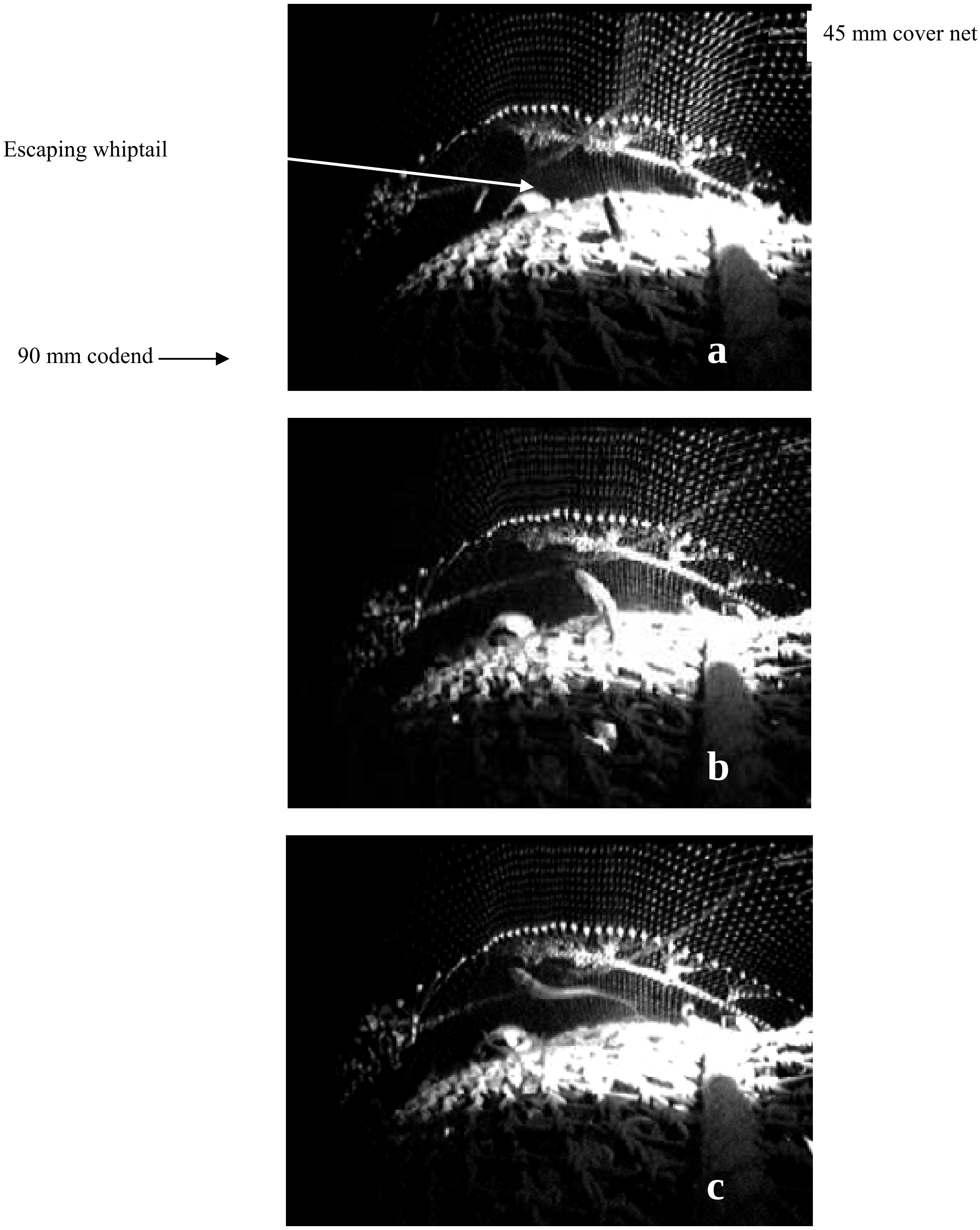


Plate 6-10. Video sequence of a toothed whiptail escaping from the codend into the small mesh codend cover. The upper image (a) shows the initial penetration of the fish through an open codend mesh. The middle image (b) shows the fish turning its body sharply while propelling itself forward, while the lower image (c) shows the fish swimming freely within the cover.

Plate 6-11. Camera located within the cover showing the codend drawstring and the size of the opening that allows fish to escape.

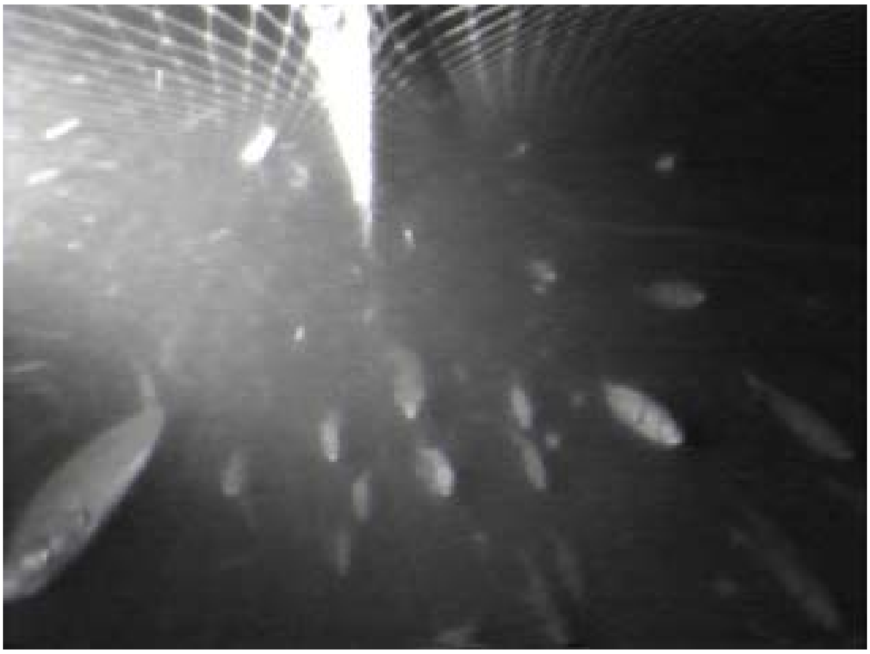


Plate 6-12. Underwater image of the trouser trawl design showing the leading edge of the separator panel. Jack mackerel are swimming with the trawl either side of the separator panel.

6.4.1.3 Trouser trawl

The location of the camera system in the trouser trawl allowed both trouser 'legs' to be viewed and the response of fish as they reached the separator panel. The video observations revealed that the separator panel between the two 'legs' of the trawl was occasionally billowing towards the starboard (with respect to the towing direction) extension leg. In effect this meant that that the trawl was not evenly divided in two, and that the effective opening of the port extension leg was far greater than that of the other. Catch analysis also indicated a bias towards the port codend, thus hampering assessment of the codend modifications. Following flume tank and at-sea testing of the trouser trawl, the inside seam of each 'leg' of the trouser trawl was sewn together. Further camera observations revealed that this modification was successful, with each 'leg' now having a more equal effective opening.

The observations of fish responding to the trouser trawl showed several species, including schools of jack mackerel and blue warehou, passing through the trawl and pausing in front of the separator panel (Plate 6-12). These species were typically cruise swimming in the towing direction and being slowly overrun by the trawl before responding to the netting panel and remaining in station for up to 30 minutes or more. They then generally moved en masse into one extension 'leg' of the trawl. Other species, however, such as whiptail, blacktip cucumber fish and threespine cardinalfish, that demonstrated limited swimming endurance, were observed moving passively back toward the codends. On several occasions, blue-eye trevalla were observed cruise swimming up and down the legs of the trouser trawl, and in one instance, were observed swimming up one leg then down the other.

6.4.1.4 Codend modifications

The lastridge rope system was designed to prevent the codend meshes from closing as the catch accumulated in the codend. The observations of this modification appeared to have been successful, with a relatively greater proportion of meshes open throughout the entire tow (Plate 6-13 a–b). The distribution of open meshes around the codend circumference also appeared to be more even, while the circumference was less circular in cross section, adopting a squarer cross section with the corners of the square adjacent the four lastridge ropes. The most notable observation of fish responding to this modification was large numbers of threespined cardinalfish swimming through the open meshes in the bottom panel of the codend soon after their arrival.

Observations of the 102 mm square-mesh panel indicated that this modification was well designed with all panel meshes fully open (Plate 6-14). Observations of fish behaviour showed good numbers of gurnards escaping through the square meshes soon after arrival in the codend. Observations of the 102 mm square-mesh codend showed large numbers of non-target species freely escaping through the open meshes. Whiptails and blacktip cucumberfish for example, were observed on numerous occasions actively swimming through the meshes located in the top, sides and bottom of the codend (Plate 6-15 and Plate 6-16). Observations of the 110 mm square-mesh codend showed many non-target species including New Zealand dory, blacktip cucumber fish and whiptails escaping through meshes in the upper section of the codend, while observations of the 110 mm diamond mesh codend showed both whiptails and threespine cardinalfish escaping through meshes in the bottom panel. Notably, few commercial species were observed escaping through the meshes of any codend modification, and those that did escape were usually small individuals just above legal size.

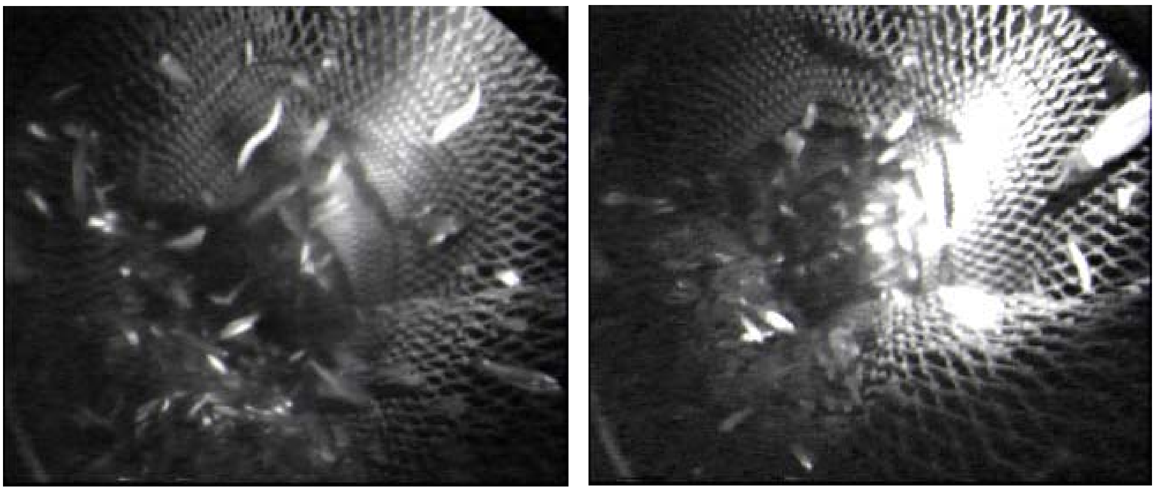


Plate 6-13. The standard codend (a) and the modified codend with lastridge ropes attached (not shown)(b). Note the increased mesh opening when the lastridge ropes are attached.

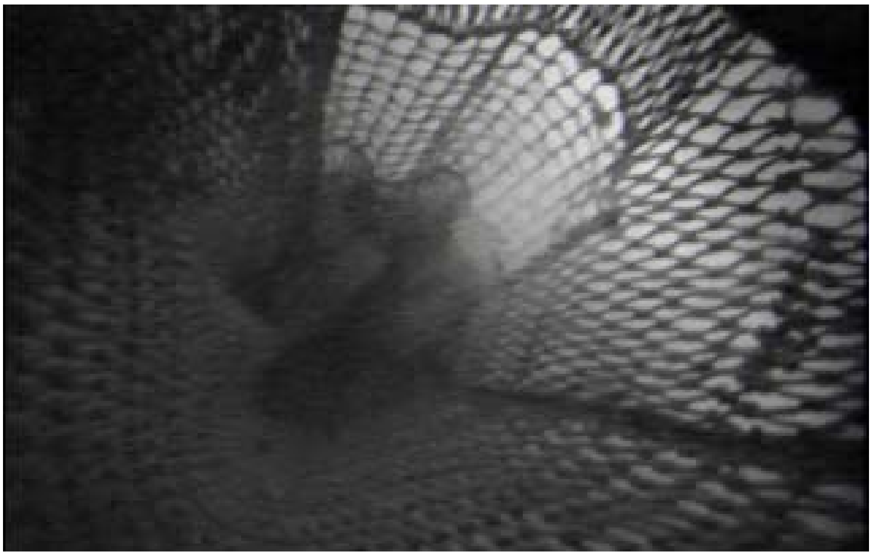


Plate 6-14. Camera directed aft towards the codend. The square-mesh panel is clearly visible and the meshes wide open.

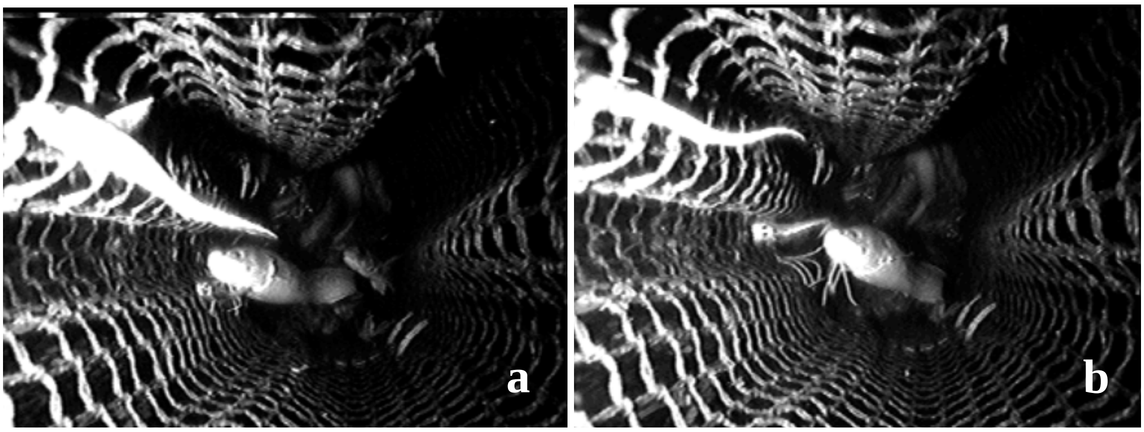


Plate 6-15. Video sequence showing a whiptail escaping from the 102 mm square mesh codend. Note pink ling in the background and the folds in the codend netting.

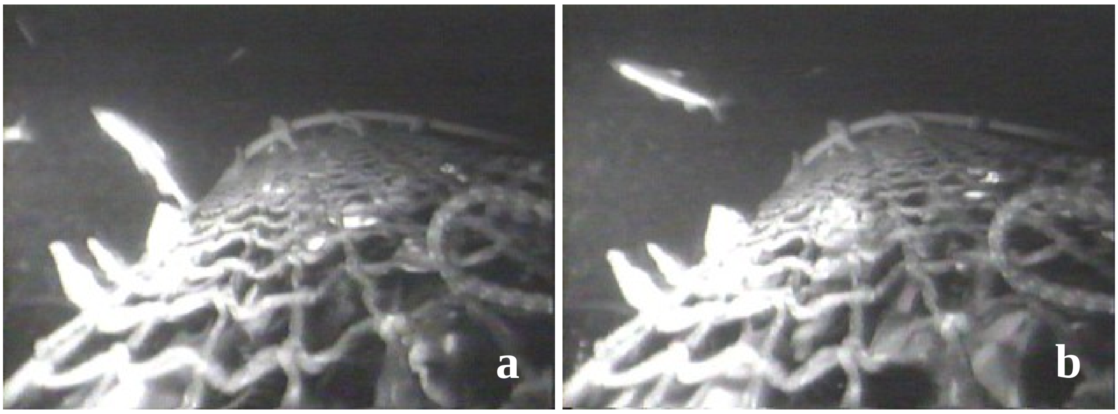


Plate 6-16. Video sequence showing an escaping blacktip cucumber fish from the 102 mm square mesh codend.

6.4.2 Observations of fish behaviour

A large number of commercial and non-commercial fish species were observed responding to the demersal fish trawls. The behaviour of these species during the capture process was wide and varied, ranging from highly active, directed burst swimming manoeuvres of short duration (events), to less active, homogenous behaviour of longer duration (states). No two species were observed responding in exactly the same manner to the trawl.

This section describes the generalised behaviour of the major commercial and non-commercial species encountered during this study. All reported behaviours are in response to a standard demersal fish trawl, from the trawl mouth to the codend. In the following tables camera location nomenclature is with respect to the towing direction and day is defined by the period 0600–1800 and night from 1800– 0600. Where referred to, n indicates the number of observations of that species observed within the field of view.

6.4.2.1 Blue grenadier

Video observations of blue grenadier were predominantly recorded on the commercial fishing grounds on the continental slope off Portland (Table 6-5). A total of 765 blue grenadier were observed responding to the trawl, and all tows occurred during daylight hours with the exception of one tow that extended early into the night.

Blue grenadier in the path of the trawl were mainly observed to be motionless on the seabed or in the water column (up to headline height) as the trawl approached. These individuals then typically displayed short burst swim manoeuvres in random directions either to avoid contact in or response to trawl contact, and were typically observed striking the netting panels in the wings and upper panel of the trawl. A few individuals were observed to orientate and cruise swim with the trawl for short periods of time (usually <10 s), before being slowly overrun by the trawl. These fish typically maintained their swimming direction as they passed into the trawl body. On some occasions, small blue grenadier was observed escaping through the open meshes of the wings.

As this species entered the trawl body, they typically performed several burst swimming manoeuvres, including burst turns sideways and upwards. The onset of these manoeuvres was not observed but was presumably a continuation of the same behaviour in the trawl mouth. These manoeuvres typically resulted in contact with the netting in the sides or top of the trawl (Plate 6-17 a–c), and occasionally resulted in small blue grenadier escaping through the trawl meshes. Those that did not escape were often observed to repeat the burst-swim-turn response towards the opposite side of the trawl and again contacting the netting. This behaviour continued as blue grenadier passed through the trawl body and into the extension section.

Upon entering the extension section of the trawl, blue grenadier were observed either continuing the active burst-swim-turn behaviour or resting motionless in the water column (presumably as they neared exhaustion). The active fish continued the burst-swim-turn behaviour in random directions, often striking the trawl netting although some individuals were observed burst swimming directly towards the codend. In the confines of the extension this behaviour was often related to the arrival of high numbers of fish, and may have been induced by crowding and contact with these fish. Blue grenadier that were initially motionless in the extension also responded to contact with other fish and were observed repeatedly performing the active burst-swim-turn behaviour. No observations of blue grenadier were obtained in the 90 mm diamond mesh codend.

Table 6-5. Summary of trawl shot and camera details during observations of blue grenadier.

Date	Region	Day / night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
11/03/00	Port	Day	378	Mouth	Right wingend	Forward/down	26
15/03/00	Port	Day	288	Mouth	Left wingend	Aft/towards mouth centre	72
15/03/00	Port	Both	648	Mouth	Left wingend	Towards centre of mouth	38
18/05/00	Port	Day	360	Mouth	Centre of headline	Aft/down	170
14/06/00	Port	Day	450	Mouth	Right wingend	Forward/down	12
29/03/01	Port	Day	414	Mouth	Centre of headline	Aft/down	60
12/03/00	Port	Day	450	Body	Centre of top panel	Aft/down	200
16/03/00	Port	Day	198	Body	Centre of top panel	Aft/down	58
19/06/00	Port	Day	306	Body	Centre of top panel	Aft/down	61
01/09/99	Berm	Day	414	Extension	Centre of top panel	Aft	43
10/10/01	Port	Day	657	Extension	Centre of top panel	Forward	25

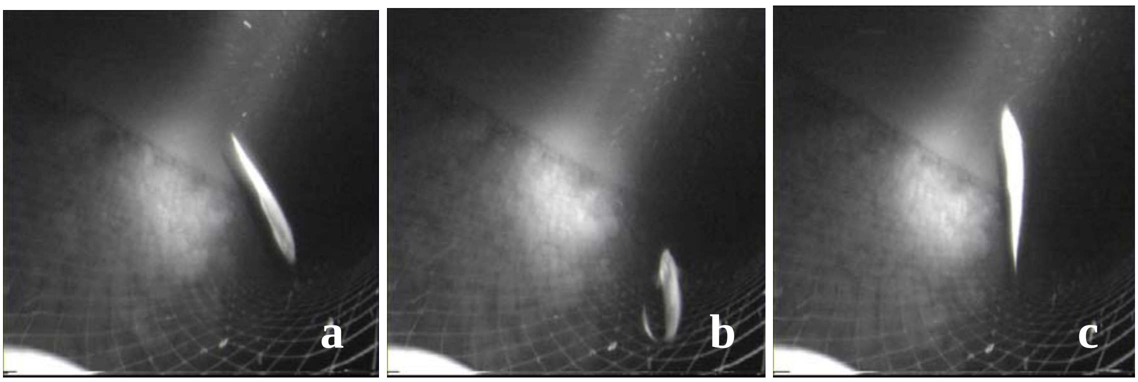


Plate 6-17. Image sequence of an individual blue grenadier striking the side panel of the trawl behind the ground gear. Immediately prior to contact the fish does not appear to respond to the approaching trawl (a). The fish responds to contact (b) and swims away from the trawl (c).

6.4.2.2 Tiger flathead

Video observations of tiger flathead were recorded on the commercial fishing grounds on the continental shelf off Bermagui (Table 6-6). A total of 1045 tiger flathead were observed responding to the trawl, and all tows occurred during daylight hours.

Observations of tiger flathead in the trawl path indicate that this species was generally motionless on the seabed or cruise swimming slowly close to the seabed (<1 m) as the trawl approached. These individuals typically responded to the approaching ground gear by repeated burst swim manoeuvres (so-called kick and glide) in a horizontal direction approximately normal to the ground gear. Between successive manoeuvres, swimming speed was less than towing speed and fish near the wings of the trawl were subsequently herded towards the bosom (centre) of the ground gear and footrope. After a short period (<60 s), these fish were unable to continue swimming ahead of the trawl and either rose a small distance above the seabed and entered the trawl, or escaped under the trawl between the rubber discs of the ground gear (Plate 6-18). Those individuals that entered the trawl typically swam slowly towards the codend whilst just clearing the lower panel of the trawl. No observations of tiger flathead were obtained in the trawl body or extension section of the trawl.

Arriving at the codend, tiger flathead were observed either swimming slowly towards the accumulated catch or remained motionless, orientated aft and overrun by the trawl. In both circumstances, most of these individuals turned slowly to orientate towards the trawl mouth as they neared the accumulated catch. Some individuals then rested on the bottom panel of the codend for a short period (<60 s) while others rose slowly upwards towards the top panel before being overrun by the trawl. Those individuals resting on the netting were eventually contacted by other fish arriving in the codend and responded with bursts swims in a random direction, often resulting in contact with the sides or upper panel of the codend. This response sometimes resulted in small tiger flathead escaping through the meshes in the top panel of the codend (Plate 6-19). Results from the footage analysis show that the dominant behaviours were cruise swimming directed aft, cruise swimming slower than trawl speed either orientated forward or changing in direction (Figure 6-2).

Table 6-6. Summary of trawl shot and camera details during observations of tiger flathead.

Date	Region	Day or night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
10/12/00	Berm	Day	91	Mouth	Centre of headline	Aft/down	580
13/12/00	Berm	Day	90	Mouth	Centre of headline	Aft/down	416
26/08/99	Berm	Day	90	Codend	Centre of top panel	Aft	49

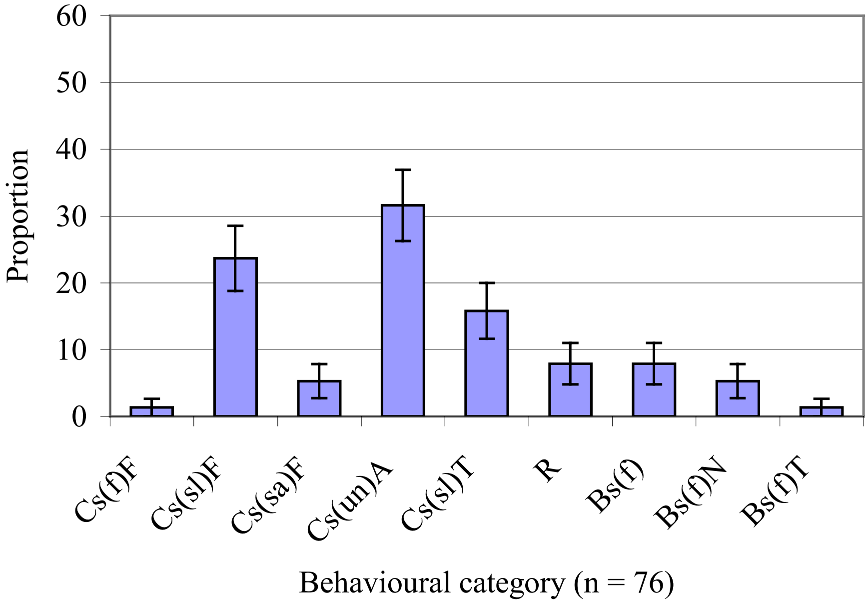


Figure 6-2. Proportion of the dominant behavioural categories (± SE) recorded for tiger flathead in the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

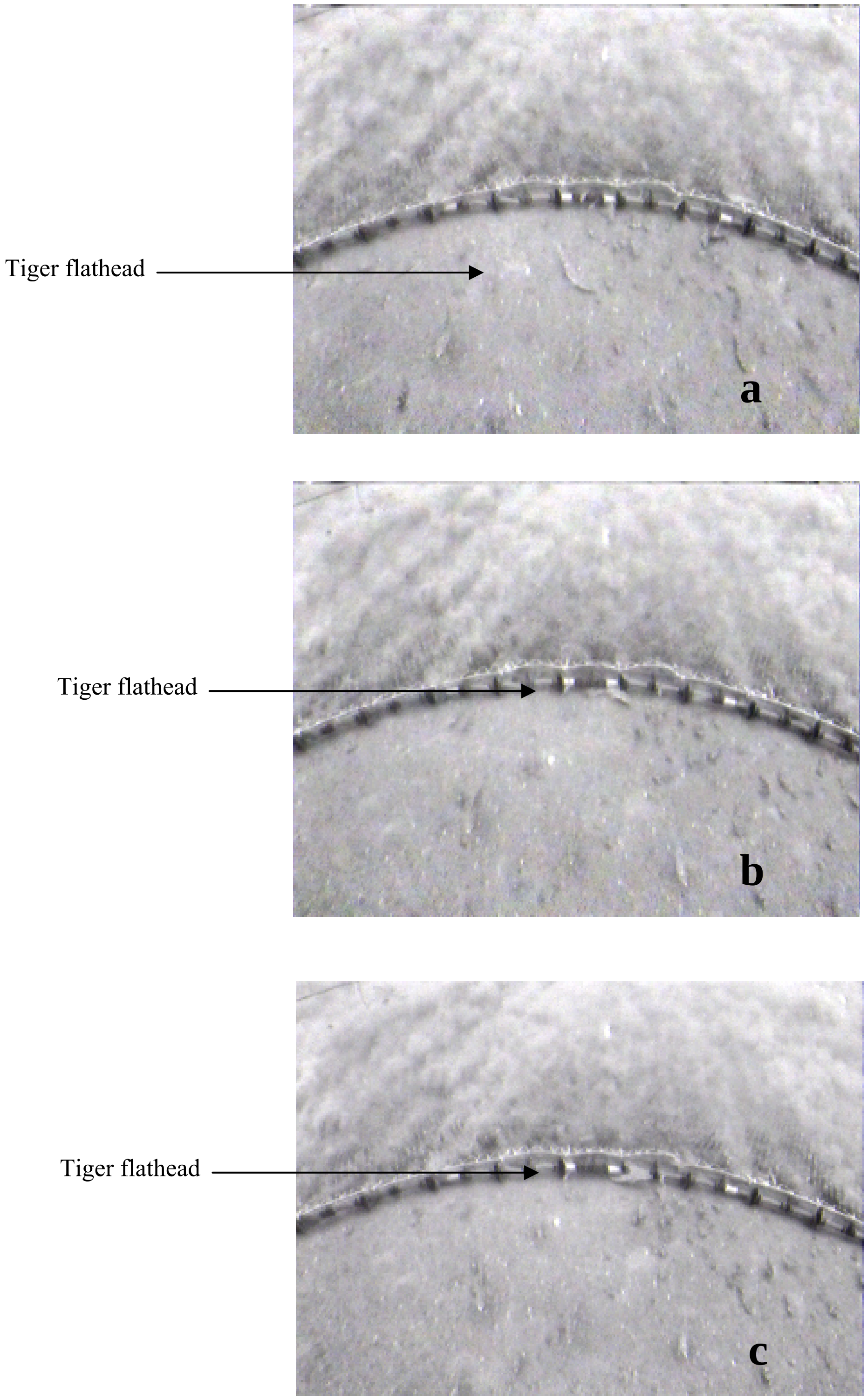


Plate 6-18. Video sequence of tiger flathead during contact with the ground gear of the trawl. Initially the flathead is approached by the trawl (a) before contacted by the ground gear (b) and rising upward into the trawl mouth (c).

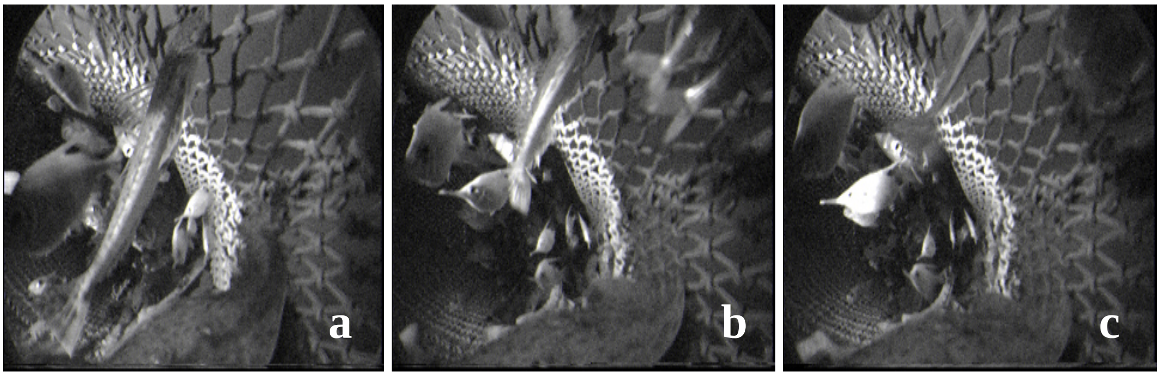


Plate 6-19. Image sequence of an individual flathead penetrating and swimming through a mesh located in the upper panel of the standard 90 mm diamond mesh codend.

6.4.2.3 Gemfish

Video observations of gemfish were recorded on the commercial fishing grounds on the continental slope off Bemagui and Portland (Table 6-7). A total of 219 gemfish were observed responding to the trawl, and all tows occurred in the daytime with two being completed in the early evening.

Observations of gemfish in the trawl path showed individuals typically located close to the seabed (<2 m) as the trawl approached. These fish then took up position just ahead of the ground gear at the bosom performing repeated bursts speed manoeuvres to avoid contact with the trawl. This behaviour was observed to continue for a short period of time (<60 s) before individuals were overrun by the trawl. As this occurred, gemfish were observed rising towards the headline of the trawl while maintaining a forward swimming direction; some individuals rising high enough to contact the top panel of the trawl.

In the trawl body, gemfish typically maintained cruise swimming at a speed sufficient to keep station with the trawl. After a short period (<60 s), however, some individuals began to perform burst swim manoeuvres to maintain station, and occasionally this was sufficient for the fish to strike the top panel of the trawl.

Video observations of gemfish in the extension piece and codend of the trawl show that individuals remained highly active, and frequently used burst swim manoeuvres to swim forward toward the trawl mouth. Some individuals were also observed using burst swim manoeuvres to swim down the codend towards the accumulated catch, while others were observed repeatedly attempting to escape through the upper panel of the codend using burst speed manoeuvres to swim into the meshes (Plate 6-20 a–c). After being highly active for some time, gemfish were observed to swim slower than trawl speed, and as they were overrun by the trawl they maintained their forward orientation but faced upward at an angle towards the sea surface. Results from the videos analysis showed that burst swimming into the netting and cruise swimming slower than the trawl speed orientated forward to the direction of tow were the dominant recorded behaviours (Figure 6-3).

Table 6-7. Summary of trawl shot and camera details during observations of gemfish.

Date	Region	Day or night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
15/03/00	Port	Both	648	Mouth	Left wingend	Towards centre of mouth	22
18/06/00	Port	Both	450	Body	Centre of top panel	Aft/down	18
10/10/01	Port	Day	630	Extension	Centre of top panel	Forward	100
28/08/99	Berm	Day	270	Codend	Centre of top panel	Forward	79

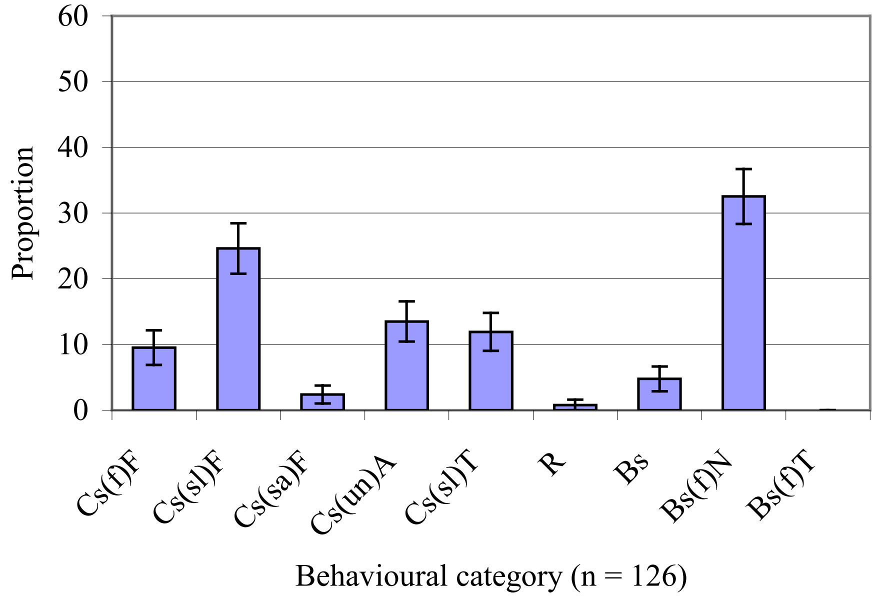


Figure 6-3: Proportion of the dominant behavioural categories (± SE) recorded for gemfish within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

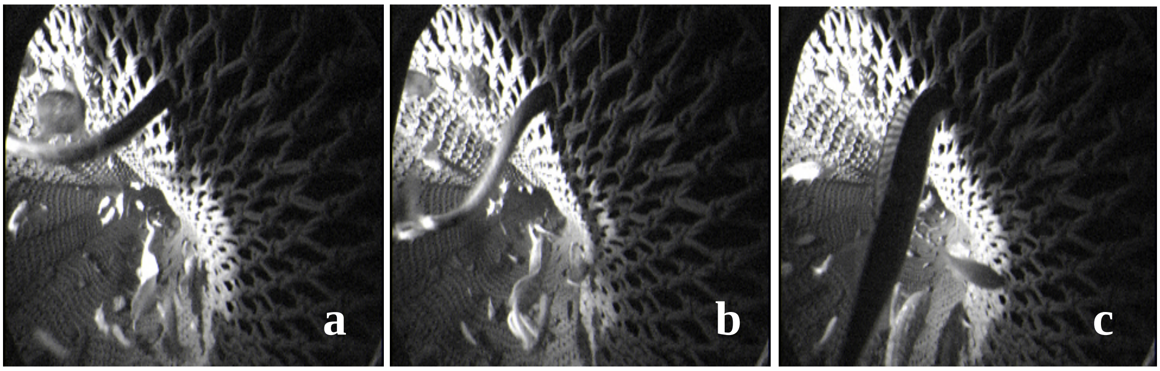


Plate 6-20. Image sequence of small gemfish attempting to penetrate a mesh in the upper panel of the codend (a and b) and ultimately failing c.

6.4.2.4 Pink ling

Video observations of pink ling were recorded on the commercial fishing grounds on the continental slope off Portland and Bermagui (Table 6-8). A total of 221 pink ling were observed responding to the trawl, and all tows occurred in the daytime with one being completed in the early evening.

Observations of pink ling in the trawl path showed individuals typically located close to the seabed (<2 m) either motionless or swimming slowly in a random direction as the trawl approached. Just prior to contact being made with the ground gear or trawl netting, individuals appeared startled, and responded with horizontal burst swim manoeuvres away from the trawl. These manoeuvres resulted in individuals near the wingends swimming toward the middle of the trawl mouth, while those already in this region of the trawl were often observed burst swimming towards the trawl body just above to the bottom panel of the trawl. Those individuals in the water column that were not contacted by the approaching trawl, simply remained motionless or were observed cruise swimming toward the trawl body. In the body of the trawl they either remained motionless or were cruise swimming. Contact with other fish or the trawl resulted in burst swim manoeuvres in a random direction.

Observations of pink ling in the extension section and codend of the trawl showed most individuals swimming slowly towards the codend close to the bottom panel of the trawl. Occasionally, individuals were noted orientated towards the trawl mouth, either motionless or swimming slowly in the forward direction before being overrun by the trawl. Reasons for the forward orientation of these fish are not clear.

Upon arrival at the codend, most individuals turned ahead of the accumulated catch and orientated towards the trawl mouth swimming at the same speed as the trawl (and possibly explains why some fish in the extension were orientated forward). To maintain this behaviour, individuals were observed to perform burst swim manoeuvres followed by cruise swimming. Pink ling often observed displaying burst swim and turn manoeuvres in the codend following tactile contact with other fish. This response appeared to be randomly orientated and often resulted in contact with codend meshes. After a period, presumably as the fish became exhausted from repeated burst swim manoeuvres, these individuals were observed swimming slower than trawl speed and were eventually overrun by the trawl whilst maintaining forward orientation. Analysis of the video observations indicate that cruise swimming either faster, slower or at the same speed as the trawl were the dominant behaviours (Figure 6-4).

Table 6-8. Summary of trawl shot and camera details during observations of pink ling.

Date	Region	Day or night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
17/11/99	Port	Day	432	Mouth	Centre of headline	Aft/down	5
11/03/00	Port	Day	450	Mouth	Right wingend	Forward/down	15
16/11/00	Port	Day	500	Mouth	Centre of headline	Aft/down	5
18/06/00	Port	Day	450	Body	Centre of top panel	Aft/down	10
19/06/00	Port	Both	468	Body	Centre of top panel	Aft/down	17
10/10/01	Port	Day	657	Extension	Centre of top panel	Forward	16
10/10/01	Port	Day	630	Extension	Centre of top panel	Forward	6
01/09/99	Berm	Day	414	Extension	Centre of top panel	Aft	82
28/08/99	Berm	Day	270	Codend	Centre of top panel	Forward	65

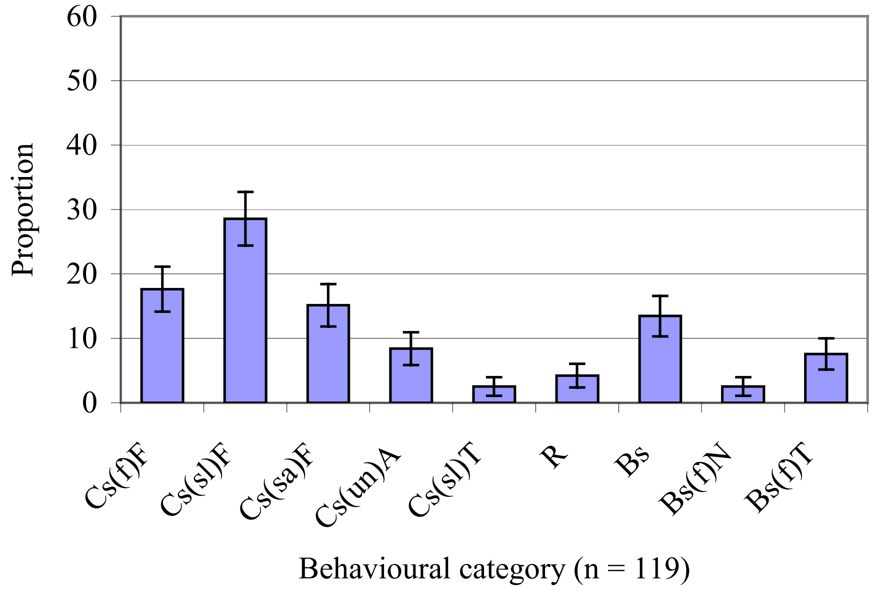


Figure 6-4: Proportion of the dominant behavioural categories (± SE) recorded for pink ling within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

6.4.2.5 Jackass morwong

Video observations of jackass morwong were recorded on commercial fishing grounds on the continental slope off Portland (Table 6-9). A total of 357 jackass morwong were observed responding to the trawl, and all tows occurred in the daytime with one being completed in the early evening.

Observations of jackass morwong in the trawl path showed individuals to be located on or near the seabed (<2 m) and either motionless or swimming slowly in a random direction as the trawl approached. Within the trawl mouth, the behaviour of individual jackass morwong did not appear to change until immediately prior to contact with the approaching ground gear or trawl netting. These fish were startled and performed repeated burst swims horizontally in random directions. These manoeuvres generally continued until the fish was overrun by the trawl. No jackass morwong were observed escaping upwards and over the headline of the trawl.

Observations of jackass morwong in the body of the trawl were dominated by the absence of swimming movement, and orientation either forward or sideways to the direction of tow. A few individuals were observed turning slowly and cruise swimming near to the bottom panel towards the extension section while others were burst swimming toward the extension. The onset of burst swimming was not observed, but presumably was caused by contact with other fish or the trawl netting.

Arriving in the extension section of the trawl, most jackass morwong were motionless in the water column and orientated sideways. Again, some individuals were observed to perform burst swims striking the side panels, possibly following contact with other fish. Once passing through the extension section and out of view (the camera was located in the aft end of the extension section directed forward), some individuals re-entered the extension section from the codend. These individuals performed repeated burst swims forward before cruise swimming at the same speed of tow with a steady tail beat frequency. Eventually these fish were overrun by the trawl and entered the codend.

Individual jackass morwong generally arrived at the codend swimming slowly near the bottom panel. These fish then turned, cruised slowly and began swimming steadily at the same speed of the net just ahead of the accumulating catch (Plate 6-21). This behaviour was maintained for a period of time (~5 mins.) before individuals slowed and then initiated burst swim manoeuvres in an attempt to maintain station or escape from the trawl. Results from the footage analysis show cruising swimming at the same speed of the trawl was the most dominant recorded behaviour within the codend (Figure 6-5).

Table 6-9. Summary of trawl shot and camera details during observations of jackass morwong. The number of individual jackass morwong observed in the field of view is also indicated.

Date	Region	Day or night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
29/03/01	Port	Day	324	Mouth	Centre of headline	Aft/down	33
19/06/00	Port	Day	306	Body	Centre of top panel	Aft/down	128
10/10/01	Port	Night	360	Extension	Centre of top panel	Forward	140
19/11/99	Port	Day	215	Codend	Centre of top panel	Aft	56

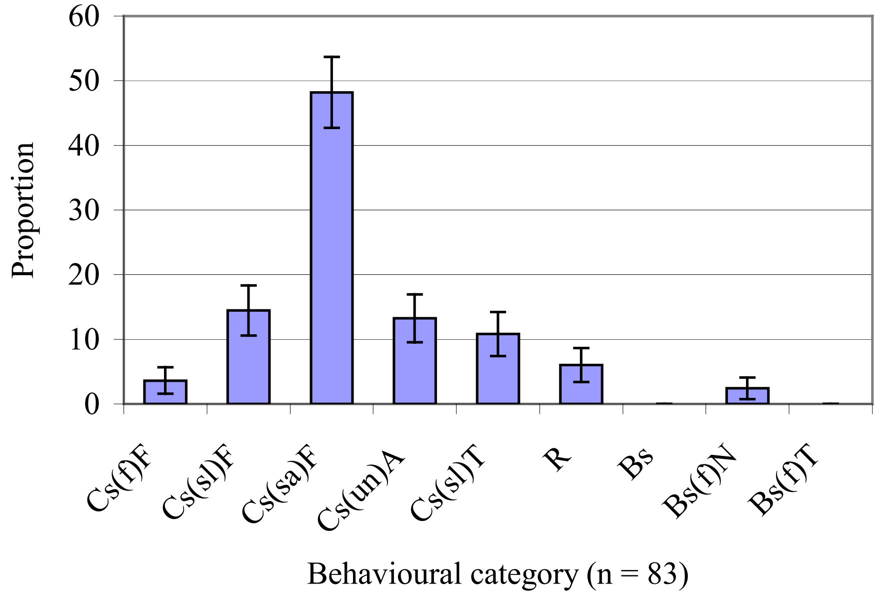


Figure 6-5. Proportion of the dominant behavioural categories (± SE) recorded for jackass morwong within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

Plate 6-21. Jackass morwong cruise swimming at the same speed as the trawl within the 'standard' 90 mm diamond mesh codend.

6.4.2.6 Silver warehou

Video observations of silver warehou within the trawl mouth, body and extension section of the trawl were recorded on the commercial fishing grounds off Portland, while observations of this species in the codend were recorded off Bermagui (Table 6-10). A total of 580 silver warehou were observed responding to the trawl, and all but one tow commenced in daylight hours.

The observations of silver warehou in the trawl path showed individuals to be located at various heights above the seabed (>3 m) and either motionless or swimming slowly in random directions as the trawl approached (Plate 6-22 a–b). Within the trawl mouth, individuals were observed swimming steadily with the trawl for extended periods (<5 mins.) before slowly being overrun by the trawl and entering the trawl body. On one occasion an entire school of silver warehou were observed cruise swimming forward and being overrun by the trawl. This school then moved out of view into the extension section for about 5 minutes before reappearing swimming towards the trawl mouth at a speed greater than trawl speed. The school was then observed to swim past the camera and out of view, and these fish were not part of the catch at the end of the tow having presumably escaped capture by swimming out of the trawl path.

In the trawl body, schools of small silver warehou were observed cruise swimming orientated forward to the direction of tow, slowly being overrun by the faster trawl and entering the extension section. In the extension section, most silver warehou were observed orientated forward attempting to maintain station with the trawl using occasional burst swim manoeuvres. These fish then turned slowly and began swimming towards the codend.

In the codend, individual silver warehou were observed orientated forward swimming at the same speed as the trawl for long periods of time (~60 s). Others that were observed swimming into the codend typically turned slowly ahead of the accumulated catch, orientated forward and swam at the same speed as the trawl before being overrun by the trawl. The duration of this behaviour was unknown, because the fish swam out of view of the camera. Results from the video analysis show that cruising swimming was the dominant behaviour, either at the same speed of the trawl and orientated forward, at an unknown speed orientated aft or turning slowly (Figure 6-6).

Table 6-10. Summary of trawl shot and camera details during observations of silver warehou.

Date	Regior	Day or night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
15/03/00	Port	Both	648	Mouth	Left wingend	Towards centre of mouth	3
14/03/01	Port	Night	270	Mouth	Centre of headline	Aft/down	30
12/03/00	Port	Day	450	Body	Centre of Top panel	Aft/down	50
17/03/00	Port	Day	198	Body	Centre of Top panel	Aft/down	40
10/10/01	Port	Day	657	Extension	Centre of Top panel	Forward	188
10/10/01	Port	Day	630	Extension	Centre of Top panel	Forward	210
28/08/99	Berm	Day	270	Codend	Centre of top panel	Forward	59

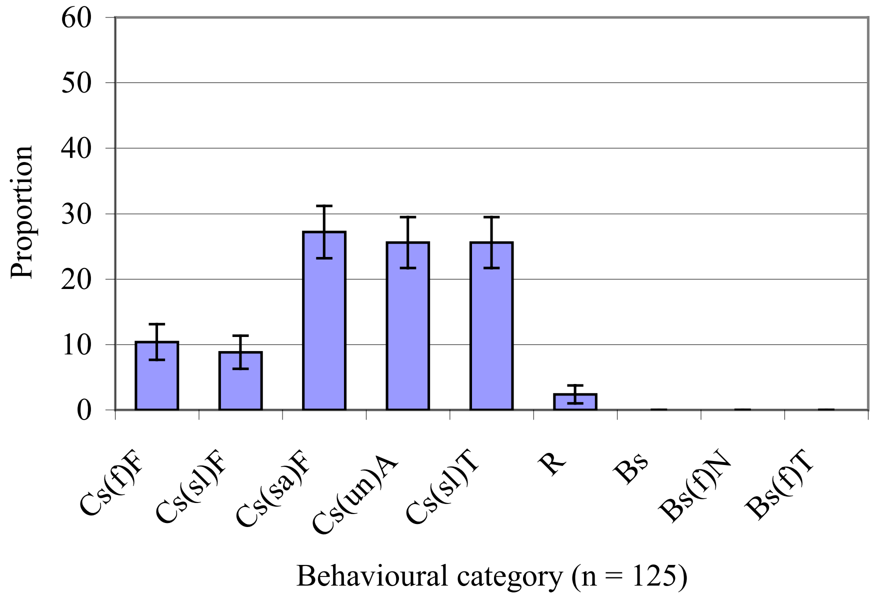


Figure 6-6. Proportion of the dominant behavioural categories (± SE) recorded for silver warehou within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

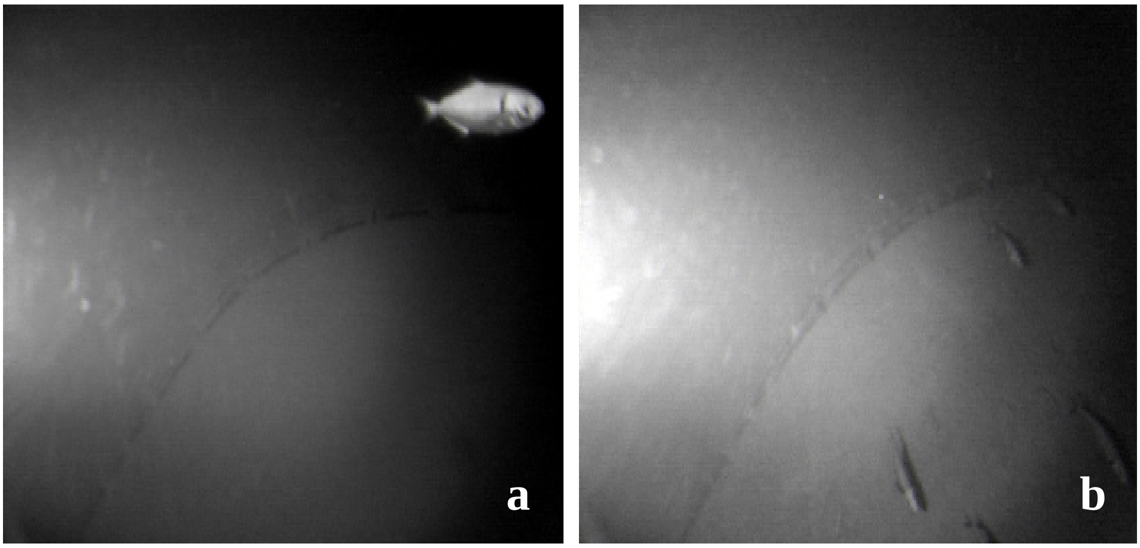


Plate 6-22 a – b. Silver warehou swimming slower than the trawl speed within the trawl mouth (a) and others swimming at the same speed as the trawl ahead of the ground gear (b).

6.4.2.7 Ocean perch

Video observations of ocean perch within the trawl mouth, body and extension section of the trawl were recorded on the commercial fishing grounds off Portland, while observations of this species in the extension section and codend were also recorded off Bermagui (Table 6-11). A total of 202 ocean perch were observed responding to the trawl, and all but one tow was completed in the hours of daylight.

Observations of ocean perch in the trawl path showed individuals typically located close to the seabed (<2 m) and either motionless or cruise swimming in random directions as the trawl approached. To avoid initial contact with the trawl, ocean perch were observed performing highly active short burst swims away from the wingends towards the centre of the trawl mouth. These fish then generally swam towards the trawl body using a sequence of burst swim - rest manoeuvres. Some small ocean perch were observed escaping capture by swimming through the meshes located in the bottom panels of the wing-ends. In the trawl body, ocean perch were generally motionless or cruise swimming slowly in the water column.

Ocean perch were observed arriving within the extension section of the trawl orientated forward to the direction of tow and motionless. A few individuals were also observed performing repeated short burst swims either forwards, toward the codend or sideways striking the side panels of the trawl. The onset of this burst swim behaviour was not observed. In the codend, ocean perch were predominantly motionless, orientated aft, and generally located closer to the bottom panel of the codend. Some individuals, however, were also observed burst swimming into the codend, while others were observed performing burst swims forward and sideways striking the side panels (not escaping through the mesh). During the early stages of the tow, with little catch in the codend, ocean perch often positioned themselves in folds of loose netting in the codend. These folds extended longitudinally, from the forward edge of the codend to part way along its length, and were most likely attributable to the absence of catch induced tension in the codend netting. Throughout the tow, many ocean perch were observed motionless, resting on the bottom panel of the codend, orientated forward. Immediately ahead of the catch, individual ocean perch were typically motionless, but were moved about the codend by turbulent water flow in the codend. Results from the footage analysis show resting was the most prevalent behaviour recorded within the standard codend (Figure 6-7).

Table 6-11. Summary of trawl shot and camera details during observations of ocean perch.

Date	Regior	Day or Night	Ave. depth (m)	Observed Net section	Camera location	Camera direction	No. of ind.
11/03/00	Port	Day	450	Mouth	Right wingend	Forward/down	8
11/03/00	Port	Day	378	Mouth	Right wingend	Forward/down	28
18/06/00	Port	Day	450	Body	Centre of top panel	Aft/down	8
19/06/00	Port	Both	468	Body	Centre of top panel	Aft/down	10
01/09/99	Berm	Day	414	Extension	Centre of top panel	Aft	69
10/10/01	Port	Day	657	Extension	Centre of top panel	Forward	15
28/08/99	Berm	Day	270	Codend	Centre of top panel	Forward	64

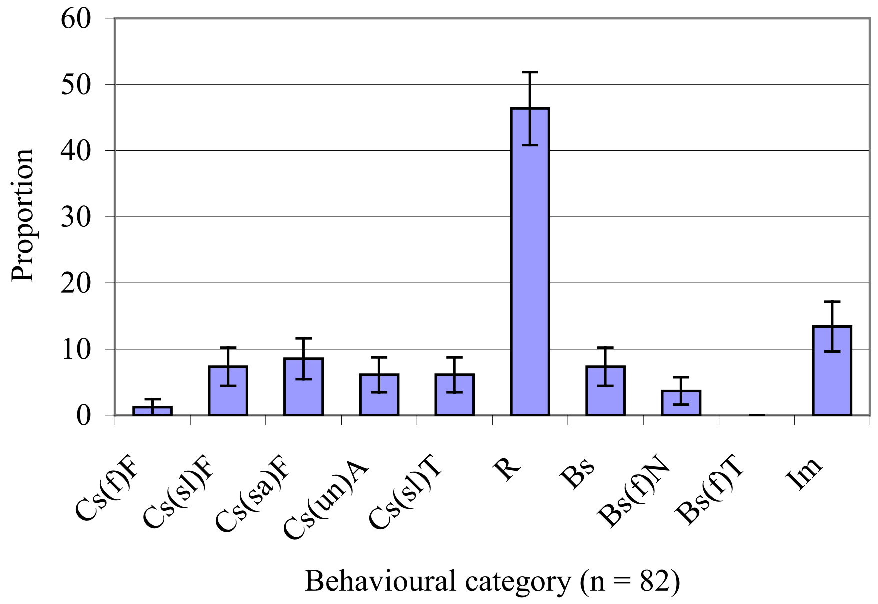


Figure 6-7. Proportion of the dominant behavioural categories (± SE) recorded for ocean perch within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

6.4.2.8 Whiptail species

Video observations of whiptails within the trawl mouth, body and extension section of the trawl were recorded on commercial fishing grounds off Portland, while observations of this species in the extension section and codend were also recorded off Bermagui (Table 6-12). A total of 1,163 whiptails were observed responding to the trawl, and all but one tow was completed in the hours of daylight.

Observations of this species in the trawl path showed individuals to be located on or near the seabed (<2 m) and either motionless or cruise swimming in a random direction as the trawl approached.

Observations of whiptails in the trawl mouth show individuals located close to the seabed and performing random burst swims horizontally to avoid contact with the trawl gear. These fish were, however, quickly overrun by the approaching trawl.

In the trawl body and extension section, individuals were generally close to the bottom panel of the trawl, motionless and orientated randomly. A few individuals did perform a burst swim manoeuvre in a random direction following contact with the trawl or other fish.

In the codend most individuals remained motionless in the water column, while others were swimming slower than the towing speed and orientated either forward or sideways/forward to the direction of tow (Figure 6-8). These individuals were generally near the lower panel of the codend, and many were observed coming into contact with the netting of the codend. This contact generally elicited a burst swim in a random direction. On several occasions, whiptails were observed motionless in the codend, seemingly being moved passively about by water turbulence immediately ahead of the accumulated catch. Results of the video analysis show resting was the dominant behaviour recorded for this species group within the standard codend.

Table 6-12. Summary of trawl shot and camera details during observations of whiptail. The number of individual whiptail observed in the field of view is also indicated.

Date	Regior	Day or Night	Ave. depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
11/03/00	Port	Day	378	Mouth	Right wingend	Forward/down	35
15/03/00	Port	Both	648	Mouth	Left wingend	Towards centre of mouth	82
16/03/00	Port	Day	468	Mouth	Right wingend	Aft	56
16/03/00	Port	Day	198	Body	Centre of top panel	Aft/down	126
01/09/99	Berm	Day	414	Extension	Centre of top panel	Aft	104
10/10/01	Port	Day	657	Extension	Centre of top panel	Forward	336
10/10/01	Port	Day	630	Extension	Centre of top panel	Forward	280
28/08/99	Berm	Day	270	Codend	Centre of top panel	Forward	144

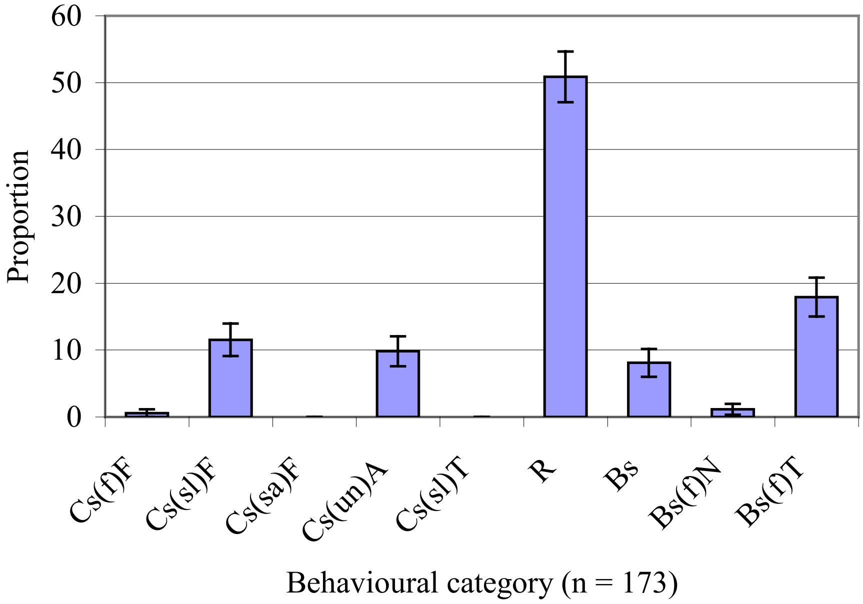


Figure 6-8. Proportion of the dominant behavioural categories (± SE) recorded for whiptails within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

6.4.2.9 New Zealand dory

Video observations of New Zealand dory were recorded on commercial fishing grounds off Portland (

Table 6-13). A total of 1,813 New Zealand dory were observed responding to the trawl, and all but one tow was completed in the hours of daylight.

Observations of New Zealand dory in the trawl path showed individuals to be typically located well clear of the seabed (>2 m) and motionless orientated in a random direction as the trawl approached. Observations within the trawl mouth showed individual New Zealand dory performing burst swim manoeuvres to avoid contact with the approaching trawl, interspersed with motionless behaviour. In the body of the trawl, New Zealand dory continued their motionless behaviour unless contacted by the trawl (Plate 6-23 a–c). In the extension section of the trawl, the motionless behaviour continued with individuals orientated randomly and quickly being overrun by the approaching trawl. The arrival of large numbers of this species usually resulted in contact or near contact with other conspecifics and burst swim manoeuvres to escape. The behaviour of New Zealand dory observed in the codend was identical to that observed in the extension section of the trawl. Results from the video analysis within the standard codend showed resting or burst swimming into the trawl netting were the dominant behaviours (Figure 6-9 and Plate 6-24 a–c).

Table 6-13. Summary of trawl shot and camera details during observations of New Zealand dory. The number of individual New Zealand dory observed in the field of view is also indicated.

Date	Regior	Day or night	Ave. Depth (m)	Observed net section	Camera location	Camera direction	No. of ind.
17/11/99	Port	Day	432	Mouth	Centre of headline	Aft/down	48
11/03/00	Port	Day	450	Mouth	Right wingend	Forward/down	78
15/03/00	Port	Both	648	Mouth	Left wingend	Towards centre of mouth	158
12/03/00	Port	Day	450	Body	Centre of top panel	Aft/down	140
19/06/00	Port	Day	216	Body	Centre of top panel	Aft/down	100
10/10/01	Port	Day	630	Extension	Centre of top panel	Forward	1030
17/11/99	Port	Day	320	Codend	Centre of top panel	Aft	259

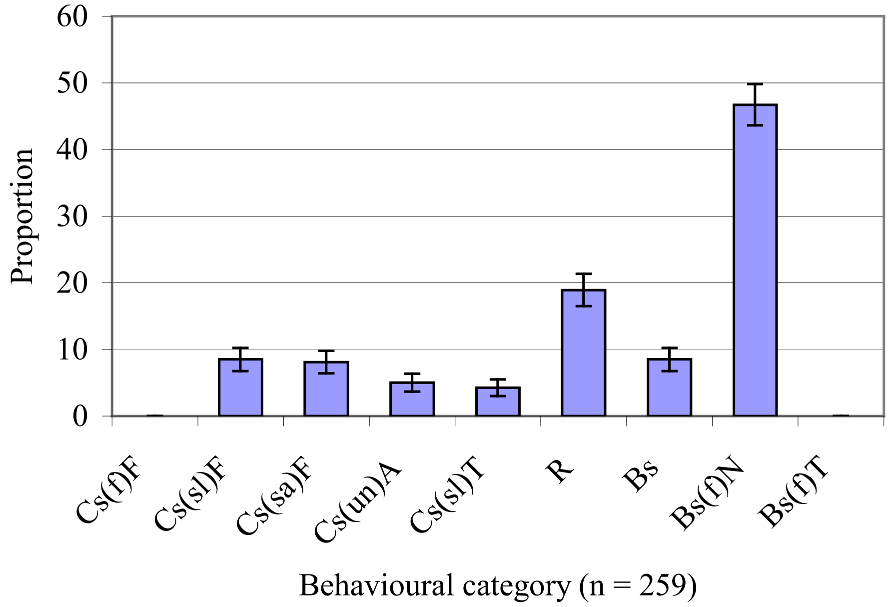


Figure 6-9. Proportion of the dominant behavioural categories (± SE) recorded for New Zealand Dory within the codend of a demersal trawl net (n is the total number of observations, behavioural categories are defined in Table 6-1).

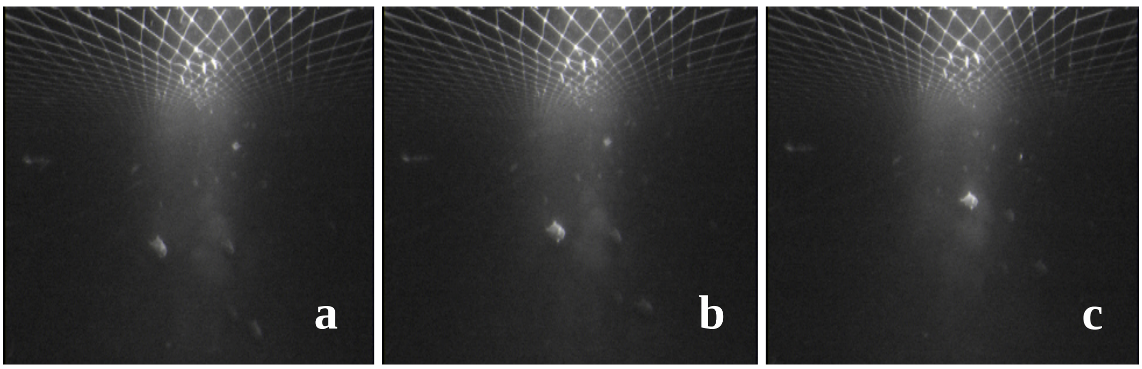


Plate 6-23. Image sequence of New Zealand dory within the trawl body performing no movement and being overrun by the trawl.

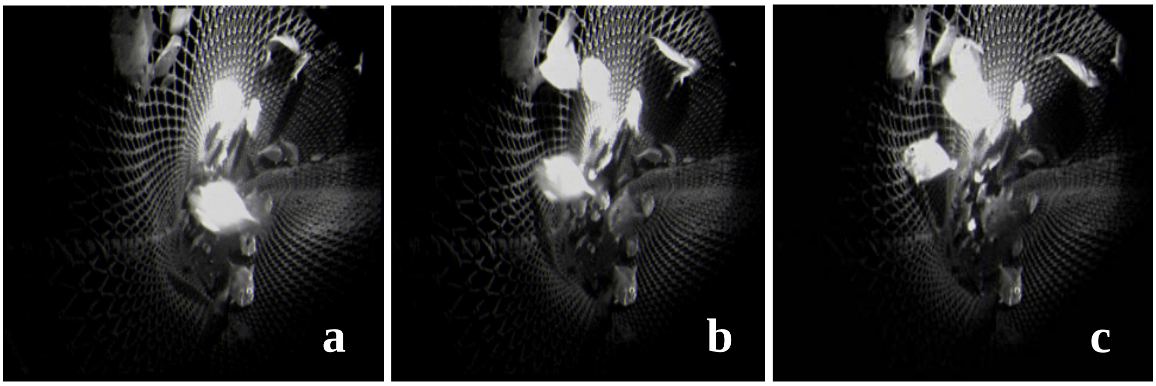


Plate 6-24. Image sequence showing an individual New Zealand dory within the codend burst swimming sideways and striking the side panel.

6.4.2.10 Swimming activity comparisons

The behaviour of all major commercial and non-commercial species observed in the codend differed substantially between species (Figure 6-10). Overall, medium activity was the most commonly observed behaviour followed by no-activity. All species exhibited medium and no-activity behaviour in the codend, while high activity was observed in all species except silver warehou.

Of the commercial species observed in the codend, medium activity was the dominant overall behaviour. The greatest proportion of medium activity behaviour by species was observed in silver warehou, and the least was observed in ocean perch. No-activity behaviour was observed in less than 5 per cent of observations of gemfish, silver warehou and jackass morwong, while 60 per cent of ocean perch behaviour was categorised by no-activity.

Of the non-commercial species, there was no clearly dominant observable activity. However, no-activity was the dominant behaviour category of whiptails, while high activity was the dominant activity of New Zealand dory.

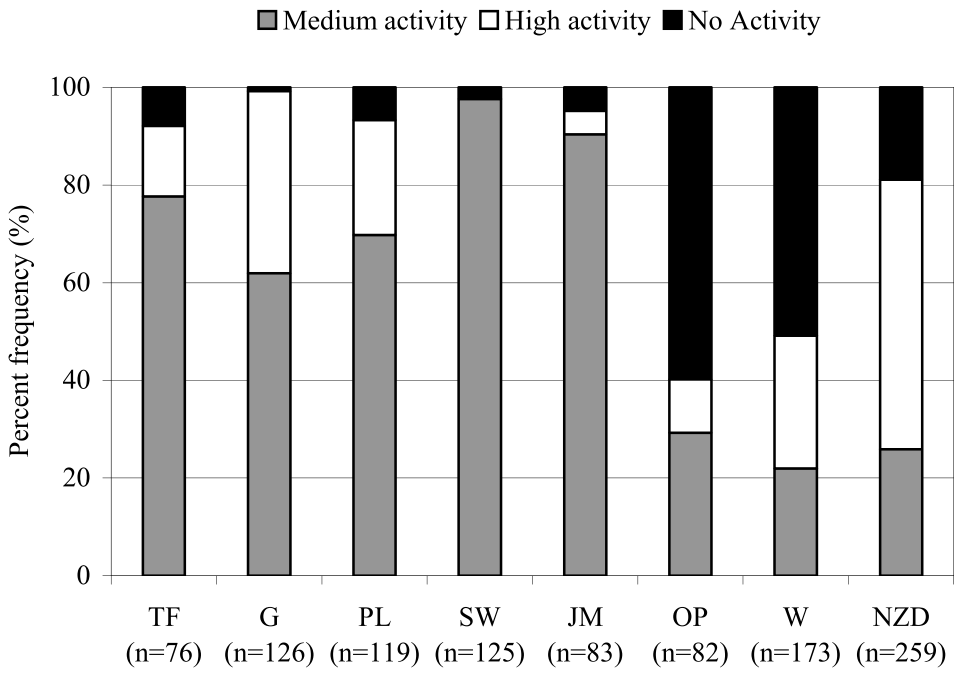


Figure 6-10: Frequency of observed codend behaviour categorised by activity levels for tiger flathead (TF), gemfish (G), pink ling (PL), silver warehou (SW), jackass morwong (JM), ocean perch (OP), whiptails (W) and New Zealand dory (NZD).

6.5 DISCUSSION

6.5.1 Underwater camera systems; limitations and utility

The underwater camera systems used in this project proved to be a highly successful means of observing fishing gear performance and fish behaviour. Both camera systems A and B provided reliable, clear video images, however the latter system with its umbilical connection between the recorder pod and lightweight camera pod, proved to be more versatile in providing images where the influence of the camera on trawl performance was a concern. The umbilical cable between the camera and recorder pods stood up well to the rigours of operation under commercial fishing conditions. The cable was potentially the weak link in the design of the camera system, being susceptible to damage due to fouling in the trawl meshes, but careful attachment to the trawl ensured reliable camera operation. On several occasions early in the project, the connector pins in the plugs at the ends of the umbilical cable or camera were damaged or broken. This was caused by inexperienced operators incorrectly aligning the pins with their respective sockets; a problem not experienced in the latter stages of the project.

The amount of lighting used to illuminate the water column ahead of the camera was typically sufficient to allow observations 5 m or more meters distant to be observed. During the early phases of the project the single light produced a narrow beam of illumination, producing a spotlight-effect on a small region in the field of view. This light was replaced with one that nominally produced a 60-degree beam of illumination, and remained in use for the remainder of the project.

The rigours imposed upon the camera housings were substantial, particularly during retrieval of the trawl as the camera and net encountered the stern ramp or deck. This was difficult to overcome, particularly in rough weather and the net crashes down on the deck. On several occasions camera operations were halted due to poor weather and concerns for the camera system, however, whilst considerable damage to the camera housings occurred there was no such damage to the camera systems.

The Sony analogue camcorders used in this project allowed up to 240 minutes of video footage to be recorded on a single VHS tape. Improved video quality could have been achieved by replacement with digital camcorders, however, this was not possible as only 90 minutes of footage can be recorded with this type of camcorder and they were not designed with a dedicated video-in signal capability (using them to record signals from an external camera meant considerable modification to the camcorder's casing and internal wiring). Recently, a new range of DVD-recordable camcorders have been introduced with up to 240 minutes recording time and video-in signal capability, and future AMC camera systems will most likely feature this type of camcorder.

6.5.2 Influence on fish behaviour

The influence of the camera systems on fish behaviour was not quantified but observations of fish in proximity to the camera suggest that some influence did occur. With the camera directed towards the codend, fish were sometimes observed moving into the region immediately behind the camera and swimming with a tail beat frequency substantially less than that of fish in other observable regions of the trawl. In these instances, the passage of the camera through the water had presumably caused turbulent eddies and wakes. In these regions some of the water is carried forward in the towing direction, and this allowed fish located within these eddies to maintain station with the trawl with a reduced tail beat frequency. Video observations in this region of the trawl indicated that fish took advantage of the eddies for a distance of 2–3 m behind the camera.

The use of lights to illuminate the trawl may have also influenced fish behaviour during the capture process. The degree that light influences fish behaviour is difficult to assess, because it is influenced by a combination of factors including time of day, ambient light levels, water turbidity, bioluminescent activity, light orientation and intensity. In this project no attempt was made to measure ambient light levels at the depths trawled, however, in oceanic waters, sufficient sunlight for deep-sea fish to respond to visual cues can penetrate to depths up to 1,200 m, while at night sufficient light exists in depths up to 600 m (Brown 1992; Bone *et al.* 1995). Given that almost all observations of fish in this project occurred during the hours of daylight in depths usually less than 650 m, the influence of light on fish behaviour may have been negligible. Moreover, both camera systems used in this study were designed with a single 20 W light to provide illumination of fish and the trawl. This follows an earlier study on the east coast of Tasmania in depths similar to that encountered in this project whereby AMC the camera system was designed with 4 x 50 W lights. The video footage was considered inadequate due to backscattering of light against suspended particles in the water column dramatically reducing the visible range. In overseas studies, several authors have used camera systems with substantially higher-powered lights and commented on their impact on fish behaviour. Wardle (1989) suggested that the use of artificial light always appears to disturb the fishes behaviour to some degree, while Glass and Wardle (1989) observed haddock responding positively to a trawl upon activating two 300W halogen lamps attached to a ROV. The ambient light conditions reported in this study were below the minimum threshold for this species to respond to visual cues. It is possible, therefore, that the use of a low-powered light in this project to avoid problems with backscattering may have proved beneficial in terms of minimising impact on fish behaviour. Moreover, the narrow beam produced by the first light, may have been superior in terms of minimal impact on behaviour despite the reduced area of illumination. In another study of haddock behaviour, Walsh and Hickey (1993) used a ROV with a single 250 W halogen lamp in low-light conditions and reported no change in fish behaviour, as reported by Glass and Wardle (1989). A suggested reason for the lack of response was that the narrower beam of light used in their study may have provided insufficient contrast for fish to respond to the approaching trawl.

Jackass morwong showed a tendency to swim directly in the cameras view for sometime indicating the camera system may have been affecting the natural swimming behaviour of these fish; either being attracted to the light source supplied by the camera system or locating the area of turbulent water caused by the camera pod’s housing.

Observations in this study have shown blue grenadier orientated and swimming along with the trawl at depths >200 ftm. Although light levels were not recorded, it is perceived no ambient light was present at these depths, however these fish were capable of exhibiting an ordered swimming pattern near the trawl mouth. This suggests that other factors such as bioluminescence and the artificial light supplied may have increased the contrast of the surrounding gear thus resulting in the fish encountered the ability to exhibit the optomotor response. Individual blue grenadier were also observed to exhibit a range of responses at the trawl mouth. It is perceived some individuals are able to detect the approaching trawl earlier than others allowing these fish to orientate and swim along slowly moving back towards the codend. Other responses observed included random burst swims or startle response performed by individuals that are assumed to be unable to detect the approaching trawl until near contact is made.

6.5.3 Behavioural differences between fish species

The selected fish species reported in this study differ greatly in shape and size. As a result, particular behaviours recorded were observed to be characteristic for particular fish species and size groups at various locations sampled within trawl nets. Using a comparative approach through categorising and recording behaviour, this study has shown that some distinct differences exist between selected fish species within the extension and codend sections of demersal trawl nets. The ability to continuously actively swim steadily for a period of time as apposed to inactive movements and passively drifting back in the water column appears to be the major differences between fish species. These differences in the observed swimming activities between fish species can be related to the overall swimming capability for a particular species that are in turn affected by various individual intrinsic factors as well as extrinsic factors.

6.5.4 Fish behaviour and selectivity within the codend

two modes of fish escapement through meshes in the codend were observed to occur: actively penetrating and swimming through or, passively being swept through the codend mesh with little movement. Observations collected within the standard 90 mm diamond mesh codend have shown the crowding of fish in the codend results in fish continuously coming into contact with each other. This tactile stimulus was observed to produce active burst of speed or startle response in a random direction by the individual. This response has been observed to allow escape of particular species small enough to swim through the meshes including gemfish, tiger flathead and blacktip cucumberfish.

Individuals observed being passively swept out of the codend appeared to be exhausted during earlier stages of the capture process. The majority of individuals undergoing passive escapement were observed to be various whiptail species. Being small in size and relatively weak swimmers, individuals were observed to exhaust quickly in the codend with a limited number of repeated active escape responses performed. As the maximum opening of meshes in diamond mesh codends has been reported to exist in a narrow band (0.5-1.5 m) in the lengthwise direction (Robertson and Ferro 1988). This restricted area of escape in diamond mesh codends may result in repeated active escape attempts being unsuccessful thus further exhausting individuals with an overall limited swimming capacity. Such individuals would therefore relying on passive inactive movements and a chance encounter with an unblocked open mesh to allow escape from the trawl net.

Observations of the codend modifications trialled revealed large numbers of whiptails actively swimming through the meshes of the 102 mm square mesh codend upon their initial arrival. This suggests that given the opportunity to escape through increased areas of open meshes, these fish have the ability to actively escape before exhausting and therefore relying on being passively swept out of the codend to escape capture.

Behavioural observations within the codend and extension have shown particular species directing active escape responses towards certain locations. For example, the majority of escape responses performed by small gemfish were directed towards the top panel while New Zealand dory were observed striking the sides of the netting in both regions. This suggests possible exclusion strategies exist for particular species whereby the placement of larger mesh openings confined to areas where active escape responses are directed towards by he unwanted species.

7 TRIALS OF MODIFIED CODENDS

7.1 INTRODUCTION

Indirect testing of gear modifications is relatively simple on twin or triple-rigged vessels which operate in most shallow water prawn fisheries and, in recent years, in some fish-trawl fisheries (twin-rig). With multiple gear, catches from nets towed independently, but simultaneously, can be compared (e.g. Broadhurst and Kennelly 1997; Briggs 1992; Graham and Kynoch 2001; Madsen *et al.* 1998).

In fisheries where only single-rigged trawlers are available, alternate haul, parallel haul or trouser trawl methods are used to assess the effects of net modifications. The alternate haul method (e.g. Broadhurst and Kennelly 1995b; Perez-Comas *et el*. 1998; Simpson 1989) is susceptible to changing conditions and population structure between hauls. To minimise variability, either relatively short tow duration or a large number of replicates are required, the latter making this method very time consuming and expensive. The parallel haul method involves two vessels, one towing the modified gear and the other towing the standard (control) gear, fishing the same ground at the same time (e.g. Armstrong *et al.* 1998; Thorsteinsson 1992). This method minimises any temporal or spatial changes during sampling but is also a relatively expensive option.

The most cost-effective method of quantifying codend modifications is the utilisation of either a divided trawl or a trouser trawl. Robertson *et al.* (1990) discussed the design and implementation of a divided or 'Siamese' trawl which was, in effect, two trawls hung side by side from a common headrope and footrope. Simpler in concept is the trouser trawl which is a single net with a dividing panel (see Wileman *et al.* 1996 for general arrangement). There are two basic designs of trouser trawl. The more complex arrangement is of a single net with a vertical dividing panel running from the front of the net (headline and footrope) to the end of the body which then separates into two extensions and codends (e.g. Walsh *et al.* 1992). Alternatively, the back end of net behind the tapered body section has no dividing panel but simply divides into two parts (legs), each with an extension section and codend (eg. Broadhurst and Kennelly 1995b). A compromise design between this and a fully divided trawl is one with a relatively short panel which divides the posterior section of the trawl body before separating into the codends. The trouser-trawl method allows for relatively straight forward comparisons of catch data between the two codends. The method assumes that there are no differences in geometry between the two sides of the trouser and that equal numbers of fish will enter each of the codends. However, these criteria are seldom met and corrective procedures for analysing selectivity data from trouser trawl experiments have been developed (Cadigan *et al.* 1996; Millar and Walsh 1992).

In the current project, ways of reducing discards were investigated by testing codends constructed of different mesh sizes and/or shapes against the standard (control) 90 mm diamond mesh codend. During initial stages of the project, the alternate-haul method was trialled but this method was found to be very time consuming and results were difficult to quantify because of the differences in time and sea conditions between tows. The trouser-trawl method was then adopted. In preference to a fully divided trawl, a trouser with a short dividing panel was designed so that it could be easily transferred among the various trawls on the chartered vessels.

The first section in this chapter details the work conducted to design and test a trouser trawl as a tool to compare different codend types. This was an iterative process that involved measurement in the AMC flume tank and fishing trials in order to develop an appropriate trouser trawl design. Once developed, the second section details the at-sea experiments conducted to determine the efficacy of different codend designs for bycatch reduction.

7.2 OBJECTIVES

7.2.1 Flume tank trials

The principal objectives of the flume tank trials were:

- To make a visual appraisal of the trouser and measure water flow at a number of paired locations in the trouser, extensions and codends; and,
- To design and test a trouser trawl suitable for the assessment of codend modifications in the bycatch reduction experiments, first with identical standard (control) codends, and then with codends of three different mesh sizes or shapes.

7.2.2 At-sea experiments

The objective of the at-sea experiments was to assess the performance of different codend configurations in terms of bycatch reduction and maintaining the commercial catch.

7.3 MATERIALS AND METHODS

Initially, modified codends were tested by the alternate haul method. This method involves the use of a single net with a standard or control codend. This net is shot for a predetermined time on a commercial shot. Once the control net is hauled, a net of identical design with a modified codend attached is then towed for a similar time on the same ground, at the same speed and in the same direction to make the two shots as similar as possible. This continues until the desired number of control versus modification replicates is achieved. Over a short time period of using this method, the variability of fish encountered during different times of day (morning and afternoon), between days, altering surface and bottom currents and accessibility to the same ground made it difficult to obtain parallel and valid comparisons. To gather enough data to allow valid comparisons and limit the variation from compared tows, it was deemed that too many replicates were required in the limited amount of time for field trials and other suitable methods for comparing codends was to be considered.

Through discussions between project researchers, independent researchers and industry, it was decided to test modifications by using the trouser trawl method. This method involves the use of one trawl net that is divided into two codends.

A trouser trawl was designed following a similar design used in Europe (Dahm *et al.* 2002). The theory behind the use of the trouser trawl is that a single trawl is used that then divides to two codends. The attractiveness of this method is that direct comparisons between a control and modified codend can be made within the one shot and uncontrolled experimental variables, as those encountered during the alternate haul trials during this project, can be kept to a minimum (Pope *et al*. 1975). Further, it is assumed that a fish encountering the trawl has an equal probability of entering either codend (Millar and Walsh 1992). This is usually achieved by placing a division of mesh vertically from headline to footrope and running down the net to the beginning of the trouser legs (Millar and Walsh 1992). There were concerns that this may adversely influence trawl geometry, therefore a small 'fish tail' divide was placed immediately forward of the trouser legs to assist in the splitting of fish into the two codends. This can be seen in Figure 7-1.

It has been suggested that by using a trouser trawl, especially when one leg of the trouser has a larger or square mesh codend, that differences in water flow between the two codends may result in unequal catches (Pope *et al*. 1975). To test this theory, the full-scale trouser was tested for water flow differences in the AMC flume tank.

7.3.1 Flume tank trials

7.3.1.1 Trouser design and construction

Figure 7-1 shows the general arrangement and plan of a trawl with the trouser attached. During construction, care was taken to have all panels, direction of knots, joining rows and seams identical on each side. On completion, the trouser, extensions and codends were symmetrical with no designated top or bottom. The overall length of the trouser with attached extensions and codends (100 meshes) was similar to that of the extension and codend of the single trawls used by the chartered vessels. The front of the trouser had a circumference of 220 meshes which was the same as, or similar to, the posterior circumferences of the body-sections of the project trawls.

The front of the trouser was divided by a vertical panel 48 meshes deep (Figure 7-1). The panel was designed to stretch about 70% of the diameter of the fishing circle and be under constant tension during trawling. The V-shaped panel projected forward into the body of the net with the top and bottom edges also shaped to be under tension. For rigidity and strength, 8 mm PE rope was seized along the top and bottom edges, and also along the V-shaped leading edge of the panel. For the flume tank tests, the trouser was rigged to a 40 mesh section of tapered body taken from one of the trawls used in the project; this section of net tapered from 270 meshes circumference at the front to 220 meshes at the join with the trouser. The upper and lower edges of the dividing panel (27 meshes long) were laced to 30 meshes of the top and bottom panels along the centre-line of the tapered body section. The mesh size of the dividing panel (90 mm) was the same as in the control codend used in all experiments.

Each leg of the trouser was constructed of four panels tapered to a 75 mesh circumference to which the extensions and codends were attached. In construction, the back of the dividing panel (48 meshes) was meshed directly to the inside panels of the two legs in a single join. The control codends were 75 x 25 meshes of 90 mm diamond mesh. Experimental codends were of similar length to the control codend: i) 90 mm square mesh (60 x 50 bars); ii) 102 mm diamond mesh (66 x 22 meshes); and iii) 102 mm square mesh (52 x 40 bars). All codend netting was double 4 mm diameter braided polyethylene twine. To facilitate closing the square-mesh codends, three meshes of diamond netting were attached to the back of each codend. For the codrope, there was a final row (reduced 2:1) of large meshes (approximately 140 mm) of 6 mm braided twine.

7.3.1.2 Flume tank and experimental procedures

Water flow through the trouser was measured experimentally in the AMC flume tank. This facility is fully described by Broadhurst *et al.* (1999a). The tank was large enough to accommodate the full-sized trouser, codends and extensions. Tests with the four combinations of codends measured the water flow at 6 pairs of locations within the trouser (A–F in Figure 7-1).

The front of the tapered section of net (270 mesh circumference) with the trouser attached was laced to a 2 m diameter aluminium-tube hoop (i.e. with a hanging ratio of about 24%). The hoop was tethered to two ‘towing’ posts (3.4 m apart) at the front of the flume tank by four 3.5 m bridles so that the hoop was positioned in the lateral and vertical centre of the tank. Equally sized bundles (28 kg) of small-mesh nylon netting, evenly secured to 1 m diameter rings, were used to provide weight and drag in each codend. Each weight was secured inside the codends to a row of meshes near the back, and the codends were then closed. To allow the flow meter transducer to penetrate into the trouser, apertures (two meshes long) were cut in the netting and marked with contrasting coloured twine. Trouser observations and flow tests were done with the flume tank at maximum flow rate i.e. about 1.35 $msec^{-1}$ (2.6 knots).

At the beginning of each set of measurements, flow in the tank was allowed to stabilise for at least three minutes (a test run indicated that the flow stabilised in less than two minutes). Beginning at one of the locations at the front of the trouser (selected at random), the current meter transducer was lowered into the centre of the trouser. Before the meter was activated, the depth of the transducer was checked from the side view of the tank to ensure that it was centrally located in the net. The current meter was switched on and the water flow measured over a 30 second interval. The data was then transmitted to the computer and the mean flow from 900 readings calculated. After each reading, the transducer was moved to the next adjacent location and the procedure repeated. When the mean flow at the 6 pairs of locations had been recorded, the pumps were switched off and the trouser was rotated through 180^{o} (in effect, this rotation alternated the side of the tank that measurements were taken for each individual codend). The full exercise was then repeated.

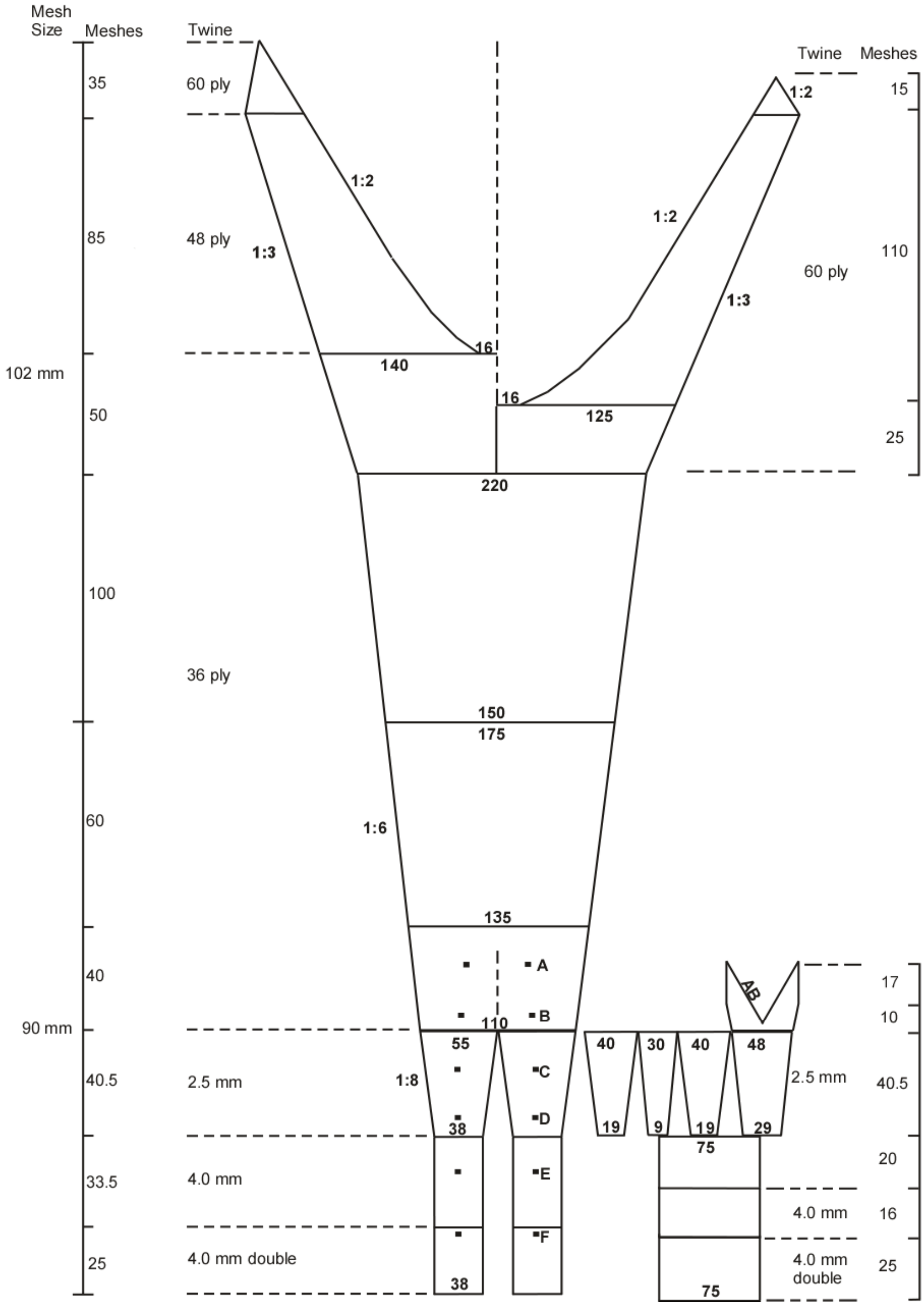


Figure 7-1. General arrangement of a typical project trawl with trouser attached. The trouser arrangement is as tested in the flume tank; A-F are positions of flow readings. Details of the trouser (on right) show the final arrangement of the extension sections (20 and 16 mesh) as used in all codend selectivity experiments.

For the trouser rigged with identical codends, the above procedures were replicated 5 times giving 10 pairs of flow readings at each of the 6 positions along the trouser. When rigged with a control codend and one of the test codends, the procedures were replicated 3 times. At the completion of the measurements for each pair of codends, the trouser was removed from the tank. Ambient water flow readings were then recorded at the equivalent positions in the tank for each location along the trouser. Ten replicates of ambient water flow data were collected during the course of the experiments.

7.3.1.3 Data analysis

Ambient water flow data, and flow data through each side of the trouser when rigged with identical (control) and experimental codends were tested for homogeneity of variances using Cochran's test, and then analysed in a two-factor fully orthogonal ANOVA (Underwood 1981). Significant differences detected in these analyses were investigated by Student-Newman-Keuls (SNK) multiple comparisons of means.

7.3.1.4 Fishing trials

Following the flume tank trials, the trouser was tested in the fishery using two control codends to determine if an equal split of catch was occurring. Initial fishing trials with the trouser indicated a consistent bias in catch to the port-side codend. This was attributed to one of the two legs rising above the other codend resulting in catch tending to be guided to the lower codend. As no design faults were detected by the flume tank tests, it seemed possible that the bias was caused by the codends twisting or being somehow unstable during trawling. Following advice from industry, the inside seams of the trouser 'legs' were laced together to keep them even and further trials were accomplished. Further fishing trials were then done with this arrangement and no bias was detected.

Eleven tows before the flume tank tests, and four tows after, were conducted with the trawl-trouser rigged with identical codends and with the same arrangement as tested in the flume tank. Fifteen tows were then done with the legs and extensions of the trouser laced together along their inside centre-lines, leaving only the codends separated. All tows were on established fishing grounds over a range of depths, with tow duration 2–3 hours and trawling speed approximately 2.8 knots.

Catches in each codend were kept separate and sorted by species; numbers and weights of each species were recorded. Catch data were analysed using two-tailed, paired *t*-tests ($p \leq 0.05$). All data were transformed (log x + 1) to stabilise the variances. Because trawling took place in a range of depths and over a time period of several months, no individual species were caught in all tows. Data were combined to major groups for analyses (sharks, rays, teleosts, cephalopods, crustaceans).

Initial analyses found that catches of "commercial teleosts" were significantly smaller in the starboard codend. In an attempt to determine the principal contributors to this difference, separate analyses were done for pink ling, dories (family Zeidae), and two arbitrary groups of species with similar physical and behavioural characteristics. These were 'benthic' teleosts [scorpaenids (Scorpaenidae); gurnards (Triglidae); flatheads (Platycephalidae); stargazers (Uranoscopidae)], and 'benthopelagic' teleosts [blue grenadier; barracouta; gemfish; warehous (*Seriolella* spp.)]. Benthic teleosts are characteristically bottom dwellers and feeders, while the benthopelagic group was composed of species which are relatively strong, active swimmers. Data for redfish catches in the trouser with joined legs were also analysed.

7.3.2 At sea experiments

Experiments comparing four modified codend types were conducted in the eastern area of the CTF; 102 mm diamond mesh, 110 mm diamond mesh, 90 mm square mesh and 102 mm square mesh codends. A 90 mm tapered diamond mesh bag was also trialled for five trawl shots. Fishing was conducted on recognised trawl grounds in depths between 39 and 310 fathoms. A total of 118 valid shots were conducted across these depths. For analysis purposes the depth was split into shots greater than 150 fathoms (63 valid shots) and shots less than 150 fathoms (55 valid shots). In depths greater than 150 fathoms, species targeted include pink ling, offshore ocean perch and mirror dory. In depths less than 150 fathoms species targeted include tiger flathead, redfish, jackass morwong, blue warehou, silver warehou, latchet, John dory and inshore ocean perch.

In the western area of the CTF, experimental comparisons of four modified codend type were also conducted; 102 mm diamond mesh, 110 mm diamond mesh, 110 mm square mesh and 102 mm square mesh codends. Fishing was conducted on recognised trawl grounds in depths between 92 and 410 fathoms. A total of 73 valid shots were conducted across these depths. Since a shot was often spread across several depths it was not considered accurate to split all shots accomplished by depth. Instead shots were split by the target species expected, which was decided by the skipper during the start of the shot, and was based on his prior knowledge of catch rates from previous shots accomplished on the same ground. Therefore comparisons were made between shots targeting deepwater flathead, deepwater bugs (*Ibacus & Thenus* spp), blue warehou, silver warehou, hapuku

(*Polyprion oxygeneios*), latchet (*Pterygotrigla polyommata*) and Gould's squid (Shallow <150 ftm) and shots targeting pink ling, blue grenadier and gemfish (Deep >150 ftm).

After the completion of each commercial tow the net was winched to the boat and both codends brought onboard. Each codend was emptied onto two independent areas of the deck and sorted separately. All commercial species, regardless of size, were first sorted from the catch from each codend. Length frequencies from dominant species of the commercial catch were taken. If catch sizes were too large to measure in their entirety, subsamples were taken. Subsamples taken depended on the total catch size, but in general a minimum of 100 individuals was randomly sub-sampled, measured and weighed. The total catch for that species was also recorded and total numbers and lengths scaled accordingly. Remaining less dominant commercial species were sorted, counted and weighed.

The remaining catch that comprised non-commercial species was then sampled. If the catch size was a manageable quantity, the non-commercial catch was measure in its entirety. Where catch rates were excessive, the non-commercial catch was sub-sampled. When sub-sampling, the total non-commercial catch was boxed to give a total number of boxes. A sub-sample was then randomly taken ranging from one to three boxes. Each sub-sample box was weighed to give a total sub-sample weight. This was then scaled up to represent the total number and weight caught for each codend.

Dominant species of the non-commercial catch were taken for length frequency analysis. Where catches of these species were too great, a sub-sample was taken. The sub-sample was measured and weighed and then scaled by total weight caught. The remaining non-commercial catch, whether it was sub-sampled or not, was sorted into species with numbers and weights recorded.

Since all research trips were undertaken with a single operator from each of the eastern and western regions of the fishery, it was considered that assuming their retention and discarding practices were uniform for the entire region could be biased for the remainder of the fleet in that area. It was decided that by incorporating a discarding ratio by weight and number where possible, for commercial species would better represent practices adopted by the entire fishery. Information from the CTS observer program, the Integrated Scientific Monitoring Program (ISMP), was used in this respect. Information on retained and discarded species was taken from the database from 1998 to 2000 inclusive. Discard and retained rates over this period for all trips undertaken were averaged to give a proportion for each length class for each species. Where no length classes were available, ratios of retained and discarded weights and numbers were derived catches recorded by ISMP observers.

Catch rates of non-commercial, commercial discard and commercial retained species were analysed using paired t-tests. Catches were transformed ln (x+1) and tested for heteroscedacity (Levene's test). Where heteroscedacity persisted, a more conservative probability level was used (0.01) to reduce the likelihood of a Type 1 error (Broadhurst *et al.* 2002; Underwood 1981). Comparisons of catches of non-commercial and commercial discard groups were analysed using one-tailed paired t-tests (testing the hypothesis that the test codends caught less than their controls), whereas the paired comparisons of catches of the commercial retained group between control and test codends were analysed in two-tailed paired t-tests.

7.4 RESULTS

7.4.1 Flume tank trials

7.4.1.1 Visual Observations

With a water flow of 1.3 m/sec, the trouser appeared to be well shaped and symmetrical. The centre-line of the tapered section in front of the trouser was pulled inwards by the dividing panel a distance equivalent to about 5 meshes (top and bottom). The dividing panel was upright and taught. A camera view from the front showed that the two openings to the trouser were symmetrical and stable. When streamed with empty codends (which tended to float), there was a little slackness at the top, front of the trouser but, with weight in the codends, this slackness disappeared. Viewed laterally, the trouser legs and codends streamed parallel to each other, and from above, the extensions and codends were evenly separated along their length. The extension sections (4 mm diameter braided netting) showed a normal circular opening at both ends but were appreciably narrower along the central area. With different combinations of codends, no change to the overall shape of the trouser was apparent.

The two square mesh codends (90 mm and 102 mm) showed appreciable folding along their lengths. This was because the fractional mesh opening of the diamond-mesh extension (about 20% of stretched mesh length) was appreciably less than the more rigid circumference of the square-mesh codend. However, the meshes in both codends retained their square shape and did not appear to be masked by the folding.

7.4.1.2 Flow data

Significant differences between the ambient water flow on each side of the tank were found at five (A, B, C, D, F) of the six positions (Figure 7-2; Table 7-1). To compensate for this bias, flow measurements through the trouser at each of the five positions were adjusted before analysis. The mean ambient flow on each side of the tank at each position was subtracted from the mean flow in the trouser at each position; the differences were then compared.

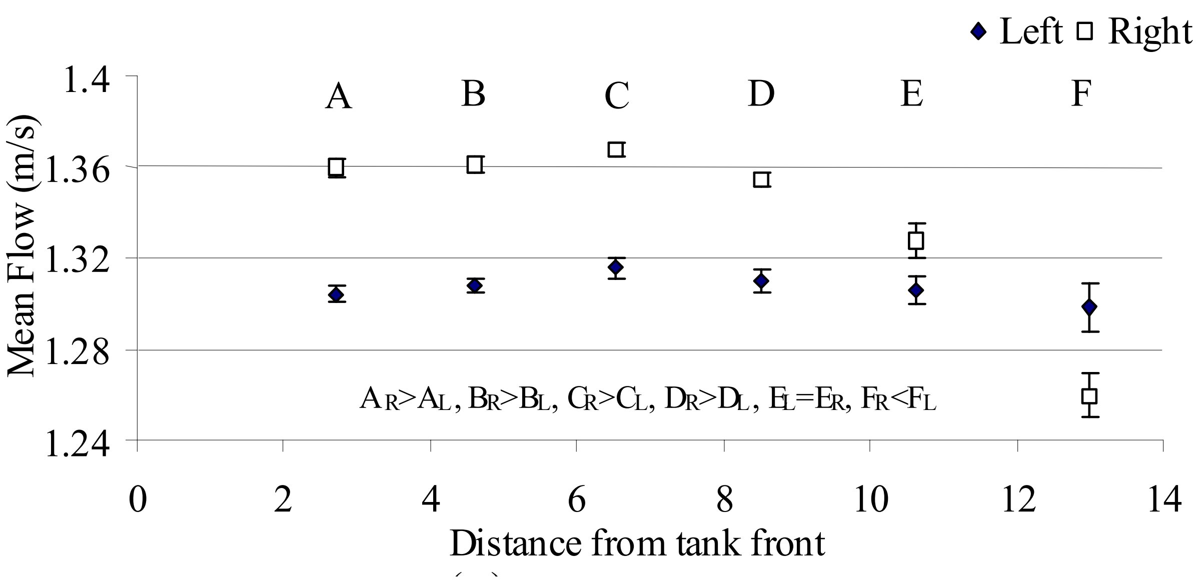


Figure 7-2. Mean flow (± SE) of water along each side (left ♦; right □) of the flume tank at the equivalent positions of the flow-measurement locations in the trouser (A– F). (< and > indicate direction of differences between left (L) and right (R) sides, in SNK tests)

Table 7-1. Summary of F ratios from the analysis of variance to determine effects on water flow at different times and positions in the flume tank.

Effect	df	Water flow (m/s)
Position	11	46.58 **
Time	3	2.77
Position x Time	33	0.57
Residual	48	

With identical (control) codends, there were no significant differences in flow across the trouser at any location (Figure 7-3; Table 7-2). There were also no significant differences in flow along the two sides of the trouser between positions A-B and B-C, and flow was almost identical to the mean ambient flow at those positions in the tank (Figure 7-3). Mean flows between positions C-D, D-E and E-F were significantly different (SNK tests) and progressively decreased.

For the three combinations with experimental codends, there were also no significant differences in flow between the two sides of the trouser at each location (Figure 7-3). As above, water flow through the trouser at the first three locations (A, B, and C) was almost identical to the mean ambient flow, but then progressively slowed towards the codends. For all codend combinations, the average flow at location D was about 6% slower than ambient; at location E, 13% slower; and in the front of the codend (location F), 36% slower.

Details of the comparisons of the water flow in the tank (Table 7-4, Figure 7-4) and the trouser trawl with codends of different mesh configurations are provided for: the 90 mm diamond control (Table 7-5, Figure 7-5); 90 mm square mesh (Table 7-6, Figure 7-6); 102 mm diamond mesh (Table 7-7, Figure 7-7); and 102 mm square mesh (Table 7-8, Figure 7-8).

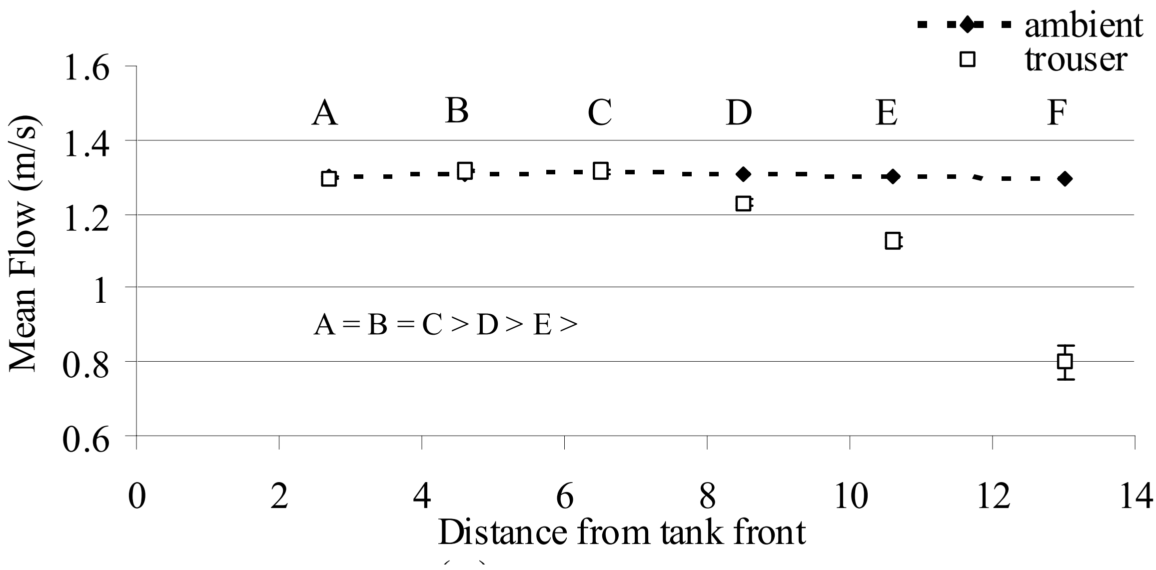


Figure 7-3. Mean ambient flow in the flume tank (♦ dotted line), and mean flow (± SE) at each location (A - F) in the trouser (□) rigged with identical 90 mm diamond mesh (control) codends. (= and > indicate direction of differences in SNK tests).

Table 7-2. Summary of F ratios from the analysis of variance to determine effects on water flow due to different positions in the trouser with identical (control) codends.

Effect	df	Water flow (m/s)
Codends	1	0.009
Position	5	514.8 **
Position x Codend	5	0.18
Residual	108	

Table 7-3. Summaries of F ratios from analyses of variance to determine effects on water flow at different codends in the trouser with test codends attached.

		Water flow (m/s)		
Effect	df	90 mm Square mesh	102 mm Diamond mesh	102 mm Square mesh
Codends	1	2.9	3.16	0.052
Position	5	292.8**	324.0**	407.8**
Position x Codend	5	0.64	0.65	0.6
Residual	60			

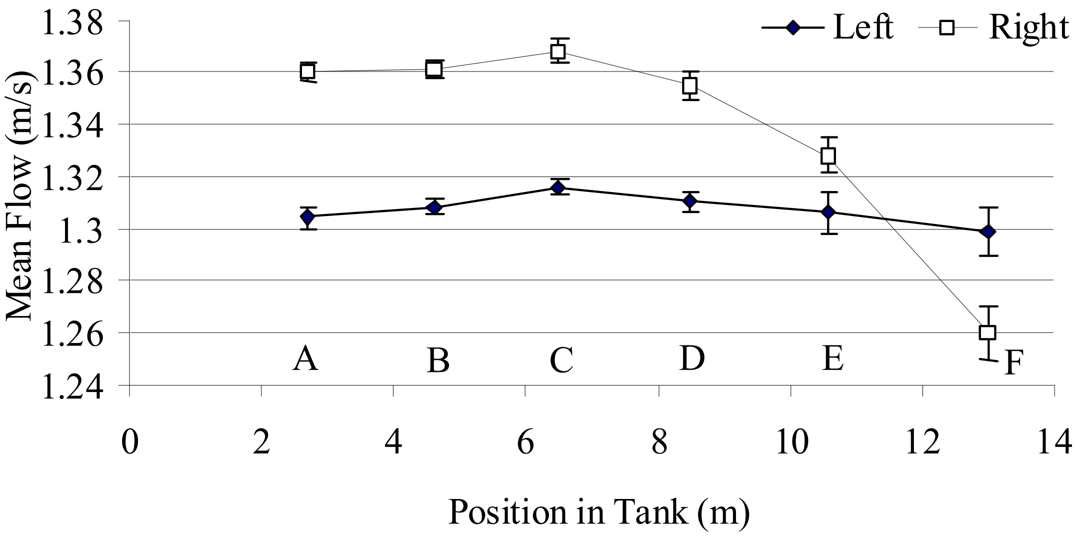


Figure 7-4. Mean flow (± SE) of water in the flume tank at the positions (m from front of tank) of each trouser measurement location (A - F).

Table 7-4. Mean flow (m/s) and SE, and mean flow differences between the sides of the tank.

Location	Position	Left	SE	Right	SE	Difference
A	2.7	1.3	0	1.36	0	0.056
B	4.6	1.31	0	1.361	0	0.053
C	6.5	1.32	0	1.368	0	0.052
D	8.5	1.31	0	1.355	0.01	0.045
E	10.6	1.31	0.01	1.328	0.01	0.022
F	13	1.3	0.01	1.26	0.01	-0.039

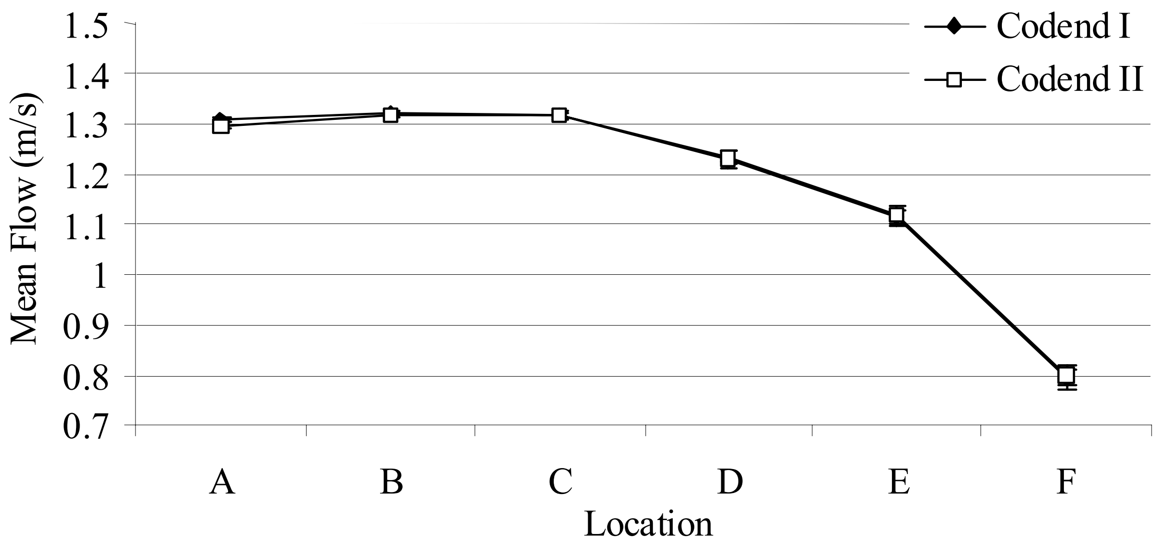


Figure 7-5. Mean flow (+ SE) at each location (A - F) in the trouser rigged with identical 90 mm diamond mesh (control) codends.

Table 7-5. Flow (m/s) data (adjusted) at the six locations (A-F) along each side of the trouser trawl with identical 90 mm diamond mesh (control) codends.

Location:	A	A	B	B	C	C	D	D	E	E	F	F
Codend:	I	II	I	II	I	II	I	II	I	II	I	II
Test												
1	1.31	1.257	1.33	1.31	1.3	1.288	1.24	1.187	1.12	1.099	0.81	0.771
2	1.32	1.277	1.34	1.33	1.33	1.318	1.3	1.297	1.01	1.179	0.66	0.811
3	1.32	1.307	1.32	1.33	1.33	1.328	1.3	1.267	1.05	1.039	0.76	0.831
4	1.3	1.297	1.32	1.33	1.33	1.348	1.25	1.257	1.19	1.129	0.84	0.801
5	1.32	1.307	1.32	1.32	1.33	1.318	1.26	1.207	1.12	1.189	0.84	0.831
6	1.287	1.3	1.32	1.3	1.298	1.3	1.227	1.25	1.169	1.12	0.821	0.88
7	1.307	1.33	1.33	1.33	1.348	1.36	1.207	1.22	1.099	1.13	0.801	0.68
8	1.307	1.3	1.32	1.32	1.318	1.33	1.117	1.21	1.109	1.02	0.841	0.81
9	1.287	1.29	1.31	1.28	1.268	1.29	1.197	1.19	1.119	1.14	0.771	0.8
10	1.317	1.3	1.33	1.33	1.308	1.32	1.197	1.25	1.129	1.15		
mean	1.308	1.297	1.324	1.318	1.316	1.32	1.23	1.234	1.112	1.12	0.794	0.802
SE	0.004	0.006	0.003	0.005	0.007	0.007	0.017	0.011	0.016	0.017	0.018	0.017
	p =	0.168	p =	0.193	p =	0.356	p =	0.788	p =	0.74	p =	0.773
		ns		ns		ns		ns		ns		ns

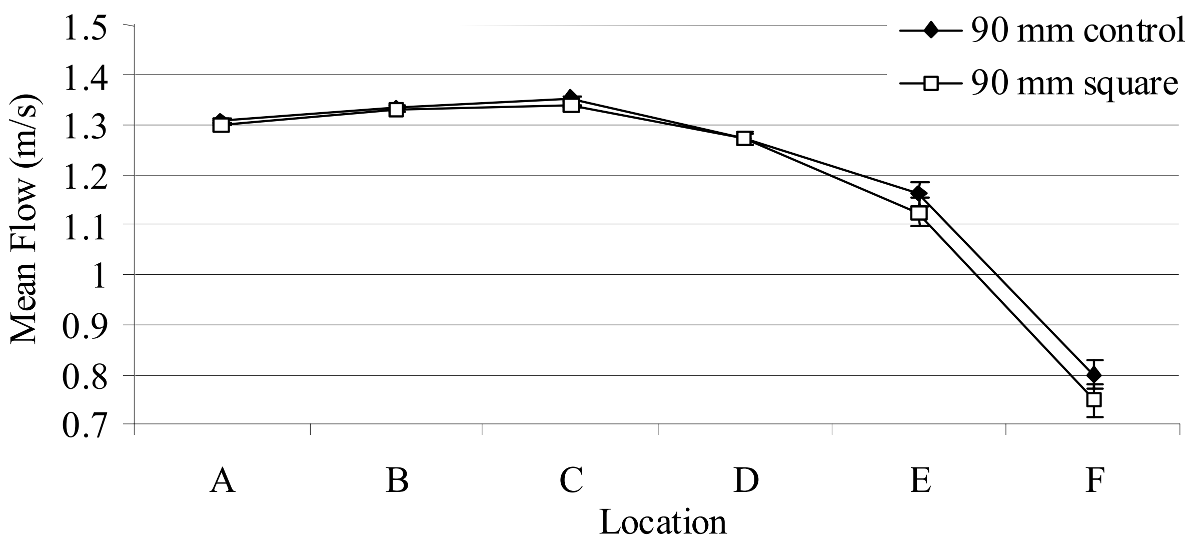


Figure 7-6. Mean flow (+ SE) at each location (A - F) in the trouser rigged with 90 mm diamond mesh (control) codend and 90 mm square mesh codend.

Table 7-6. Flow (m/s) data (adjusted) at the six locations (A-F) along each side of the trouser trawl with 90 mm control codend (I) and 90 mm square mesh codend (II).

Location:	**A**	**A**	**B**	**B**	**C**	**C**	**D**	**D**	**E**	**E**	**F**	**F**
Codend:	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Test												
1	1.29	1.294	1.32	1.337	1.35	1.338	1.26	1.295	1.14	1.21	0.75	0.739
2	1.31	1.304	1.33	1.337	1.36	1.358	1.22	1.295	1.11	1.11	0.81	0.869
3	1.3	1.314	1.33	1.327	1.37	1.338	1.3	1.315	1.13	1.19	0.81	0.829
4	1.314	1.3	1.337	1.33	1.358	1.33	1.265	1.23	1.13	1.16	0.799	0.7
5	1.314	1.31	1.347	1.34	1.358	1.34	1.305	1.24	1.27	1.01	0.919	0.64
6	1.324	1.29	1.347	1.32	1.338	1.33	1.275	1.26	1.2	1.13	0.719	0.71
mean	1.309	1.302	1.335	1.332	1.356	1.339	1.271	1.273	1.163	1.135	0.801	0.748
SE	0.005	0.004	0.004	0.003	0.004	0.004	0.013	0.014	0.025	0.029	0.028	0.035
	p =	0.305 ns	p =	0.546 ns	p =	**0.021** *	p =	0.931 ns	p =	0.476 ns	p =	0.261 ns

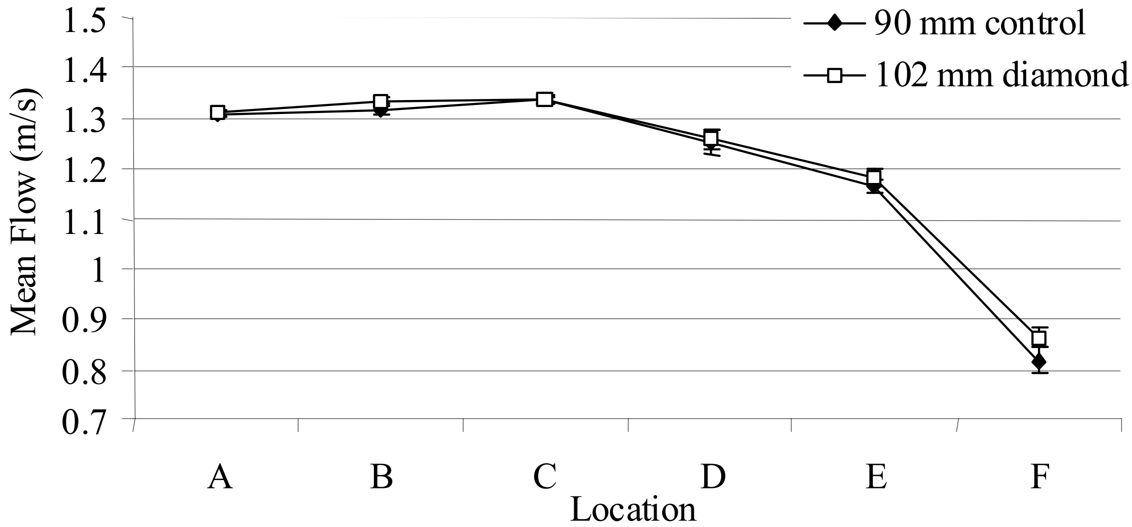


Figure 7-7. Mean flow (± SE) at each location (A - F) in the trouser rigged with 90 mm diamond mesh (control) codend and 102 mm diamond mesh codend.

Table 7-7. Flow (m/s) data (adjusted) at the six locations (A-F) along each side of the trouser trawl with 90 mm control codend (I) and 102 mm diamond mesh codend (II).

Location:	A	A	B	B	C	C	D	D	E	E	F	F
Codend:	I	II	I	II	I	II	I	II	I	II	I	II
Test												
1	1.32	1.294	1.34	1.347	1.35	1.318	1.28	1.255	1.2	1.19	0.83	0.919
2	1.32	1.324	1.33	1.357	1.36	1.338	1.29	1.235	1.17	1.15	0.87	0.879
3	1.3	1.324	1.3	1.337	1.35	1.328	1.32	1.295	1.2	1.24	0.86	0.909
4	1.314	1.32	1.317	1.34	1.318	1.35	1.185	1.25	1.12	1.13	0.729	0.84
5	1.284	1.3	1.287	1.31	1.318	1.33	1.175	1.19	1.12	1.16	0.769	0.79
6	1.314	1.3	1.317	1.32	1.338	1.36	1.255	1.32	1.18	1.23	0.849	0.84
mean	1.309	1.31	1.315	1.335	1.339	1.337	1.251	1.258	1.165	1.183	0.818	0.863
SE	0.006	0.006	0.008	0.007	0.007	0.006	0.024	0.019	0.015	0.018	0.023	0.02
	p =	0.84 ns	p =	0.089 ns	p =	0.865 ns	p =	0.831 ns	p =	0.455 ns	p =	0.17 ns

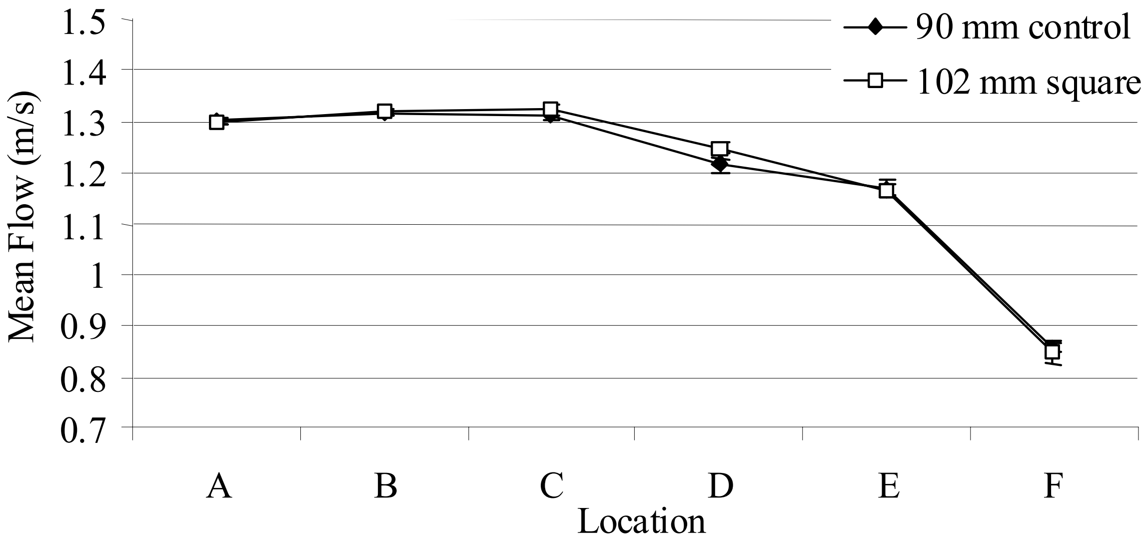


Figure 7-8. Mean flow (± SE) at each location (A - F) in the trouser rigged with 90 mm diamond mesh (control) codend and 102 mm square mesh codend.

Table 7-8. Flow (m/s) data (adjusted) at the six locations (A-F) along each side of the trouser trawl with 90 mm control codend (I) and 102 mm square mesh codend (II).

Location:	**A**	**A**	**B**	**B**	**C**	**C**	**D**	**D**	**E**	**E**	**F**	**F**
Codend:	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
Test												
1	1.29	1.284	1.32	1.327	1.29	1.298	1.18	1.225	1.18	1.13	0.93	0.859
2	1.29	1.274	1.29	1.307	1.31	1.298	1.22	1.255	1.2	1.2	0.87	0.829
3	1.32	1.294	1.33	1.307	1.37	1.338	1.28	1.215	1.18	1.15	0.9	0.879
4	1.304	1.31	1.317	1.33	1.298	1.32	1.185	1.21	1.12	1.12	0.769	0.81
5	1.294	1.32	1.327	1.33	1.298	1.33	1.215	1.24	1.16	1.24	0.839	0.84
6	1.314	1.32	1.327	1.32	1.308	1.36	1.225	1.32	1.17	1.15	0.829	0.86
mean	1.302	1.3	1.319	1.32	1.312	1.324	1.218	1.244	1.168	1.165	0.856	0.846
SE	0.005	0.008	0.006	0.004	0.012	0.01	0.015	0.017	0.011	0.019	0.023	0.01
	p =	0.864 ns	p =	0.828 ns	p =	0.467 ns	p =	0.256 ns	p =	0.881 ns	p =	0.701 ns

7.4.2 Fishing trials

Table 7-9 and Table 7-10 summarise the catch data and analyses for the fishing trials. In both trouser configurations (original and legs/extensions joined), over 90% of the total catch (by weight) was fish. Cephalopods and crustaceans comprised a relatively small proportion of the catch weight, but crustaceans (mainly deepwater prawns and bugs, *Ibacus alticrenatus*) contributed almost one third (32%) of the catch numbers in the original trouser rig, and about 16% in the second rig.

7.4.2.1 Trouser with legs and extensions separate

Sharks and crustaceans were about evenly distributed between the codends but mean catches of rays, teleost groups, and cephalopods were 15–30% greater in the port-side codend (Table 7-9). On average, 44% of the total catch weight and 41% of the total catch number were in the starboard codend. Analyses of the data found significant differences between the two codends in catch numbers and weights for total rays, commercial teleosts, total teleosts, and total catch. Of the commercial teleosts, pink ling, dories and 'benthic' teleosts were relatively evenly distributed between the codends. Less than 40% of 'benthopelagic' teleosts were caught in the starboard codend; catch weights of 'benthopelagic' teleosts were significantly different.

7.4.2.2 Trouser with legs and extensions joined

Overall, 48.3% of the mean total catch weight, and 49.6% of total catch numbers were in the starboard codend (Table 7-10). The differences between the two codends in mean total catch, and the shark, ray, teleost and crustacean components, were all less than 10%. Analyses revealed no significant differences in catches of these groups between codends. The small catches of cephalopods were significantly greater in the port codend.

Table 7-9. Mean catch weights (kg) and numbers (± SE) in the port and starboard codends of the trawl trouser in its original configuration (legs and extensions separate). P values are for two-tailed paired *t*-tests comparing port and starboard catch data; significant P values are in bold; n = number of replicates.

	Trouser legs separate						
		Port		Starboard			
	n	mean	s.e.	mean	s.e.	% total	P
Wt of total sharks	15	116.9	53.2	116.2	57.4	49.9	0.129
No. of total sharks	15	111.9	56.1	112.9	63.1	50.2	0.109
Wt of total rays	15	23.8	9.9	13.1	4.5	35.5	**0.028**
No. of total rays	15	19.9	7.7	16.0	7.1	44.6	**0.004**
Wt of total sharks & rays	15	141.6	58.6	130.1	60.2	47.9	0.196
No. of total sharks & rays	15	131.8	61.0	128.9	65.4	49.4	0.671
Wt of total comm. teleosts	15	156.4	32.3	112.0	20.5	41.7	**0.001**
No. of total comm. teleosts	15	180.1	38.5	127.4	23.9	41.4	**0.004**
Wt of pink ling	14	28.4	11.9	25.6	12.2	47.4	0.103
No. of pink ling	14	26.7	12.4	27.0	13.7	50.3	0.192
Wt of total dories	12	4.6	1.5	4.7	1.1	50.5	0.192
No. of total dories	12	10.2	3.4	9.3	2.5	47.7	0.262
Wt of benthic teleosts	15	18.7	4.1	17.4	4.3	48.2	0.504
No. of benthic teleosts	15	37.8	8.6	29.5	6.2	43.8	0.808
Wt of benthopelagic teleosts	14	69.8	24.8	45.0	14.0	39.2	**0.032**
No. of benthopelagic teleosts	14	73.0	28.7	42.6	10.6	36.9	0.067
Wt of total redfish	-						
No. of total redfish	-						
Wt of total discard teleosts	15	120.8	34.8	86.8	23.7	41.8	0.101
No. of total discard teleosts	15	895.3	261.6	570.4	123.3	38.9	0.082
Wt of total teleosts	15	277.1	58.3	198.7	39.0	41.8	**0.004**
No. of total teleosts	15	1075.4	282.0	697.8	142.1	39.4	**0.036**
	Trouser legs separate						
		Port		Starboard			
	n	mean	s.e.	mean	s.e.	% total	P
Wt of total fish	15	418.7	106.2	328.9	89.3	44.0	**0.006**
No. of total fish	15	1207.2	310.1	826.7	183.5	40.7	0.074
Wt of misc. cephalopods	15	26.6	8.3	18.8	5.2	41.4	0.184
No. of misc. cephalopods	15	55.1	16.9	42.7	11.7	43.7	0.174
Wt of misc. crustaceans	13	18.0	4.5	14.9	3.3	45.3	0.478
No. of misc. crustaceans	13	517.6	140.8	469.2	152.9	47.5	0.537
Wt of total catch	15	460.9	107.0	360.6	89.1	43.8	**0.004**
No. of total catch	15	1710.9	322.0	1276.0	236.4	40.6	**0.010**

Table 7-10. Mean catch weights (kg) and numbers (± SE) in the port and starboard codends of the trawl trouser with the legs and extensions joined. P values are for two-tailed paired *t*-tests comparing port and starboard catch data; significant P values are in bold; n = number of replicates.

	Trouser legs joined						
		Port		Starboard			
	n	mean	s.e.	mean	s.e.	% total	P
Wt of total sharks	15	34.2	11.3	34.4	9.0	50.2	0.669
No. of total sharks	15	13.6	2.6	11.9	2.8	46.7	0.909
Wt of total rays	15	28.5	6.2	25.4	6.7	47.1	0.051
No. of total rays	15	67.5	22.5	57.4	18.6	46.0	0.071
Wt of total sharks & rays	15	62.7	13.0	59.8	12.8	48.8	0.611
No. of total sharks & rays	15	81.1	22.6	69.3	18.4	46.1	0.066
Wt of total comm. teleosts	15	188.7	51.1	185.3	62.4	49.6	0.073
No. of total comm. teleosts	15	1346.1	649.2	1420.8	786.4	51.4	0.074
Wt of pink ling	8	21.4	9.2	16.2	6.4	43.1	0.167
No. of pink ling	8	14.6	3.8	12.7	3.8	46.5	0.678
Wt of total dories	15	10.6	2.4	11.9	3.3	52.9	0.544
No. of total dories	15	25.1	5.8	25.1	6.8	50.0	0.869
Wt of benthic teleosts	15	42.3	8.0	39.9	7.5	48.5	0.339
No. of benthic teleosts	15	135.9	23.5	127.3	22.4	48.4	0.310
Wt of benthopelagic teleosts	8	6.4	2.4	5.6	1.6	46.7	0.643
No. of benthopelagic teleosts	8	5.8	2.1	5.9	2.1	50.4	0.663
Wt of total redfish	10	138.7	63.5	146.4	78.7	51.4	0.128
No. of total redfish	10	1544.7	876.6	1709.7	1089.5	52.5	0.205
Wt of total discard teleosts	15	86.52	19.9	73.3	14.0	45.9	0.254
No. of total discard teleosts	15	835.8	121.3	708.2	91.2	45.6	0.264
Wt of total teleosts	15	275.3	61.9	258.6	73.5	48.4	0.087
No. of total teleosts	15	2181.9	713.0	2129	849.9	49.4	0.167
	Trouser legs joined						
		Port		Starboard			
	n	mean	s.e.	mean	s.e.	% total	P
Wt of total fish	15	338.0	60.2	318.4	71.3	48.5	0.450
No. of total fish	15	2263.0	717.6	2198	852.9	49.3	0.787
Wt of misc. cephalopods	15	9.3	2.5	6.1	1.6	39.6	**0.003**
No. of misc. cephalopods	15	29.3	6.7	22.7	4.7	43.7	0.052
Wt of misc. crustaceans	8	26.5	11.4	24.1	10.6	47.6	0.299
No. of misc. crustaceans	8	722.4	290.3	769.6	381.2	51.6	0.141
Wt of total catch	15	361.4	58.5	337.4	70.5	48.3	0.065
No. of total catch	15	2677.6	697.8	2630.9	844.4	49.6	0.137

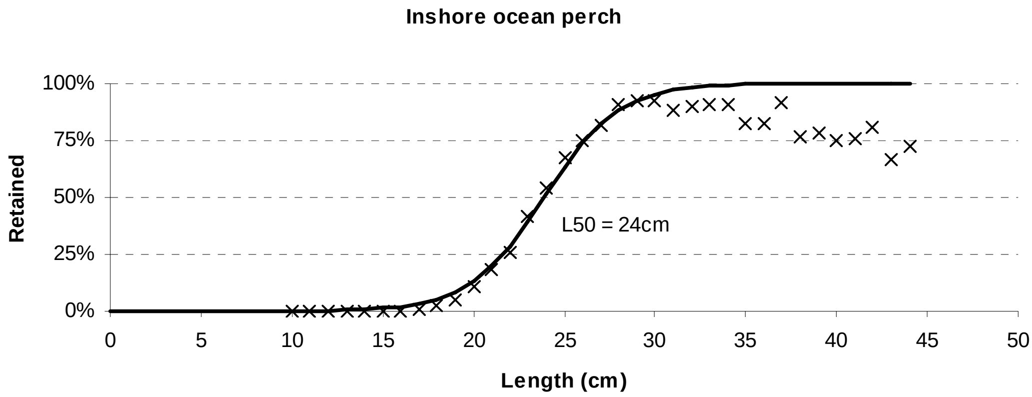
7.4.3 At-sea experiments

7.4.3.1 Market selectivity ogives for quota species based on ISMP data

In addition to any selectivity that might occur in the net, skippers and crew tend to sort through the catch and discard any species (quota or non-quota) that they consider to be of little or no commercial value on the market. We have referred to this as "market selectivity" in this report. Market selectivity is usually influenced by the size of the fish, although this is not always the case

(Knuckey and Liggins 1999). ISMP data were analysed to determine the market selectivity for all quota species so as to compare what sized fish would be likely to be retained or discarded for the different codend configurations (Figure 7-9 to Figure 7-13). Based on their market selectivities, catches of commercial species were assigned to commercial discard and commercial retained categories for analyses.

A



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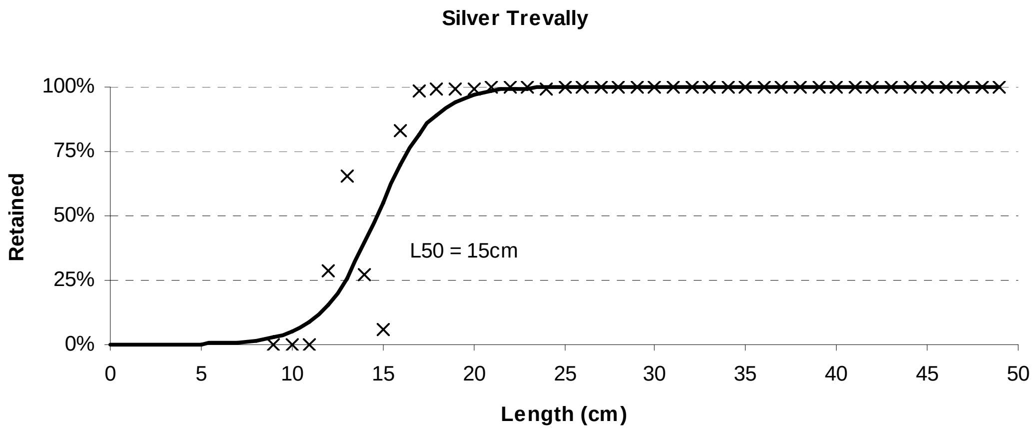


Figure 7-9. Market selectivity ogives for commonly discarded quota species calculated from ISMP data. Each point (x) marks the % retained at a given 1cm length-class and the line (—)represents the estimated logistic market selectivity curve..

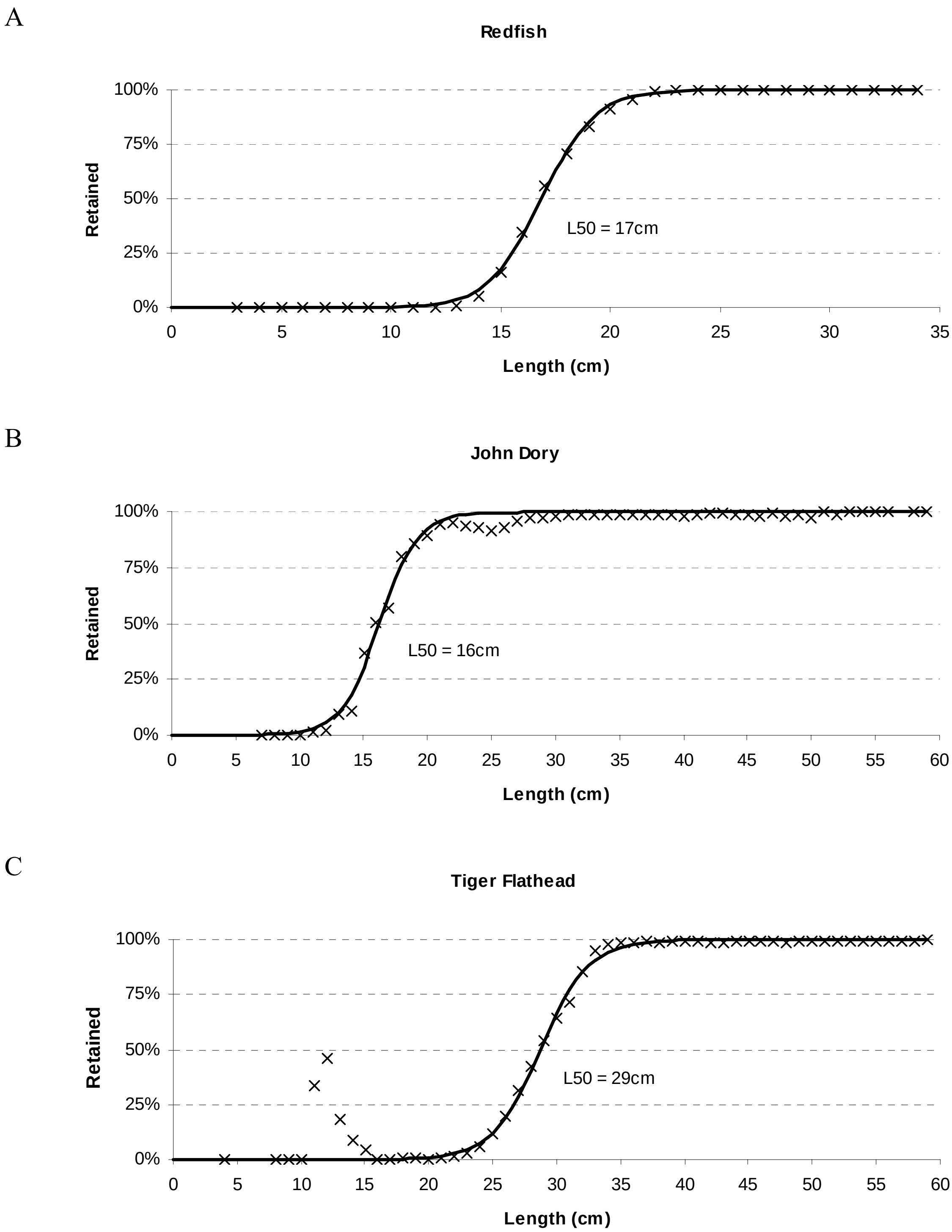
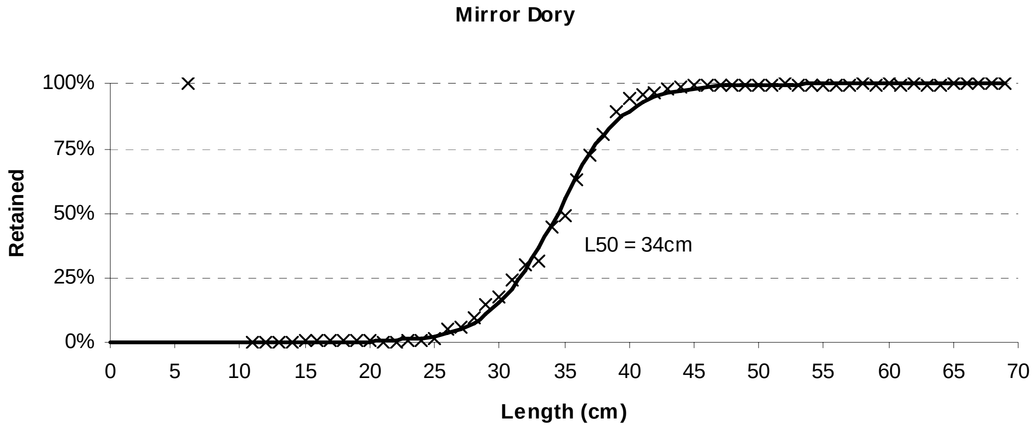


Figure 7-10. Market selectivity ogives for commonly discarded quota species calculated from ISMP data. Each point (x) marks the % retained at a given 1cm length-class and the line (—) represents the estimated logistic market selectivity curve.

A



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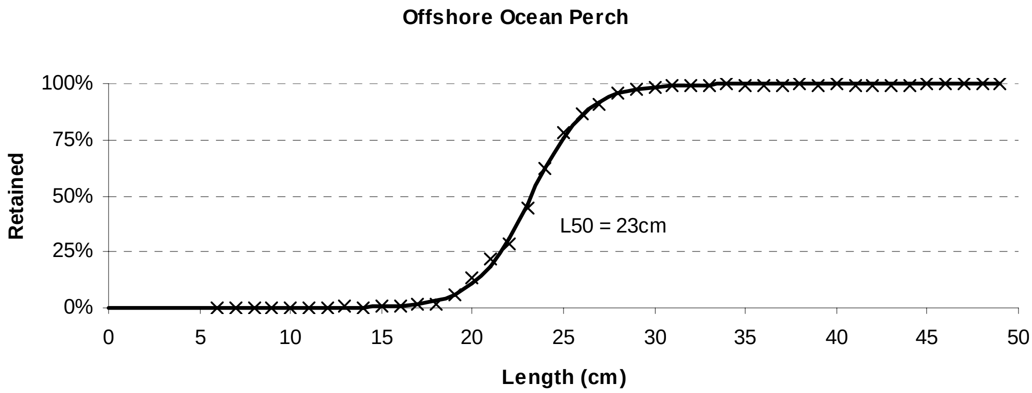

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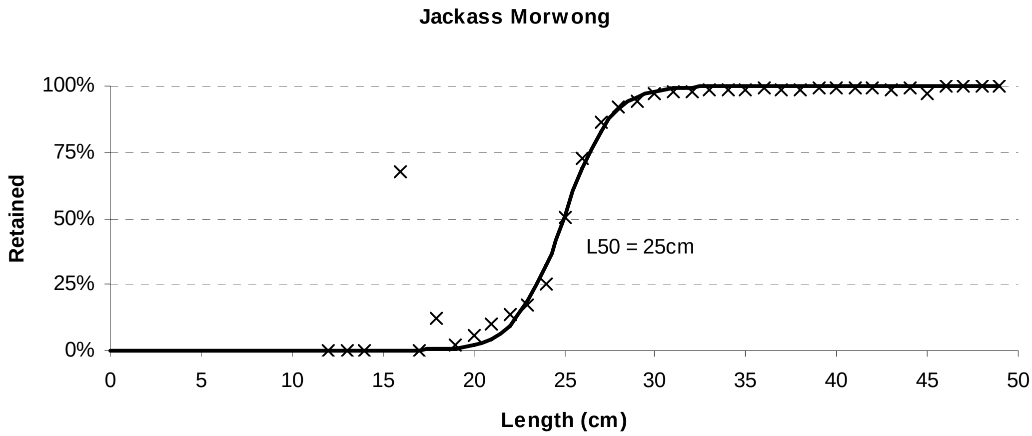
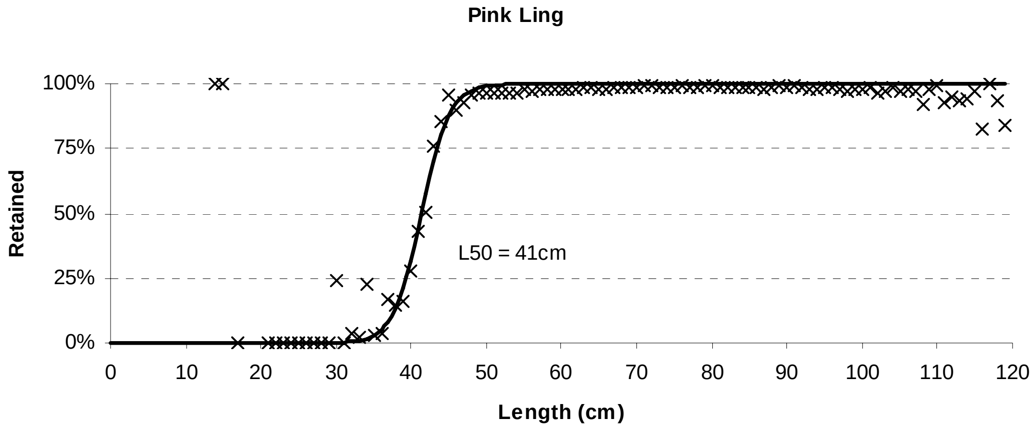


Figure 7-11. Market selectivity ogives for commonly discarded quota species calculated from ISMP data. Each point (x) marks the % retained at a given 1cm length-class and the line (—) represents the estimated logistic market selectivity curve.

A



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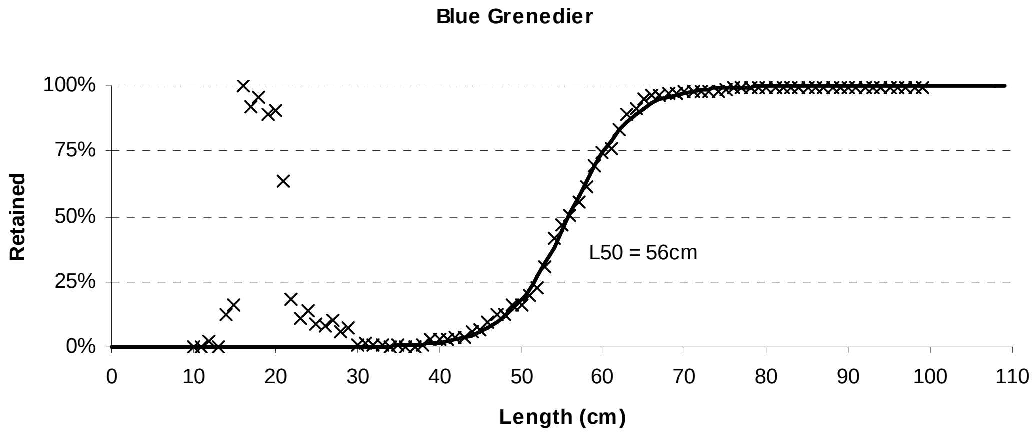

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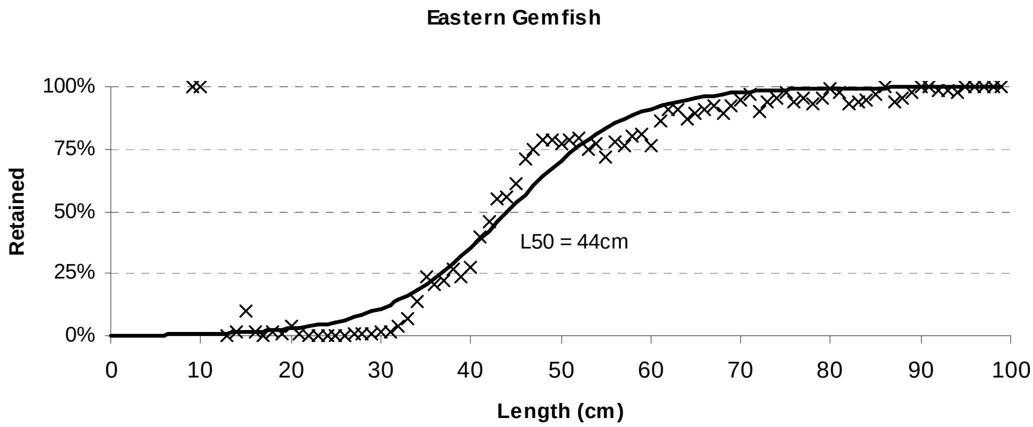
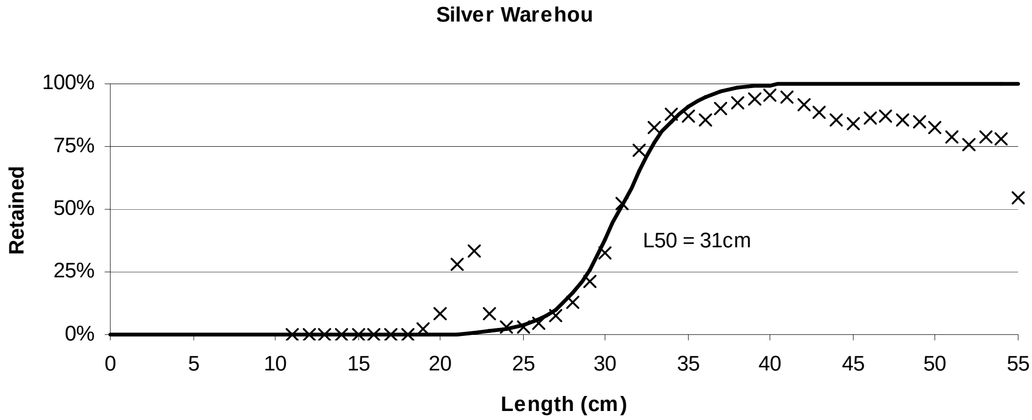


Figure 7-12. Market selectivity ogives for commonly discarded quota species calculated from ISMP data. Each point (x) marks the % retained at a given 1cm length-class and the line (─) represents the estimated logistic market selectivity curve.

A



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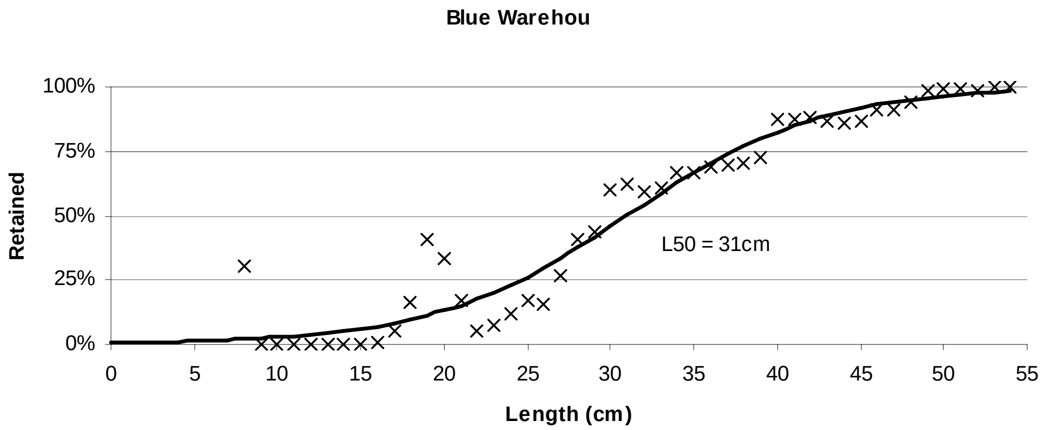


Figure 7-13. Market selectivity ogives for commonly discarded quota species calculated from ISMP data. Each point (x) marks the % retained at a given 1cm length-class and the line (—) represents the estimated logistic market selectivity curve.

7.4.3.2 Commercial and non-commercial discarded and retained fish in standard (90 mm diamond) and test meshes.

Based on the ISMP data, experimental catches during the codend trials were divided up into non-commercial discards, commercial discard (includes some quota species) and retained commercial species (including all retained quota species) for the analysis.

It is important to note that while it is valid to compare the relative levels of catch between the standard 90 mm diamond mesh and test mesh within given test mesh size, it is not valid to compare the absolute values of either the standard 90 mm diamond mesh or test mesh between test meshes sizes. This is because the trials of different test mesh sizes may have been undertaken at different times of the year and in different oceanographic conditions and not enough replicate samples were taken to allow for this level of potential variation between experimental shots.

The catch of non-commercial discards was significantly reduced in all test codends trialled in deep water off Bermagui, and catches of commercial discarded were reduced by the 90 mm square and 102 mm diamond codends (Table 7-11, Figure 7-14). Most test codends also caught less commercial retained fish at this site, except for the 90 mm square codend for which there was no significant difference in weight of catches.

The 90 mm square made no significant difference to catches of any of the three groups of species in shallow water off Bermagui, apart from reducing the number of non-commercial discard fish caught (Table 7-12, Figure 7-15). All other test codends significantly reduced the weight and numbers of non-commercial discards and commercial discards, and also the numbers of commercial retained fish caught. There were no significant differences between the weights of commercial retained species caught using 102 mm diamond and 102 mm square codends.

The 102 mm diamond codend reduced catches of all groups, except ut the weight of catches commercial retained species in deep water trials off Portland (Table 7-13, Figure 7-16). The 102 mm square and 110 mm diamond codends both significantly reduced the numbers of non-commercial discard fish, but made little difference to weights and numbers of other species groups. A significant reduction in the catch of non-commercial discard species was observed in the 110 mm square codend, with no reduction in the catch of commercial retained species.

Results of sea trials in shallow water off Portland were almost identical to those in deep water. The 102 mm diamond codend caught less non-commercial discard species, but a similar weight of commercial retained species to the control codend (Table 7-14, Figure 7-17). The 102 mm square and 110 mm diamond codends made little difference to catches apart from the latter catching a significantly lower number of non-commercial discard species. Reduced catches of non-commercial discard species were observed in the 110 mm square codend, however, unlike in the deepwater trials, this test codend also significantly reduced catches of commercial retained fish.

Table 7-11. Number of replicates (n), mean weight (kg) and numbers (± SE) per shot and paired t-test results (ns = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$) of non-commercial discard, commercial discard and commercial retained fish by control and test codends from deep water (>150 fth) off Bermagui (east).

	Weight per tow					Number per tow				
	Control net		Test net			Control net		Test net		
	Mean	SE	Mean	SE	Sig. Diff.	Mean	SE	Mean	SE	Sig. Diff.
90 Square (n=16)										
Non-commercial Discard	83.9	16.3	57.8	11.3	**	698.6	138.7	300.6	70.3	***
Commercial Discard	25.8	8.6	23.9	8.7	*	81.5	33.7	71.5	35.3	***
Commercial Retained	180.3	26.2	161.0	22.0	n.s.	278.1	60.0	206.2	41.2	**
102 Diamond (n=14)										
Non-commercial Discard	67.4	8.0	47.0	11.2	***	781.4	125.6	401.5	128.4	***
Commercial Discard	4.5	2.4	2.3	1.4	***	19.0	5.1	6.7	1.8	***
Commercial Retained	252.9	81.0	199.9	72.3	*	427.0	89.3	299.2	68.8	***
102 Square (n=10)										
Non-commercial Discard	126.2	26.4	75.8	17.2	**	1123.3	230.1	470.7	152.5	***
Commercial Discard	26.2	7.6	25.8	9.3	n.s.	101.1	26.4	85.3	29.7	n.s.
Commercial Retained	135.8	22.5	91.9	15.4	*	315.3	66.9	173.1	33.1	***
110 Diamond (n=21)										
Non-commercial Discard	109.6	19.7	70.4	11.4	**	1282.4	224.1	579.7	103.0	***
Commercial Discard	45.3	9.5	51.4	14.1	n.s.	200.8	45.6	210.1	59.4	**
Commercial Retained	203.6	27.5	157.0	21.6	*	503.4	78.9	355.8	60.4	**

Table 7-12. Number of replicates (n), mean weight (kg) and numbers (± SE) per shot and paired t-test results (ns = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$) of non-commercial discard, commercial discard and commercial retained fish by control and test codends from shallow water (<150 fth) off Bermagui (east).

	Weight per tow					Number per tow				
	Control net		Test net			Control net		Test net		
	Mean	SE	Mean	SE	Sig. Diff.	Mean	SE	Mean	SE	Sig. Diff.
90 Square (n=8)										
Non-commercial Discard	232.2	69.6	213.9	57.4	n.s.	643.1	174.1	515.8	163.8	*
Commercial Discard	17.9	7.1	21.0	11.7	n.s.	183.0	74.4	193.1	94.8	n.s.
Commercial Retained	101.8	23.6	117.6	44.0	n.s.	398.5	108.4	485.5	212.7	n.s.
102 Diamond (n=13)										
Non-commercial Discard	54.8	10.4	47.3	12.6	*	546.1	92.8	223.0	41.6	***
Commercial Discard	13.6	3.0	4.7	1.3	***	263.0	62.5	85.9	25.3	***
Commercial Retained	101.0	9.5	88.8	17.2	n.s.	352.1	29.0	221.0	21.4	***
102 Square (n=14)										
Non-commercial Discard	104.3	17.1	94.4	22.5	*	546.5	57.6	224.6	52.2	***
Commercial Discard	10.0	3.8	4.2	1.8	***	78.1	28.6	23.6	9.5	***
Commercial Retained	168.8	45.7	179.1	63.4	n.s.	533.3	131.9	417.6	153.8	***
110 Diamond (n=17)										
Non-commercial Discard	98.2	16.1	74.2	14.8	**	740.9	105.5	374.7	62.5	***
Commercial Discard	37.1	15.1	7.4	4.3	***	560.9	328.5	61.8	22.1	***
Commercial Retained	123.8	22.4	63.5	13.7	***	937.9	450.4	189.8	27.5	***

Table 7-13. Number of replicates (n), mean weight (kg) and numbers (± SE) per shot and paired t-test results (ns = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$) of non-commercial discard, commercial discard and commercial retained fish by control and test codends from deep water (>150 fth) off Portland (west).

	Weight per tow					Number per tow				
	Control net		Test net			Control net		Test net		
	Mean	SE	Mean	SE	Sig. Diff.	Mean	SE	Mean	SE	Sig. Diff.
102 Diamond (n=12)										
Non-commercial Discard	130.1	22.9	95.5	16.3	**	831.1	159.5	373.2	97.8	***
Commercial Discard	6.6	1.1	4.5	1.3	**	15.9	3.1	7.6	1.9	***
Commercial Retained	163.5	19.6	157.6	24.6	n.s.	265.1	66.0	215.2	49.5	**
102 Square (n=10)										
Non-commercial Discard	105.6	20.7	88.3	22.2	n.s.	699.9	188.0	513.5	194.0	*
Commercial Discard	18.4	5.9	5.7	1.9	**	54.0	12.0	22.3	7.9	n.s.
Commercial Retained	192.9	55.1	224.0	78.4	n.s.	161.2	34.6	137.2	48.1	n.s.
110 Diamond (n=12)										
Non-commercial Discard	138.1	31.1	135.2	35.9	n.s.	964.9	201.6	868.0	379.6	**
Commercial Discard	5.8	1.4	3.3	0.7	n.s.	7.3	1.5	5.1	1.0	n.s.
Commercial Retained	256.2	33.3	240.1	36.4	n.s.	708.2	180.4	708.0	207.3	n.s.
110 Square (n=10)										
Non-commercial Discard	212.8	51.6	154.9	53.8	*	1146.5	315.3	844.7	319.6	**
Commercial Discard	3.8	1.0	2.8	0.9	*	5.2	1.8	3.6	1.3	n.s.
Commercial Retained	259.1	71.1	333.3	162.0	n.s.	348.8	108.9	360.5	132.7	n.s.

Table 7-14. Number of replicates (n), mean weight (kg) and numbers (+ SE) per shot and paired t-test results (ns = not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$) of non-commercial discard, commercial discard and commercial retained fish by control and test codends from shallow water (<150 fth) off Portland (west). # denotes insufficient samples of commercial discard species caught to perform paired t-test.

	Weight per tow					Number per tow				
	Control net		Test net			Control net		Test net		
	Mean	SE	Mean	SE	Sig. Diff.	Mean	SE	Mean	SE	Sig. Diff.
102 Diamond (n=12)										
Non-commercial Discard	164.7	36.9	99.3	14.3	*	1032.7	327.5	491.7	145.6	*
Commercial Discard	0.8		1.3	0.4	#	1.0		2.0	0.5	#
Commercial Retained	176.9	35.0	157.7	31.6	n.s.	422.4	53.1	363.0	67.5	*
102 Square (n=10)										
Non-commercial Discard	239.5	104.8	271.3	146.1	n.s.	2105.7	1153.5	2608.7	1606.1	n.s.
Commercial Discard	16.7	5.8	48.3	32.6	n.s.	23.9	12.3	87.8	63.6	n.s.
Commercial Retained	328.8	78.2	381.6	144.2	n.s.	491.8	96.5	585.5	214.9	n.s.
110 Diamond (n=12)										
Non-commercial Discard	155.8	85.8	125.3	69.8	n.s.	909.3	489.3	550.3	265.7	*
Commercial Discard	34.4	20.1	22.6	13.0	n.s.	69.1	41.0	39.8	26.7	n.s.
Commercial Retained	417.9	112.9	329.8	67.6	n.s.	664.7	129.6	580.7	130.3	n.s.
110 Square (n=10)										
Non-commercial Discard	75.2	10.3	39.9	6.0	**	333.6	51.2	173.8	33.5	**
Commercial Discard	6.4	1.6	3.4	1.2	n.s.	5.9	1.5	3.3	1.1	n.s.
Commercial Retained	377.3	48.6	219.7	27.4	***	615.4	62.7	293.2	50.1	***

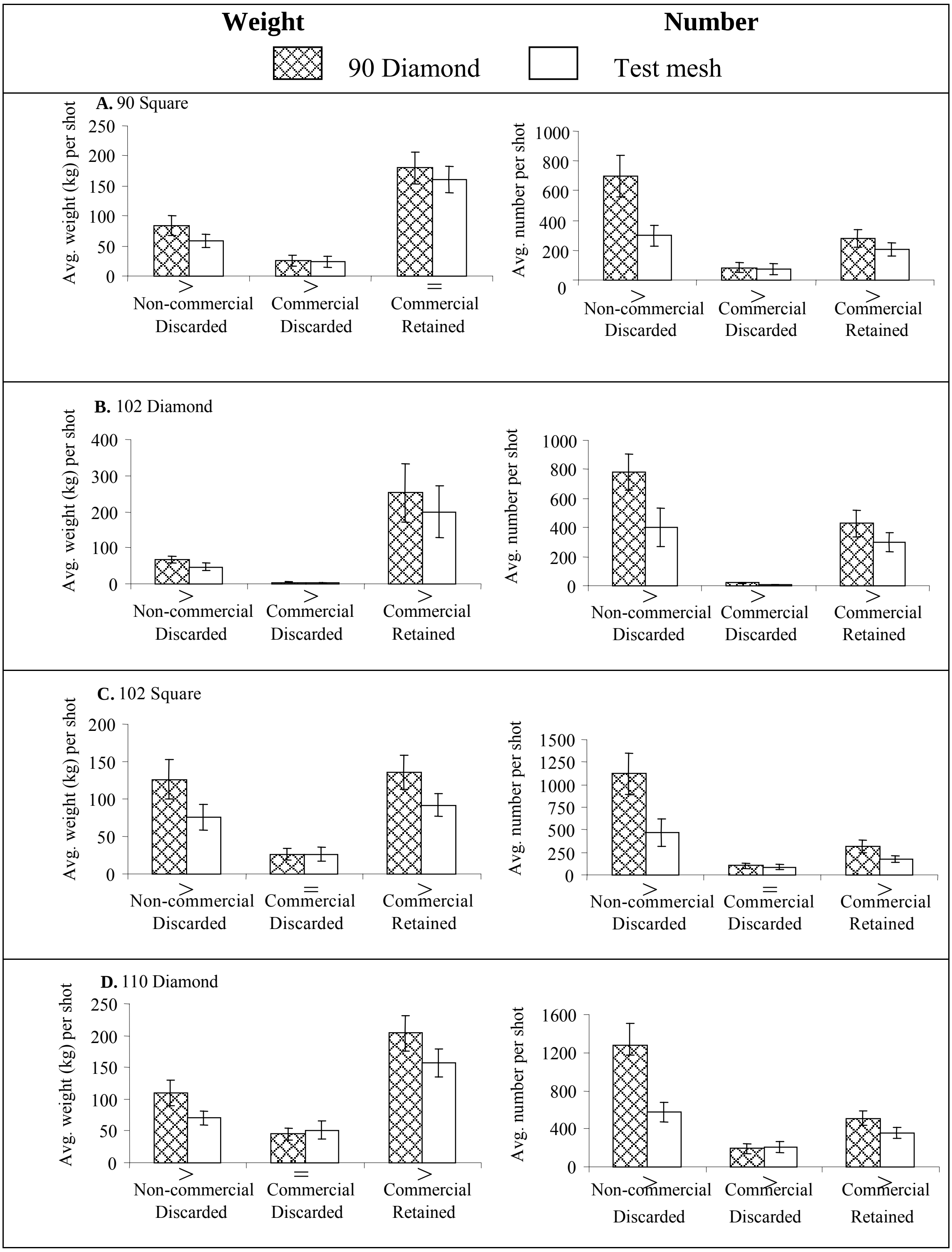


Figure 7-14. Average weight (left column) and number (right column) per shot of commercial and non-commercial fish discarded and retained from deep water (>150 fth) off Bermagui (east). The test mesh is: A, 90 mm Square; B, 102 mm Diamond; C, 102 mm Square; D, 110 mm Diamond. Error bars +1SE. Symbols > and< denote significant differences and the direction of that difference; = denotes no significant difference. (File: East deep mods).

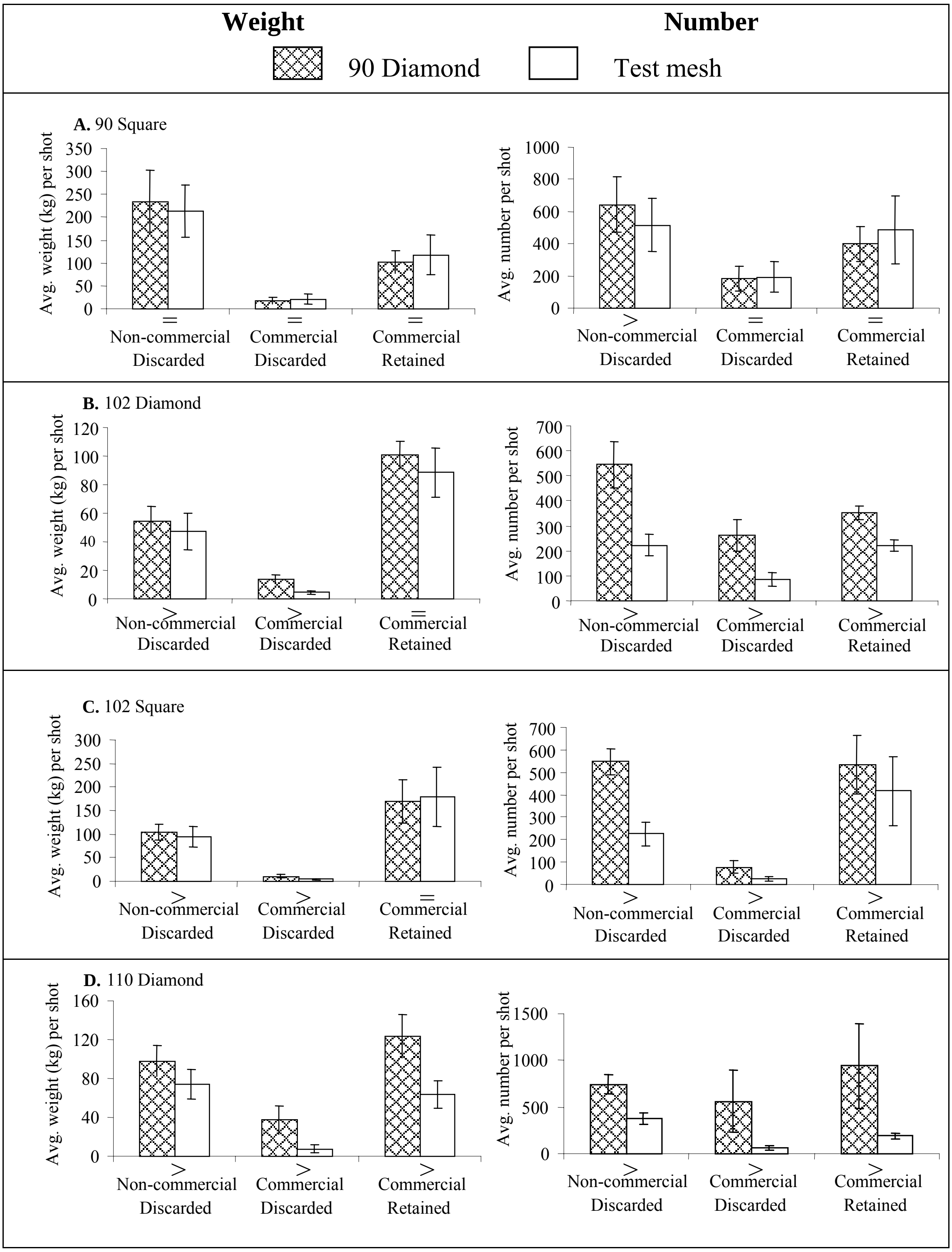


Figure 7-15. Average weight (left column) and number (right column) per shot of commercial and non-commercial fish discarded and retained from shallow water (<150 fth) off Bermagui (east). The test mesh is: A, 90 mm Square; B, 102 mm Diamond; C, 102 mm Square; D, 110 mm Diamond. Error bars $\pm$1SE. Symbols > and< denote significant differences and the direction of that difference; = denotes no significant difference. (File: East Shallow mods).

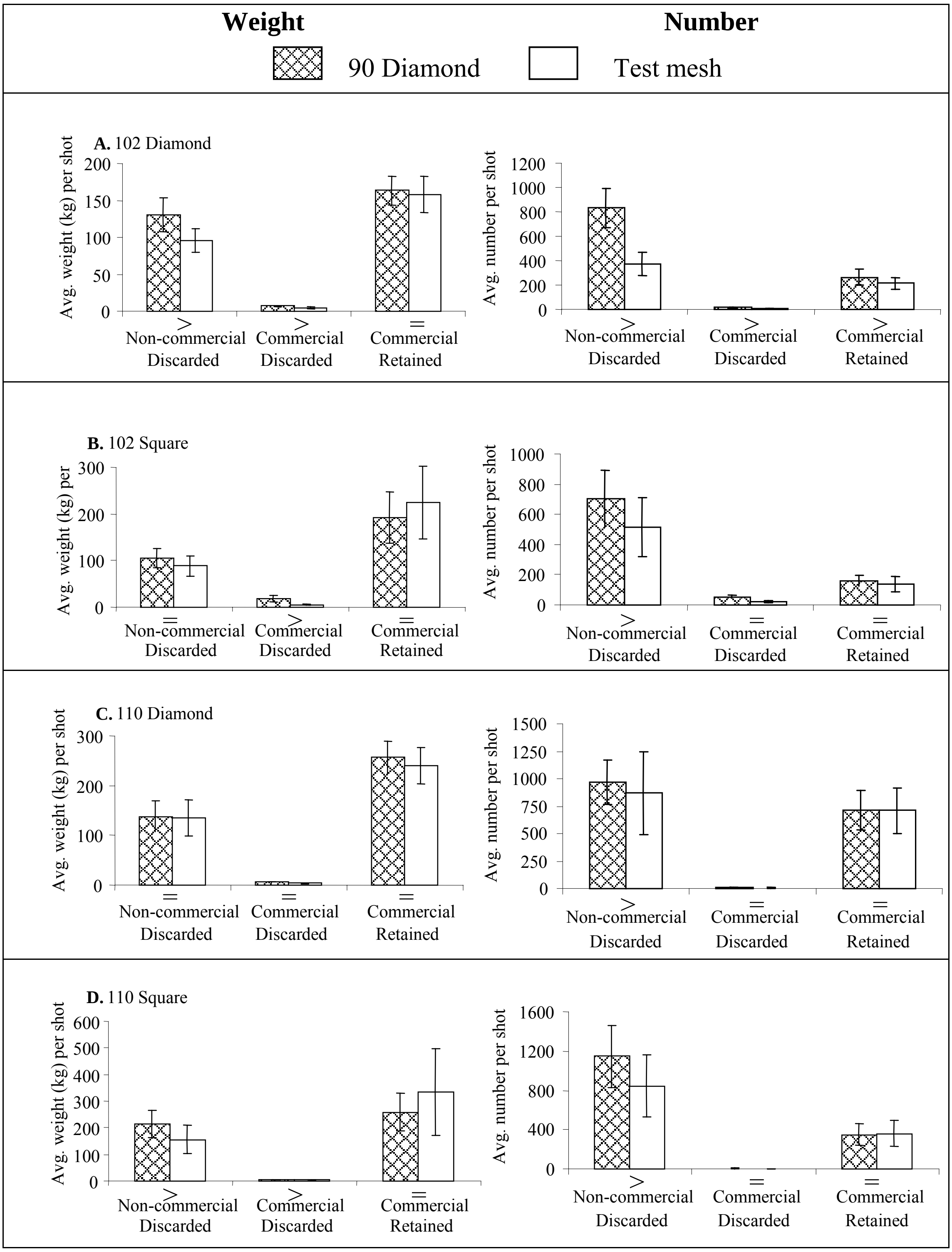


Figure 7-16. Average weight (left column) and number (right column) per shot of commercial and non-commercial fish discarded and retained from deep water (>150 fth) off Portland (west). The test mesh is: A, 102 mm Diamond; B, 102 mm Square; C, 110 mm Diamond; D, 110 mm Square. Error bars ±1SE. Symbols > and< denote significant differences and the direction of that difference; = denotes no significant difference. (File: West deep mods).

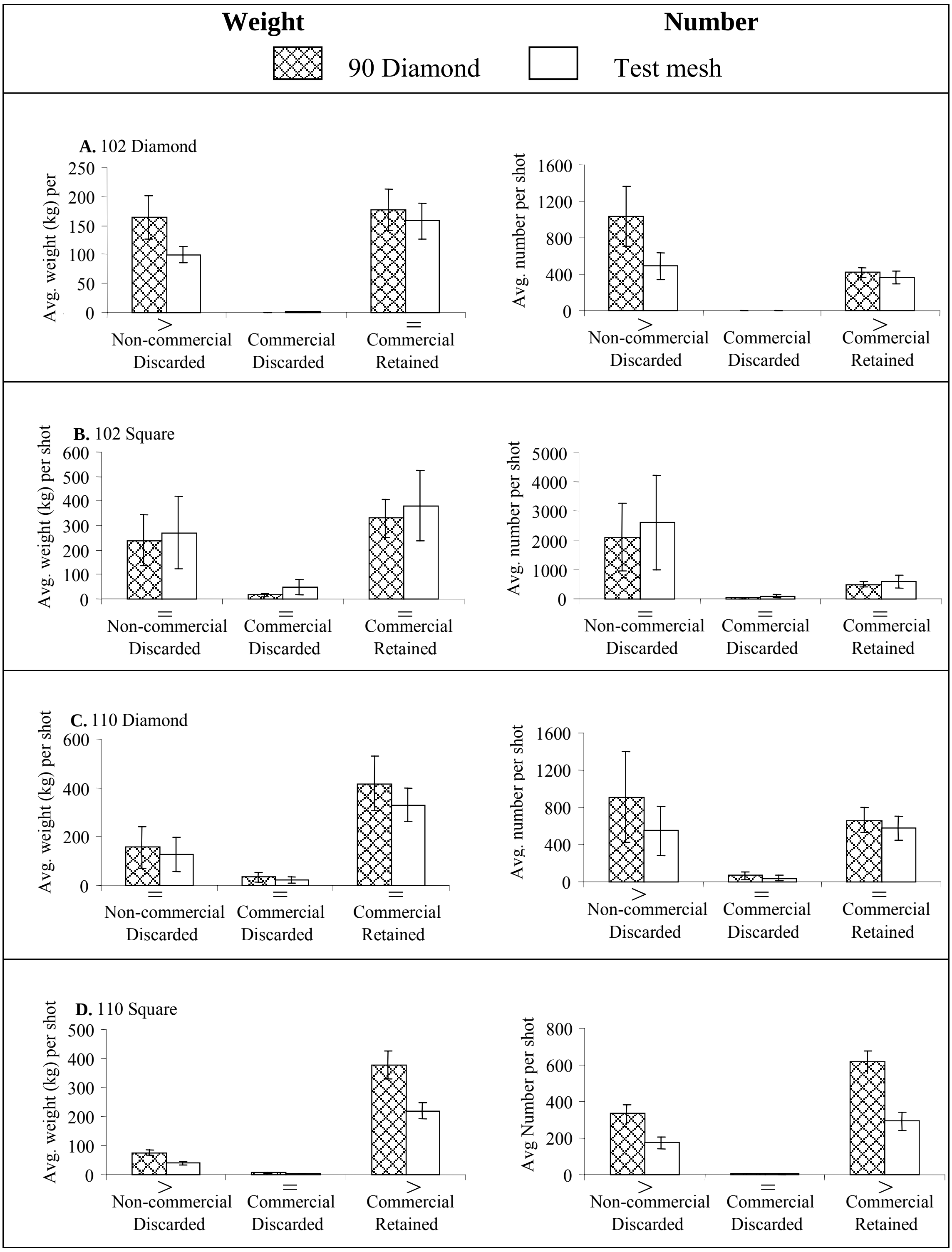


Figure 7-17. Average weight (left column) and number (right column) per shot of commercial and non-commercial fish discarded and retained from shallow water (<150 fth) off Portland (west). The test mesh is: A, 102 mm Diamond; B, 102 mm Square; C, 110 mm Diamond; D, 110 mm Square. Error bars ±1SE. Symbols > and< denote significant differences and the direction of that difference; = denotes no significant difference. (File: West shallow mods).

7.4.3.3 Weight and number of discarded fish species in standard (90 mm diamond) and test meshes.

Catches of blacktip cucumberfish, grey whiptail, threespine cardinalfish and toothed whiptail were all reduced in deep water off Bermagui using the 102 mm diamond (Figure 7-18), 102 mm square (Figure 7-19) and 110 mm diamond (Figure 7-20) codends. The latter two test codends also greatly reduced catches of other discard species including armoured gurnard (*Peristedion picturatum*), common sawbelly and spiny flathead (*Hoplichthys haswelli*).

All test codends caught less round snouted gurnard than the control codend in shallow water off Bermagui, and the 102 mm diamond, 102 mm square and 110 mm diamond codends also caught much less blacktip cucumberfish and grooved gurnard than the control codend (Figure 7-21). The 110 mm diamond codend also caught a smaller number of common bellowsfish.

As in deep water off Bermagui, test codends in deep water off Portland caught less blacktip cucumberfish and toothed whiptail (Figure 7-22 and Figure 7-23). In particular, the 110 mm square codend nearly eliminated the catch of blacktip cucumberfish altogether. Catches of grey whiptail were also reduced by the 110 mm square codend, but unexpectedly, more so by the two 102 mm codends than the larger codend. Numbers of banded bellowsfish caught were also greatly reduced in catches using the 110 mm square codend.

Much less New Zealand dory, blacktip cucumberfish and southern whiptail (*Caelorinchus australis*) were caught by the 102 mm diamond codend in shallow water sea trials off Portland (Figure 7-24). The 102 mm square codend saw a reduction in catches of a greater variety of species including blacktip cucumberfish, jack mackerel, bigscale rubyfish and southern whiptail (Figure 7-24). Catches of even more species were reduced using the 110 mm square codend. These included thetis fish (*Neosebastes thetidis*), toothed whiptail, draughtboard shark, and New Zealand dory, while bigscale rubyfish, blacktip cucumberfish and jack mackerel were nearly totally excluded from the catch (Figure 7-25).

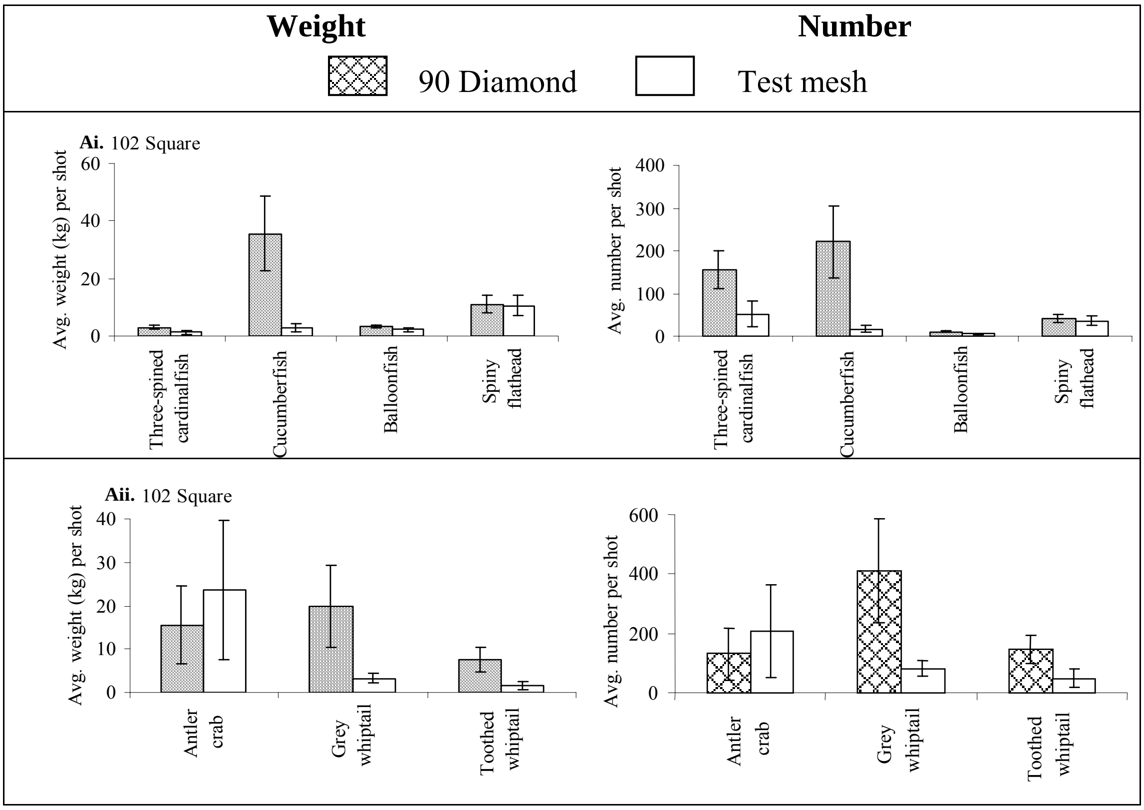


Figure 7-18. Average weight (left column) and number (right column) per shot of discarded fish from deep water (>150 fth) off Bermagui (east). The test mesh is: A, 102 mm Square. (90 mm Square not shown; 102 mm Diamond, see Figure 7-19; 110 mm Diamond, see Figure 7-20). Error bars ±1SE.

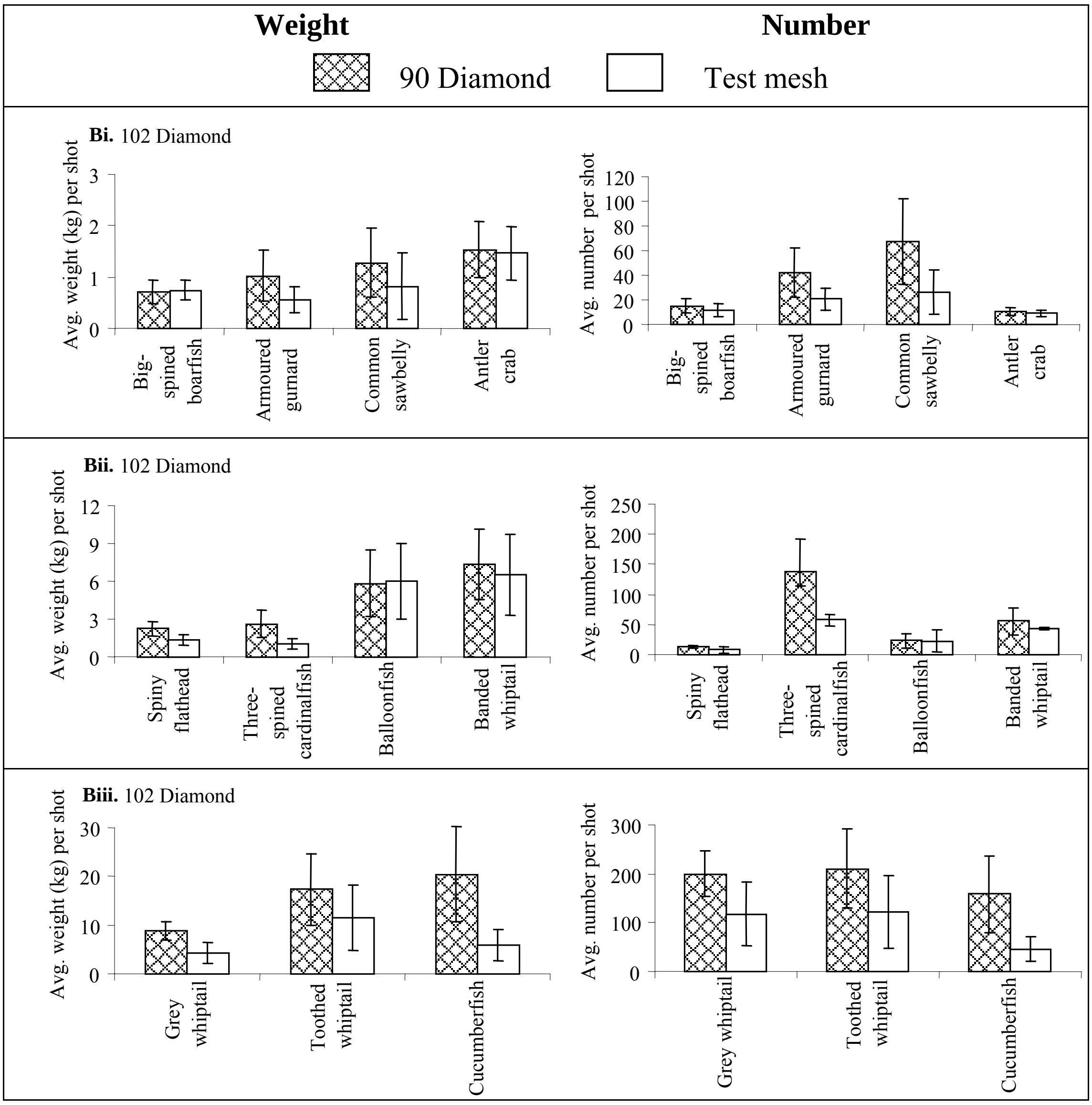


Figure 7-19. Average weight (left column) and number (right column) per shot of discarded fish from deep water (>150 fth) off Bermagui (east). The test mesh is: B, 102 mm Diamond. (90 mm Square not shown; 102 mm Square, see Figure 7-18; 110 mm Diamond, see Figure 7-20). Error bars ±1SE.

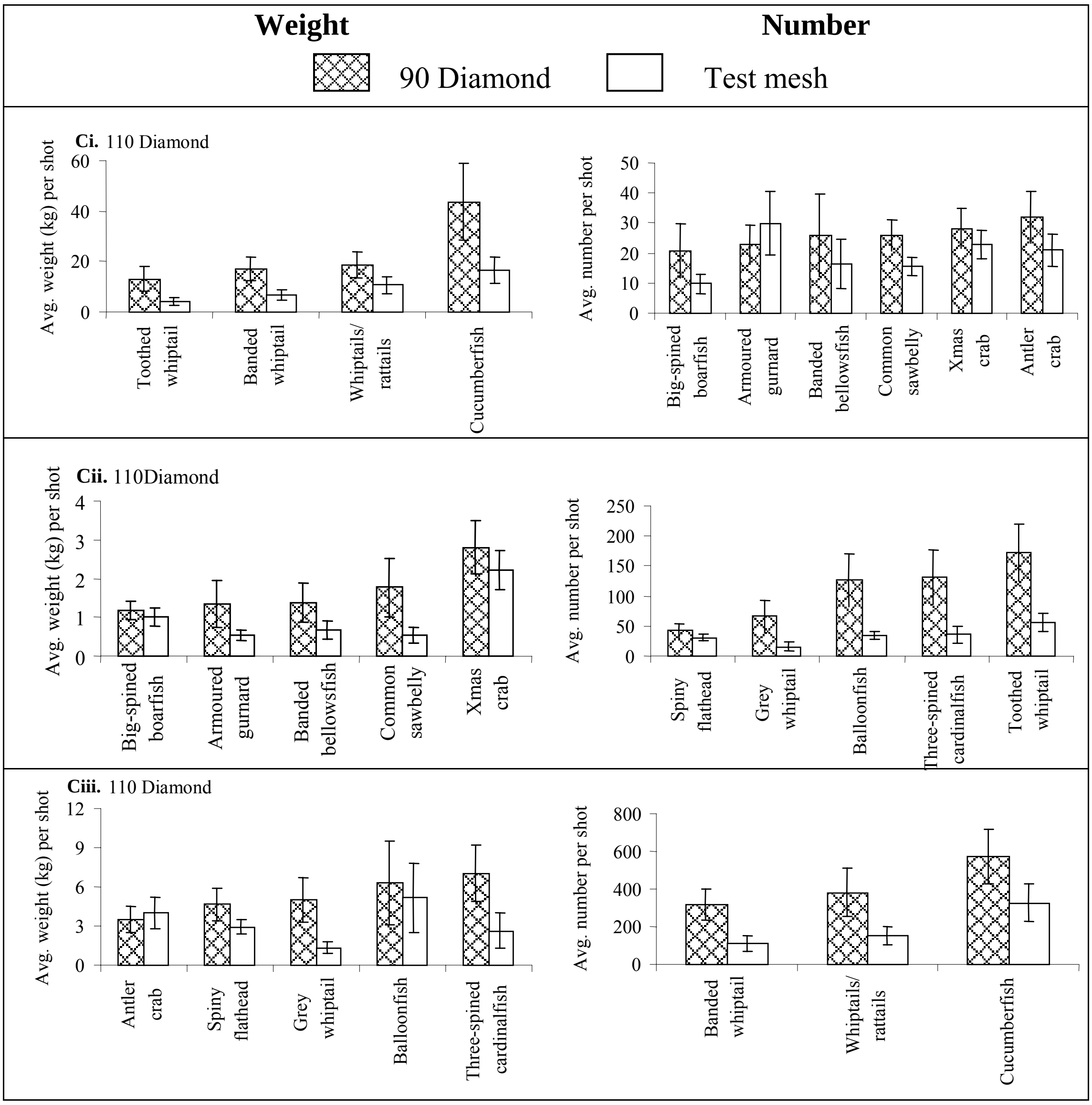


Figure 7-20. Average weight (left column) and number (right column) per shot of discarded fish from deep water (>150 fth) off Bermagui (east). The test mesh is: C, 110 mm Diamond. (90 mm Square not shown; 102 mm Square, see Figure 7-18; 102 mm Diamond, see Figure 7-19). Error bars ±1SE.

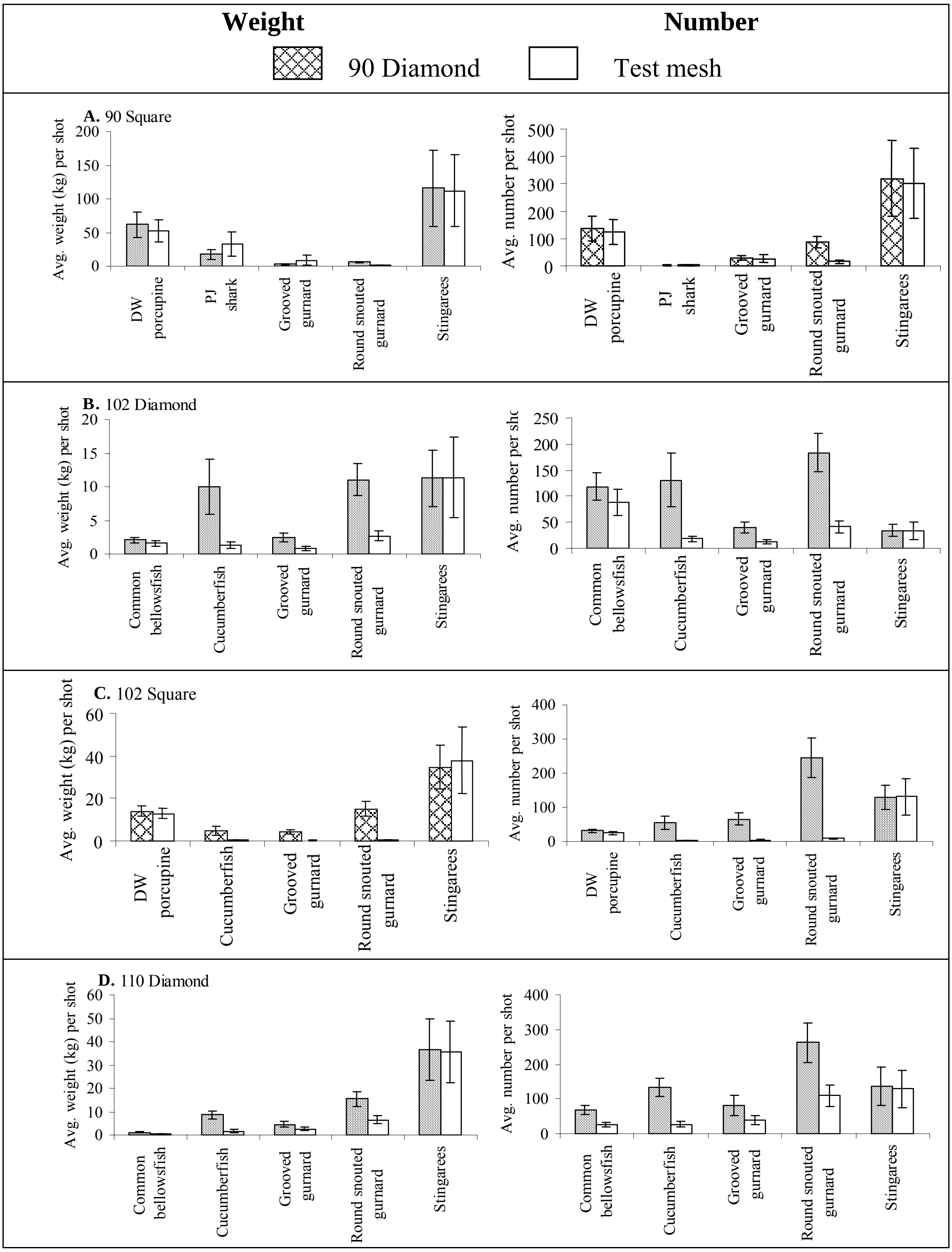


Figure 7-21. Average weight (left column) and number (right column) per shot of discarded fish from shallow water (<150 fth) off Bermagui (east). The test mesh is: A, 90 mm Square; B, 102 mm Diamond; C, 102 mm Square; D, 110 mm Diamond. Error bars $\pm$1SE.

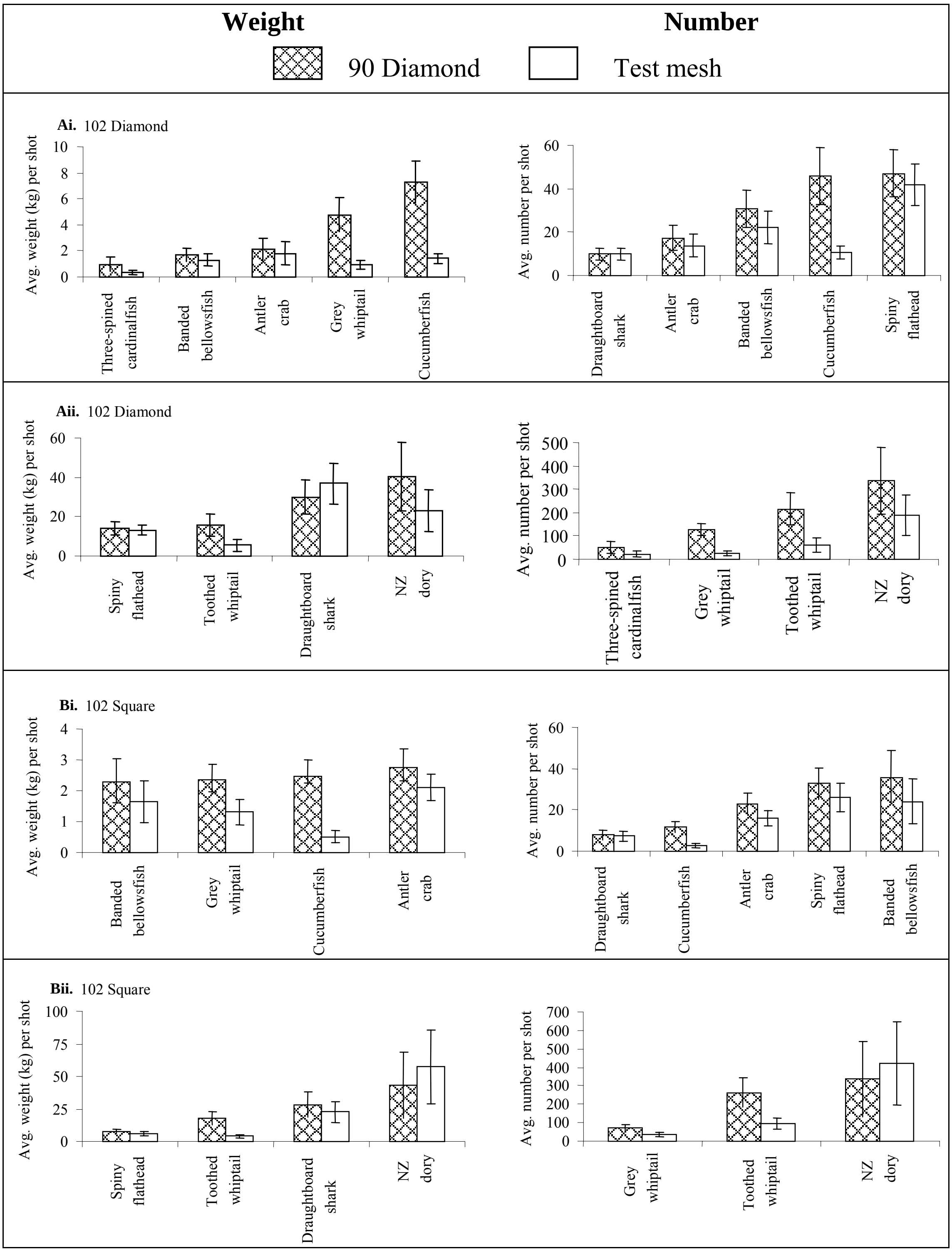


Figure 7-22. Average weight (left column) and number (right column) per shot of discarded fish from deep water (>150 fth) off Portland (west). The test mesh is: A, 102 mm Diamond; B, 102 mm Square. (110 mm Diamond and 110 mm Square see Figure 7-23). Error bars ±1SE.

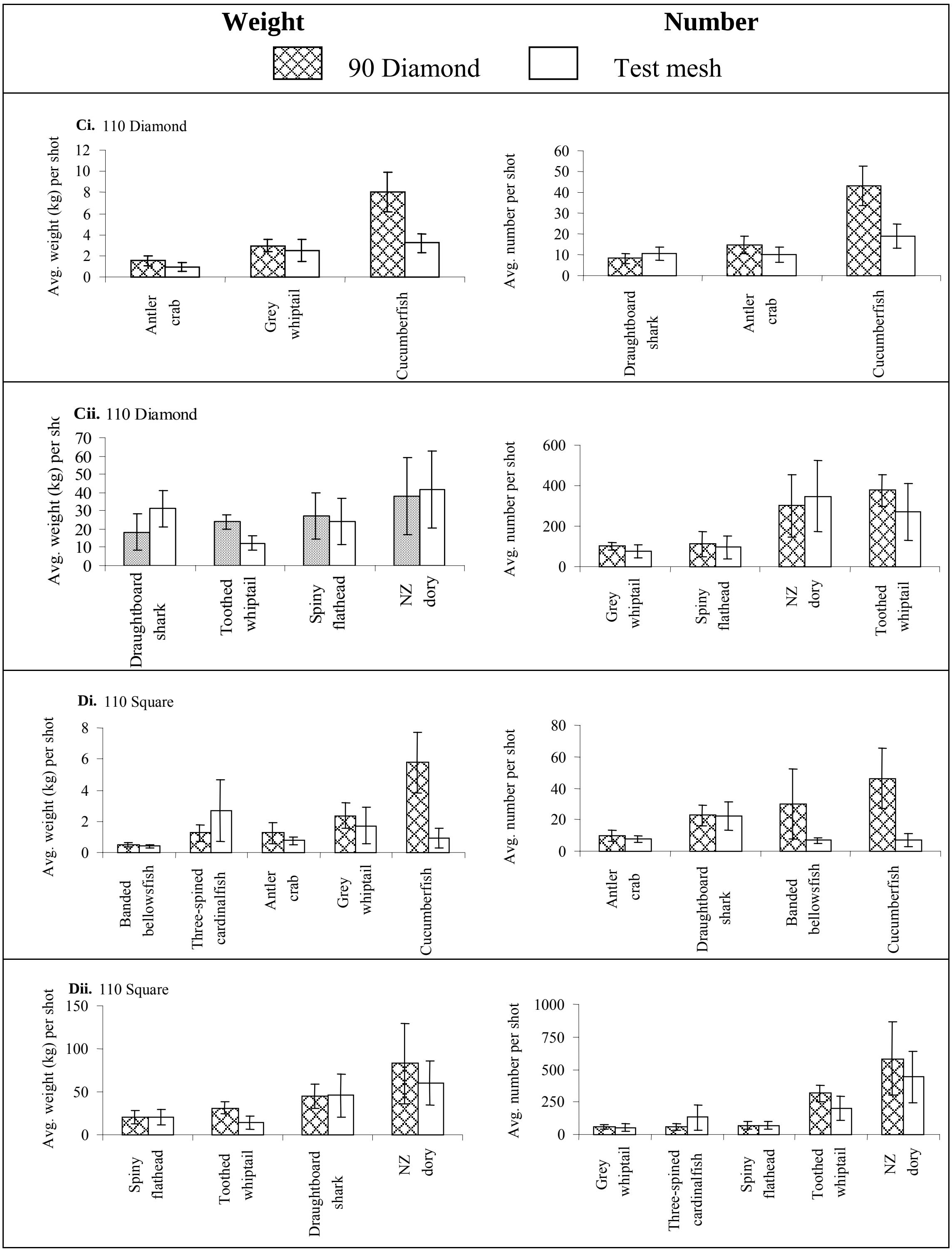


Figure 7-23. Average weight (left column) and number (right column) per shot of discarded fish from deep water (>150 fth) off Portland (west). The test mesh is: C, 110 mm Diamond; D, 110 mm Square. (102 mm Diamond and 102 mm Square see Figure 7-22). Error bars ±1SE.

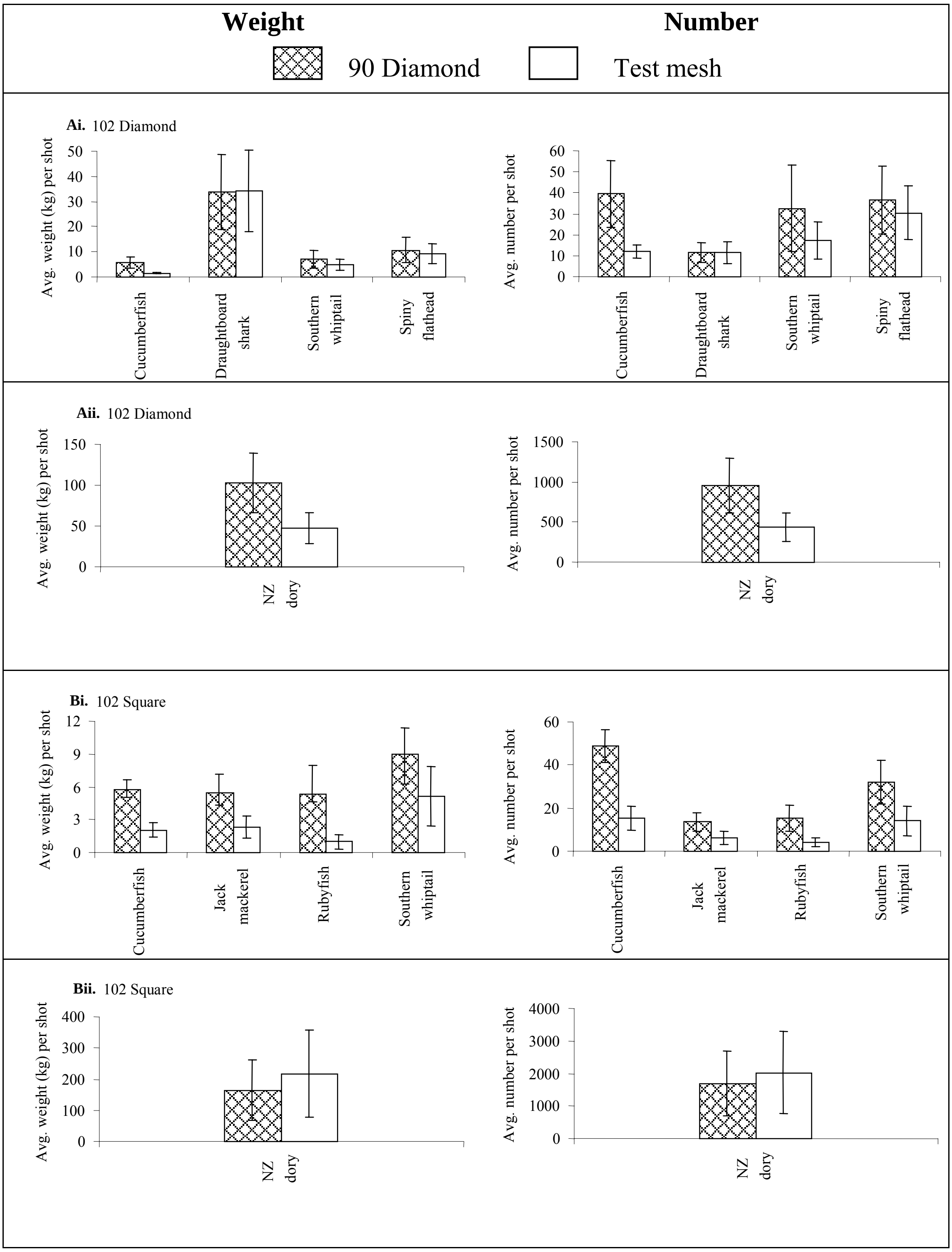


Figure 7-24. Average weight (left column) and number (right column) per shot of discarded fish from shallow water (<150 fth) off Portland (west). The test mesh is: A, 102 mm Diamond; B, 102 mm Square. (110 mm Square Figure 7-25). Error bars ±1SE.

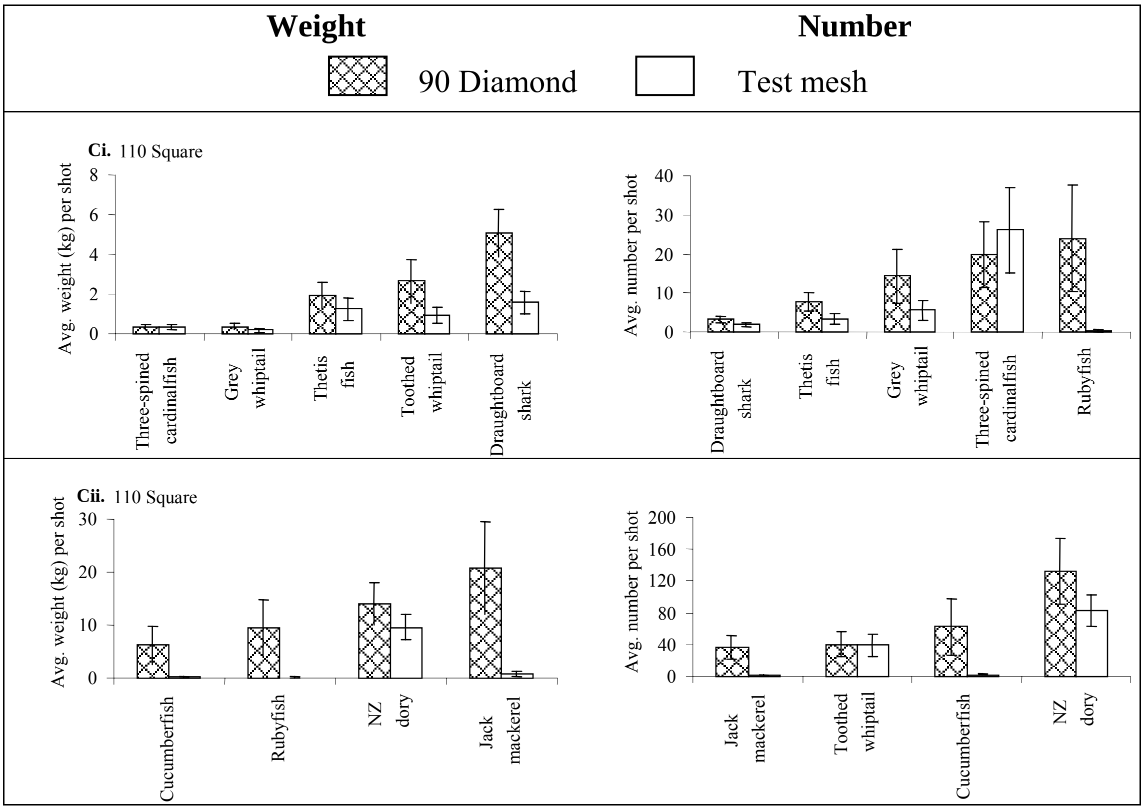


Figure 7-25. Average weight (left column) and number (right column) per shot of discarded fish from shallow water (<150 fth) off Portland (west). The test mesh is: C, 110 mm Square. (102 mm Diamond and 102 mm Square see Figure 7-24). Error bars ±1SE.

7.4.3.4 Weight and number of retained and discarded commercial fish species in standard (90 mm diamond) and test meshes.

Use of the 90 mm square codend made little difference to the catches of most commercial species in deep water off Bermagui, apart from reducing the number of pink ling retained, and offshore ocean perch discarded (Figure 7-26). The 102 mm diamond codend had a greater effect of reducing commercially retained species including mirror dory (*Zenopsis nebulosus*), pink ling and Gould's squid, while also reducing the catch of discarded offshore ocean perch (Figure 7-26). Retained catches of pink ling and offshore ocean perch were reduced using both 102 mm square and 110 mm diamond codends, that latter also reduced catches of retained Gould's squid (Figure 7-27). Both of these codends also saw a small reduction in the discarded catch of offshore ocean perch, but an increase in the catch of discarded mirror dory.

Less retained and discarded tiger flathead and retained velvet leather jacket, but more retained and discarded redfish were caught in the 90 mm square codend than in the control in shallow water off Bermagui (Figure 7-28). The 90 mm square codend caught less retained and discarded redfish and tiger flathead, retained silver trevally and velvet leatherjacket (*Meuschenia scaber*) and discarded inshore ocean perch (Figure 7-29). Reduction in catches of retained and discarded commercial species by the 102 mm codend was similar to that of the 90 mm square codend except that it also caught less retained Gould's squid and slightly more silver trevally than the control net (Figure 7-30). Decreased catches of retained cuttlefish (Family Sepiidae), Gould's squid, inshore ocean perch, octopus (Family Octopodidae), redfish, silver trevally and tiger flathead, as well as discarded inshore ocean perch, redfish and tiger flathead were all observed in the 110 mm diamond codend compared to the control codend (Figure 7-31).

The use of test nets made little difference to retained catches of blue grenadier in deep water off Portland (Figure 7-32 – Figure 7-35), perhaps with the exception of the 110 diamond codend (Figure 7-34). The 110 mm square codend caught much less retained and discarded gemfish and retained offshore ocean perch and Gould's squid. Of the test nets, only the 102 mm square and 110 mm diamond codends caught less discarded blue grenadier than the controls with the former also catching much smaller numbers of offshore ocean perch. The 102 mm diamond mesh caught much smaller numbers of greeneye dogfish (*Squalus mitsukurii*).

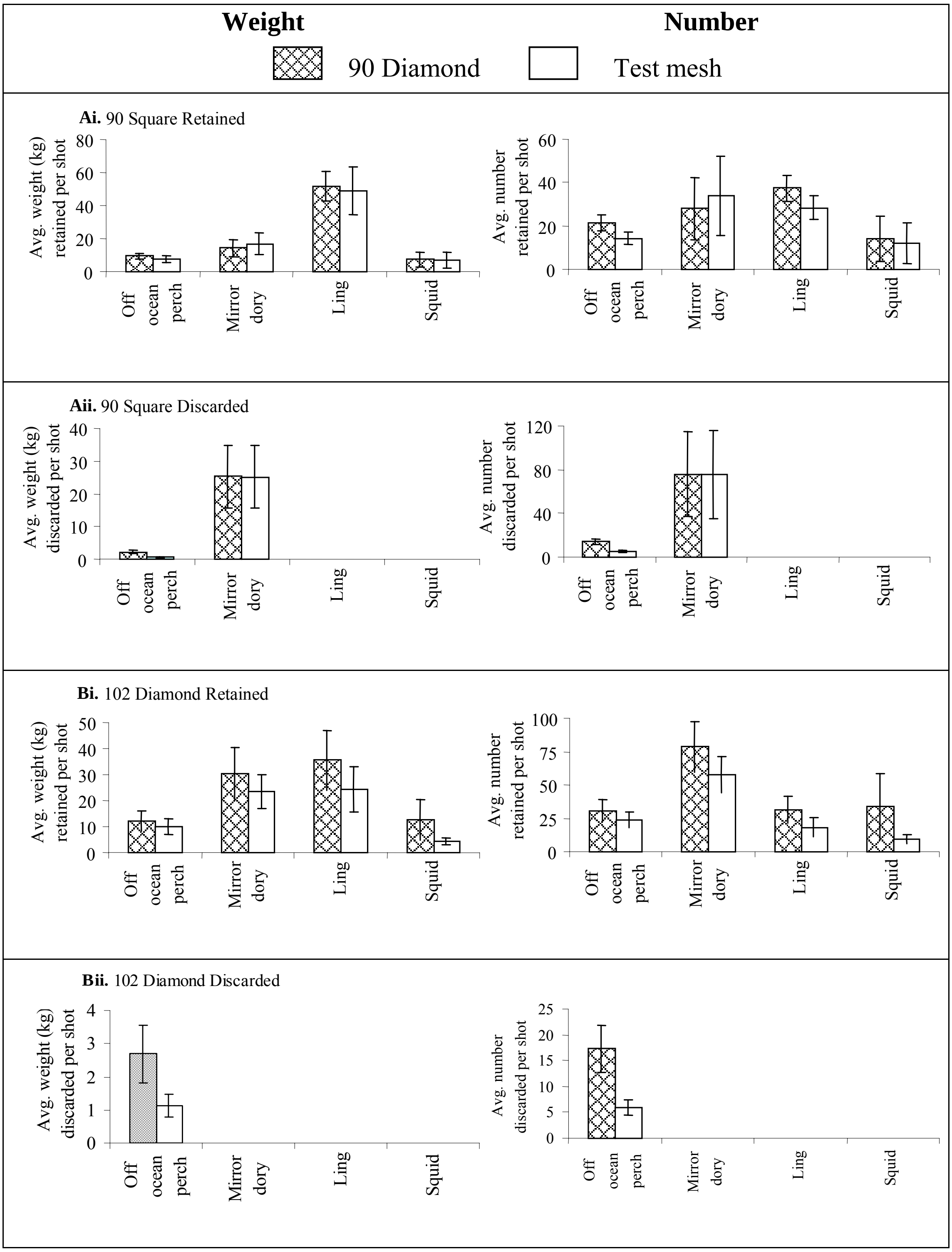


Figure 7-26. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (>150 fth) off Bermagui (east). The test mesh is: A, 90 mm Square; B, 102 mm Diamond. (102 mm Square and 110 mm Diamond see Figure 7-27). Error bars +1SE.

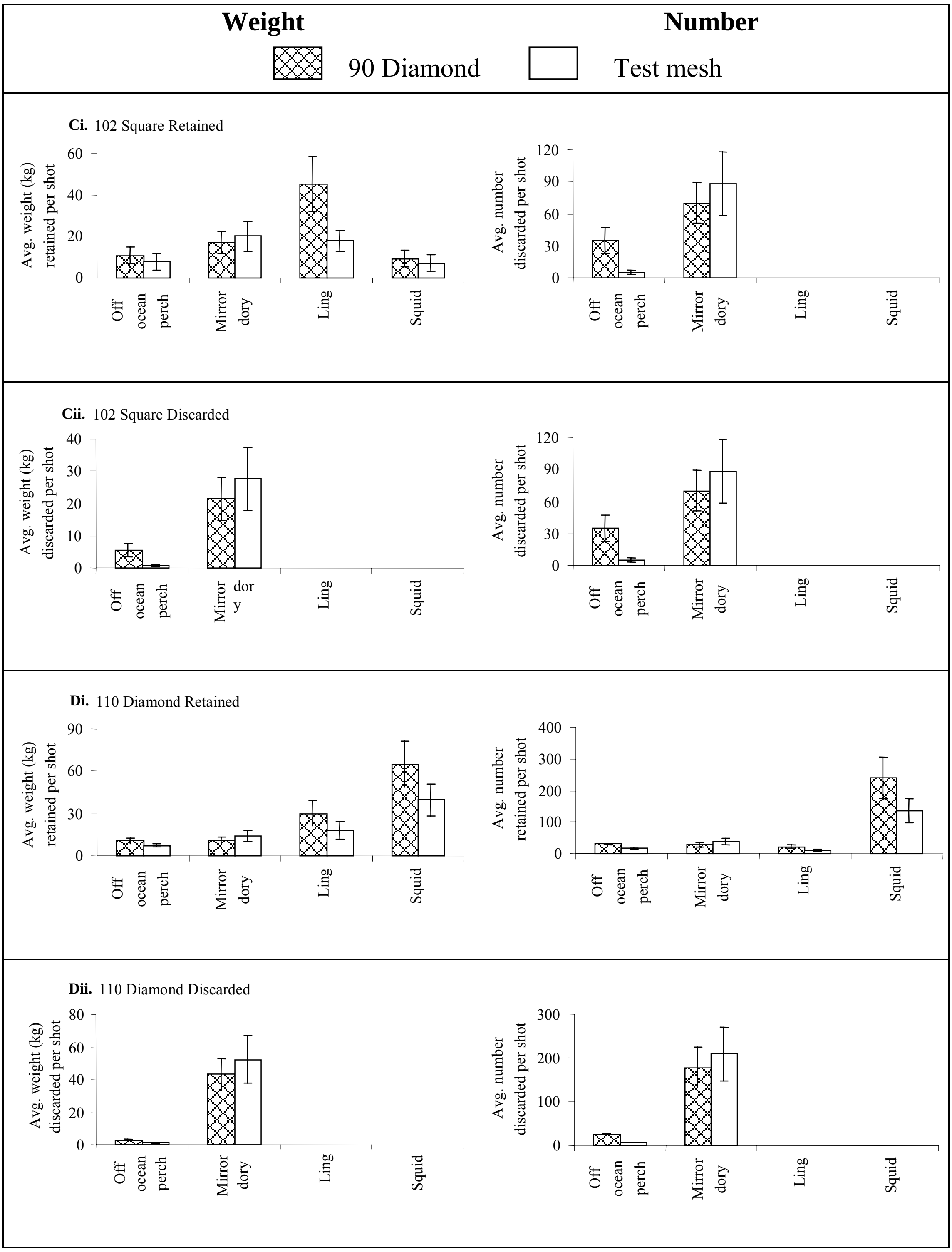


Figure 7-27. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (>150 fth) off Bermagui (east). The test mesh is: C, 102 mm Square; D, 110 mm Diamond. (90 mm Square and 102 mm Diamond see Figure 7-26). Error bars ±1SE.

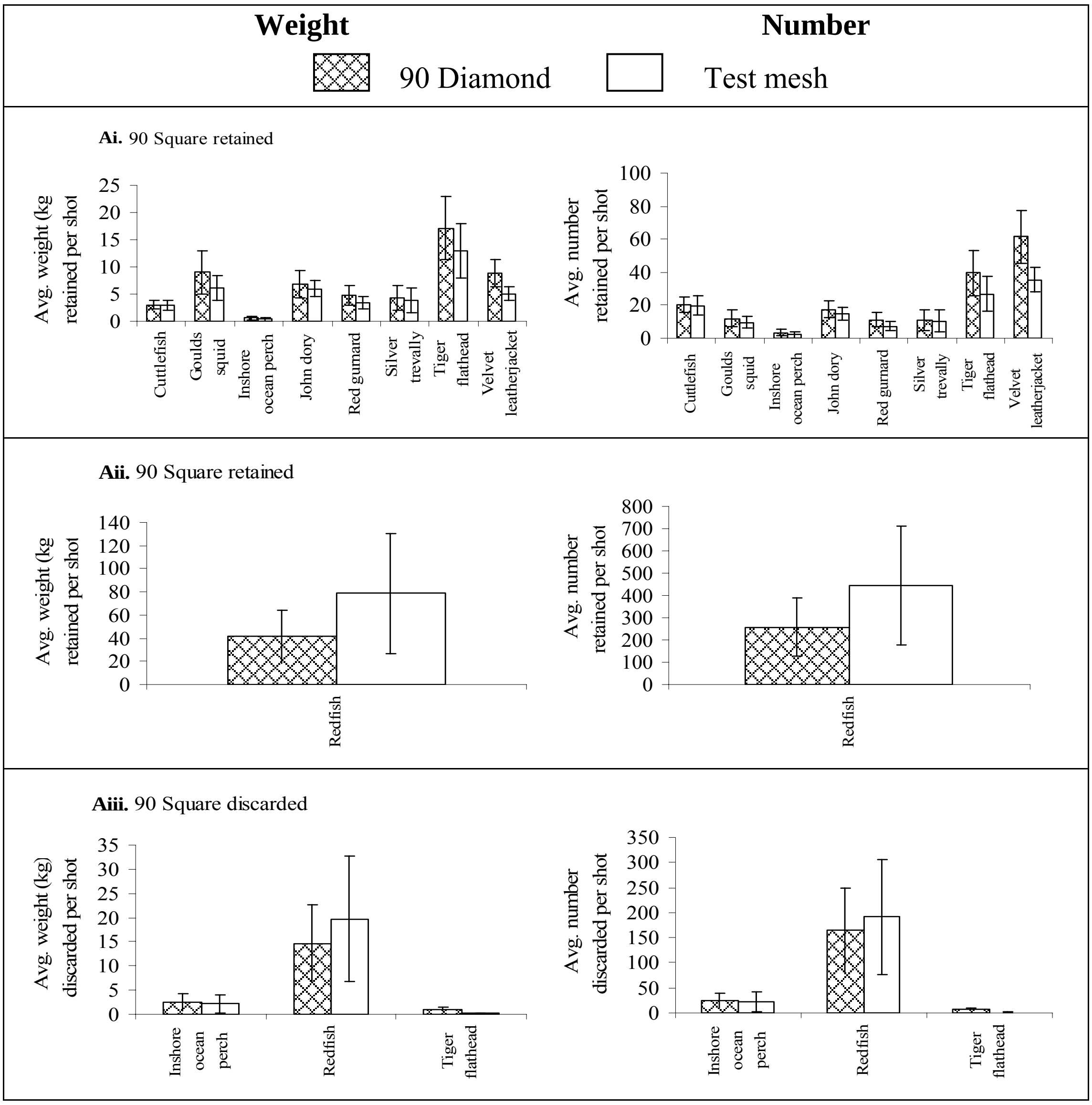


Figure 7-28. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from shallow water (<150 fth) off Bermagui (east). The test mesh is: A, 90 mm Square; (B, 102 mm Diamond see Figure 7-29, C, 102 mm Square see Figure 7-30 and D, 110 mm Diamond see Figure 7-31). Error bars ±1SE.

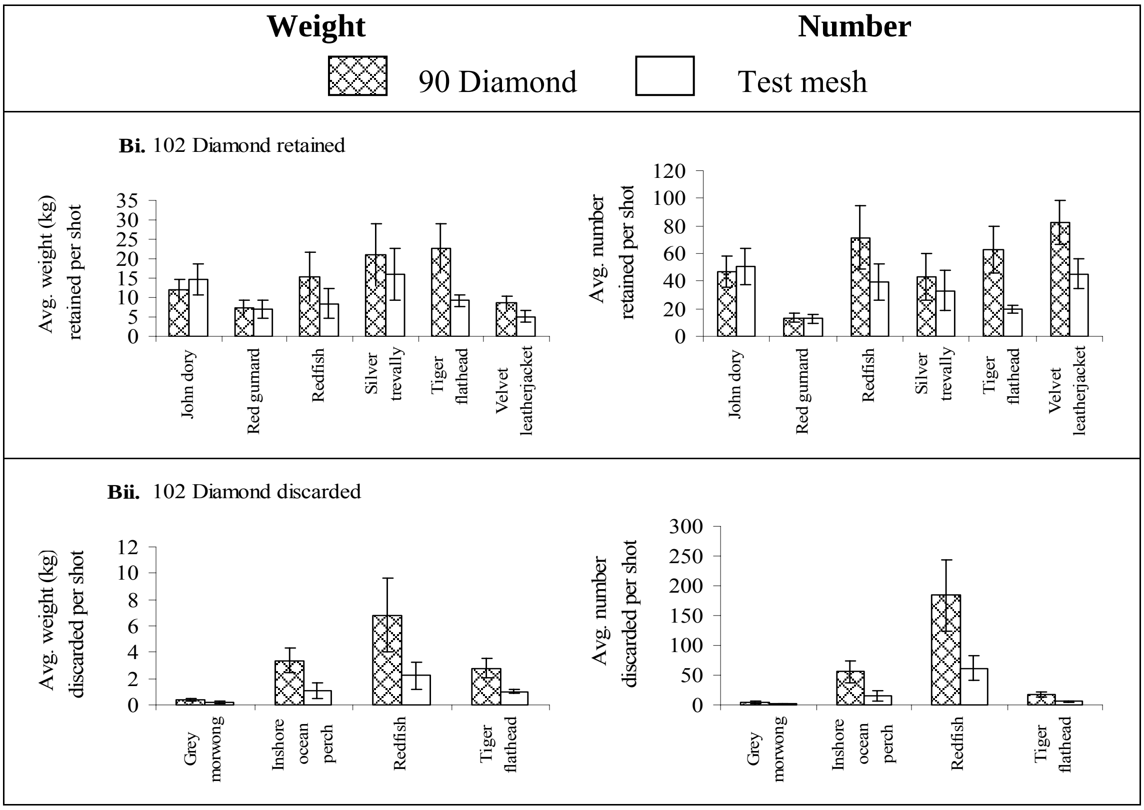


Figure 7-29. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from shallow water (<150 fth) off Bermagui (east). The test mesh is: B, 102 mm Diamond; (90 mm Square, see Figure 7-28, 102 mm Square, see Figure 7-30 and 110 mm Diamond see Figure 7-31). Error bars ±1SE.

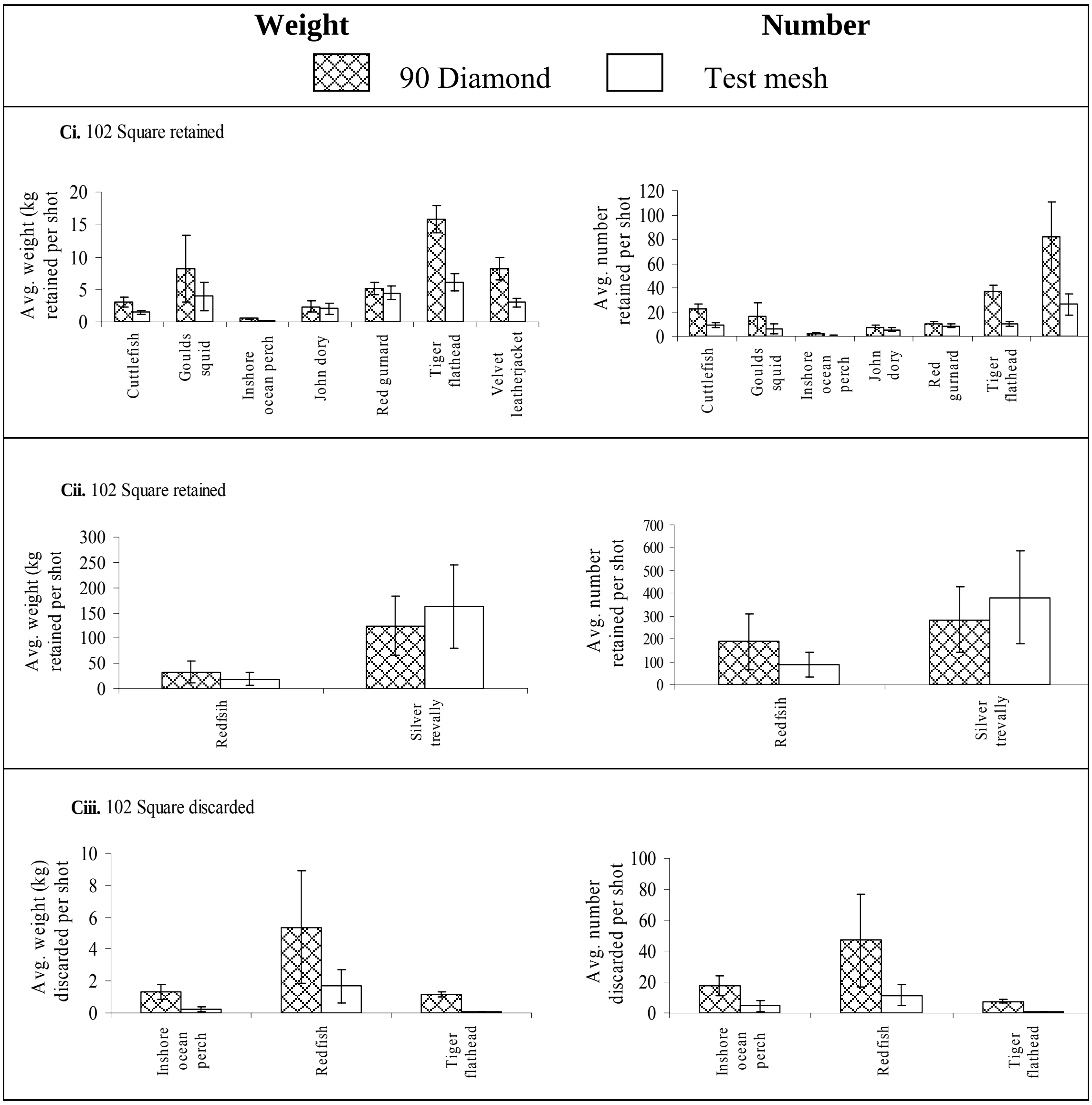


Figure 7-30. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from shallow water (<150 fth) off Bermagui (east). The test mesh is: C, 102 mm Square. (90 mm Square, see Figure 7-28, 102 mm Diamond see Figure 7-29 and 110 mm Diamond see Figure 7-31). Error bars ±1SE.

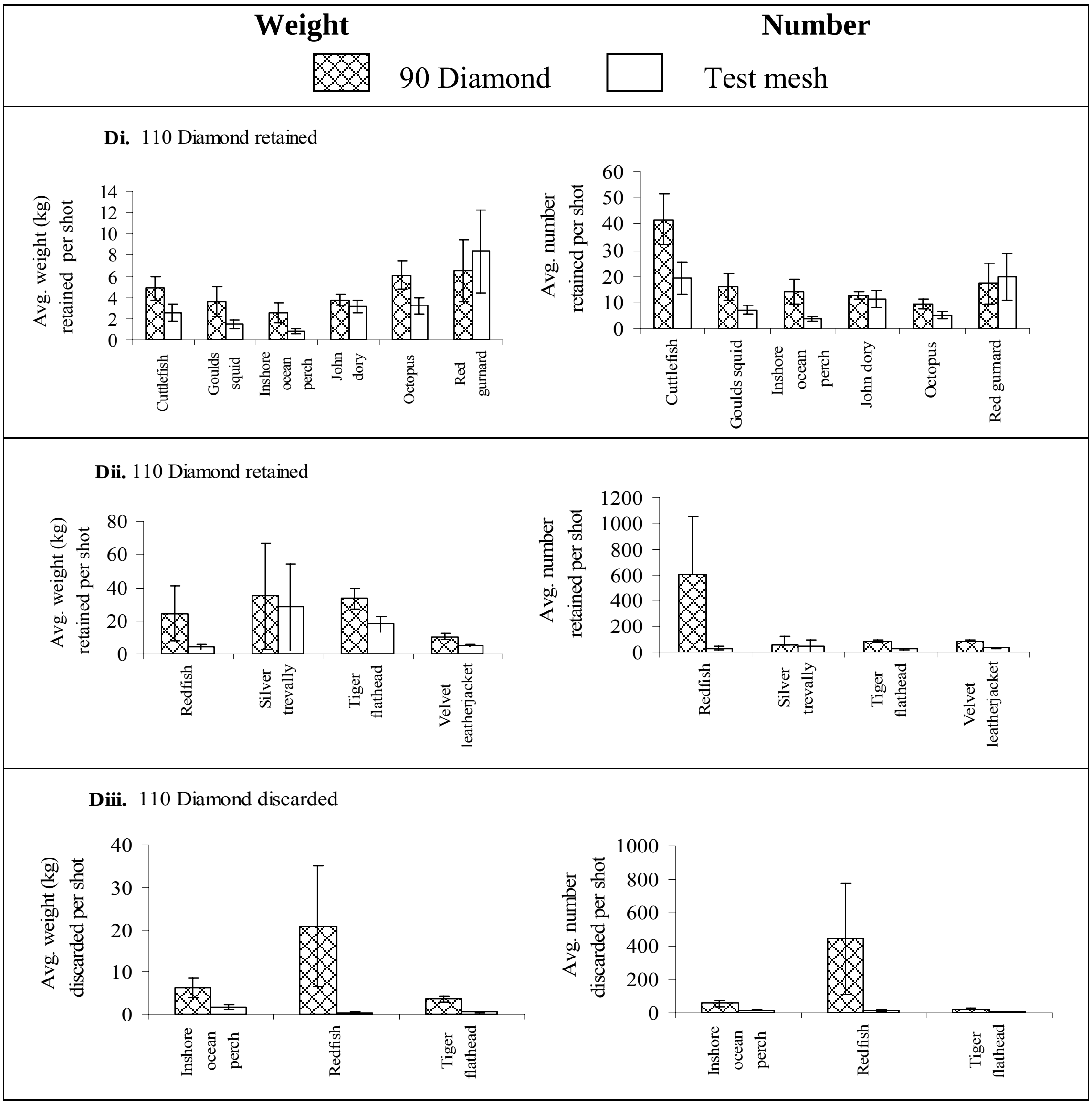


Figure 7-31. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (<150 fth) off Bermagui (east). The test mesh is: D, 110 mm Diamond. (90 mm Square, see Figure 7-28, 102 mm Diamond see Figure 7-29 and 102 mm Square see Figure 7-30). Error bars ±1SE.

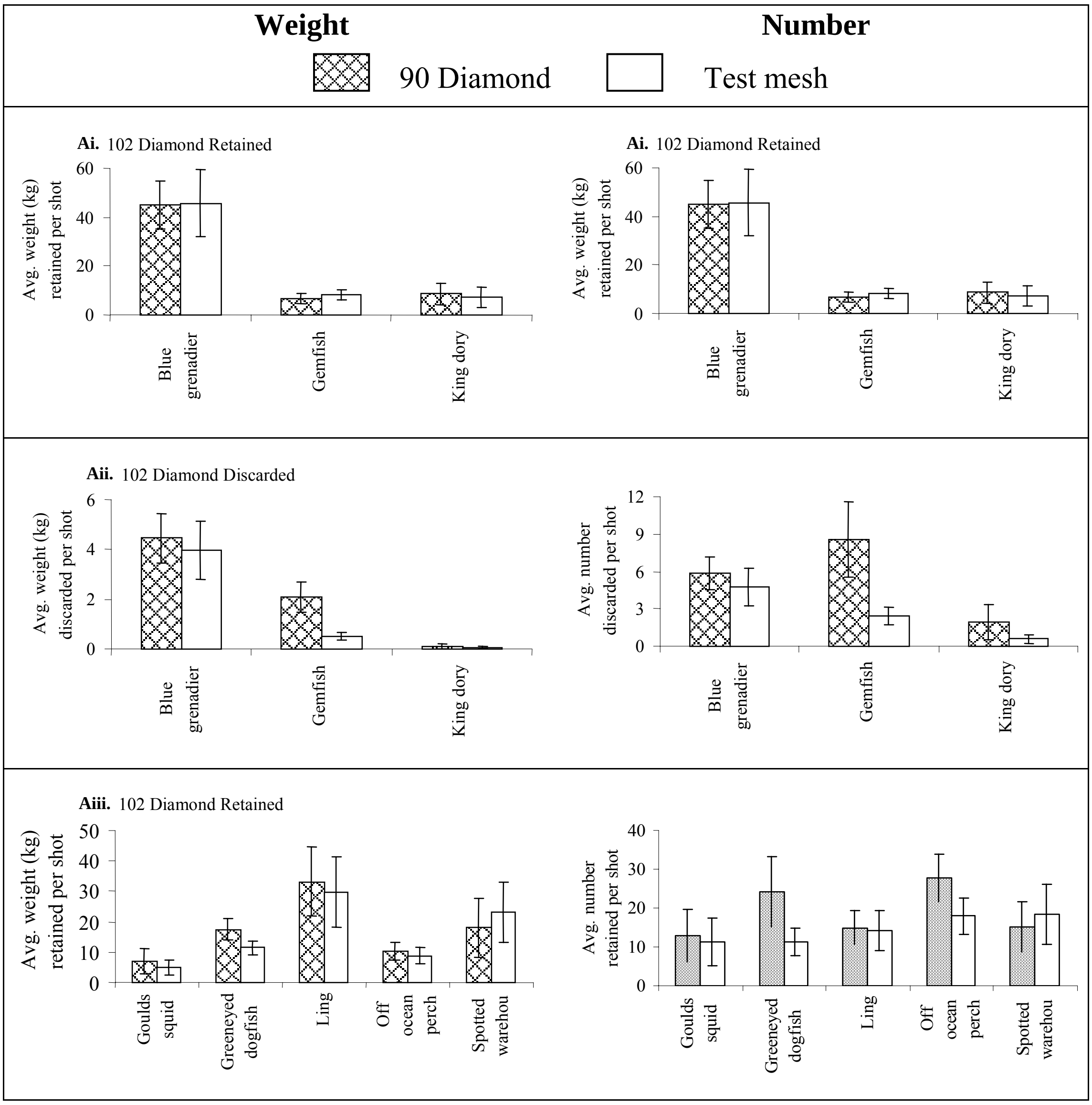


Figure 7-32. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (>150 fth) off Portland (west). None of the species in Aiii. were discarded. The test mesh is: A, 102 mm Diamond. (102 mm Square, see Figure 7-33; 110 mm Diamond, see Figure 7-34; 110 mm Square, see Figure 7-35). Error bars ±1SE.

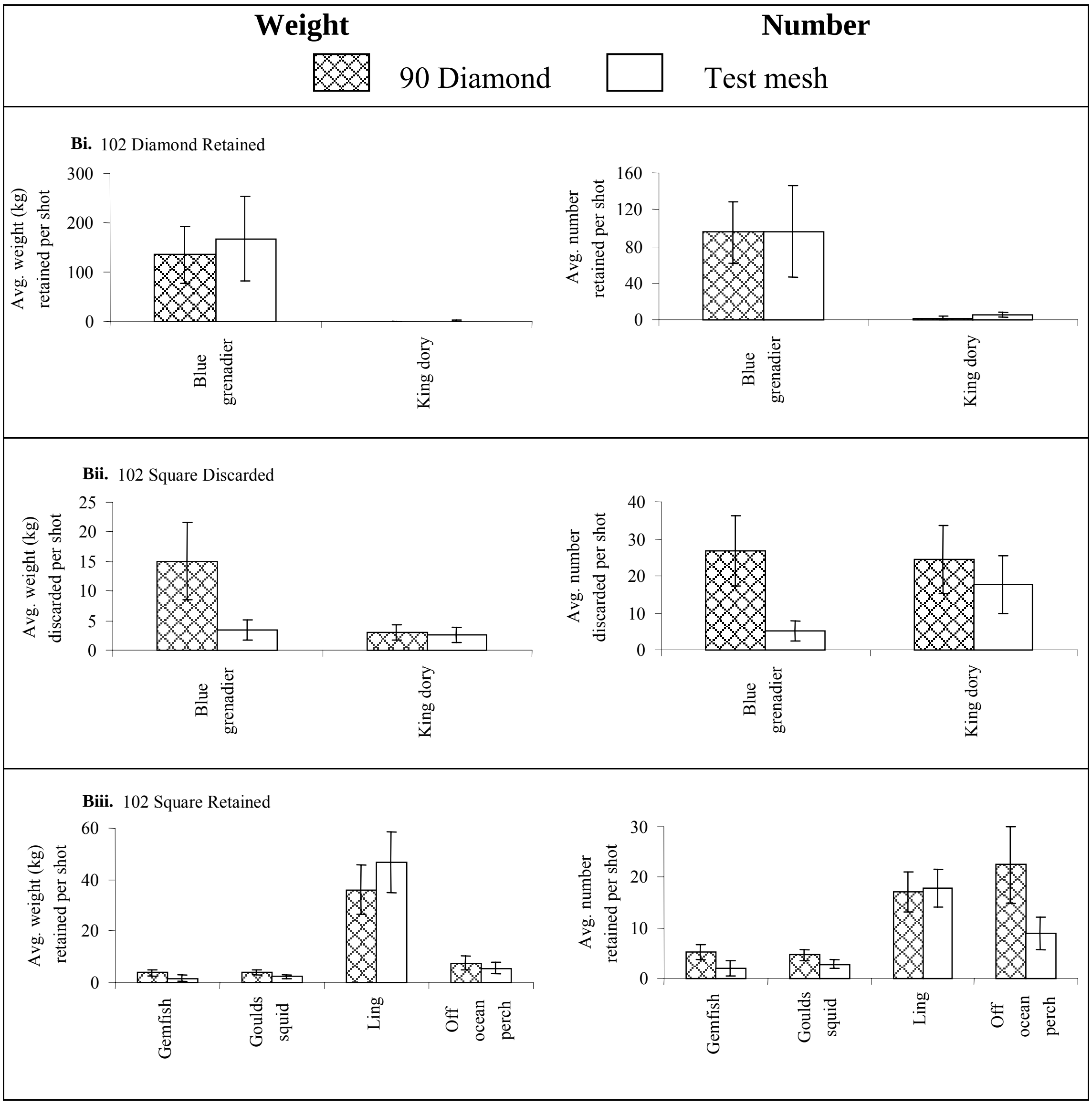


Figure 7-33. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (>150 fth) off Portland (west). None of the species in Biii. were discarded. The test mesh is: B, 102 mm Square. (102 mm Diamond, see Figure 7-32; 110 mm Diamond, see Figure 7-34; 110 mm Square, see Figure 7-35). Error bars ±1SE.

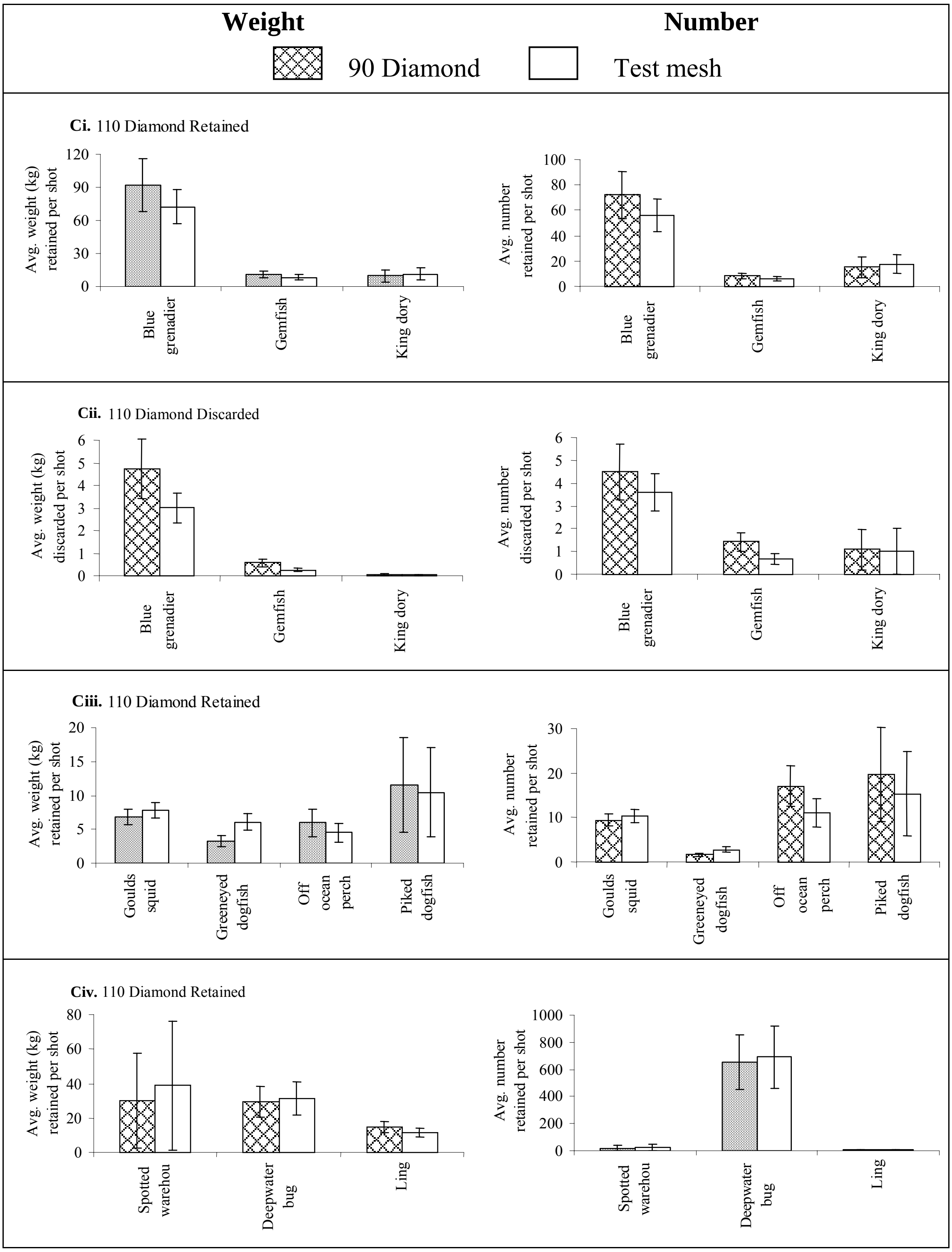


Figure 7-34. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (>150 fth) off Portland (west). None of the species in Ciii. and Civ. were discarded. The test mesh is: C, 110 mm Diamond. (102 mm Diamond, see Figure 7-32; 102 mm Square, see Figure 7-33; 110 mm Square, see Figure 7-35). Error bars ±1SE.

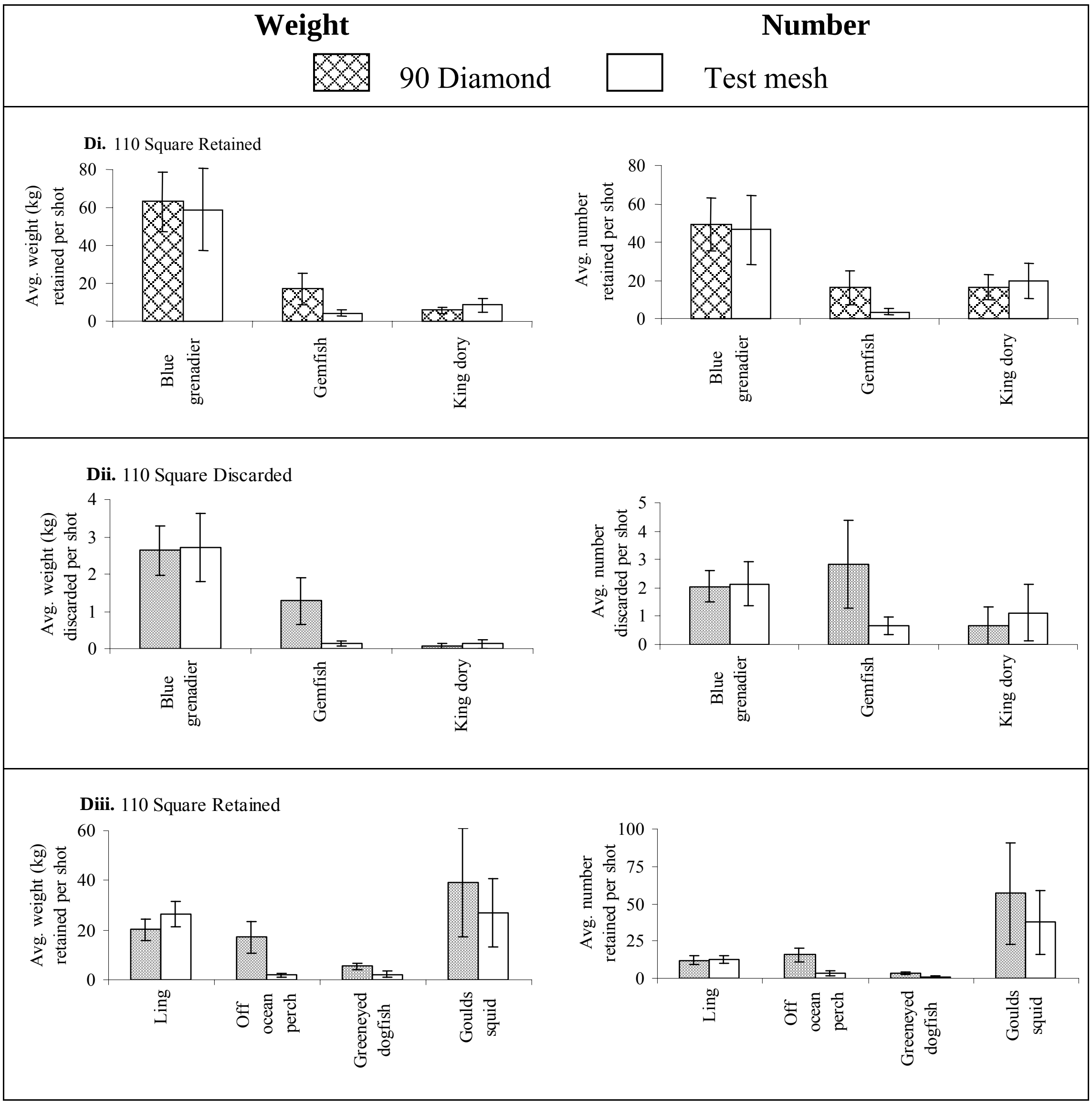


Figure 7-35. Average weight (left column) and number (right column) per shot of retained or discarded commercial fish from deep water (>150 fth) off Portland (west). None of the species in Diii. were discarded. The test mesh is: D, 110 mm Square. (102 mm Diamond, see Figure 7-32; 102 mm Square, see Figure 7-33; 110 mm Diamond, see Figure 7-34). Error bars ±1SE.

7.4.3.5 Comparison of length frequency of retained and discarded commercial fish species from the East in standard (90 mm diamond) and test meshes.

The 102 mm diamond, 102 mm square and 110 mm diamond codends all caught less discarded tiger flathead (Figure 7-37), inshore ocean perch (Figure 7-38), eastern gemfish (Figure 7-39), offshore ocean perch (Figure 7-40) and redfish (Figure 7-41), but generally also caught less retained fish of each of those species. The 90 mm square codend caught less discarded tiger flathead as well as less discarded and retained offshore ocean perch. The 90 mm square and 102 mm diamond codends did not appear to affect the size distribution of pink ling caught, but reduced the overall catch of that species, while, the other two test nets greatly reduced the catches of 45–60 cm pink ling (Figure 7-42). Test nets appeared to make very little difference to length composition of mirror dory (Figure 7-43).

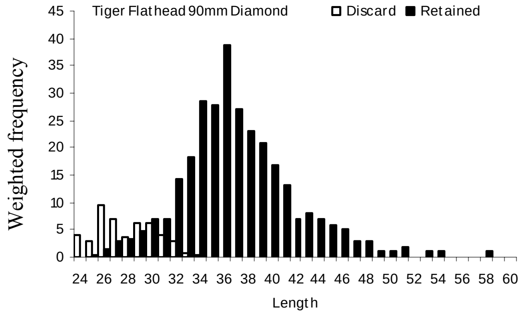
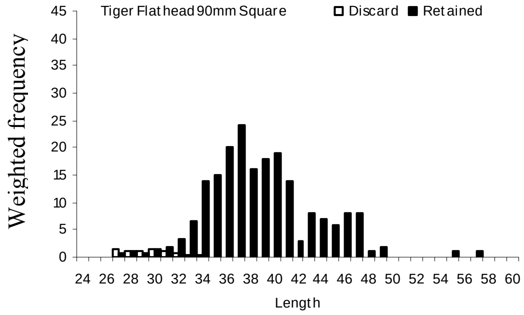
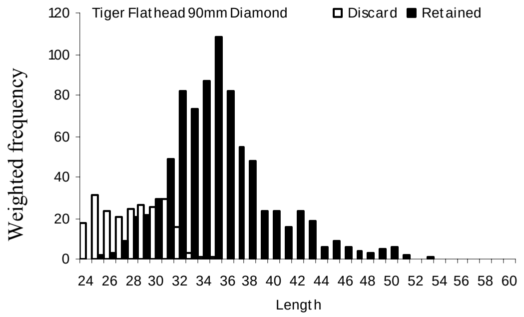
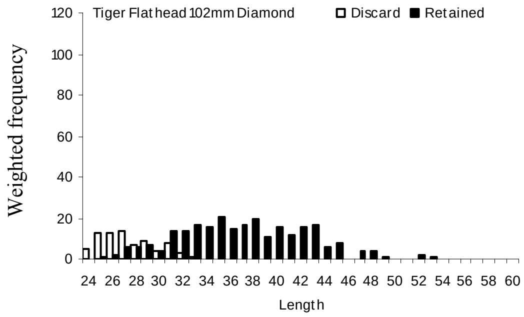
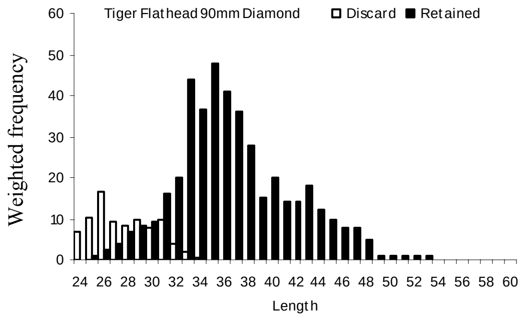
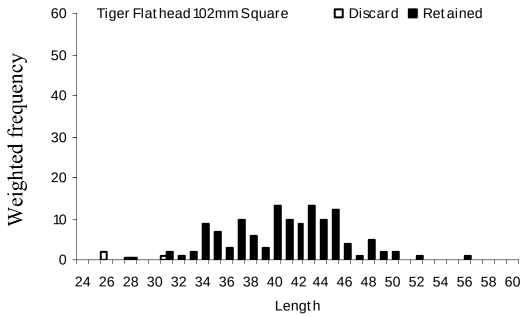
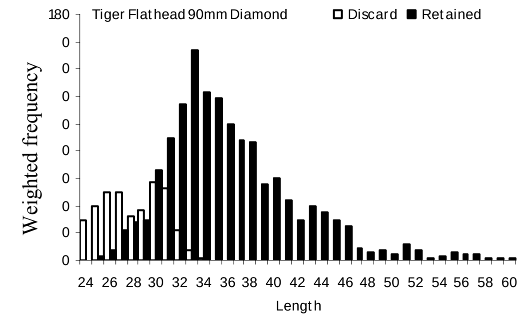
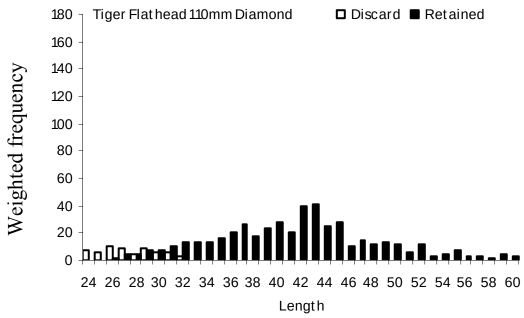
Tiger Flathead	90 mm diamond	Test-mesh
90 S		
102 D		
102 S		
110 D		

Figure 7-36. Length frequency distributions of retained (■) and discarded (□) tiger flathead caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

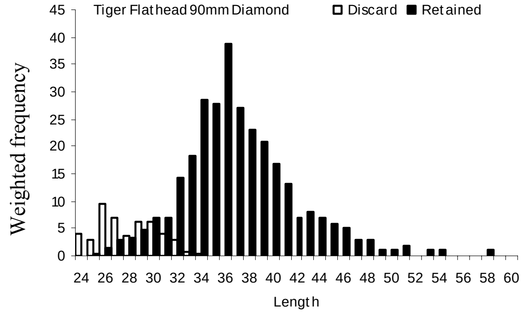
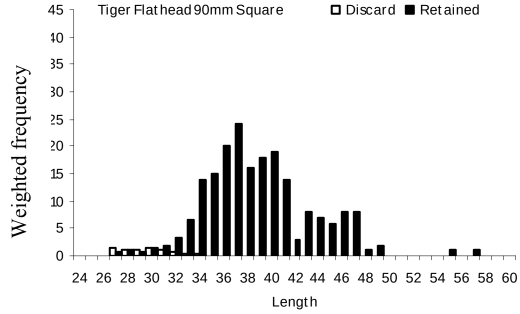
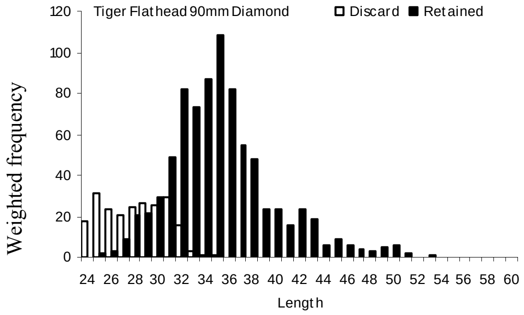
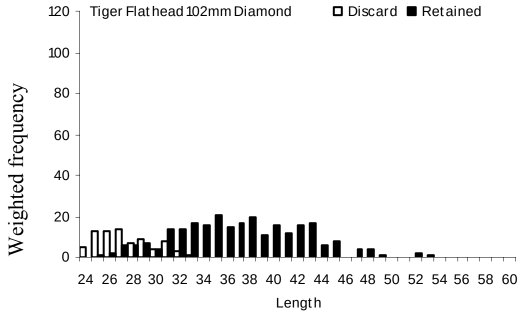
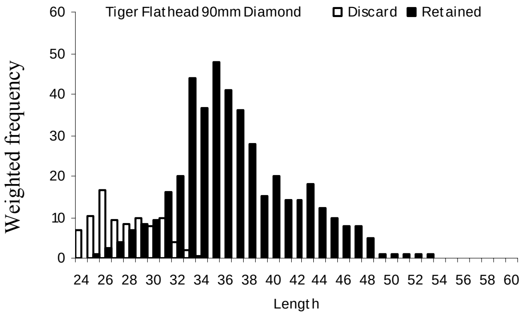
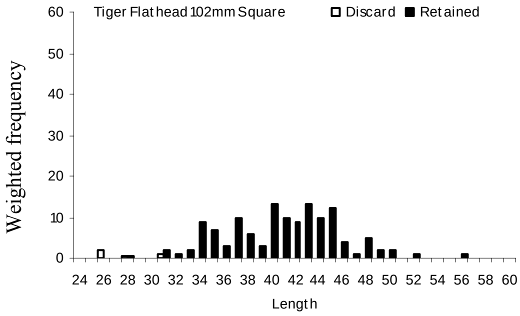
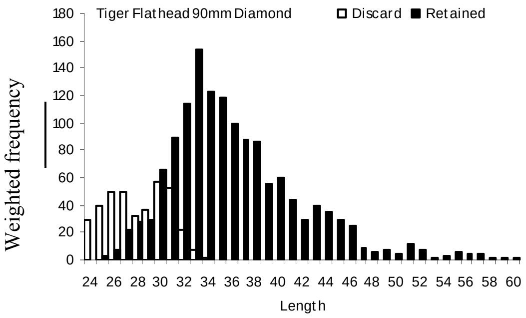
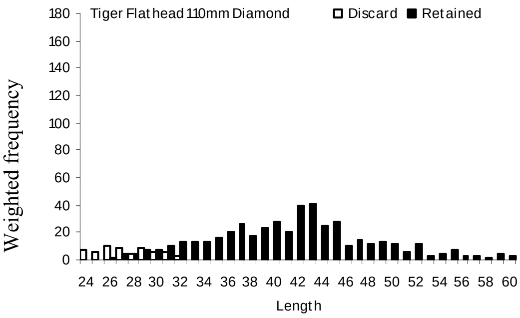
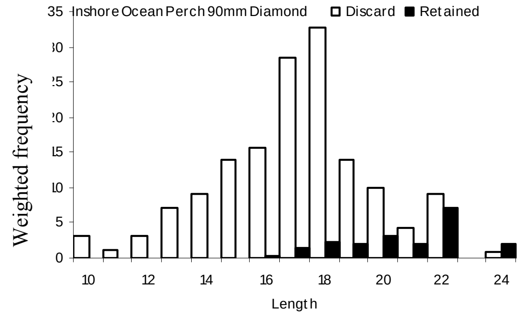
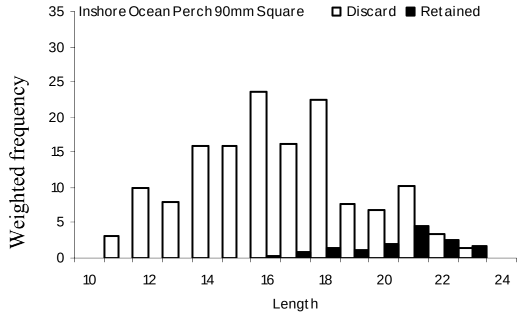
Tiger Flathead	90 mm diamond	Test-mesh
90 S		
102 D		
102 S		
110 D		

Figure 7-37. Length frequency distributions of retained (■) and discarded (□) tiger flathead caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

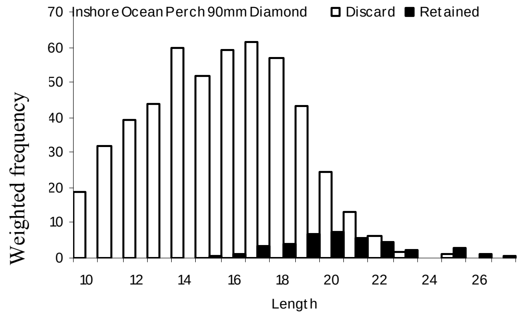
Inshore Ocean Perch	90 mm diamond	Test-mesh

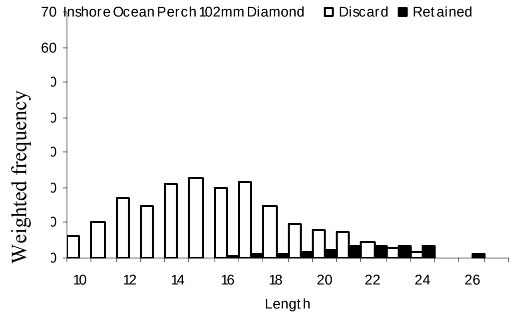
90 S



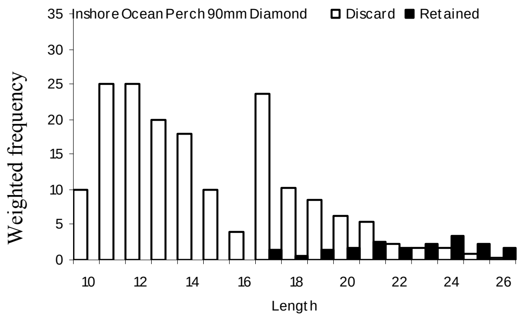


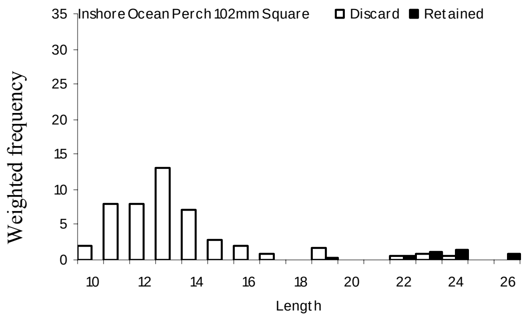
102 D



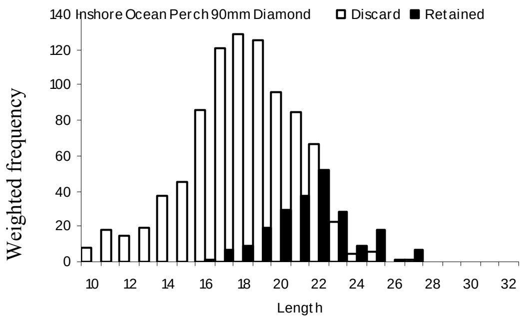


102 S





110 D



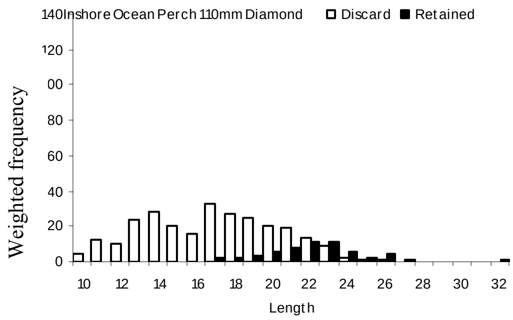


Figure 7-38. Length frequency distributions of retained (■) and discarded (□) inshore ocean perch caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90-mm Square-mesh (90 S); 102-mm Diamond-mesh (102 D); 102-mm Square-mesh (102 S); and, 110-mm Diamond (110 D).

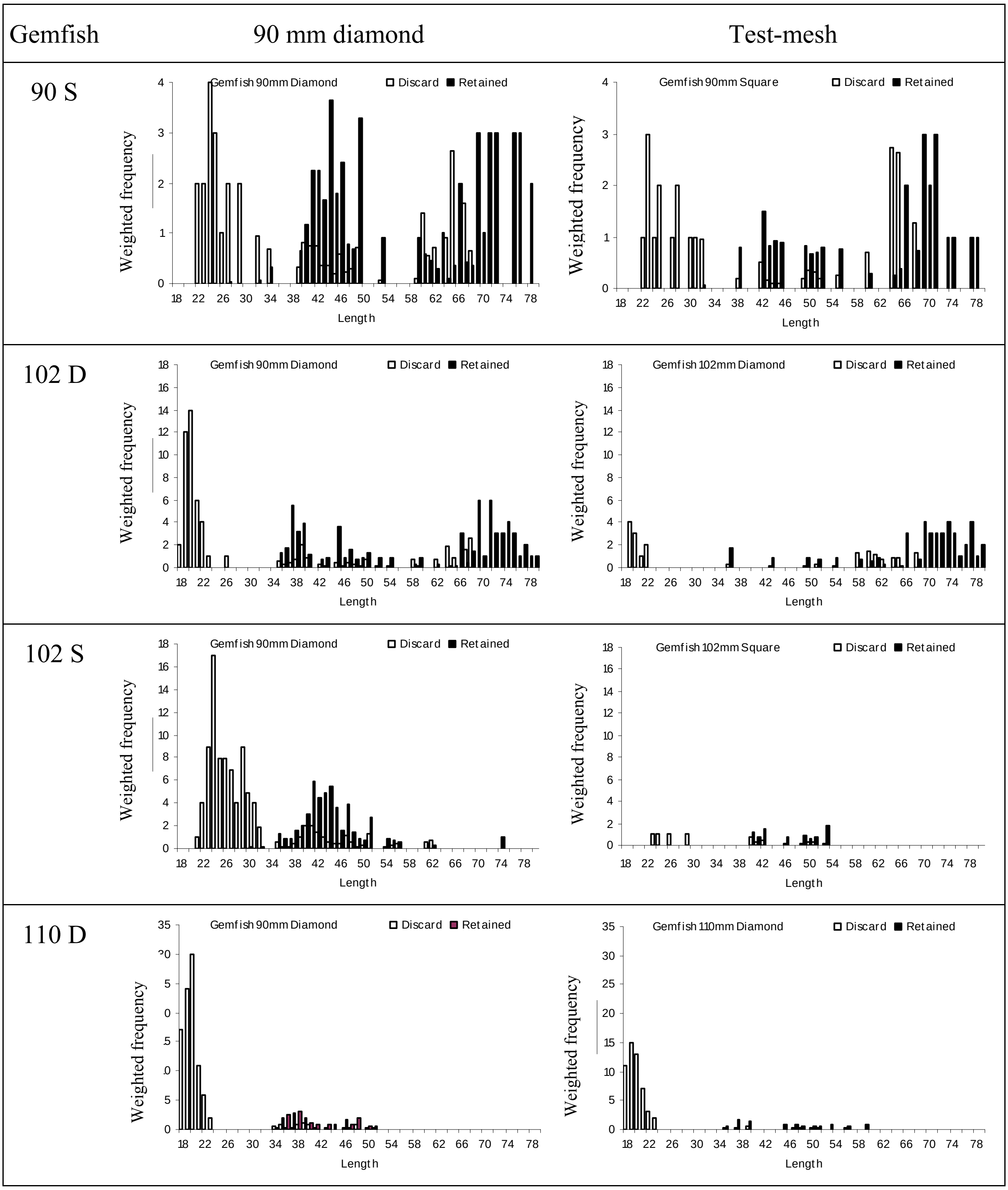
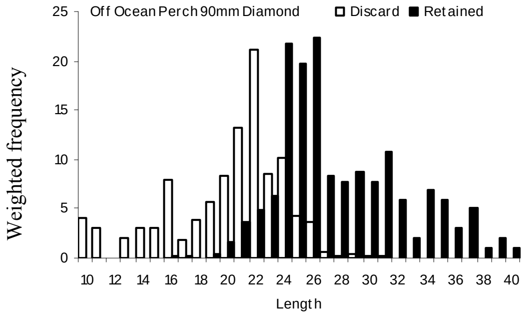
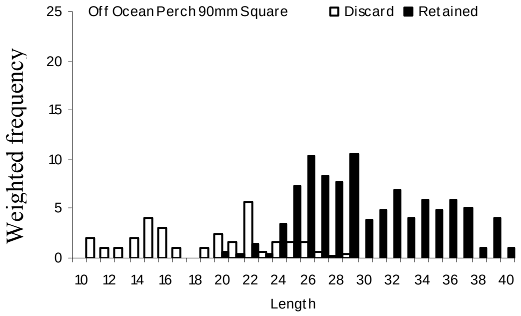


Figure 7-39. Length frequency distributions of retained (■) and discarded (□) gemfish caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

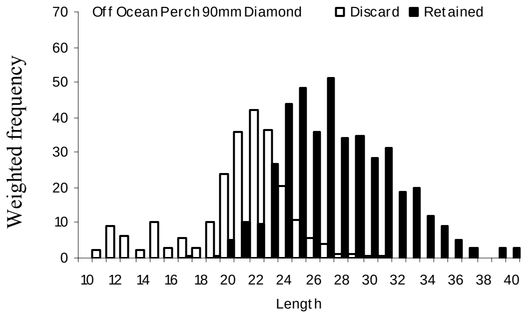
Offshore Ocean Perch	90 mm diamond	Test-mesh

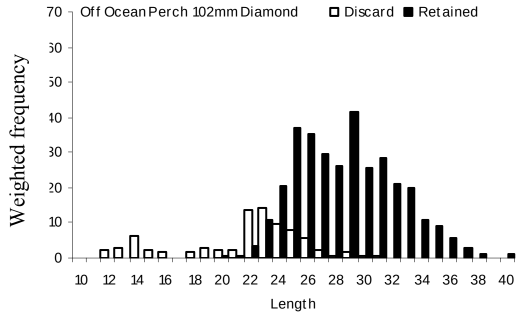
90 S



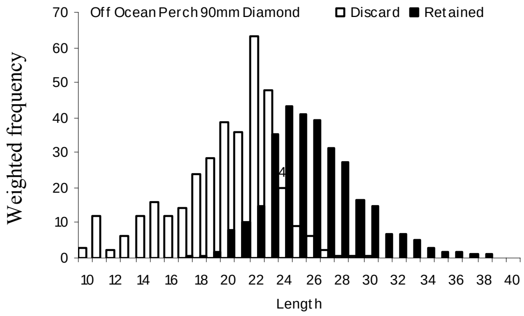


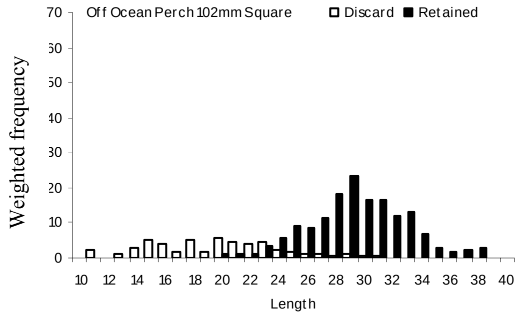
102 D



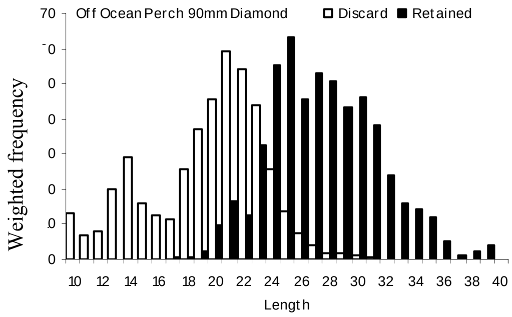


102 S





110 D



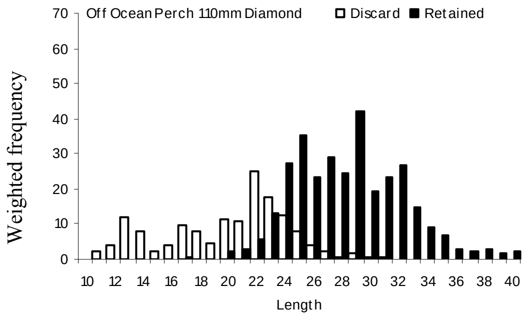


Figure 7-40. Length frequency distributions of retained (■) and discarded (□) offshore ocean perch caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

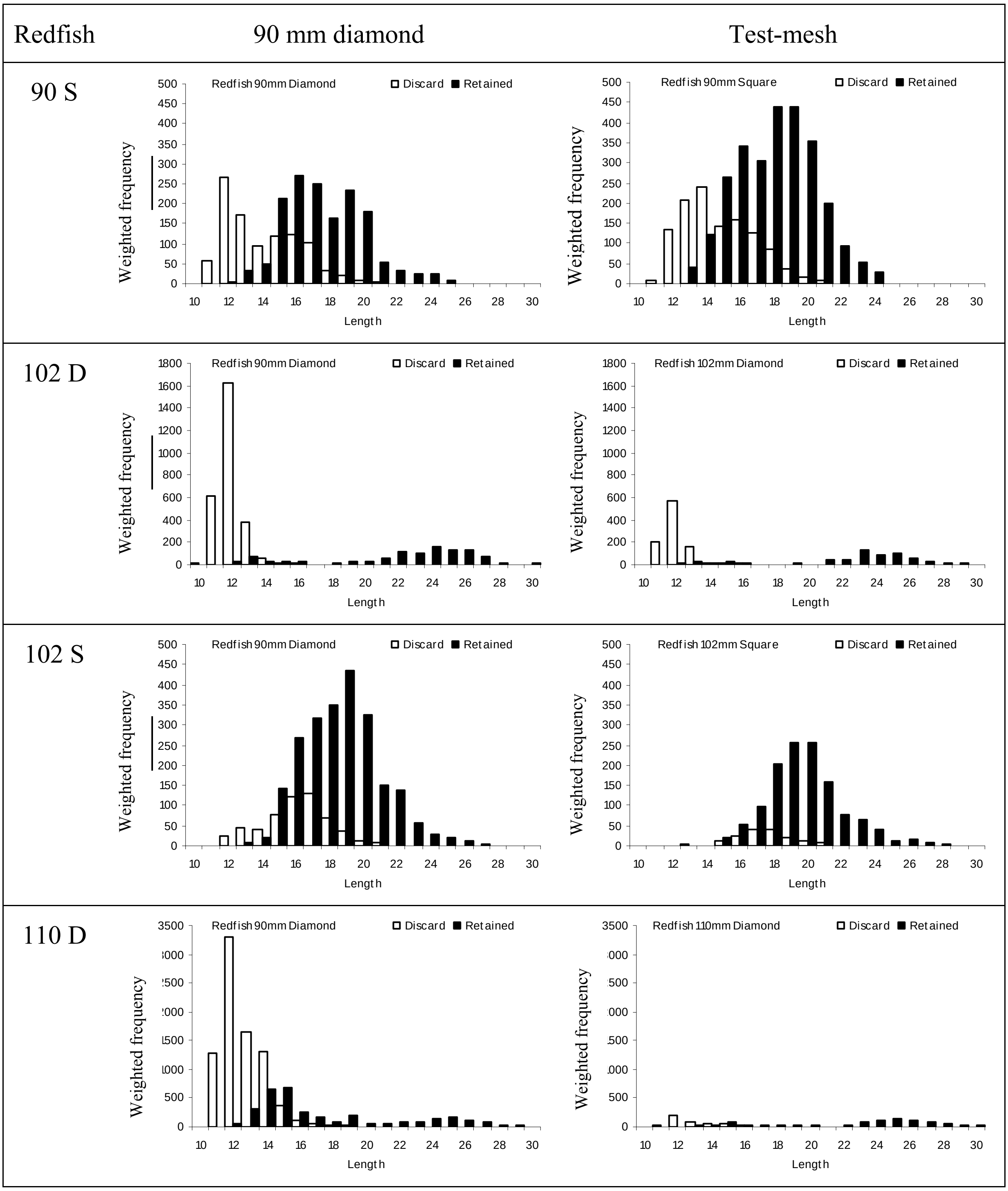


Figure 7-41. Length frequency distributions of retained (■) and discarded (□) redfish caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

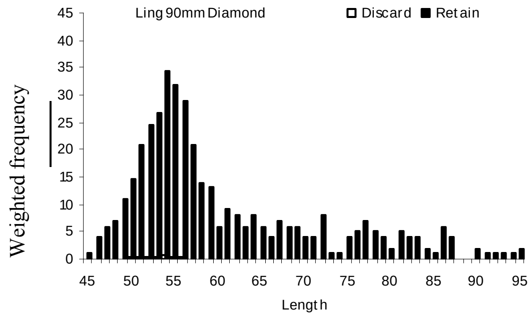
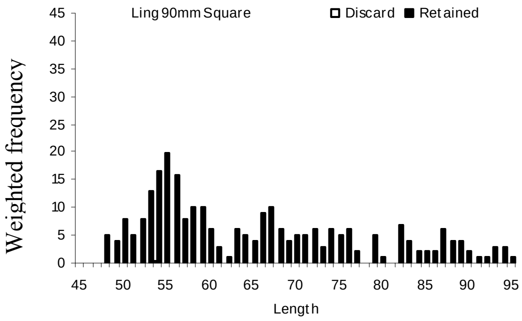
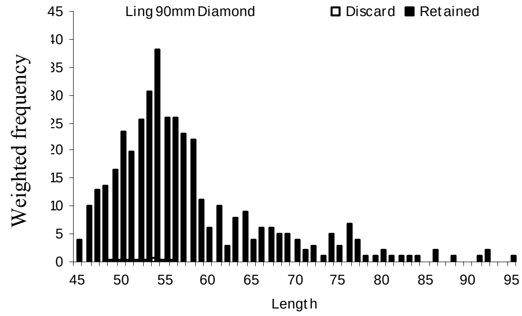
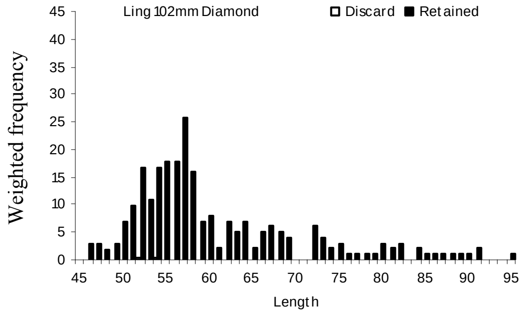
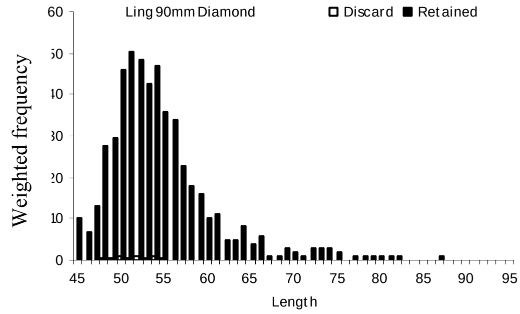
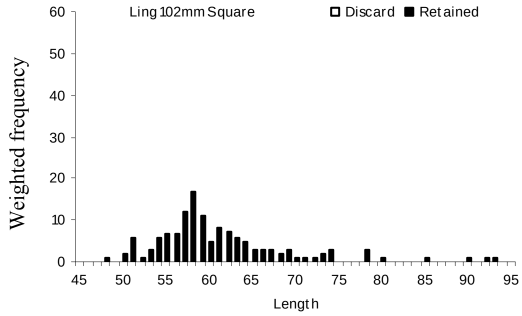
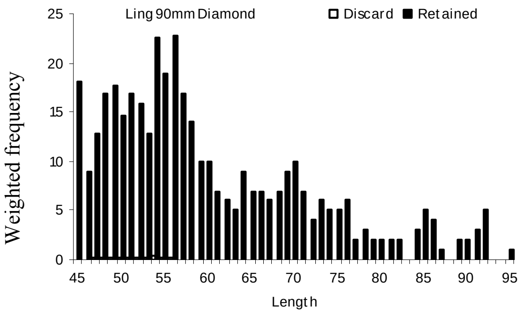
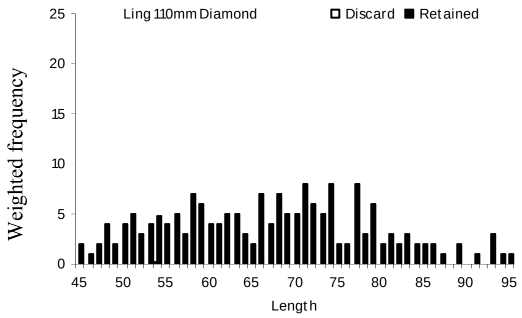
Pink ling east	90 mm diamond	Test-mesh
90 S		
102 D		
102 S		
110 D		

Figure 7-42. Length frequency distributions of retained (■) and discarded (□) pink ling caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

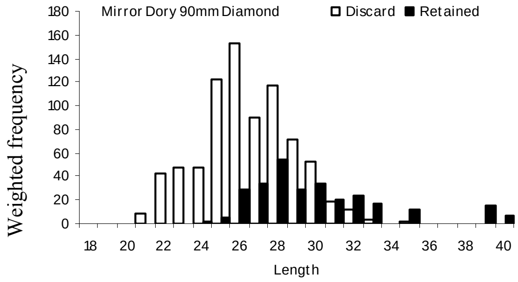
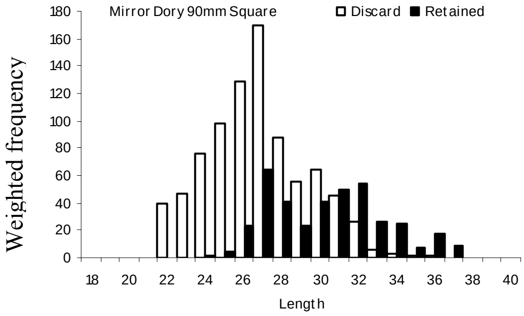
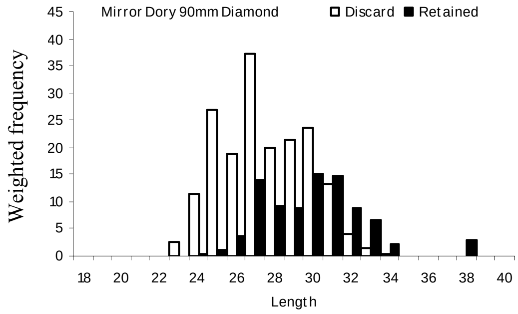
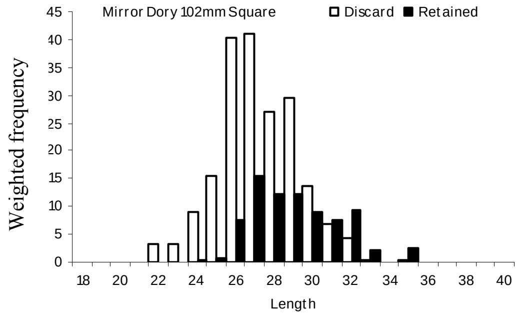
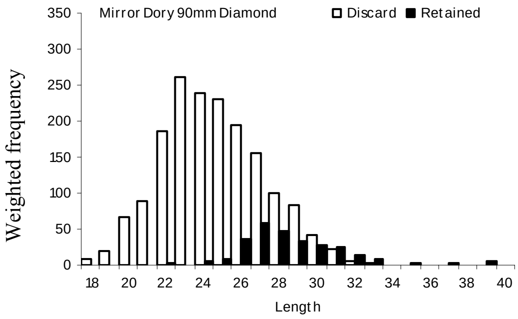
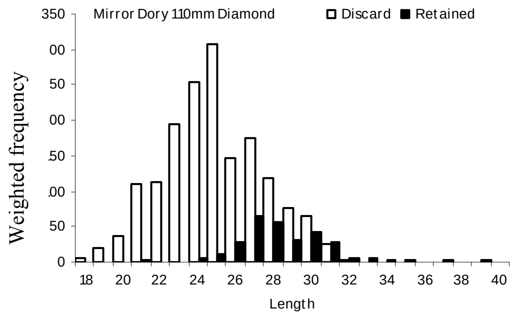
Mirror Dory	90 mm diamond	Test-mesh
90 S		
102 D		
102 S		
110 D		

Figure 7-43. Length frequency distributions of retained (■) and discarded (□) mirror dory caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

7.4.3.6 Comparison of length frequency of other fish species from the East in standard (90 mm diamond) and test meshes.

The effects on length composition of other species in the east varied from species to species. All test nets contained reduced catches of small (10–20 cm) grey morwong, and the 110 mm diamond codend had a particularly large effect on catches of jackass morwong of all sizes (Figure 7-44). The 90 mm square and 110 mm diamond appeared to reduce the catch of small silver trevally, however more fish 23–29 cm were caught by the 102 mm square mesh than by the control net (Figure 7-45). All test nets reduced catches of small banded whiptail and Gould's squid (Figure 7-46). A major decrease in the catch of small piked dogfish (*Squalus acanthias*) was observed in the 102 mm square codend, while the 110 mm diamond codend caught more large (>47 cm) fish (Figure 7-47). Only the 90 cm squared codend appeared to make much difference to the size composition of red gurnard, catching less fish <35 cm (Figure 7-47). Catches of roundsnout gurnard, toothed whiptail and blacktip cucumberfish of all sizes were reduced in all test codends in which they were measured (Figure 7-48 and Figure 7-49).

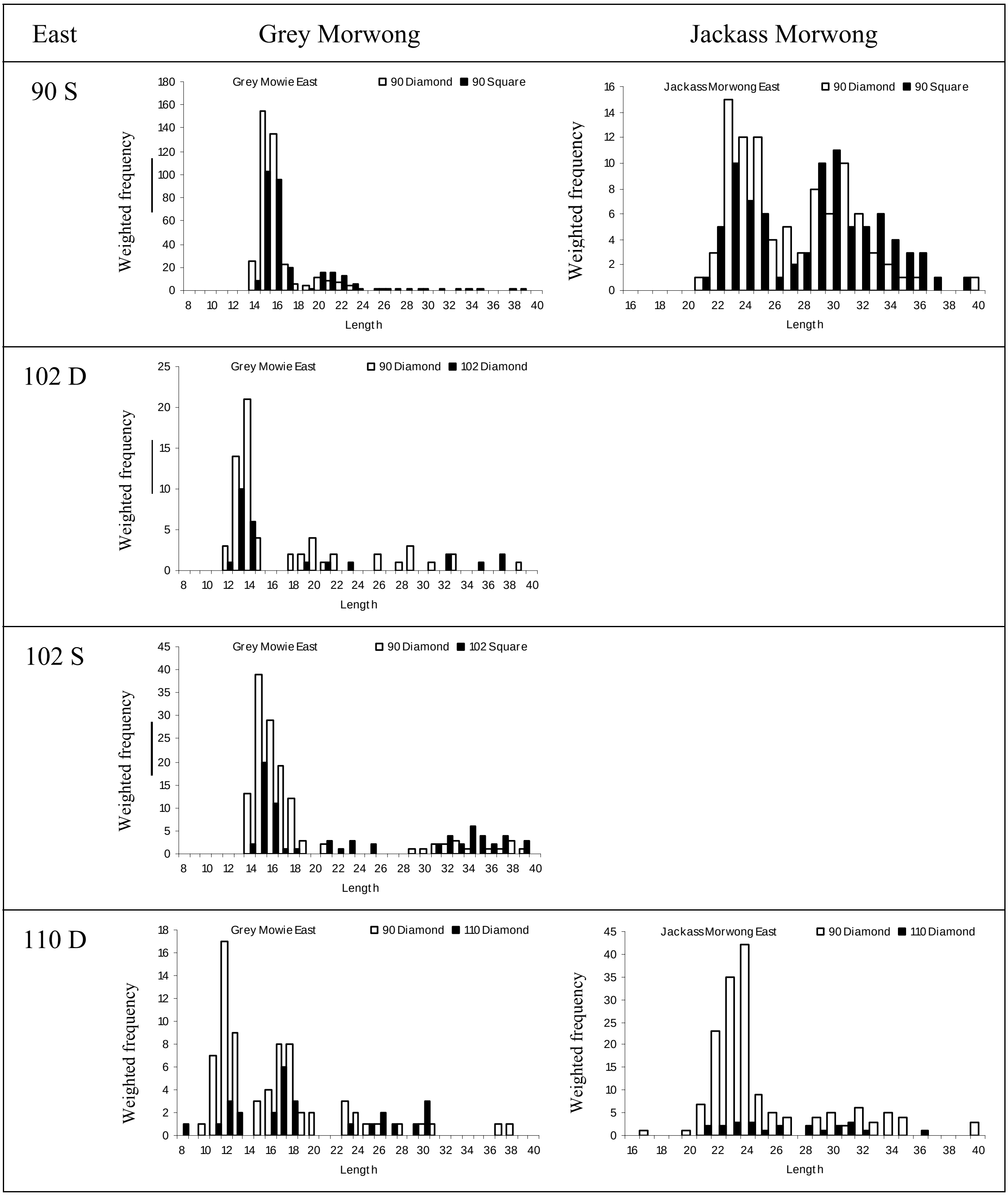


Figure 7-44. Length frequency distributions of grey morwong and jackass morwong caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

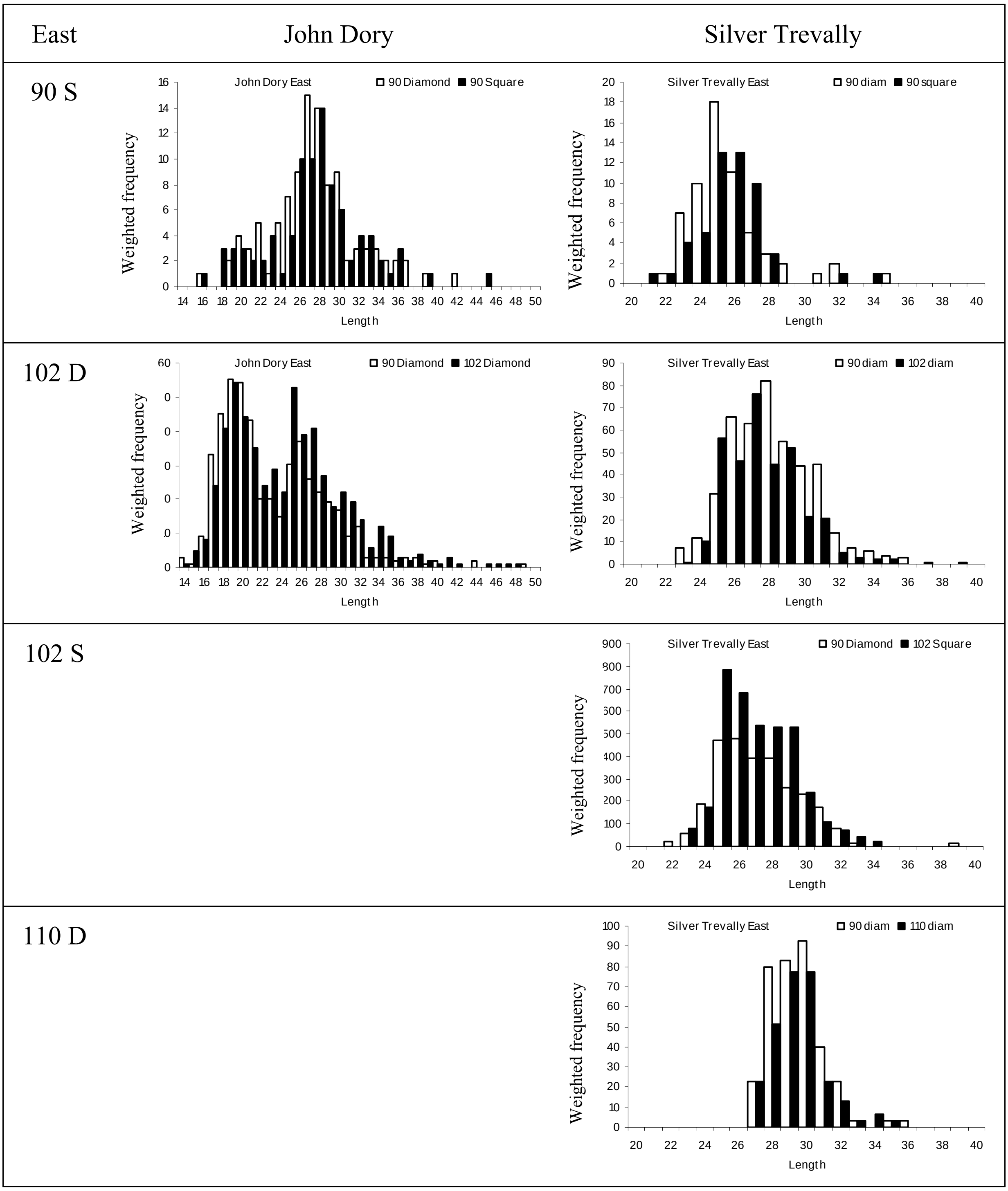


Figure 7-45. Length frequency distributions of John dory and silver trevally caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

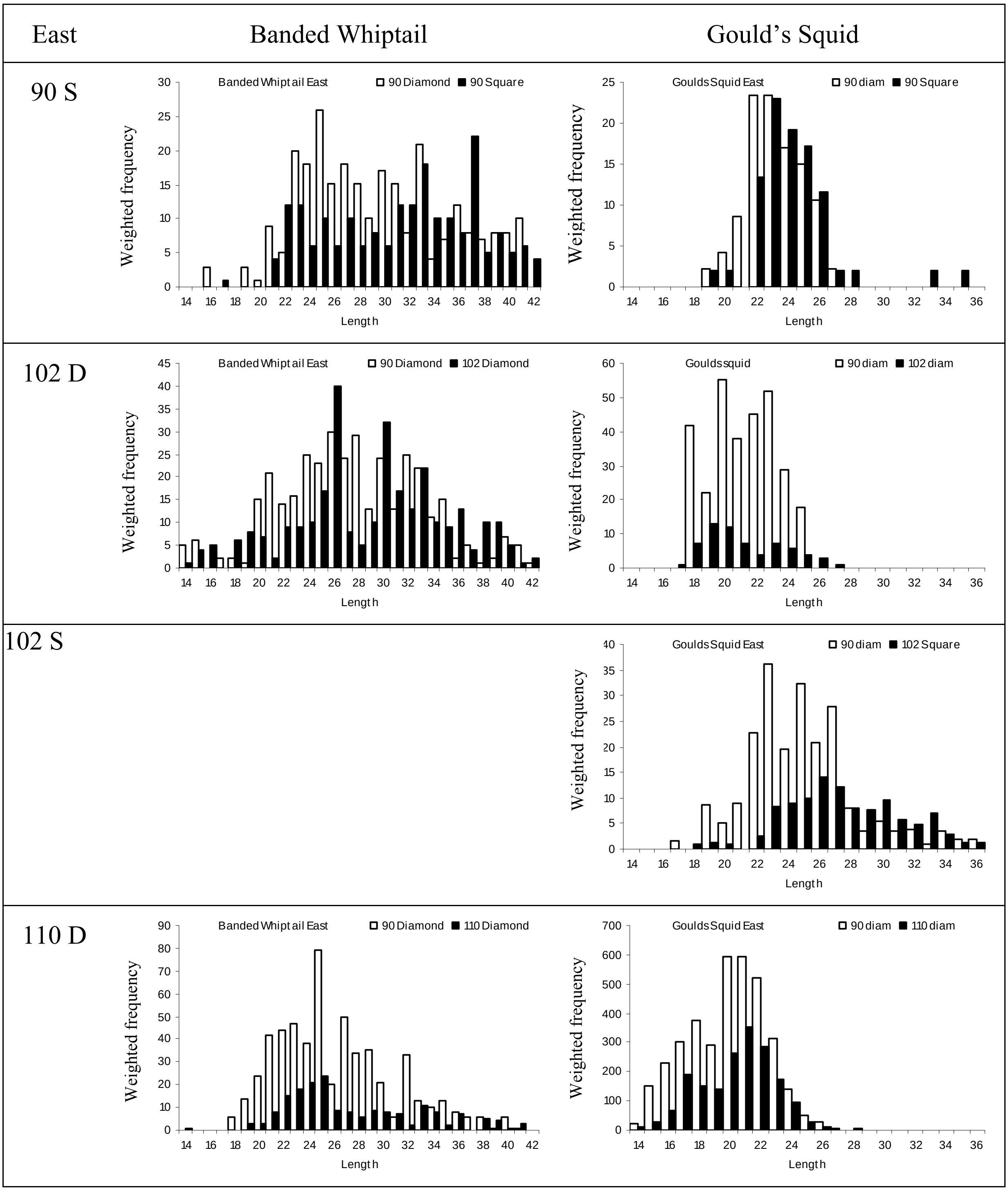


Figure 7-46. Length frequency distributions of retained banded whiptail and Gould's squid caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

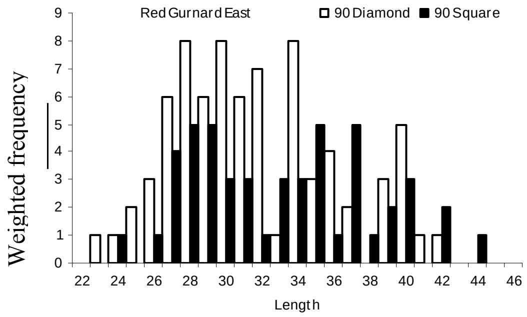
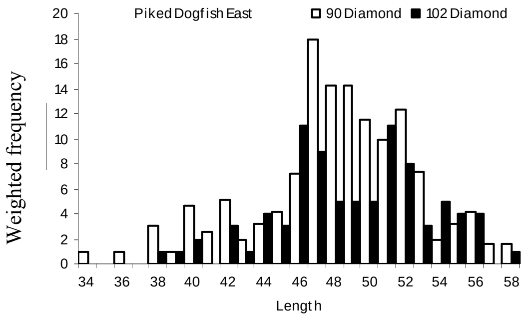
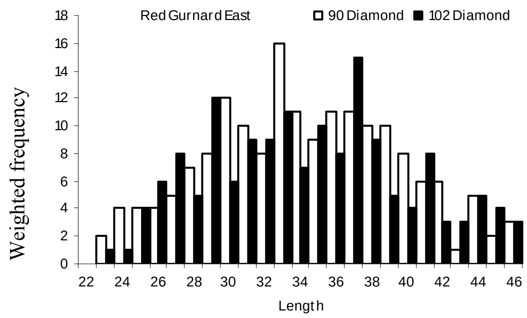
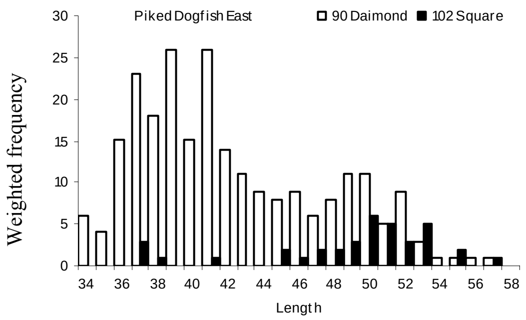
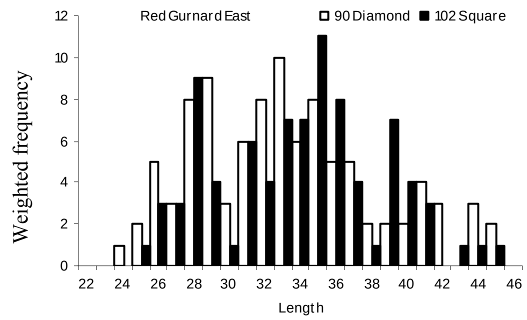
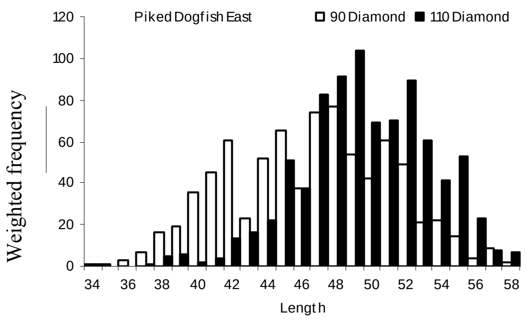
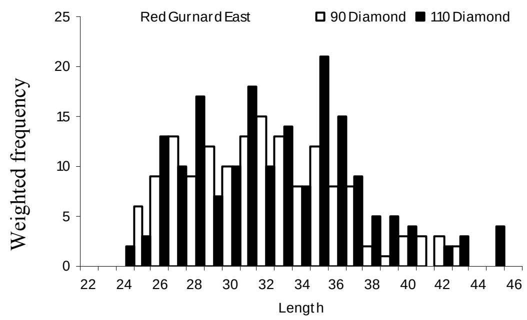
East	Piked Dogfish	Red Gurnard
90 S		
102 D		
102 S		
110 D		

Figure 7-47. Length frequency distributions of piked dogfish and red gurnard caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

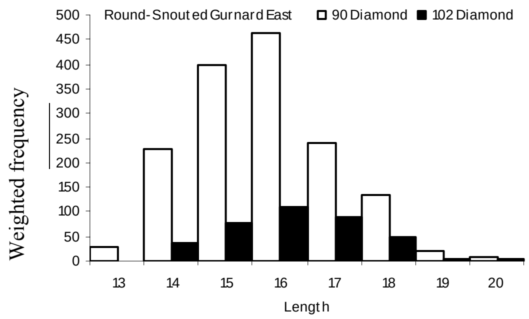
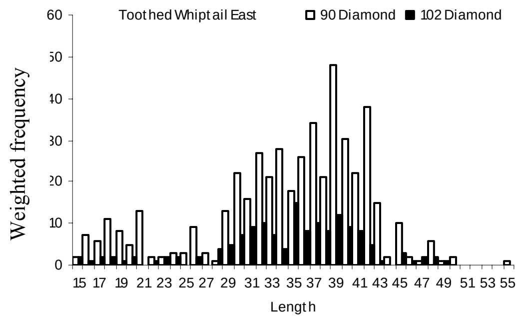
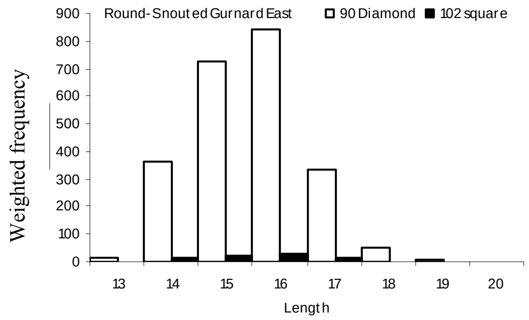
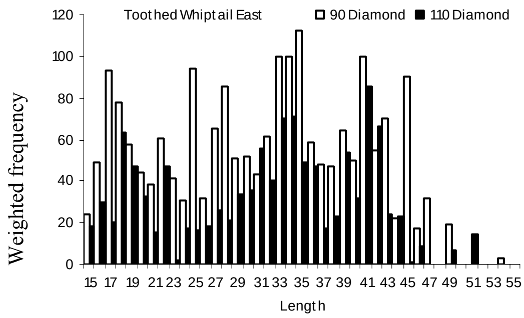
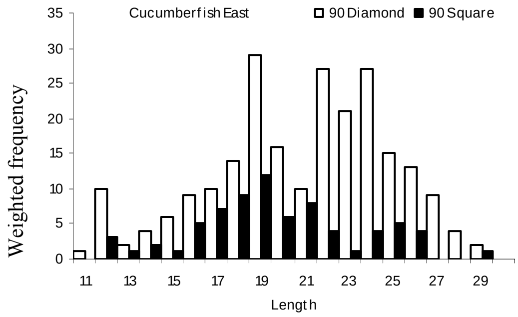
East	Roundsnout Gurnard	Toothed Whiptail
102 D		
102 S		
110 D		

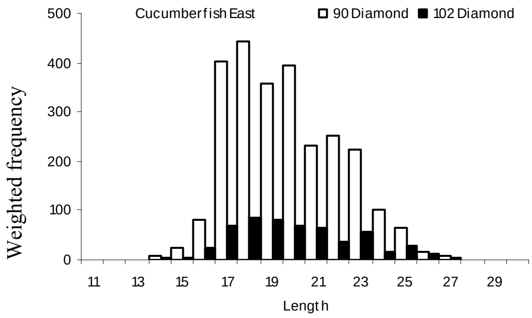
Figure 7-48. Length frequency distributions of roundsnout gurnard and toothed whiptail caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

East Blacktip cucumberfish

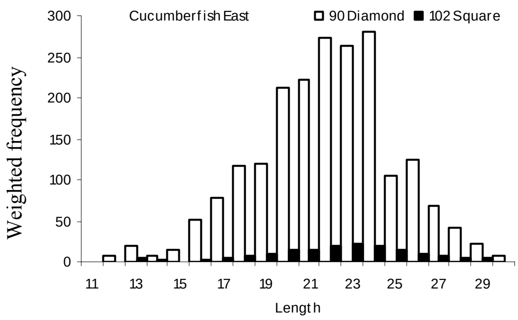
90 S



102 D



102 S



110 D

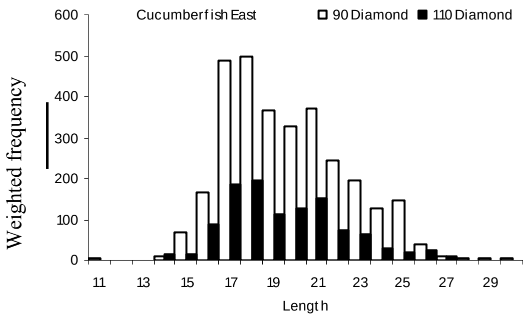


Figure 7-49. Length frequency distributions of blacktip cucumberfish caught in the East in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 90 mm Square-mesh (90 S); 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D).

7.4.3.7 Comparison of length frequency of retained and discarded commercial fish species from the West in standard (90 mm diamond) and test meshes.

The 102 mm diamond condend did not affect the size composition of blue grenadier in the west, however the 102 mm square codend greatly reduced the catch of blue grenadier <63 cm (Figure 7-50). The two 110 mm codends appeared to make no difference to the size composition of blue grenadier, however few small or large fish appear to have been encountered during those trials. The 102 mm square codend appeared to catch more large (>31 cm) blue warehou, while the 110 mm diamond codend caught much less small discards (Figure 7-51). The 110 mm square codend appeared to make little difference to the size composition. All test codends appeared to reduce the catch of small pink ling (<60 cm) and the 110 mm diamond codend also appeared to reduce catches of medium sized pink ling (Figure 7-52). The two 102 mm test codends reduces catches of small (<30 cm), discarded silver warehou (Figure 7-53). The 110 mm square codend increased the catch of large retained and discarded silver warehou.

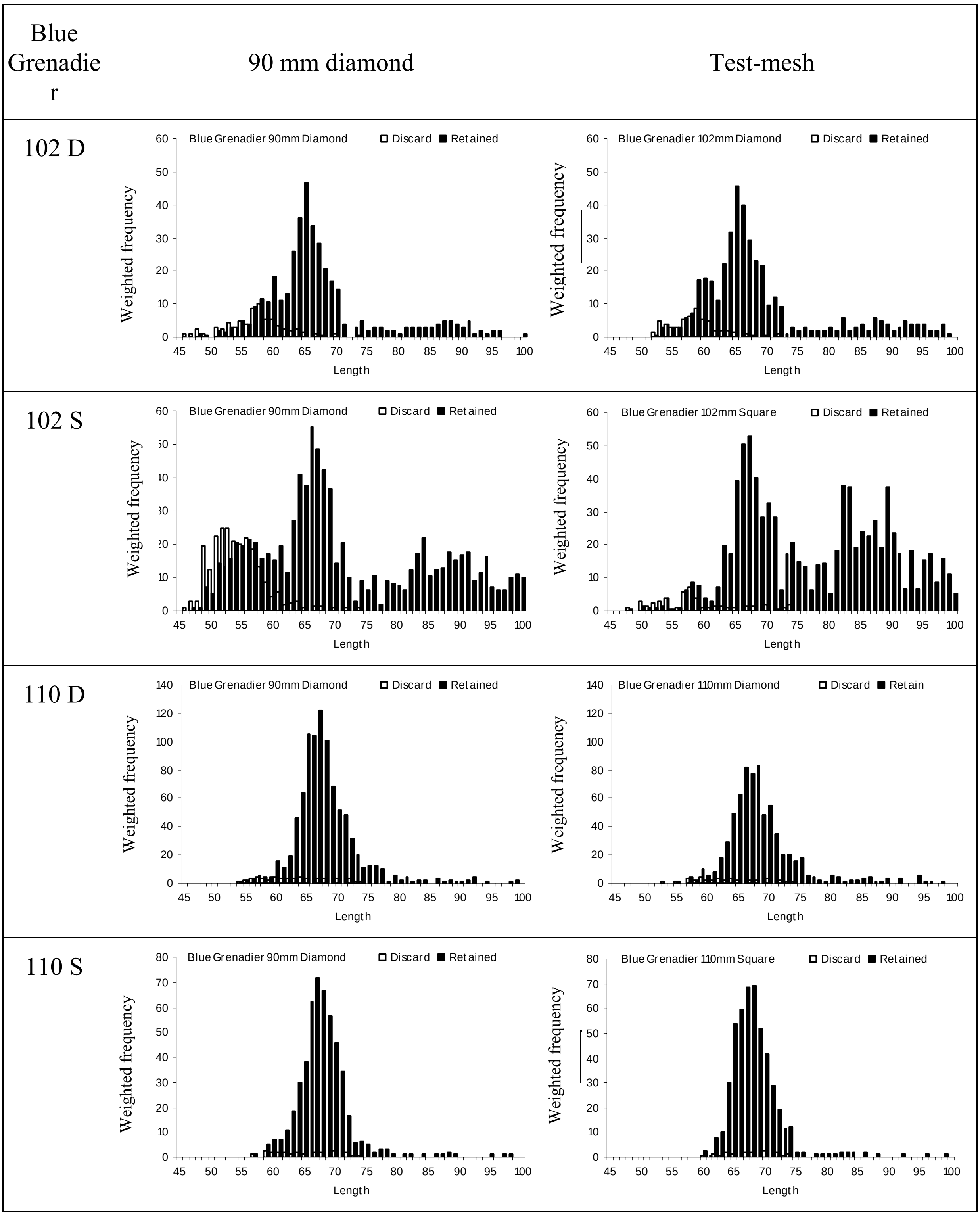


Figure 7-50. Length frequency distributions of retained (■) and discarded (□) blue grenadier caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

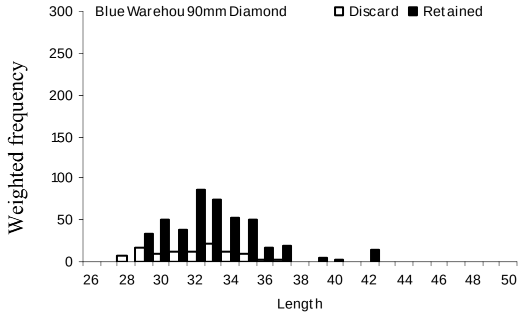
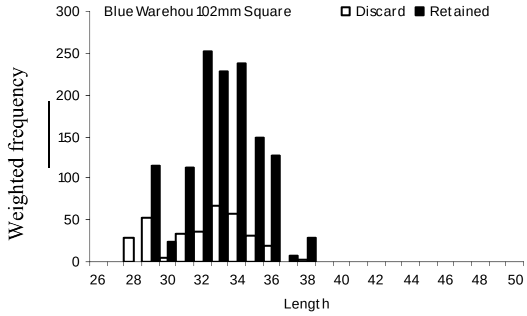
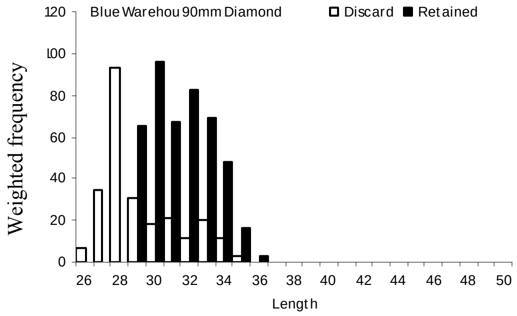
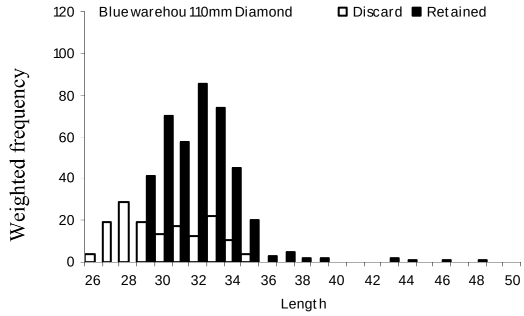
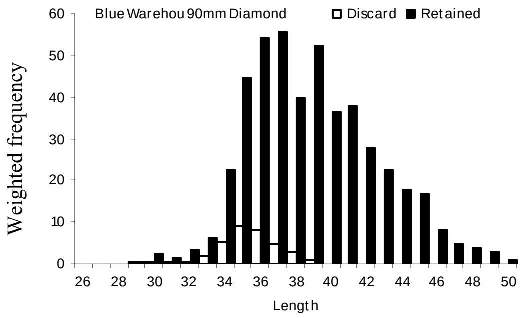
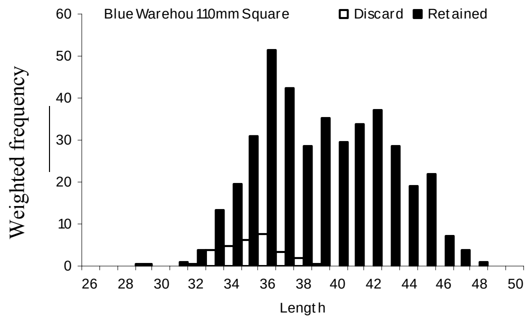
Blue Warehou	90 mm diamond	Test-mesh
102 S		
110 D		
110 S		

Figure 7-51. Length frequency distributions of retained (■) and discarded (□) blue warehou caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

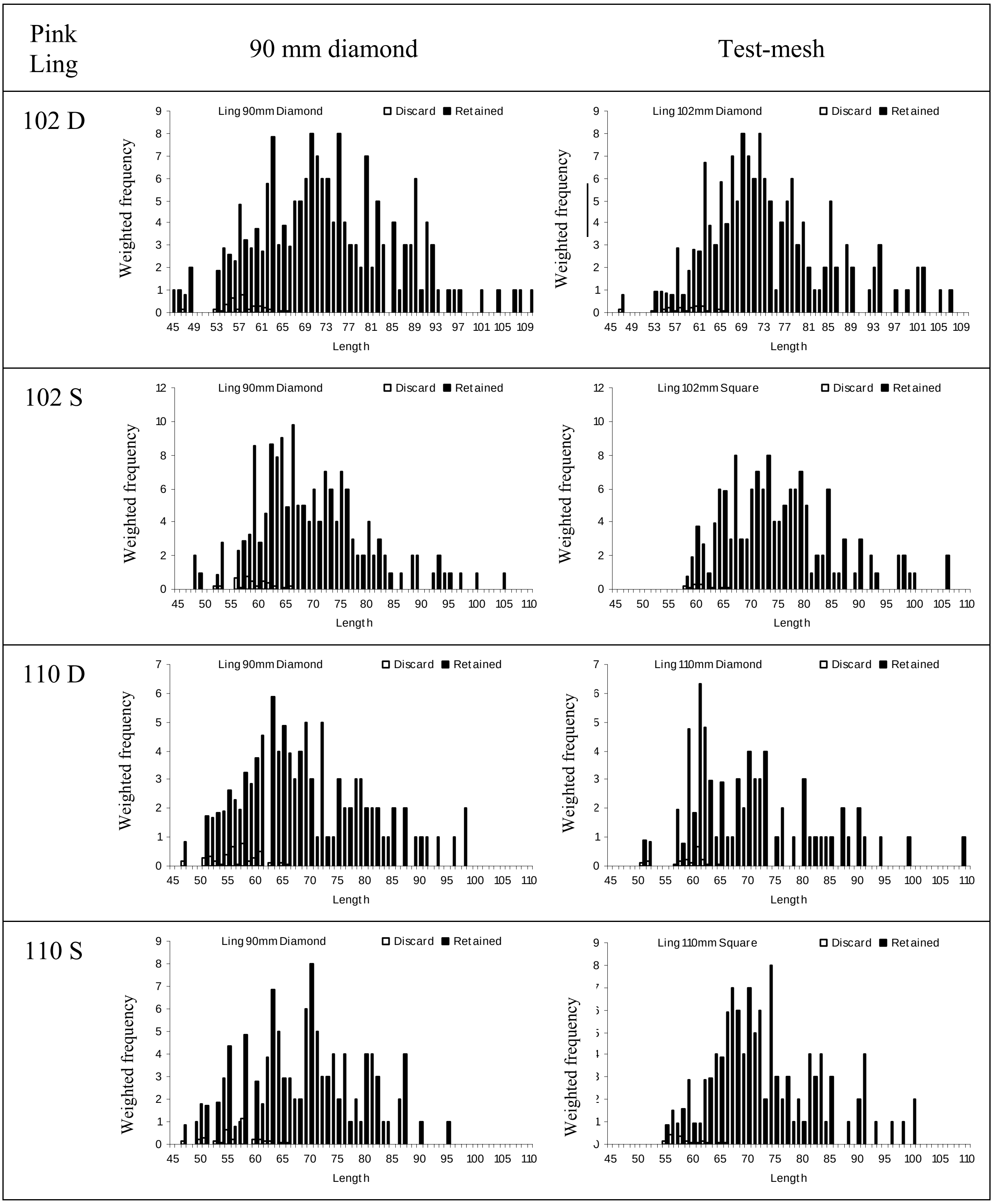


Figure 7-52. Length frequency distributions of retained (■) and discarded (□) pink ling caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

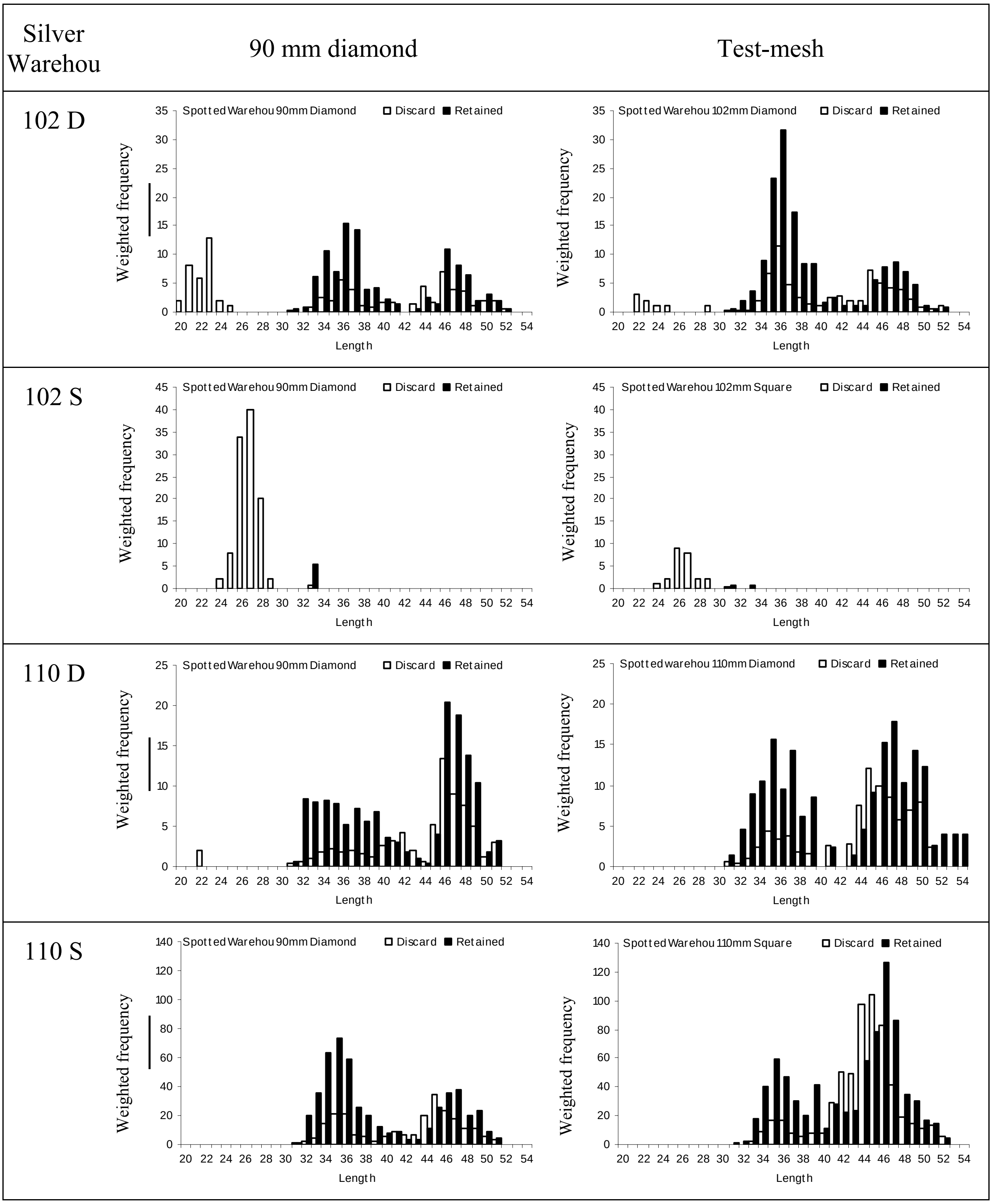


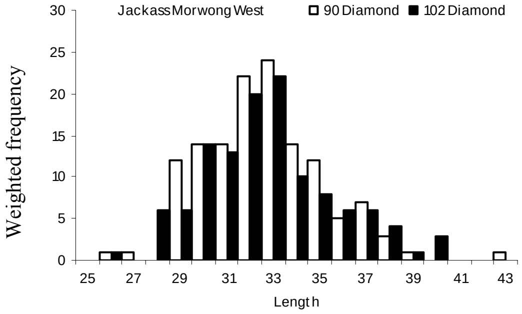
Figure 7-53. Length frequency distributions of retained (■) and discarded (□) silver warehou caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

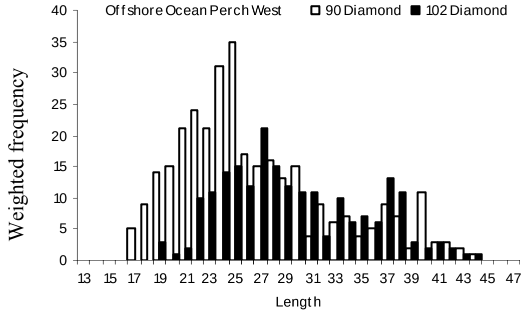
7.4.3.8 Comparison of length frequency of other fish species from the West in standard (90 mm diamond) and test meshes.

None of the test nets in which they were measured made much difference to length the composition of jackass morwong, however the 102 mm, 102 mm square and 110 mm codends caught significantly less small (<29 cm) offshore ocean perch (Figure 7-54). All test nets consistently caught less small (<18 cm) New Zealand dory than the control nets (Figure 7-55). There appeared so be a small reduction in catches of small (<50 cm) piked dogfish in the two diamond test codends, however the two square codends almost totally excluded catches of small piked dogfish (Figure 7-55). Each of the test nets appeared to catch less toothed whiptail across the range of lengths observed with the diamond codend nets having the greatest affect on catches of small fish (<21 cm) (Figure 7-56). Deepwater flathead were only measured in the two 102 mm codends and their control nets, with both test nets showing greatly reduced catches of fish less than 43 cm (Figure 7-56). Catches of blacktip cucumberfish were reduced across all length classes observed in all test nets, and were almost excluded entirely from catches by the 110 mm square codend (Figure 7-57). Only the use of 102 mm square codend made a small difference to the catches of small (<34 cm) latchet (Figure 7-57). The two 102 mm codends reduced the catch of small (<25 cm) Gould's squid, while the 110 mm square codend reduced the catch of Gould's squid almost right across the length distribution observed (Figure 7-58). Catches of small (<13 cm) king dory (*Cyttus traversi*) were reduced in all test nets except the 110 mm square codend, which surprisingly made little difference to the length composition (Figure 7-58).

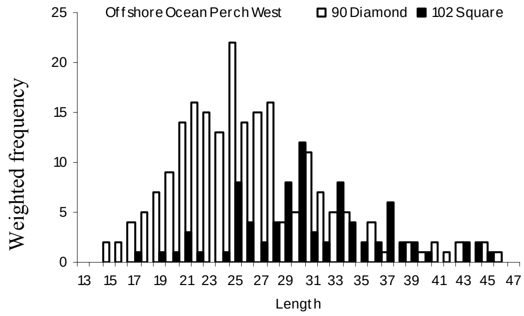
West | Jackass Morwong | Offshore Ocean Perch

102 D

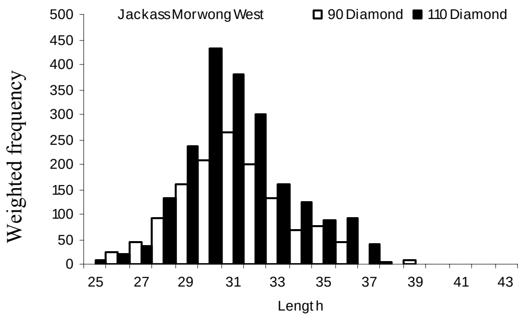




102 S



110 D



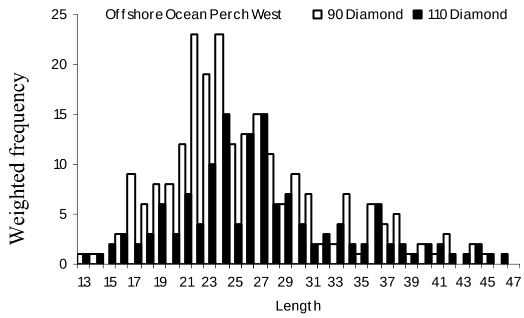


Figure 7-54. Length frequency distributions of jackass morwong and offshore ocean perch caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

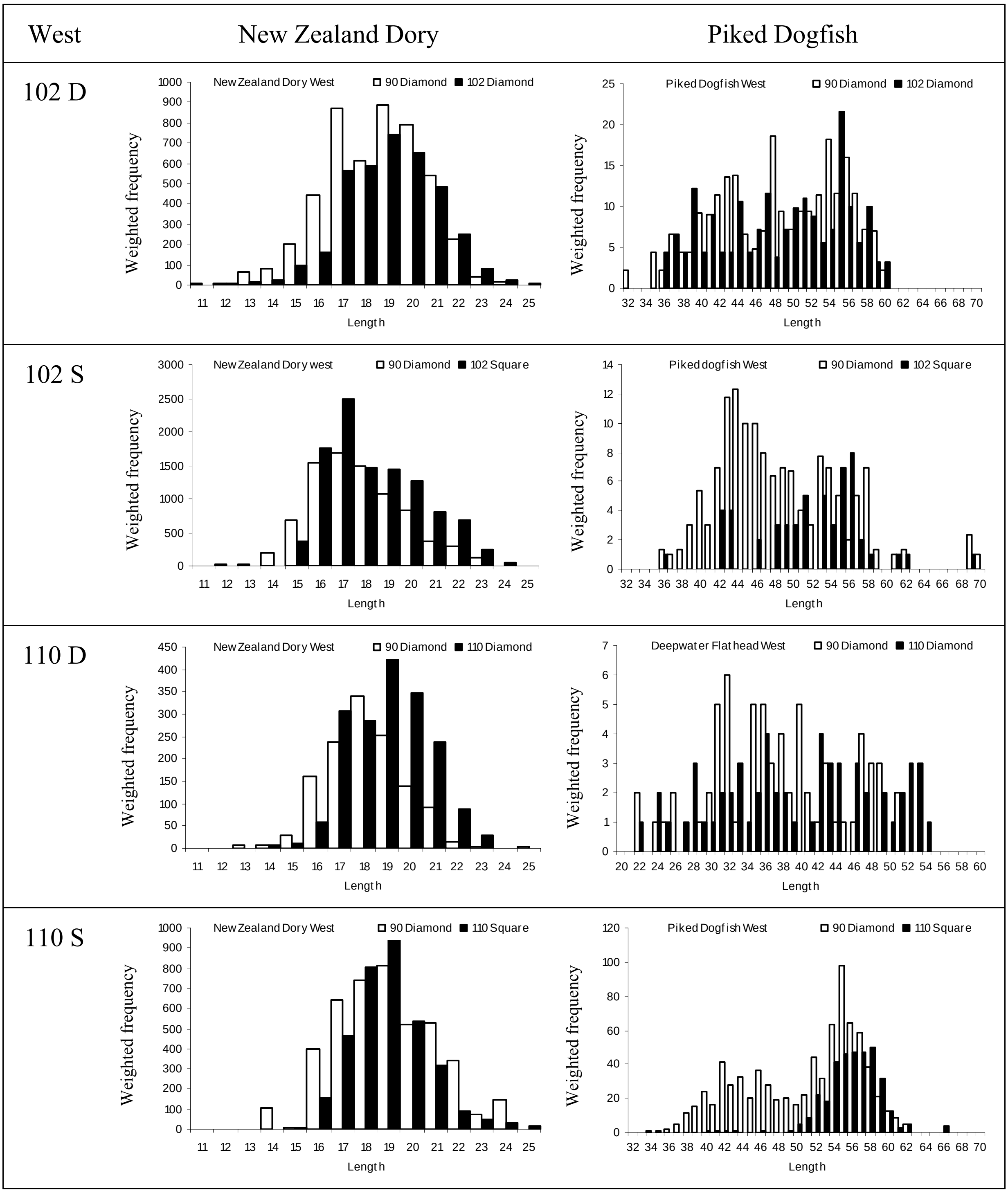
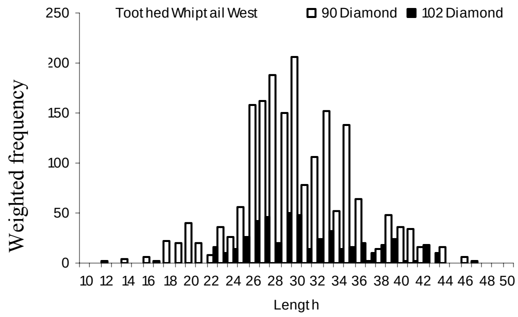
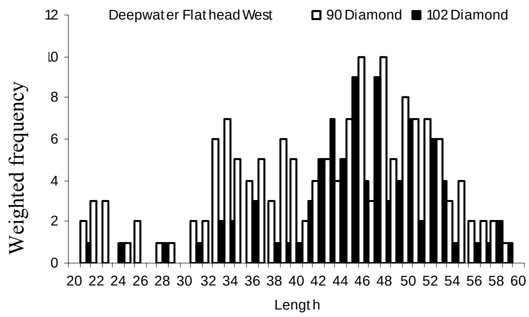


Figure 7-55. Length frequency distributions of New Zealand dory and piked dogfish caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

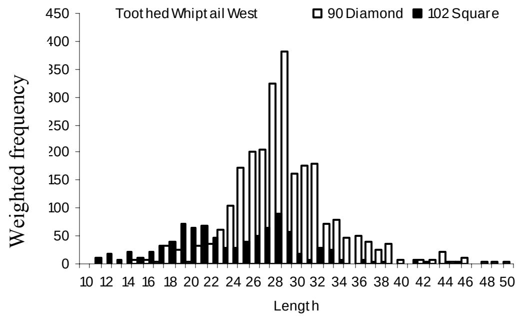
West	Toothed Whiptail	Deepwater Flathead

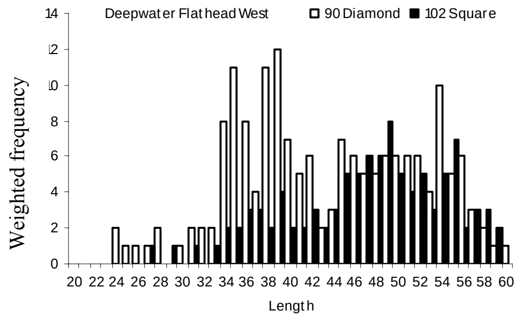
102 D



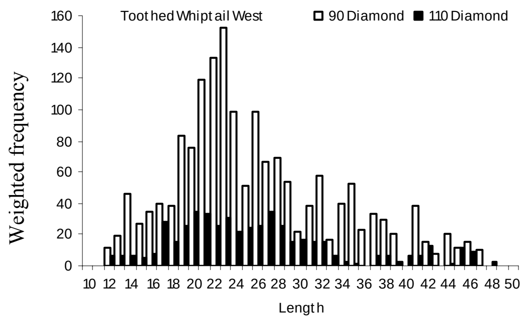


102 S





110 D



110 S

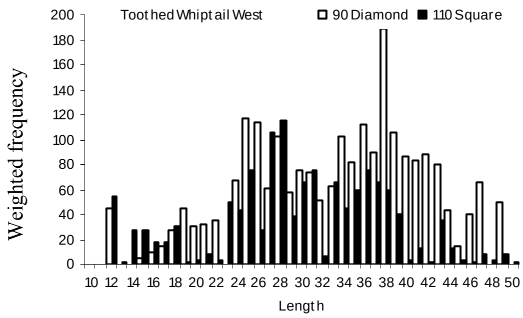


Figure 7-56. Length frequency distributions of toothed whiptail and deepwater flathead caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

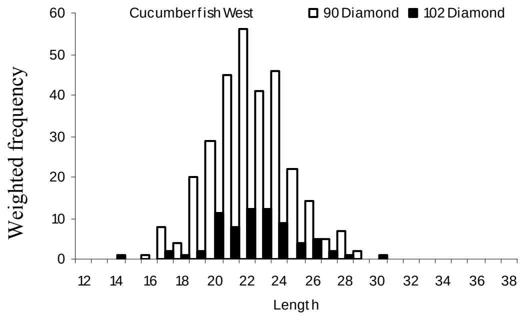
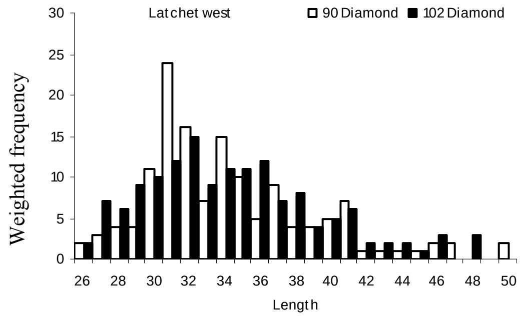
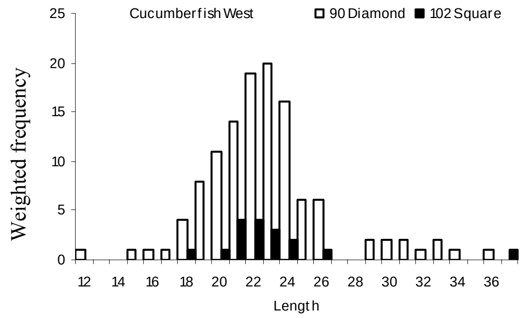
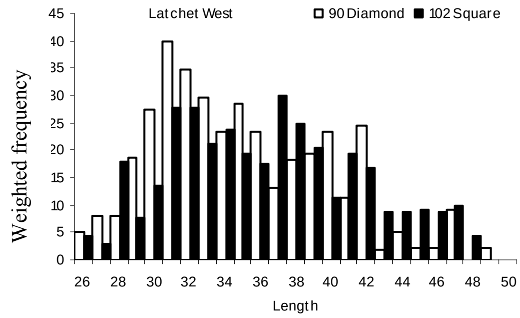
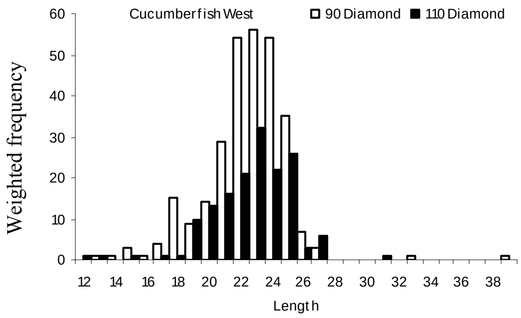
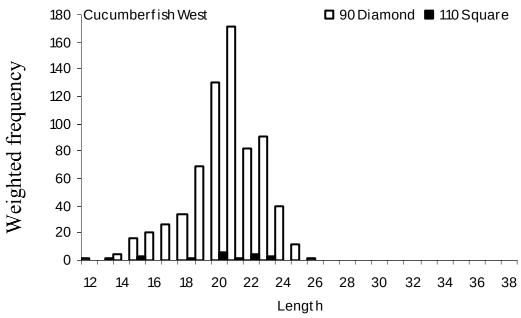
West	Blacktip cucumberfish	Latchet
102 D		
102 S		
110 D		
110 S		

Figure 7-57. Length frequency distributions of blacktip cucumberfish and latchet caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

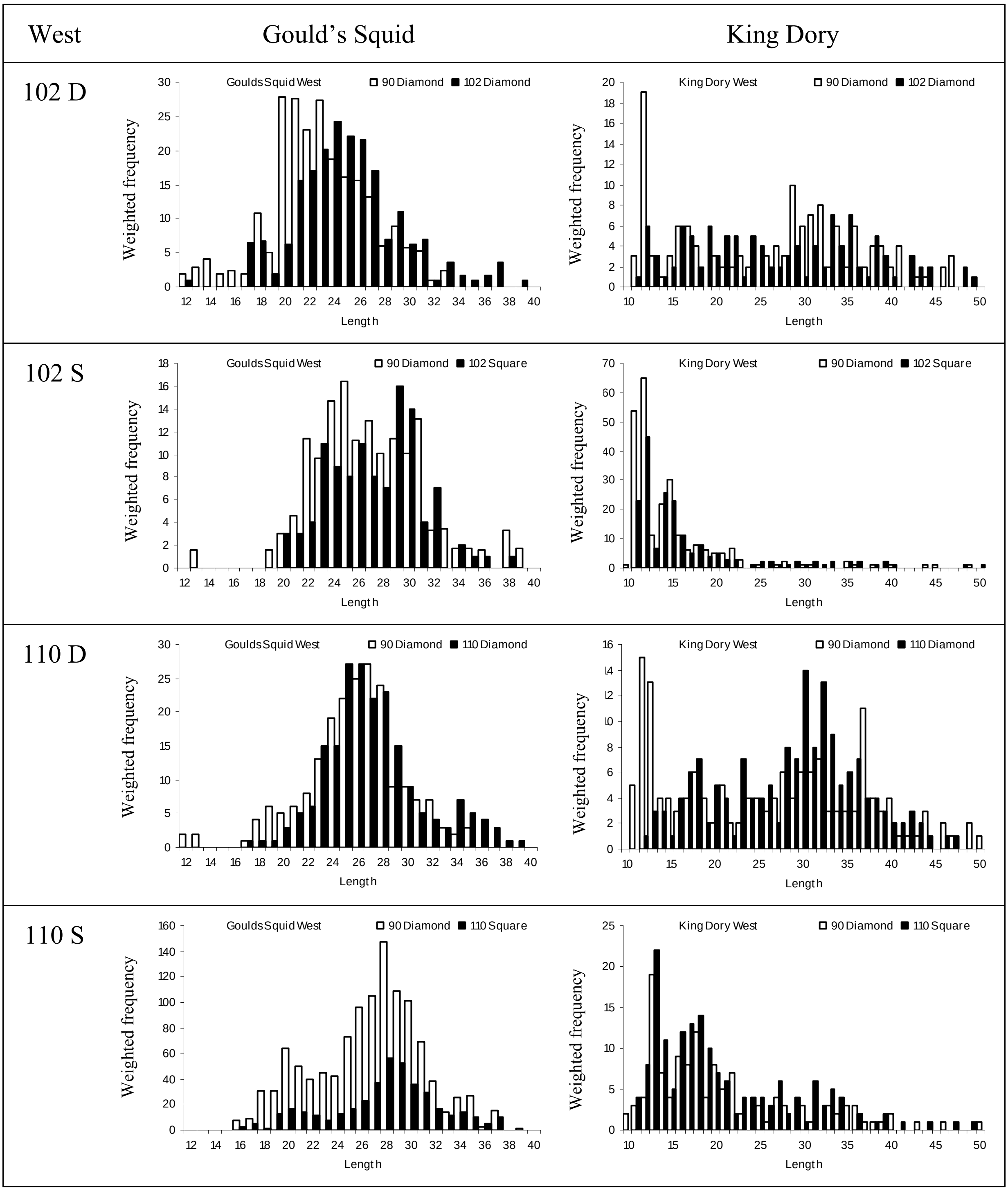


Figure 7-58. Length frequency distributions of Gould's squid and king dory caught in the West in a standard 90 mm diamond-mesh codend compared to test-mesh codends: 102 mm Diamond-mesh (102 D); 102 mm Square-mesh (102 S); and, 110 mm Diamond (110 D); and, 110 mm Square-mesh (110 S).

7.5 DISCUSSION

7.5.1 Flume tank trials

7.5.1.1 Trawl-trouser design and operation

The flume tank tests were done with the maximum water flow available, 1.35 m/sec (2.6 knots), which is close to the normal trawling speed (2.8–3.0 knots) of the chartered trawlers. Visual inspection of the trouser in the tank revealed no apparent design faults although the narrowing of the extension sections at their centres was of concern. To avoid possible problems with blockage, the 33 mesh extensions were reduced to 16 meshes in length, and 20 mesh sections of lighter material (2.5 mm diameter) substituted at the back of the trouser. That no significant differences in flow between the sides of the trouser were detected supported the visual observation that the trouser construction was symmetrical. This suggested that there was no technological difference (as tested statistically) between the sides of the trouser that should cause any bias in catches. The dividing panel was seen to be upright and taught and its operational symmetry was supported by the observation that no fish became meshed in it during any experimental trawling. Wileman *et al*. (1996) suggest that meshing of fish in particular parts of a net may indicate changes in fish behaviour caused by design anomalies in that section. During all trawling, no meshed fish were observed down the tapered sections or extensions of the trouser.

Trawls used throughout the fishery mostly have 100 mesh circumference codends and extensions but it was impractical to fit codends of that capacity to the trouser. The 75 mesh codends (or equivalent) were considered sufficiently large to evaluate the effects of codend modifications. The square-mesh codends for the project were made with greater circumference than that suggested by Robertson (1986). He recommended the ratio of two diamond meshes in the adjoining extension to each bar (mesh) of the square-mesh codend. However, a square-mesh codend with a 38 bar circumference but with similar capacity (volume) to the control codend would need to be about twice the length of the control. This would unbalance the trouser and pose problems when lifting the catch aboard. As a compromise, the project square-mesh codends were made about the same length as the control and with circumferences of 60 bars (90 mm mesh) and 52 bars (102 mm mesh). Although the extra meshes resulted in some peripheral slackness, the flume tank observations (and subsequent video footage during trawling) suggested that fish escapement was unlikely to be greatly hindered.

After the flume tank trials, the arrangement of the trouser rigged to the 40 -mesh body section was maintained as a unit. It proved to be relatively simple and quick to join the 270 mesh front of the trouser-body directly to the equivalent position on the different trawls. The forward V of the dividing panel of the trouser therefore remained permanently rigged to the trouser-body. Similarly, a 16 mesh extension was permanently attached to each of the different codends. When codends were routinely swapped during trawling experiments, the separation and reattachment were done at the joins between the 20 mesh and 16 mesh sections of the extensions instead of at the more complicated joins between the extensions and codends with experimental mesh size and/or shape.

The construction and operation of a trawl-trouser is simpler than for a fully divided trouser trawl. Wileman *et al*. (1996) detail the intricacies in designing and testing a full trouser trawl and point out that great care must be taken with the dimensions of the dividing panel. If too tight, the panel may lift the ground gear, or if too slack, fish behaviour may be affected by billowing. An advantage of a short dividing panel is that to maintain rigidity, it can be put under tension without affecting other parts of the trawl. The panel in the trawl-trouser described in this paper was designed to pull the centre-lines of the top and bottom panels a little inwards, but was positioned sufficiently far back in the net to not affect the shape of the mouth.

7.5.1.2 Flume tank tests

The difference in water flow along each side of the flume tank was unexpected and compromised the interpretation of results. However, the differences in flow were consistent over the four days of the experiments, justifying the correction of data before analyses. Correcting the data by taking the difference between the flow readings with and without the net present in the tank gave an unbiased measure of the effect of the net, for each net and each location. Not to make these corrections would have been equivalent to treating the underlying flow differences as though they were random, and this would have greatly reduced the sensitivity of the experiment.

As care was taken to construct this trouser symmetrically, it was no surprise that the flume tank tests demonstrated that the flow was, in fact, similar down each side of the trouser when it was rigged with identical codends. The finding of no significant differences in flow when the experimental codends were attached was less predictable. During flume tank experiments with prawn-trawl codends, Broadhurst *et al*. (1999a) found that the extent of forward displacement of water (expressed as reduction in flow) varied with codend construction, and with the amount of (simulated) catch in the codend. In these experiments, it is possible that the effects of the weights in the codends (wrapped netting tied to hoops) were sufficient to mask any small change in flow due to differences in codend mesh. These weights provided stability to the codends during the experiments, but also were a major influence on flow through the back half of the trouser. Their effect on flow was measurable as far forward as location D, a distance of 6.5 m from the back of the codends. This strongly suggests that if unequal quantities of fish accumulate in the codends during trawling, it is likely that there would be unequal changes in flow through the two sides of the trouser that may be detected by fish some distance forward of the codends. Although the sensitivity and reaction of fish to very small differences in water flow is unknown, it is possible that any differences could influence fish moving towards the codends.

The main perceived difficulty with the trouser-trawl method for measuring mesh selectivity is the problem of ensuring a similar flow of water through both legs of the trouser (Pope *et al*. 1975). This is a systemic problem as codends of differing mesh size and/or shape are unlikely to have identical flow characteristics. The effect of any differences on fish behaviour in codends is difficult to quantify, and it is possible that some small differences in flow not detected in these experiments, or differences that were not statistically significant, do in fact have some impact on the senses of fish. However, the effects of any differences in flow from codends of different mesh size or shape are probably minimised in large trawls where the codends are separated from the area dividing the front of the trouser by relatively long trouser-legs and extension sections.

7.5.1.3 Fishing trials

A trawl-trouser was used for comparative codend selectivity trials because it was the most suitable method to achieve the aims of this project. Trouser trawls are frequently used to test the mesh selectivity of codends with different mesh sizes or shapes (eg. Walsh *et al.* 1992), or to test the effectiveness of bycatch reduction devices (Broadhurst and Kennelly 1995b). The trouser trawl is designed to have similar numbers and sizes of fish enter each of the codends. However, unequal catches in the two codends can occur and the assumption of equal split probability may not be satisfied (Millar and Walsh 1992). To address this problem, corrective procedures for analysing selectivity data from trouser trawl experiments have been developed (e.g. Cadigan *et al.* 1996; Millar and Walsh 1992).

A trouser that could be easily attached to a number of different nets was designed and constructed. Its portability gave the project operational flexibility in that the trouser could be transferred from net to net, not only on the one vessel but also between vessels in different ports. The flume tank observations and flow experiments confirmed the design symmetry of the trawl-trouser but did not reveal the cause unequal split of catches that consistently biased towards one side of the trouser. A video camera mounted in various positions in the net failed to show any twisting, blockage or lack of symmetry. The bias in the catch to one side of the trouser was effectively rectified by a relatively minor change to the rig which reduced the differences between the codends to within normal experimental variability. This was achieved by joining the legs and extension sections of the trouser based on the experience of the fishers involved in the project. They believed that the back-end of a normal trawl frequently twists when a long extension section is inserted in front of the codend. The legs and extension sections of the trouser were therefore laced together in an effort to minimise any independent movement of each leg, and to generally increase the stability of the trouser during trawling.

With the trouser-legs laced together, catches between the two codends were more evenly split and any differences were within the bounds of experimental variability. This arrangement of the trouser was subsequently retained for all testing of experimental codends, and to further mitigate any bias in the data, the codends were routinely swapped between the trouser legs.

The highly variable catch rates and inconsistent species composition among the catches complicated the analyses of the catch data. However, a breakdown of the commercial teleost catches suggested that the benthopelagic species were the main contributors to the initial uneven catch split. These species were grouped for analysis because they were all relatively large and/or strong swimmers. Some footage from the video camera mounted in front of the openings to the trouser showed gemfish swimming back out of one side of the trouser and then entering the other side during trawling. This indicates that these species have the ability to actively move from one side to the other, but any impediment that may have stimulated their movement out of one side of the trouser was beyond the range of the camera. Pink ling, dories, and benthic teleosts were more evenly split between the codends; these are generally more sedentary fish which mostly swim in short bursts and probably are incapable of sustaining sufficient swimming activity to move from one codend to the other.

The use of a trouser trawl is frequently the most economic and practical method for assessing codend modifications or bycatch reduction devices. However, our experience demonstrated that the design and operation of similar trawls for gear modification experiments should first be carefully checked for balanced distribution of catches into the codends. Some variability in catches between the codends of a trouser trawl is to be expected, but if codends are regularly swapped between the sides of the trouser, and appropriate analytical methods used, perceived drawbacks with trouser trawl data are usually less than for alternative methods.

7.5.2 At sea experiments

7.5.2.1 Market selectivity ogives for quota species based on ISMP data

Although they may occur at the same time, there are generally two levels of sorting that occur once fish are landed on the deck of a trawler. Species that have no commercial value are sorted out and discarded. Species that usually have some potential commercial value are also sorted based on the skipper's (or crew's) best judgement on what fish will return a profit if retained. This can be influenced by a variety of factors on the day including market prices, quantities being landed, quality and size (length) of fish (Liggins and Knuckey 1999). For quota species, retention can also be influenced by quota availability and/or quota lease price. This sorting occurs subsequent to any selectivity that may occur in the trawl net during fishing. Some species have such high market value that they are usually always retained if quota is available (e.g. blue-eye trevalla or gummy shark (*Mustelus antarcticus*)). For many commercial species, however, small fish may be discarded because they have little commercial value. This onboard commercial sorting or "market selectivity" has been well captured by the onboard observers of the ISMP. For most of the species, there is a reasonably tight size range (5–10 cm) in which they change from being fully discarded to fully retained e.g. John dory (Figure 7-10B), offshore ocean perch (Figure 7-11B), jackass morwong (Figure 7-11C) and pink ling (Figure 7-12A). For a few species, the size range over which they may be either retained or discarded is very broad e.g. mirror dory (Figure 7-11A), blue grenadier (Figure 7-12B), gemfish (Figure 7-12C), and blue warehou (Figure 7-13B). It should be emphasised that these figures represent the market selectivity "on average" and are pooled over vessels, seasons and areas. On any particular vessel in a certain season and area, however, there might be a quite precisely defined size at which fish is retained.

The importance of understanding the market selectivity of fish is that with respect to fish size (length), discarding of commercial species mainly occurs when the selectivity of the gear is such that it catches smaller fish than would normally be retained for the market. Put another way, size-related discarding of commercial species will be minimised when gear selectivity retains the same size fish determined by the market selectivity. This project has demonstrated that there a numerous commercial species for which the gear selectivity could be improved to catch fish that are more suitable for retention for the market. A good example of this is redfish. The gear selectivity of 90 mm diamond mesh is such that 50% retention occurs at about 13 cm (Figure 5-12) whereas the market selectivity is such that 50% retention occurs at 17 cm (Figure 7-10A). This mismatch in gear and market selectivity determines that a lot of small redfish (<17 cm) will be discarded.

7.5.2.2 Commercial and non-commercial discarded and retained fish in standard (90 mm diamond) and test meshes.

The influence of changing codend mesh type on catch composition is highlighted in this report. Compared to the standard 90 mm diamond codend, the square mesh codends and larger diamond mesh codends showed a general improvement by reducing discards, however the reduction in discards sometimes came the cost of total commercial catches. It is also realised that given the multispecies nature of this fishery, and the large geographical scale over which it operates, that the observed differences in catches between mesh types vary with area and depth fished. For example, the 102 mm square codend significantly reduced the number of non-commercial discard, commercial discard and commercial retained fish caught in shallow water off Bermagui (Figure 7-15), and all groups except commercial discards in deep water off Bermagui (Figure 7-14), but made no significant difference in shallow water off Portland (Figure 7-17), and reduced the number of non-commercial discards and the weight of commercial discards in deep water off Portland (Figure 7-16).

The orientation of mesh on a net greatly influences the size of the opening available for escape (Robertson and Stewart 1988). Under the weight of the catch, trawl nets are pulled tight, elongating the diamond mesh so that its lateral width is about 15% – 30% of the stretched mesh length (Broadhurst *et al*. 1999b; Broadhurst *et al*. 2006a; Robertson 1986). This may reduce the opportunity of escape for fish, except those that are dorsally compressed such as flatheads. In a direct comparison of 90 mm square mesh against 90 mm diamond mesh in deep water off Bermagui, the square mesh codend caught 31% less non-commercial discards by weight, and 57% less by number (Table 7-11). Surprisingly, captures of tiger flathead were also reduced by about 25% in the square codend (Figure 7-28), however modelling the influence of modified codends in deepwater off Portland showed that even the 102 mm square mesh codend would not reduce discarding of deepwater flathead (Figure 8-4).

The 102 mm square codend actually caught a significantly greater weight of commercial retained fish than the control net in deep water off Bermagui (Figure 7-14). The main retained commercial species impacted were pink ling, Gould's squid and offshore ocean perch (Figure 7-26 and Figure 7-27). Pink ling were largely retained over the entire range of lengths observed, but the impact of increasing mesh size in the codend was seen mostly in fish less than 60 cm length, particularly in the 102 mm square and 110 mm diamond codends (Figure 7-42). A decrease in catches of small (<23 cm) offshore ocean perch was observed, however, as with pink ling, the 102 mm square and 110 mm diamond codends also reduced catches across the entire length composition (Figure 7-40). Investigation of the use of square mesh panels (as opposed to the entire codend comprising of square mesh), could be useful in removing some of the unwanted catch, while retaining more commercially valuable species (e.g. Armstrong *et al.* 1998). Despite reduced catches of small discarded species such as offshore ocean perch, there was no overall difference in the catch of the commercial discards group as a whole by the larger two nets because the both caught more discarded mirror dory than the control net (Figure 7-27). Examination of the length frequency distribution of that species in the test and control nets show that they are very similar (Figure 7-43). The greatest reduction in catches of non-commercial discard species was observed for blacktip cucumberfish, threespined cardinalfish, common sawbelly and various whiptail species (Figure 7-18, Figure 7-19 and Figure 7-20).

The test codends had less impact on the retained catch of commercial retained species in shallow water off Bermagui than in deeper water, but more impact on catches of commercial discard species. The 102 mm diamond, 102 mm square and 110 mm diamond codends all reduced the weight and number of non-commercial and commercial discards, but only the largest of those nets reduced the weight of commercial retained catches. Non-commercial species reduced by the test codends included blacktip cucumberfish, grooved gurnard and common bellowsfish (Figure 7-21). Test codends reduced the both retained and discarded catches of the commercially important tiger flathead and redfish (Figure 7-28 and Figure 7-29). Reductions in catches were observed across a large range in size classes of fish in the three larger codends, but were particularly evident for smaller fish of each species (Figure 7-37 and Figure 7-41). Broadhurst and Kennelly (1995a) also observed a large reduction in catches of both retained and discarded tiger flathead on 100 mm diamond mesh compared to the 90 mm diamond control net, and found that catches were reduced across the length frequency distribution. They concluded that changing mesh size might not be an effective technique for excluding a maximum number of undersize individuals for that species. Catches of the largely discarded inshore ocean perch were also reduced over a wide size range by the test codends (Figure 7-38). The larger the codend mesh size, the larger the decrease in commercial retained catches, and the greater the number of retained species affected.

Test nets were effective at reducing either the weight or number of non-commercial and commercial discards, while having little impact on catches of commercial retained species in deep water off Portland (Figure 7-16). As in deep water off Bermagui, catches of blacktip cucumberfish, threespine cardinalfish, and various whiptails were among the non-commercial species most reduced using the test codends (Figure 7-22 and Figure 7-23). Captures of blacktip cucumberfish and toothed whiptail were reduced across all size classes observed (Figure 7-56 and Figure 7-57). Reduced catches of discarded gemfish and blue grenadier were the main species contributing to the drop in commercial discards (Figure 7-32, Figure 7-33 and Figure 7-34). The reduction in catches of discarded blue grenadier was mostly of small fish (<60 cm) by the 102 mm square codend. The two larger nets or their respective controls did not catch enough fish in that size range to enable comparison, however, the 110 mm diamond codend appeared to reduced catches across the size distribution encountered (Figure 7-50).

Catches of non-commercial discards were inconsistent in shallow water off Portland, with there being little or no difference in catches by the 102 mm square and 110 mm diamond codends, but significantly less in the two other test nets (Figure 7-17). In the two 102 mm codends, catches in the non-commercial discard group were dominated by New Zealand dory, with the 102 mm diamond codend catching less New Zealand dory that the control, and the 102 mm square codend catching less than the control (Figure 7-24). This was consistent with deepwater shots off Portland (Figure 7-22), and appears to have been a result of the 102 mm diamond codend catching more small (<18 cm) fish, and the 102 mm square codend catching more large (>18 cm) fish. Given the compressed, but deep bodied profile of this species, it is possible that they have a higher chance of escaping the diamond mesh because it is stretched to a greater width than the square mesh, and if on hitting the net they turn horizontally, they can escape over a greater size range. No differences were observed in catches of commercial discard species, however, overall these were low. The 110 mm square codend was the only test net that caught significantly less commercially retained fish than the control off Portland by weight (Figure 7-17).

8 MODELING THE EFFECTS OF MODIFIED CODEND

8.1 INTRODUCTION

It is apparent from the previous chapter that any increase in codend mesh size, or change in mesh configuration to reduce the bycatch of small fish will result in some loss of commercial species and therefore an immediate loss in revenue. It is necessary, however, to balance this immediate loss against potential future gains from yield or biomass increases in commercial stocks, if we are to properly understand this trade-off. Quantitative exploration of this trade-off is the focus of this chapter.

The standard fishing mesh used in the CTS is 90 mm double braid diamond mesh. We calculate the size range of fish that this gear catches for each of the major target species in the CTS. For each species considered, we initially used the known annual tonnages caught, known size- and age-distributions of this catch, and known biological parameters (e.g. growth curves) to calculate the stock size and depletion (stock size in 2003 relative to that in 1986) for each species. This amounts to a generic stock assessment for every species. We attempted to stabilise the assessments by constraining the model estimate depletion to lie between 20% and 40% of pristine — a reasonable assumption for a CTS species. We also constrained the median estimated discard proportion to be similar to that estimated by the ISMP. When a quantitative stock assessment is done for a single species, more careful consideration is given to tailoring the model for that species than was done here. Like all stock assessments the results, particularly the estimated stock size, may be wrong, and our biomass estimates were clearly in error.

We then adopted a much simpler approach in which we assumed that each stock was in deterministic equilibrium, given a particular fixed fishing mortality rate. We used expert opinion (A.D.M. Smith, CSIRO, *pers comm.*) to provide estimates of available biomass for each stock, and stock depletion informed from more detailed stock assessments. These figures were used to calculate a constant recruitment size and the value of the constant fishing mortality rate. The stock was then projected into the future, assuming this same fishing mortality rate, using different fishing gear selectivity curves (the 90 mm diamond standard, 102 mm diamond, 110 mm diamond, 90 mm square, 102 mm square or 110 mm square codends). In our previous, more elaborate model, some allowance had to be made for lower availability of some age classes to the fishery. It was clear from the age structure of the catches compared with that predicted when applying the standard gear's selectivity curve that some younger age classes of some species were not fully available to the gear. The availability of these age classes was estimated as a parameter of the model. These estimates were assumed to be correct and were applied within the simpler model.

The objective of this modelling is not to predict future yields, and it is acknowledged that fishing effort and fish recruitment are likely to change. Instead, we look to compare our estimates of future yield, economic value, discarding and stock size of a hypothetical fishery that continues to use 90 mm diamond codend with other hypothetical fisheries that use each of the alternative meshes. This allows us to see how much these change immediately after the fishery adopts a new mesh, and how long it takes to realise any benefits.

8.2 MATERIALS AND METHODS

8.2.1 Calculating gear selectivities from trouser trawl data

Data collected in the trouser trawl experiments (Chapter 7) were used to calculate the selectivity curve for each of the modified gears for each of a range of species. The assumption is made that the same numbers of fish in each length category were available to both sides of the trouser trawl. The selectivity for the control gear (the 90 mm diamond mesh) is assumed to be known from the covered codend experiment. Any difference between the number of fish from a given length class caught in each half of the trawl is assumed to be due to differences in gear selectivity and random noise only. The number of fish of a particular species that are caught by the control gear, belonging to a given length class *l* is:

$$C_l^{cont} = q^{cont} N_l^{pop} S_l^{cont} \qquad (1)$$

where C_l^{cont} is the number of fish (of the given species) belonging to length class *l* that were caught by the control gear,

q^{cont} is a constant of proportionality describing the "catchability" of the given species to the control gear,

N_l^{pop} is the number of fish belonging to length class *l* that were presented to the gear, and

S_l^{cont} is the gear selectivity of the control gear for fish in length class *l*.

Similarly, for the modified gear

$$C_l^{\text{mod}} = q^{\text{mod}} N_l^{pop} S_l^{\text{mod}} \qquad (2)$$

where “mod” refers to the modified gear and “cont” to the control gear.

Solving equation (1) for N_l^{pop} , and substituting this into equation (2) gives:

$$C_l^{\text{mod}} = q \left(C_l^{cont} / S_l^{cont} \right) S_l^{\text{mod}} \qquad (3)$$

Where $q = q^{\text{mod}} / q^{cont}$. You would expect *q* to be close to 1.0, unless there was a bias causing fish to enter the trawl leg containing one or the other gear. Any consistent bias in water movement, to the right for example, should have been cancelled by the regular switching of the gears. The *p* parameter is similar to the *p* used by Millar and Walsh (1992) to describe the probability that a fish would enter one or other leg of the trouser trawl

Equation 3 has two unknowns: *q* and S_l^{mod}. Like the control gear, the modified gear’s selectivity pattern is assumed to be logistic:

$$S_l^x = 1 / \left(1 + \exp\left[S^{1,x} \left(S^{2,x} - l \right) \right] \right) \quad (4)$$

where S_l^x is the selectivity for gear *x* and length class *l* for a given species,

$S^{1,x}$ is the slope parameter for gear *x*, and

$S^{2,x}$ is the length-at-50%-selectivity for gear *x*.

There is no reason to believe that the slope parameter (S^1) differs among diamond gears, so the parameter calculated for the control gear (diamond) is used for the 102 mm and 110 mm diamond gears. Similarly, all three square gears are assumed to share a single S^1 value. The tapered 90 mm diamond gear is allowed a unique S^1 value. Every mesh has a unique S^2 and *q* value. Note that there ought to be a subscript for species in all the equations shown above. For each species up to eight parameters are estimated: a *q* and an S^2 for each of the six modified gears, a single S^1 for the square gears, and an S^1 for the tapered diamond gear.

Excel solver was used to find the parameter values that minimised the sum of the squared differences between the observed and expected C_l^{mod} values. Note that when, for example, the parameters of the 102 mm diamond gear were estimated, the observed catch data (C_l^{cont} and C_l^{mod}) were pooled across only those tows where the control gear and the 102 mm diamond gear were used together.

8.2.2 Model design

From Murawski (1984), Sainsbury (1984), Pikitch (1987), Gribble and Dredge (1994), and Quinn and Deriso (1999), for a single species, yield-per-recruit (y):

$$y = \sum_{t=1}^{t=T} \left[Q_t W_t N_t (1 - e^{-(FS_t + M)}) \frac{FS_t}{FS_t + M} \right] \quad (1)$$

where t is age, T is maximum age, Qt is market selectivity at age t, Wt is weight at age t, Nt is number at age t, F is full-recruitment fishing mortality, St is selectivity at age t, and M is natural mortality. Wt is computed from mean length of fish aged t and the length and weight relationship:

$$L_t = L_\infty (1 - e^{-k(t - t_0)}) \quad (2)$$

and

$$W_t = aL_t^b \quad (3)$$

Number at age t (Nt) is:

$$N_t = N_{t-1} e^{-(FS_t + M)} \quad (4)$$

F is computed from

$$F = Eq \quad (5)$$

where E is fishing effort (hour of trawling), and q is catchability coefficient. Selectivity (St) is assumed to have logistics curve:

$$S_t = \frac{1}{1 + e^{s_1 (s_2 - L_t)}} \quad (6)$$

where s_1 and s_2 are selectivity parameters with $s_2 = L_{50}$ which indicates that 50% of fish are selected by the gear.

Value-per-recruit (v) is incorporated into the model with age specific price per unit of weight,

$$v = \sum_{t=1}^{t=T} (p_t y_t) \quad (7)$$

where pt = price in dollars for fish aged t. It is often that the market price is based on length instead of age. The mean length of fish aged t needs to be calculated from the length-at-age function.

For multiple species, yield-per-recruit (Y):

$$Y = \frac{\sum_{i=1}^{i=NS} R_i y_i}{\sum_{i=1}^{i=NS} R_i} \qquad (8)$$

where i is species, NS is total number of species, and Ri is relative recruitment of species i. Similarly, relative value-per-recruit (V) for multiple species becomes:

$$V = \frac{\sum_{i=1}^{i=NS} R_i v_i}{\sum_{i=1}^{i=NS} R_i} \qquad (9)$$

To compute Y and V, species specific parameters are needed. Biological parameters, such as growth, length-weight relationship, and natural mortality, were obtained from various sources including age-growth studies, field surveys, and stock assessment models. Selectivity curves for each species were obtained as mentioned previously. Fishing effort (E) was calculated from the fishery logbook collected and maintained by the Australia Fishery Management Authority (AFMA). In addition to these parameters, two parameters, relative recruitment (Ri) and catchability coefficient (qi), are also required to compute Y and V. These two parameters are usually not available from field surveys or single-species stock assessment. In this study, we adopted the method used by Allen (1966) and Sainsbury (1984) to estimated Ri and qi using the AFMA logbook data. Details on sources and derivation of all parameters are listed in the following sections and in Table 8-1, Table 8-2, Table 8-3, Table 8-3, and Table 8-5.

For each gear type, Y and V are calculated and compared. The differences in Y and V values between gear types result from different selectivity between gears as all other parameters remain same.

It is likely that the lost yield will occur at present time due to changes from the standard gear (90 mm diamond) to the modified gears, as the later will allow more small fish to escape the nets. To estimate the lost yields, Y and V for the modified gears are calculated using the same methods but with Nt values being those used in calculating the standard gear. Different percentages of yield for the modified gears are then computed as:

$$D_m^y = 100 \frac{y_m - y_s}{y_s} \qquad (10)$$

where m is the modified gear, and s is the standard gear. Different percentages of value (D_m^v) for the modified gears are also computed in the same way.

Those fish that are presently caught by the standard gear but escape the modified gears represent the lost yield at present time, but will become additional future recruitment to the fishery as they grow into catchable sizes. Number of years for those fish to grow into catchable sizes is function of sizes and growth rates of fishes that escape from the standard gear. Assuming only a modified gear is to be used in the future, number of years for the fishery to get current yield Δ_m can be computed by projecting the population into the future with current Nt values.

8.2.3 Estimation of R and q

Parameters R and q are required for computing multiple species yield-per-recruit. These two parameters are estimated from field surveys and independent estimates using other methods, such as stock assessment (Murawski 1984; Gribble and Dredge 1994). Since no such estimates are available for the CTS species, the method developed by Allen (1966) and Sainsbury (1984) was used here. This method uses time series of commercial catch and effort data with known natural mortality (M). It is assumed that the time series is from the inception of the fishery, and that the population has constant natural mortality, catchability coefficient, and annual recruitment, however these assumptions are not well met for CTS species. For example, time series of catch and effort are not from the inception of the fisheries, and we know that annual recruitment fluctuates dramatically for some species such as blue grenadier (e.g. Punt *et al.* 2001). In addition, these species distribute widely over the whole SESSF area and are therefore subject to capture by other fisheries in other areas, and data on bycatch and discards at sea are not regularly reported in AFMA logbooks. These problems are not easily resolved as there is no alternative to estimate R and q at present time.

For a single species, Allen's method states that number of fish at year t (Nt) is:

$$N_t = RK - B_t \qquad (11)$$

where R is recruitment, and

$$K = \frac{1}{1 - \mathrm{e}^{-M}} \qquad (12)$$

where M is natural mortality, and

$$B_t = \sum_{t'=1}^{t'=t-1} C_{t'} e^{-M(t-t')} \qquad (13)$$

where Ct' is catch at year t', and t and t' range from 1 to T, which is total number of years in the time series of catch and effort data. The estimated catch ($\hat{C}$) for any year is $qE\bar{N}$, where E is fishing effort and $\bar{N}$ is the average population size. Again assuming the fishing occur before natural mortality during each year, then

$$\hat{C}_t = qE_t(N_t - 0.5C_t) \qquad (14)$$

By minimize the least squares of difference

$$\sum_{t=1}^{t=T} (\hat{C}_t - C_t)^2 \qquad (15)$$

R and q can be estimated from

$$R = \frac{GQ - PU}{UG - XP} \qquad (16)$$

and

$$q = \frac{GU - XP}{XQ - U^2} \qquad (17)$$

where G,Q,P,U, and X are defined by

$$G = K\sum_{t=1}^{t=T} E_t C_t \qquad (18)$$

$$Q = \sum_{t=1}^{t=T} E_t^2 (B_t + 0.5C_t)^2 \qquad (19)$$

$$P = \sum_{t=1}^{t=T} E_t C_t (B_t + 0.5C_t) \qquad (20)$$

$$U = K\sum_{t=1}^{t=T} E_t^2 (B_t + 0.5C_t) \qquad (21)$$

$$X = K^2 \sum_{t=1}^{t=T} E_t^2 \qquad (22)$$

Time series of catch and effort data were extracted from the AFMA logbooks. Only trawl catches and effort were used in the estimation. Since the logbook only contain catch data in weight (kg), catch data were converted into numbers of catch by dividing catch by mean weight of each species. Mean weight for each species was estimated from field trial data obtained during this project. Time series of catch and effort data were derived for the period of 1986 to 1999. However, estimation of R and q was not successful for some species (e.g. negative R and q values) using all data from 1986 to 1999. Number of years in the time series were then truncated from both ends of the period until a reasonable (positive) estimate of R and q were obtained.

Table 8-4 and Table 8-5 show estimated R and q values, discard probabilities, discard rates, model biomass and independent biomass estimates for the east and the west.

The method described here was unable to estimate credible population sizes for the species considered. However, catch-at-age data were included and this enabled the estimation of discarding- and availability-at-age functions which were used in the subsequent equilibrium method. These estimated values derive from the age-structured data and will not have been greatly influenced by the estimated population size. They are therefore considered reliable enough to be used as described below.

8.2.4 Calculating population parameters

Historical data were used to estimate recruitment (and hence population size), catchability (which relates fishing mortality rate to fishing effort) and, for some species, logistic curves describing discarding-at-age and depth-at-age.

The population was assumed to be in fished equilibrium at the start of 1986, and projected to 2003 with catches (corresponding to the observed effort) removed annually. At the start of 2003 the stock was no longer in equilibrium. Future projections were then performed, assuming that the 2003 effort level remained constant. The control gear (90 mm diamond codend) was used for the historical period as it was the gear used by the commercial fishery at the time. Future projections were performed for each of the six gear types considered here (including the control gear).

The intention was not to undertake a full stock assessment. In particular, we had no interest in calculating annual recruitment strength. We attempted to calculate average recruitment for each species so that the forward projections for each could be combined to give an overall picture of how a fishery-wide change to a new mesh size might affect catches and the value of the catch for all species combined.

The modelling described below was applied separately for each species considered. All of the parameters and data sources listed ought to include a subscript for species, but these are omitted.

8.2.4.1 First year

At the start of 1986 it was assumed that the population was in fished equilibrium and that the 1986 effort level had been held steady in previous years:

$$N_{1986,a} = R\exp\left[-M(a-1)-F_{1986}\right] \qquad 1 \le a \le x \qquad (5)$$

where $N_{1986,a}$ is the number of fish of age a in the population at the start of 1986,

R is the number of fish of age 1 (an estimated parameter),

M is instantaneous natural mortality rate,

F_{1986} is instantaneous fishing mortality rate,

and x is the maximum age, note that no plus group is used.

8.2.4.2 Catches

The method used is similar to that of Sainsbury (1984). Fishing mortality is given by:

$$F_y = q\,E_y \qquad (6)$$

where F_y is the fishing mortality in year y,

q is a constant of proportionality indicating catchability, and

E_y is the effort (in 1000's of trawl hours).

The catch-at-age is:

$$C_{y,a} = A_a\,S_a^x\,N_{y,a}e^{-0.5M}\,q\left[E_y^{shallow}P_a^{shallow} + E_y^{deep}\left(1-P_a^{shallow}\right)\right] \qquad (6)$$

where $C_{y,a}$ is the catch (in numbers) of age a in year y,

A_a is an availability function (this is set to 1 in most cases),

S_a^x is the selectivity of gear x for age a (for the historical data x is the 90-mm diamond gear),

$N_{y,a}$ is the number of fish of age a in the population year y,

$P_a^{shallow}$ is the proportion of the population aged a that are present in the shallow depth range (<=200 m in the east and <=275 m in the west), and

E_y^d is the effort in year y in either the shallow or deep depth zone.

Equation 6 means that the catch (which is taken in a lump in the middle of the year) is the number of fish in the population at mid year (after half the natural mortality) that are available to capture by the gear, and present in the depth zone in which the effort is expended. This is multiplied by q which essentially converts effort units into fish units. The availability function (A_a) was seldom used but allowed us to force the model to avoid capturing very young fish when necessary. For most fish, the gear selectivity is such that young fish are not captured, but for some (e.g. pink ling) gear selectivity is close to 1 for young fish. These small fish are not generally caught by the fishery because they are either not on the trawl the grounds or are not available to the trawls (possibly in untrawlable terrain, or in the extreme shallows or up off the bottom).

The discarded component of the catch is:

$$d_{y,a} = C_{y,a}\,\widetilde{P}_a \quad (7)$$

where $d_{y,a}$ is the number of fish discarded in year y aged a, and

$\widetilde{P}_a$ is the proportion of fish aged a that are discarded.

Similarly, the retained component ($c_{y,a}$)of the catch is:

$$c_{y,a} = C_{y,a}\left(1 - \widetilde{P}_a\right) \qquad (8)$$

$\widetilde{P}_a$ is given by a logistic of the form shown in equation 4 except that the slope parameter ($S^{1,x}$ in equation 4) is multiplied by -1 so that the curve has its maximum at age 1. The same is true of the $P_a^{shallow}$ function. The four parameters of these two functions are: $S^{1,d}$ and $S^{2,d}$ for the discard function and $S^{1,dc}$ and $S^{2,dc}$ for the depth function.

Catch in numbers is converted to yield ($Y_{y,a}$) and discard in numbers to discard weight ($D_{y,a}$) by multiplying by the mean weight-at-age (w_a).

The population is updated by removing catches at mid-year, and by accounting for natural mortality:

$$N_{y+1,a} = \left(N_{y,a-1} e^{-0.5M} - C_{y,a-1}\right) e^{-0.5M} \quad (10)$$

8.2.4.3 Length and weight

The von Bertalanffy growth equation was used to give the mean length-at-age. For most species, the parameters of the von Bertalanffy equation were available from Central Ageing Facility (CAF) growth studies. When not available we fitted the von Bertalanffy equation to the age-length data supplied by the CAF. Parameters of the allometric length-weight relationship were obtained from the literature. This and the selectivity equation were applied to the mean length-at-age. No correction was made to mid-year (i.e. the mean weight-at-age was the von Bertalanffy for age a not for age a+0.5) because the von Bertalanffy and allometric equations are almost certain to have been calculated with data that were not back-calculated to the start of the year.

8.2.4.4 Price

Monthly average price data was obtained from the Sydney Fish Market (SFM) for each of extra small, small, medium, large and extra large grades for each species. The weight of fish in each grade sold in each month was also available from SFM. The annual average per kilogram value for each species was calculated as the average across all months, weighted by the monthly total weight sold. The unit used is $ per kilogram of fish (whole weight). For fish that are usually processed at sea, the processed weight was converted to whole weight using the AFMA conversion factors (John Garvey, AFMA, *pers comm*). Information on the size of fish represented in each grade came from the SFM data.

To convert value-at-length to value-at-age, while acknowledging that grades are not absolutely fixed and that fish length varies at age, a straight line was fitted to value-per-kg, through the mid-point of each grade's length window (Figure 8-1). The value-at-age was read from this graph using the mean length-at-age. The smallest and largest grades have open ended size windows (e.g. <20 cm or >60 cm). For those size grades, the mid-point was chosen by assuming that the true size window is equal in width to the next size window up or down (e.g. the midpoint of the '<20 cm' grade was taken to be 15 cm if the next grade up was '20 cm–30 cm' i.e. 10 cm wide).

Price per kilo at age was not allowed to be less than the price of the smallest grade or greater than that of the largest grade (see Figure 8-1). Silver warehou had a calculated price for the largest grade that was much lower than smaller grades, this grade was left out of the calculation of the straight line. Note that redfish never seem able to grow into the larger grades. This is because redfish have great variation in length at age. The von Bertalanffy curve for that species goes through the middle of the scatter of data points so that Linf is smaller than the true maximum length. This, and the poor ALKs for several years, were the main reasons that Thomson (2002a) chose to use catch-at-length instead of catch-at-age in their redfish stock assessments. This may also be the reason for the inability of blue warehou to grow into the maximum size grade.

8.2.4.5 Data

Effort in the east was calculated by summing the hours spent trawling for all shots in which any of the species considered in the east were caught. The same was done in the west using the group of species considered there except that blue grenadier effort in deeper water was calculated separately and only added to the total for blue grenadier and silver warehou calculations. Greeneye dogfish were also used in the west although these were not considered in further analyses. Effort was split into that expended shallower and deeper than 200 m in the east, and 275 m in the west.

Yields were calculated by summing all catches, in each year, for each species considered. Like effort these are split into shallow and deep. SEF1 logbook data were used for both catch and effort. No correction was made to SEF2 landed catches as our experience is that the correction factors are reasonably invariant and therefore the relative recruitment values which we are attempting to calculate will not be affected.

Age composition data for landed catches and discards were calculated using age-length-keys. These were applied to length frequency information collected in ports, and to ISMP onboard measures of the length frequencies of the discarded component of the catch. Onboard length frequencies for the retained component were not used as the port measured length frequencies usually show similar distributions and have much greater sample sizes. Discard length frequencies were calculated by weighting each up by the size of the catch in each shot, then summing within each season by fishing zone, and then catch weighting by the catch in each season by zone and summing these to get a length frequency for the year. The port length frequency was similarly weighted by season and zone before summing.

John dory were aged only once, during 1993, and no length frequency was available for that year. As the method used requires age composition data this ALK was applied to all years for which length frequencies were available (1998–2003). It was unfortunate that this was necessary but the method applied does not attempt to estimate recruitment residuals and there is little sign of inter-annual variation in John dory length frequencies.

We decided to constrain the populations' female spawning biomasses to lie between 20% and 40% of pristine. That seems to be a reasonable rule-of-thumb for most CTS species (although clearly not all) and helped to constrain the estimated parameters within reasonable bounds.

8.2.4.6 Estimation technique

Modelling was implemented in Microsoft Excel, using the Solver function to minimise the negative log likelihoods. We assumed a lognormal error distribution for yields and multinomial for catches- and discards-at-age. In addition, two constraints were applied: that the median estimated discard be close to that measured by the ISMP, and that the spawning biomass fall within 20–40% of its pristine level (i.e. depletion between 20% and 40%). The spawning biomass constraint was applied in an attempt to prevent the estimator from exploring implausible areas of parameter space, and because 20–40% seems to be the correct level for most commercial CTS stocks. Neither of these is a rigid constraint. The discard constraint was applied by adding the sum of the squared difference between the ISMP and the median estimate discard to the negative log-likelihood, multiplied by 10000. The spawning biomass constraint is effected by adding the difference between the absolute value of the estimated depletion and either 20 or 40 (whichever is closest) multiplied by 1000, to the negative log-likelihood.

The weights used for the log-likelihoods were chosen to reflect the level of belief in each of the data sources (this level was judged over many years of performing SESSF stock assessments). The values used were 0.3 for port catches-at-age; 0.9 for the shallow discards-at-age; 0.3 for the deep discards-at-age; 0.2 for both the shallow and deep yield data. In addition, the catch- and discard-at-age data were weighted by their relative sample sizes.

Solver was also to calculate the fishing mortality rate and number of recruits that give the estimated depletion and stock size. Because the solution is exact, a simple sum of squares objective function was used and Solver was run until this quantity was negligibly different from zero.

8.2.5 Model projections: Finfish

Once the parameters of the model had been estimated, the stock was projected into the future.

Recruitment was assumed to remain fixed at the calculated level. Fishing mortality rate was also kept constant at the calculated level. Six separate projections were done for each species — one for each of the gears. That for the standard gear showed no change from year to year because the stock remains in equilibrium. The biomass of the stock, value of the catch, and size of the retained and discarded yields were calculated for each future year, and displayed relative to the equilibrium value (referred to herein as the reference level).

8.2.6 Model projections: Gould's squid

Gould's squid live for no more than one year and recruitment was assumed to be constant so there are no inter-annual population dynamics, no population growth as a result of using a larger mesh. In reality, Gould's squid grow throughout the year so using a mesh that selects larger individuals would give Gould's squid a change to grow. Catches would increase as the year progressed and the average weight of Gould's squid caught would be greater. No growth information was available for this study so Gould's squid were assumed not to grow and there is no advantage, in terms of allowing the stock to recover and grow larger, in changing to a larger mesh size. A single yield figure was calculated for each alternative mesh. Note that no estimate of biomass was available from this model as catchability, q, was not estimated.

The assumption that recruitment is constant means that the stock size is the same every year. Therefore the model has no power to estimate q. This had to be set to 1 and R estimated. This R is therefore not comparable with the R values estimated for the finfish species q. Separate Rs were calculated for deep and shallow water.

Length frequency data were available for the catch off the east coast. This was used, together with the known selectivity of the control gear, to calculate the relative numbers-at-length that were available to the gear (by dividing the number captured-at-length by the gear selectivity for that length). When selectivity is small, this calculation becomes inaccurate. As we were interested in gears that capture larger animals than the control gear we were not interested in animals that even the control gear is unlikely to catch. This calculation was therefore only preformed for length groups for which control selectivity is greater than 0.05. This gives a length frequency for the population that is available to the gear (note that it is relative, not absolute, because q is unknown).

The expected yield for Gould's squid in year y is:

$$\hat{Y}_y^{dc} = \sum_l \overline{N}_l w_l \, S_l^{90d} \, q \, R^{dc} \, E_y^{dc} \qquad (6)$$

where $\hat{Y}_y^{dc}$ is the expected yield during year y from either shallow or deep water,

$\overline{N}_l$ is the relative numbers-at-length in the population,

w_l is the weight of a Gould's squid in length class l,

S_y^{90d} is the selectivity,

R^{dc} is the relative recruitment in deep or shallow, and

E_y^{dc} is the effort in shallow or deep during year y

Note that $\overline{N}_l$ times S_y^{90d} gives the observed length frequency of the catch except that $\overline{N}_l$ was not calculated for length classes whose gear selectivity was low. The observed length frequency was therefore used here. However, the likely yield that would result from using a particular trawl mesh was calculated using $\overline{N}_l$.

8.3 RESULTS AND DISCUSSION

8.3.1 Selectivity Results

Random noise ensured that *q* was not exactly one, but most estimates are reassuringly close to 1 indicating no bias. Where the estimated *q* differs greatly from 1, this generally indicates a small sample size and uncertain fit. In these cases the estimated values of the other selectivity parameters should also be regarded with caution. The estimated selectivity parameter values are shown in Table 8-2.

For cases where selectivity could not be estimated (because of insufficient or no data), the selectivity for the next smallest mesh for which data were available was used in the forward projections. For square mesh, the next smallest square mesh was used, or if none was available, the standard gear's selectivity was used. When the estimated selectivity curve for 102 mm mesh showed that smaller fish were selected than for 90 mm mesh, the 102 mm selectivity was discarded and replaced by that for 90 mm. If that for 102 mm was smaller than that for 110 mm but both captured larger fish than 90 mm, the smaller of the two was used for both. For three species (redfish, deepwater flathead and king dory) the 90 mm square mesh captured smaller fish than 90 mm diamond. This was considered feasible as it might be due to the shape rather than the size of the fish.

Figure 8-2 shows selectivity curves for each species plotted together, including "market selectivity". Market selectivity is the 90 mm diamond gear selectivity-at-age multiplied by 1 minus the estimated discard probability-at-age and shows the "selectivity" curve for the landed component of the catch.

8.3.2 Modelling Results

The parameters estimated when fitting to historical data are shown in Table 8-4 and Table 8-5. Fits to the yield data are shown in Figure 18-3 and Figure 18-4 and to age composition data in Figure 18-5 to Figure 18-10. Fits to the Gould's squid yield data are shown in Figure 18-11 and to the Gould's squid length frequency in Figure 18-12.

Note that effort is assumed to be known without error. It would have been preferable to have assumed that yield was known exactly and to estimate effort because yield data is thought to be quite accurate. In multispecies fisheries like the CTS it is difficult to estimate the effort that is directed towards a particular species and factors such as alteration in vessel fishing power and practice can alter effective effort (catchability) over time. Unfortunately this could not be accounted for with the model structure used here. Similarly, a length- rather than an age-based model would have been more accurate but more difficult to implement, cumbersome to work with, and would have introduced greater uncertainty.

Despite a number of assumptions not being met, the fits to the data are surprisingly good on the whole (Figure 18-3 and Figure 18-4). The assumption that we have the correct effort series is worse for species that can be targeted by the fishery (e.g. blue grenadier and gemfish). The assumption is particularly poor on the west coast as well where effort has increased steadily. An attempt was made to improve these calculations by excluding effort that resulted in blue grenadier catches in deep water, thereby reducing the effect of recent abundance and quota increases in for this species. This had little effect as this effort was a very small part of the total (Figure 18-4). However, much of the recent blue grenadier catch was taken by highly efficient factory trawlers which would have altered the catchability for blue grenadier and the major bycatch species silver warehou.

Note that catches by non-trawl vessels have not been considered by the model. This is probably reasonable for most species but might be inappropriate for some such as blue-eye trevalla, which are taken in significant numbers by non-trawl vessels.

The gear selectivity parameters calculated for 90 mm diamond gear have been used here. For some species catches deeper and shallower than 200 m in the east and 275 m in the west are modelled and the stock is split, by age, between depth zones. Other than this, availability is not modelled. In some of the cases described below, the model expects large catches of small fish that do not appear in the data. This leads to larger than observed discard rates and to poor fits to the discard-at-age data. This may be because small fish are not available to the fishery perhaps because they have a pelagic distribution or are found in areas that are not fished (e.g. on the shelf in the west). Alternatively, it might also be because the von Bertalanffy curves used are inaccurate because they were based on samples that under represent small fish. It was necessary, in some cases, to assume that young fish were not available to the fishery.

On the whole, stock sizes seem to be underestimated by the model used here. This result is difficult to interpret. The main ways in which this method differs from the assessments listed in Table 8-4 and Table 8-5 are that recruitment is constant, not coupled to stock size, and that the effort series is unstandardised and includes a number of shots that would have yielded little or none of the target species. Standardisation of the effort series, and changes in targeting and fishing efficiency will alter the effective effort for each species. However, the very low stock sizes which this model is capable of producing probably result from the assumption that recruitment is not linked to stock size. Very small stocks can therefore yield average recruitment, even if all fish are caught before they reach breeding age.

8.3.3 Effect of changing gear type

Total commercial stock biomass, retained yield, value of catch and discards for each gear type are shown for the east and west in Figure 8-3 and Figure 8-4. The relative value of catches of each species are shown for the east and west in Figure 8-5 and Figure 8-6. Note that not all species were caught with each of the gears used. The effect of using different gear types on catch value differs from species to species, but each follow a similar pattern. Catch values are almost exclusively negative initially (relative to using the reference level using standard 90 mm diamond codend), and the gear that shows the greatest initial drop, generally turns around show the greatest increase in value at the end of the time series modelled. This demonstrates that while modifying gear to reduce bycatch will impact on profitability of fishing operations initially, if the correct gear is chosen, then future benefits in profitability will likely be realised after some time.

Importantly, all modified codends tested led to a considerable decrease in discarding of commercial species. It should be noted however, that forecasted improvements to yield and catch value depend on the survivorship of those fish that escape the net. This has not been quantified, and so could not be modelled during this project, however it is likely that survivorship will vary from species to species. Methods have been developed to measure post escape survival in trawl fisheries, and would be suitable for use in the CTS (e.g. Lehtonen *et al*. 1998)

8.3.3.1 The East

Of the four test codends trialled in the east, the 102 mm diamond codend had the least impact on the initial (Year 0) value, retained yield and discards, however, total biomass of commercial species increased to greater levels than for the 90 mm square mesh because of the benefits of reducing discards of blue grenadier (Figure 8-3). Total value using the 102 mm diamond codend initially dropped by about 4%, but reached the reference level by Year 3, and increased to about 2.5% above reference level. Total commercial discards decreased by a total of about 7% over the long-term, with the majority of that comprised of redfish and blue grenadier.

Not surprisingly, the greatest overall decrease in commercial discarding was observed using the 110 mm diamond codend (Figure 8-3), which was initially nearly 40% below the reference level, and stabilised at around 30% of the reference level. Redfish and tiger flathead comprised the majority of reduced discards, while blue grenadier, offshore ocean perch and gemfish were minor components. As a consequence of allowing more commercial fish to escape, catch value decreased significantly initially to nearly 15% below the reference level, before reaching the reference level by Year 5 and stabilising at about 4% above that level by about Year 11. The recovery was due largely to the increased yield value of pink ling and tiger flathead catches. Value of catches of gemfish, inshore ocean perch and offshore ocean perch also recovered to well above reference levels using 110 mm diamond codends, while value of Gould's squid catches remained about 15% below references levels for the entire period modelled (Figure 8-5). Total commercial biomass increased to about 13% above the reference level by Year 14 through large increases in biomass of blue grenadier, tiger flathead, redfish and pink ling.

The square codends generally performed poorly in terms or retained yield, with the 90 mm and

102 mm codends dropping by 5% and 13% initially (Year 0), and then increasing to only 1% below and 1% above reference levels respectively (Figure 8-3). Results in terms of value however were similar with the 90 mm square codend increasing to 2% above the reference level. This was largely due to small increases in yield of the highly valued pink ling and tiger flathead. As with all test nets trialled (apart from the 102 mm diamond codend), the retained yield and value of Gould's squid remained well below reference levels for the entire period modelled. Commercial discards were reduced by about 10% overall comprising almost entirely of tiger flathead.

Results of modelling 102 mm square and 110 mm square codends are almost identical, and so because the 110 mm square codend was not trialled in the east, only results for the 102 mm square codend will be discussed here (Figure 8-3). The value of catches using the 102 mm square codend increase to above reference level by Year 6, and increased to about 3% above that level by the end of the period modelled. Main species comprising this increase were pink ling, tiger flathead and gemfish, while the value of Gould's squid remained below the reference level. Value of Gould's squid catches were about 25% below the reference Gould's squid catch level for the entire period modelled (Figure 8-5). Total commercial discards using the 102 mm square codend decreased by 30% initially, and stabilised at about 25%, comprising mostly of tiger flathead, redfish and blue grenadier.

8.3.3.2 The West

Using the 102 mm diamond codend in the west resulted in an initial decrease in total catch value of 8%, followed by and increase past the reference level during Year 4 to a maximum of 3% above the reference level towards the end of the period modelled (Figure 8-4). Pink ling were almost entirely responsible for this increase, while a persistent decrease in value of deepwater flathead catches stopped the increase from being higher. Looking at the species individually, the 102 mm diamond codend initially reduced the value of the blue grenadier catch before recovering to the reference level in Year 6 (Figure 8-6). Commercial biomass increased to about 2% of the reference level by the end of the period modelled with deepwater flathead, pink ling and blue grenadier comprising the majority of the increase. Reduced discarding of about 28% of the reference level (mostly pink ling, deepwater flathead and blue grenadier) was constant throughout the period modelled.

Results using the 110 mm diamond codend were very similar to those of the smaller diamond codend. The initial decrease in value of commercial catches was about 12%, but value increased past the reference level during Year 5 and only reached just higher than that when the 102 mm diamond codend was used despite a greater increase in value of pink ling catches. This is because the small increase was offset by a reduction in value of Gould's squid catches, which was constant at about 20% below the reference for the value of catches of that species across the time period modelled (Figure 8-6). The value of pink ling catches initially decreased by more than 30%, before recovering to about 15% above the reference level. The total commercial biomass increased to about 3% above reference levels with — as for the 102 mm diamond codend — deepwater flathead, pink ling and blue grenadier comprising the majority of the increase. Decreased discards also comprised the same species as for the 102 mm diamond codend (pink ling, deepwater flathead and blue grenadier).

The 90 mm square codend was not trialled in the west, and modelling results are very similar to those for the 102 mm square codend, so only the former will be discussed here. Initially the total value of catches decreased to about 11% of the reference level with pink ling and Gould's squid mostly responsible for the decrease (Figure 8-4). Value of Gould's squid catches decreased to a greater extent in the square mesh codends than the diamond mesh codends. Total value reached the reference level during Year 4 and a maximum of about 3% above the reference level at the end of the period modelled. Commercial biomass increased to about 2% above reference level with pink ling and blue grenadier comprising the majority of the increase. Those two species also comprised the great majority of the decrease in discarding (~20%) modelled for the 102 mm square codend.

Use of the 110 mm square codend resulted in the loss of so much of the commercial catch that value did not recover above the reference level by the end of the period modelled. Total retained yield dropped initially by 20%, comprising mostly of deepwater flathead, Gould's squid and pink ling, and recovered to only about 2% below the reference level (Figure 8-4). Yield of blue warehou increased significantly after just one year of modelling, and similarly increased in value to 13% above reference level in the same year (Figure 8-6). Value of pink ling increased above the reference level by Year 3. The large, reasonably constant decrease in value of deepwater flathead catch, and to a lesser extent Gould's squid, resulted in the total value of the catch remaining about 9% below the reference level. Commercial discards using the 110 mm square codend were about 70% lower than the reference levels comprising mostly of blue warehou, deepwater flathead, pink ling and blue grenadier. The resulting increase in commercial biomass was the largest seen of any of the experiments, increasing to about 7% of the reference level. Deepwater flathead benefitted most from the increased mesh size.

Table 8-1. Estimates of available biomass and stock size relative to pristine (depletion) obtained from A.D.M. Smith (CSIRO, *pers comm*)

Species	Available Biomass (tonnes)	Depletion	Explanation
EAST			
Blue grenadier	40,000	0.4	From latest assessment (Tuck and Thomson 2003)
Pink ling	3,000	0.2	In consultation with Klaer and Thomson (*pers comm*), considering latest assessment - Klaer 2003
Redfish	6,000	0.25	adjusted upwards from last assessment (Thomson 2002a)
Mirror dory	3,000	0.3	Pure guess
John dory	1,000	0.25	Pure guess
In. ocean perch	500	0.25	Pure guess
Off. ocean perch	1,000	0.3	Pure guess
Tiger flathead	10,000	0.4	Based on latest assessment (Cui *et al.* 2003)
Jackass morwong	8,000	0.35	Based on latest assessment (Fay, 2004)
Gemfish	500	0.1	Guestimate
WEST			
Blue grenadier	6,000	0.4	From the Tuck and Thomson 2003 (noting that the dome-shaped selectivity could be a problem)
Pink ling	3,000	0.2	In consultation with Klaer and Thomson (*pers comm*), considering latest assessment - Klaer 2003
Off. ocean perch	500	0.5	Pure guess
Deepwater flathead	110	0.87	1% (roughly SEF catch divided by GAB catch) of 2004 assessment of available biomass, and the depletion from that stock assessment (Brent Wise, BRS, *pers comm*)
Gemfish	1,000	0.3	Guestimate
Blue warehou	650	0.18	Based on latest assessment (Punt and Smith 2004)
Silver warehou	11 000	0.5	Based on stock assessment (Bruce Taylor, Victorian DPI, *pers comm*)
King dory	1,500	0.4	Based on Model 1 results

Table 8-2. Control gear selectivity (90 mm diamond) from covered codend data, and modified gear selectivity parameters from trouser trawl data.

	Diamond meshes						Square meshes						
Species		90mm diamond[1]	102 diamond		110 diamond			90 mm square		102 square		110 square	
	S[1]	S[2]	*q*	S[2]	*q*	S[2]	S[1]	*q*	S[2]	*q*	S[2]	*q*	S[2]
Blue grenadier	0.193	42.34	0.96	53.60	1.34	62.09	0.316	0.97	51.21	1.15	63.89	0.92	59.88
Pink ling	0.284	40.84	1.02	53.65	0.93	57.73	0.204	1.00	50.96	1.05	61.78	0.80	58.44
Redfish	1.039	16.65	0.91	16.60	0.74	16.48	1.058	1.24	17.10	1.18	17.95		
Mirror dory[3]	15.539[1]	15.540[1]	1.02	16.95	0.97	17.92	18.117	0.92	19.50	0.95	21.86		
John dory	15.539[1]	15.540[1]					0.905	1.03	15.50	0.56	0.25		
In. ocean perch	0.571	15.56	0.35	14.63	0.15	13.55	0.279	6.89	26.90	0.29	18.99		
Off. ocean perch	0.382	18.25	1.13	25.06	0.80	23.36	0.579	0.99	25.71	1.47	28.72	0.14	0.62
Tiger flathead	0.428	26.522	0.36	25.97	1.19	39.32	0.345	1.13	34.42	0.94	40.09		
Deepwater flathead	0.417	33.87	0.61	37.68	0.62	38.07	2.962	0.81	34.95	0.34	69.51	0.93	47.61
Jackass morwong	21.939[1]	21.94[1]	0.89	28.99	0.90	24.11	0.187	1.60	26.19	11.02	52.53	1.25	0.00
Gemfish	0.055	33.68	2.84	93.17	0.68	43.64	0.096	0.47	43.13	0.07	32.04	0.33	54.14
Blue warehou	17.609[1]	17.609[1]			1.42	32.89	14.344	1.75	24.98			0.84	26.44
Silver warehou	18.83	25.02	1.44	33.98	1.00	29.57	0.676	0.76	0.07			1.13	33.26
Gould's squid	0.247	13.106	0.67	0.00	1.17	20.66	0.361	1.45	22.71	1.88	27.54		
King dory	1.365	12.649	0.58	13.23	1.06	14.55	1.816	0.47	10.88	0.85	12.65	1.13	12.55
Silver trevally													

Table 8-3. Biological and population parameters of species modelled.

Species	Max. age	M	Growth			Length-weight	
			L_∞	K	t_0	a $(kg.cm^{-1})$	b
Blue grenadier	25	0.18	104	0.17	-1.77	$3.75e^{-6}$	3.013
Pink ling	28	0.16	123	0.12	-2.05	$02.93e^{-6}$	3.139
Redfish	44	0.10	25.0	0.30	-0.15	$6.26e^{-5}$	2.72
Mirror dory	14	0.30	65.0	0.16	-0.38	$1.640e^{-5}$	3.000
John dory	12	0.25	66.0	0.10	-1.48	$5.48e^{-6}$	2.517
In. Ocean perch	17	0.10	13.6	0.234	0	$1.81e^{-5}$	2.997
Off. Ocean perch	62	0.07	43.7	0.114	0	$1.81e^{-5}$	2.997
Tiger flathead	20	0.20	55.4	0.175	-2.64	$2.49e^{-5}$	3.31
Deepwater flathead	33	0.16[7]	56.8	0.259	-0.81	$2.084e^{-6}$	3.20
Jackass morwong	38	0.12	52.0	0.34	-0.45	$2.2e^{-5}$	2.951
Gemfish	17	0.24	110.0	0.16	-1.02	$1.43e^{-6}$	3.390
Blue warehou	14[6]	0.50	55.0	0.28	-0.69	$3.0e^{-6}$	2.9
Silver warehou	14	0.25	63.0	0.46	-0.65	$1.53e^{-5}$	3.0
Gould's squid	1	-	-	-	-	$1.15e^{-4}$	2.609
King dory	32	0.16[7]	49.36	0.123	-0.74	$3.52e^{-5}$	2.895
Silver trevally	24	0.10[5]	44.5	0.34	-1	$4.43e^{-5}$	2.786

Table 8-4. Estimated parameters and quantities of interest in the East. Blanks indicate parameters that were not used. $\overline{D}$ is the average discard rate estimated. B_{2003}^{1+} is the biomass of all fish aged 1 and over. B_{2003}^{ave} is the available biomass (numbers times gear selectivity times any availability factor times weight, summed over age), and B_{2003}^{sp} f is the spawning biomass of females only, m+f indicates males and females combined. "ISMP D rate" gives the range of discard rates presented in Garvey (1998), Knuckey and Sporcic (1999), Knuckey (2000), Knuckey et al. (2001), or calculated from ISMP data by the authors, or taken from the stock assessment referenced in the final column. Discard rates prior to 1996 are not considered.

	R	*q*	Discard probability		Proportion in shallow		$\overline{D}$	ISMP D rate	Model biomass in tonnes			Independent biomass estimates	
Species	'000 fish	y^{-1}.'000h^{-1}	$S^{1,d}$	$S^{2,d}$	$S^{1,dc}$	$S^{2,dc}$	%	%	B_{2003}^{1+}	B_{2003}^{ave}	B_{2003}^{sp} f	B	Type and source
Blue grenadier	1065	6.74E-03	1.829	47.96			20	0.5-62	1650	1391	169	31000	B_{2002}^{sp} f E+W (Tuck and Thomson 2003)
Pink ling	1204	6.79E-03	0.271	49.84	0.137	5.0	23	1-24	1817	1452	175	22000 or 5000	B_{2002}^{sp} f E+W (Klaer 2003)
Redfish	26335	2.77E-04	0.412	14.37	0.050	5.0	4	2-33	55164	50819	24122	3090	B_{2001}^{sp} f East (Thomson 2002a)
Mirror dory[1]	1838	2.60E-03	0.459	30.35			18	12-24	2172	1925	617	1000	B_{2001}^{1+} East (Hall 2002)
John dory	49208	4.05E-03	0.232	29.69			65	3-10	1184	959	58		
In. Ocean perch	185	2.13E-03	30.00	20.70			17	50-66	109	97	0		
Off. Ocean perch	937	2.85E-03	0.905	21.04			8	9-27	1165	1013	250		
Tiger flathead[2]	678	2.25E-03	5.101	34.53			10	5-14	7208	5547	3192	14000	B_{2002}^{sp} f E+W (Cui *et al.* 2003)
Jackass morwong	1245	8.16e-4					0	2-6	10351	8795	5078	10000	B_{2003}^{sp} f East (Fay *pers comm*)
Gemfish	682	1.04E-02	4.008	31.72			9	12-24	587	399	12	600-3000	B_{1998}^{ave} East (Punt 1999)
Gould's squid	4.9; 6.0	1.0									440*		
Silver trevally								0-1				1800	B_{2001}^{1+} East (Hall 2002)

* Estimated yield (tonnes) using 2003 effort levels and 90mm diamond gear

[1] Fitted to an average discard rate of 15%

[2] Fitted to an average discard rate of 10%

Table 8-5. Estimated parameters and quantities of interest in the WEST. Blanks indicate parameters that were not used. Grey shading indicates that parameters calculated in the east were used in the west.

	R	*q*	Discard probability		Proportion in shallow		Ave model D rate	ISMP D rate	Model biomass in tonnes			Independent biomass estimates	
Species	'000 fish	y^{-1}.'000h^{-1}	$S^{1,d}$	$S^{2,d}$	$S^{1,dc}$	$S^{2,dc}$	%	%	B^{1+}_{2003}	B^{ave}_{2003}	B^{sp}_{2003} f	B	Type and source
Blue grenadier	23100	3.98E-04	1.800	48.00			1%	0.5-62	179673	173416	69872	31000	B^{sp}_{2002} f E+W (Tuck and Thomson 2003)
Pink ling	896	1.02E-03	0.273	49.88	0.136	5	3%	1-24	7023	6746	2660	22000 or 5000	B^{sp}_{2002} f E+W (Klaer 2003)
Off. Ocean perch	103	2.34E-03	30.000	25.52			9%	9-27	201	184	62		
Deepwater flathead	6452	8.15E-06	0.800	37.97			5%	~10%	17233	16112	0	8500	B^{1+}_{2001} GAB (Wise and Tilzey 2002)
Gemfish	240	1.15E-02					0%	2-4	146	94	1		
Blue warehou[1]	9435	1.43E-01	0.446	30.94			8%	4-9	869	395	190	??	B^{sp}_{2001} f E+W Punt and Smith 2004
Silver warehou	2074	1.84E-03	0.100	5.00			10%	1-15	14100	10746	6453	63000	B^{sp}_{2001} f E+W (Bruce Taylor, Victorian DPI, *pers comm*)
Gould's squid	44.7, 3.4	1.0											
King dory[2]	1410	8.24E-04	7.874	31.28			23%	2-30	3438	3417	1719		

[1] Fitted to average observed discard rate of 5%

[2] Fitted to average observed discard rate of 10%

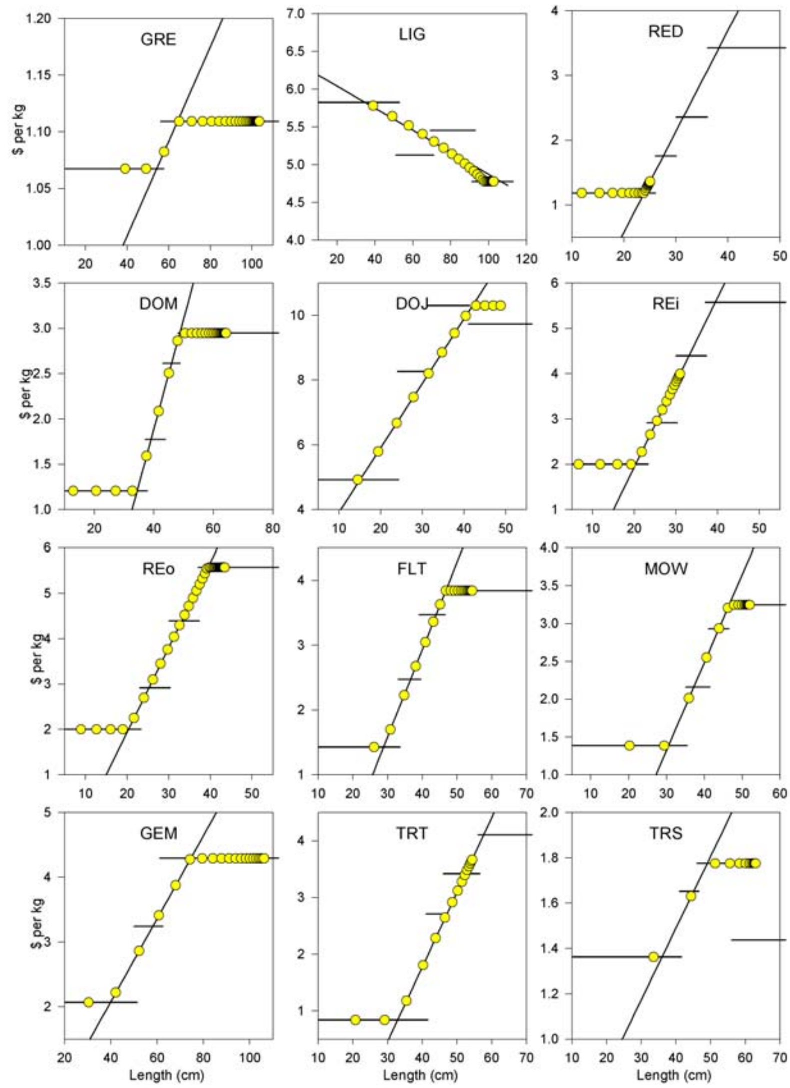
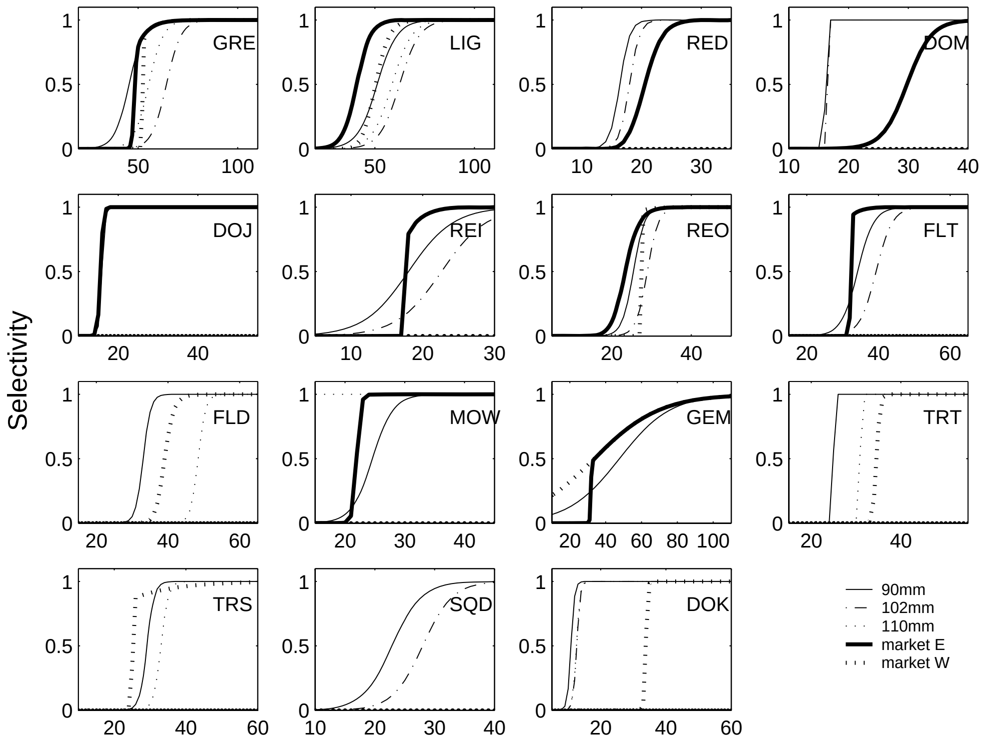


Figure 8-1. Annual average price-per-kilogram of whole weight, by size grade for each species. A straight line was fitted through the mid-point of each grade.



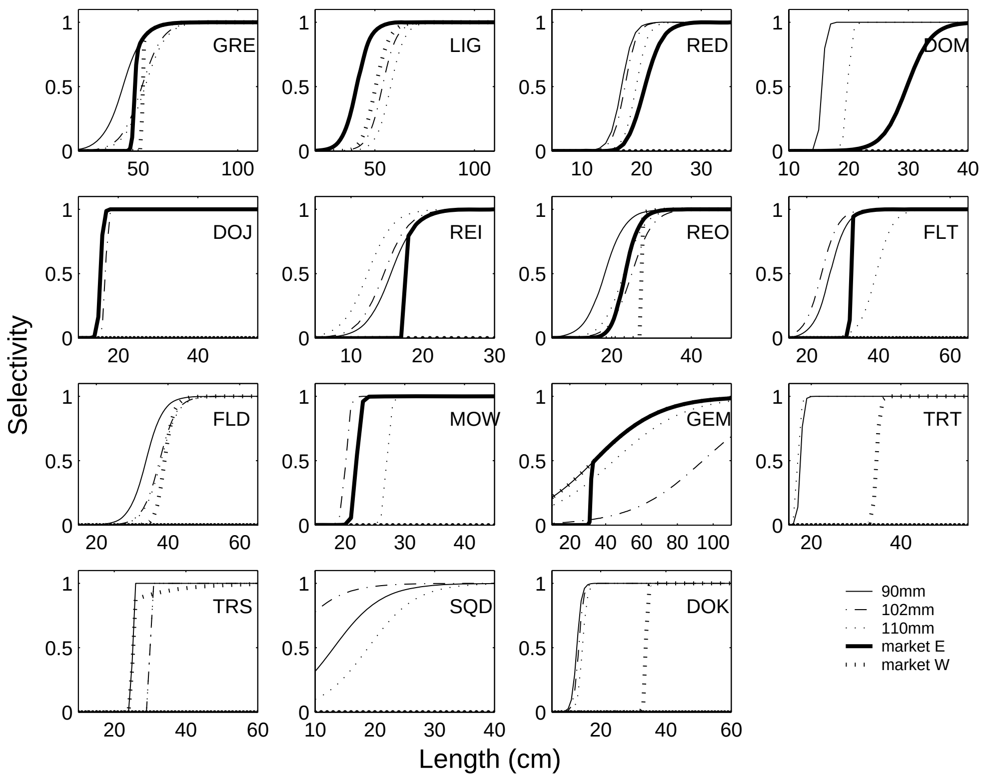
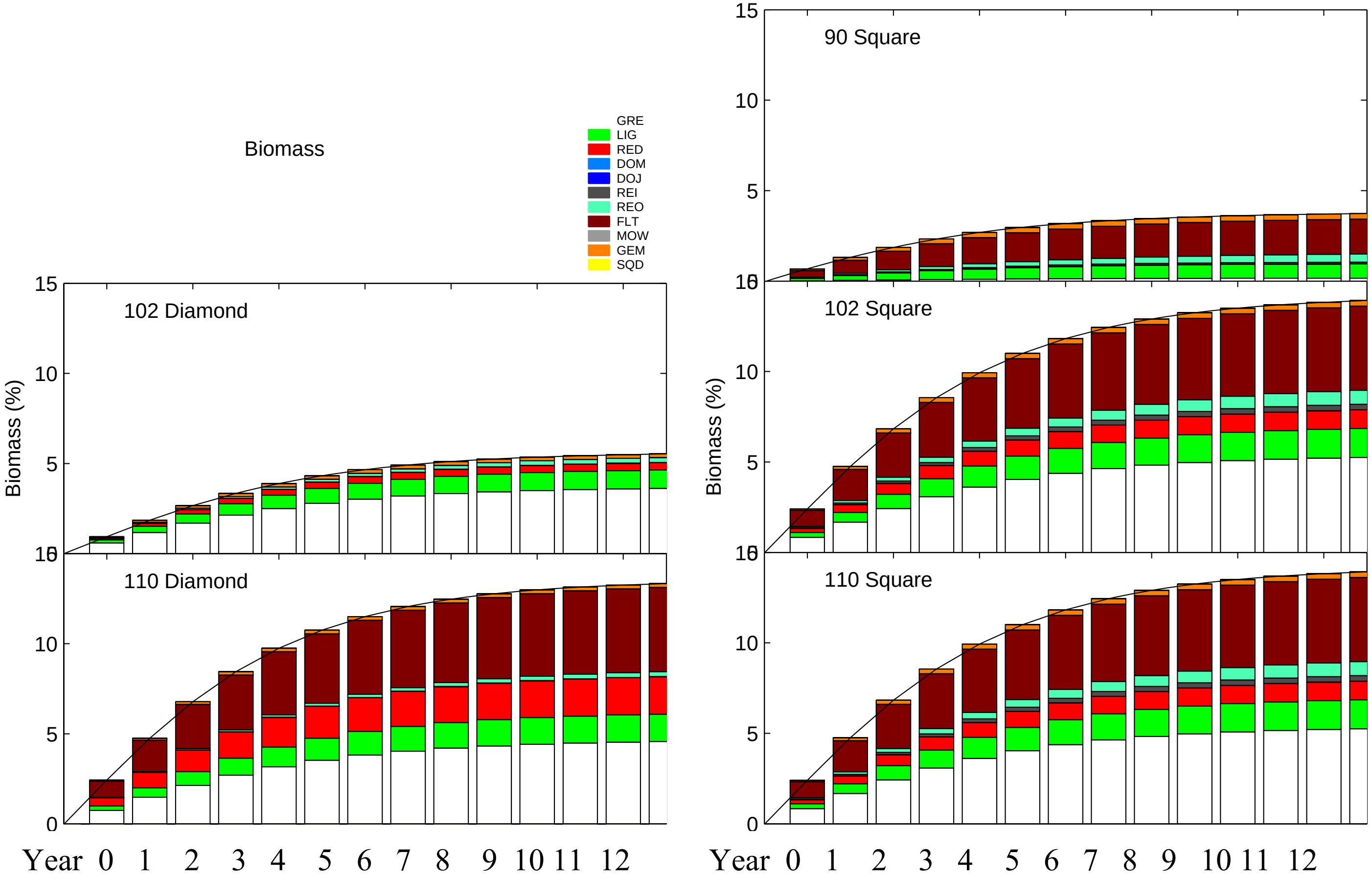
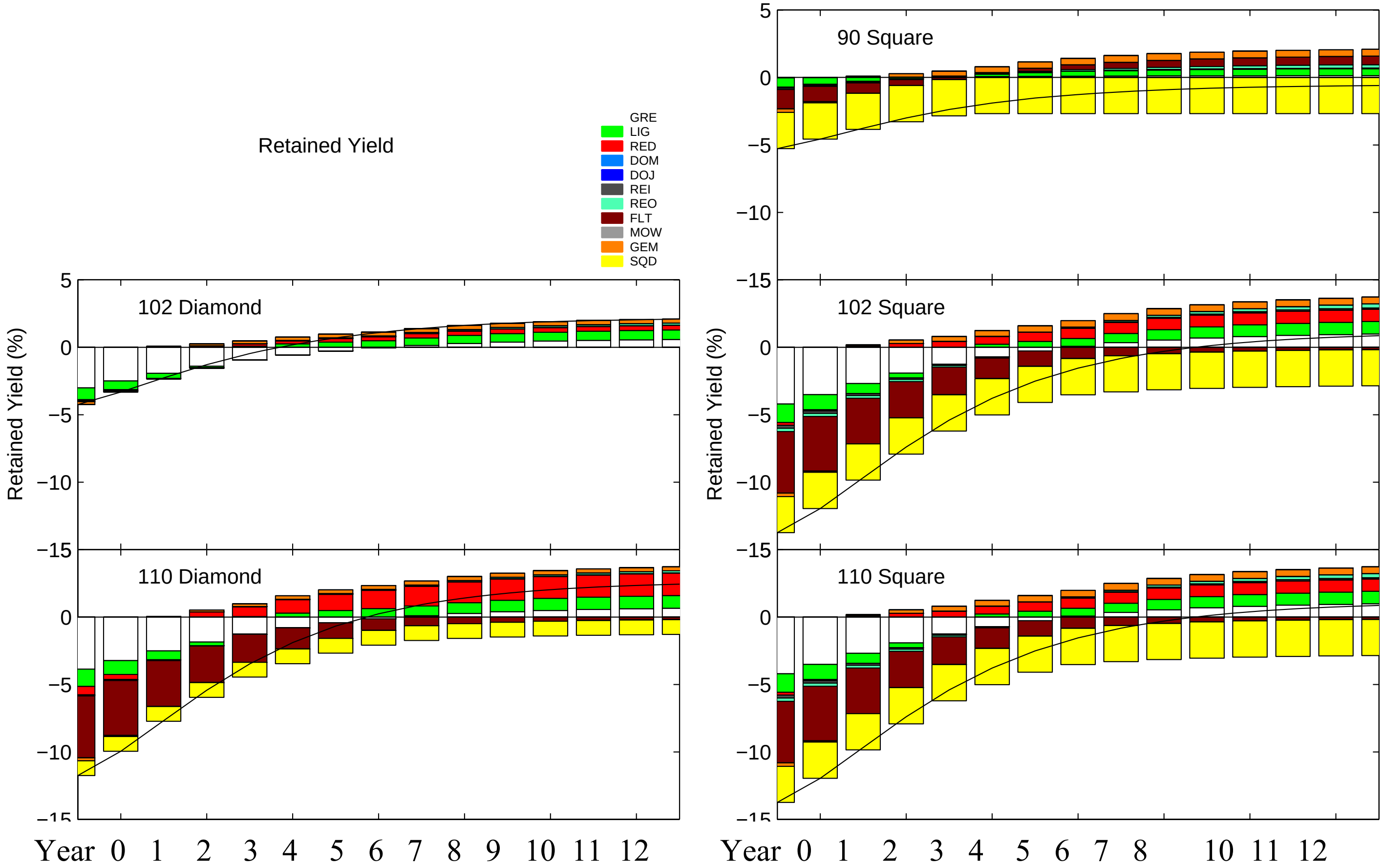
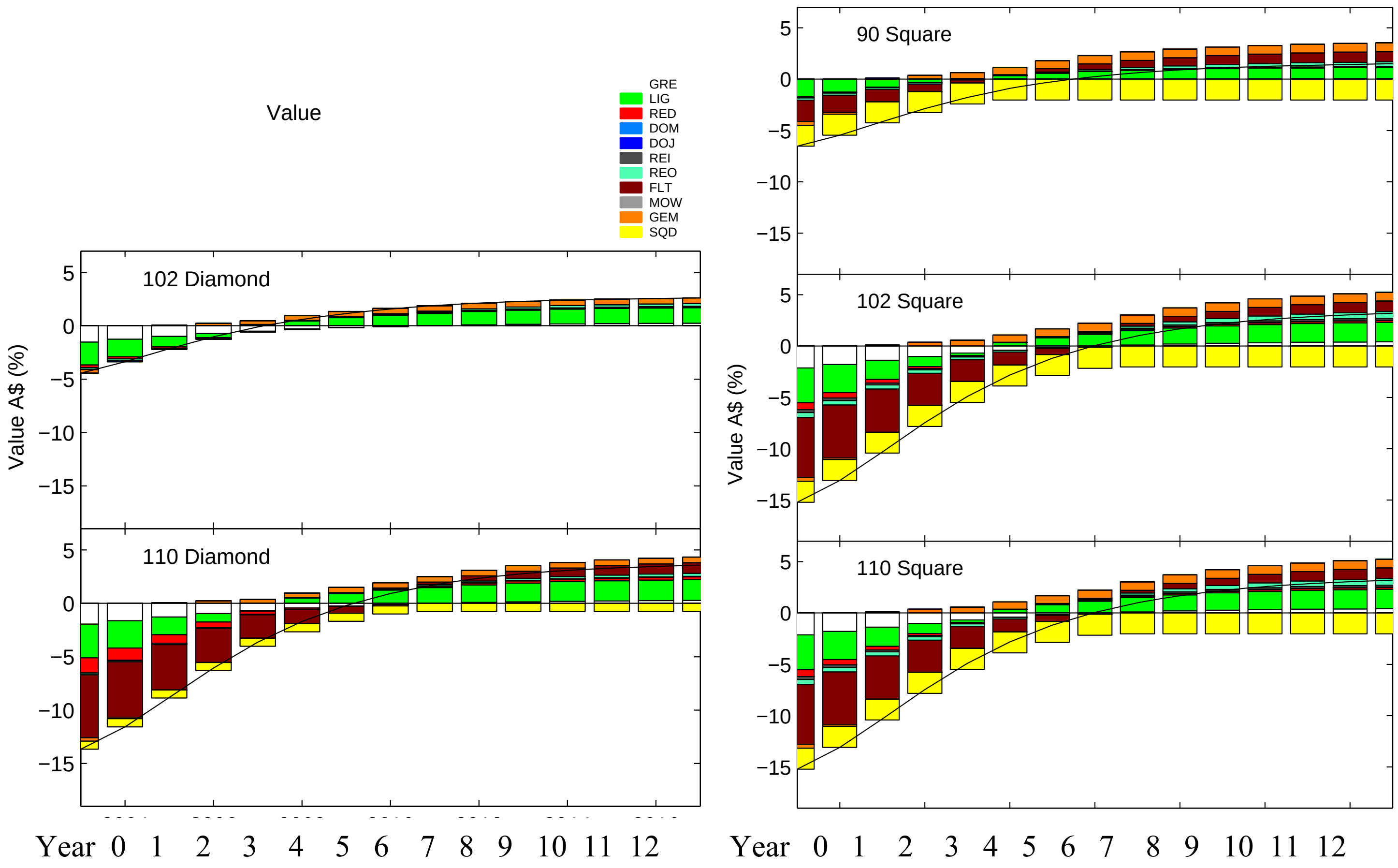


Figure 8-2 Selectivity patterns for all gears and species along with 'market preference' which is the 90 mm diamond selectivity pattern multiplied by 1 minus the estimated discard probability at length. This is intended to give the 'selectivity' pattern for the landed catch.


Biomass
GRE
LIG
RED
DOM
DOJ
REI
REO
FLT
MOW
GEM
SQD
90 Square
102 Diamond
102 Square
110 Diamond
110 Square
Biomass (%)
Biomass (%)
15
10
5
0
Year 0 1 2 3 4 5 6 7 8 9 10 11 12
Year 0 1 2 3 4 5 6 7 8 9 10 11 12


Retained Yield
GRE
LIG
RED
DOM
DOJ
REI
REO
FLT
MOW
GEM
SQD
90 Square
102 Diamond
102 Square
110 Diamond
110 Square
Retained Yield (%)
Retained Yield (%)
5
0
−5
−10
−15
Year 0 1 2 3 4 5 6 7 8 9 10 11 12
Year 0 1 2 3 4 5 6 7 8 10 11 12


Value
GRE
LIG
RED
DOM
DOJ
REI
REO
FLT
MOW
GEM
SQD
102 Diamond
110 Diamond
90 Square
102 Square
110 Square
Value A$ (%)
5
0
−5
−10
−15
Year 0 1 2 3 4 5 6 7 8 9 10 11 12

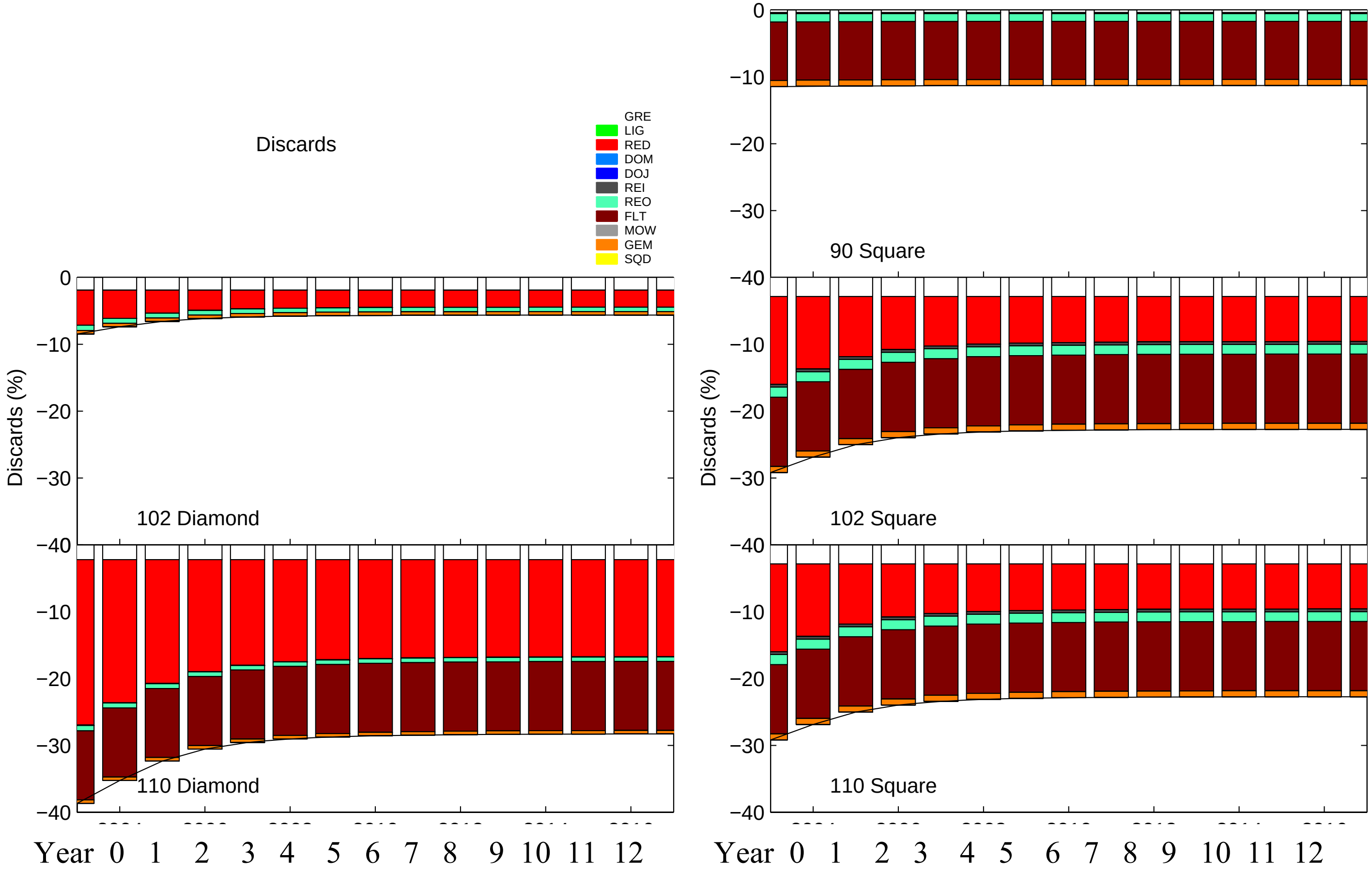
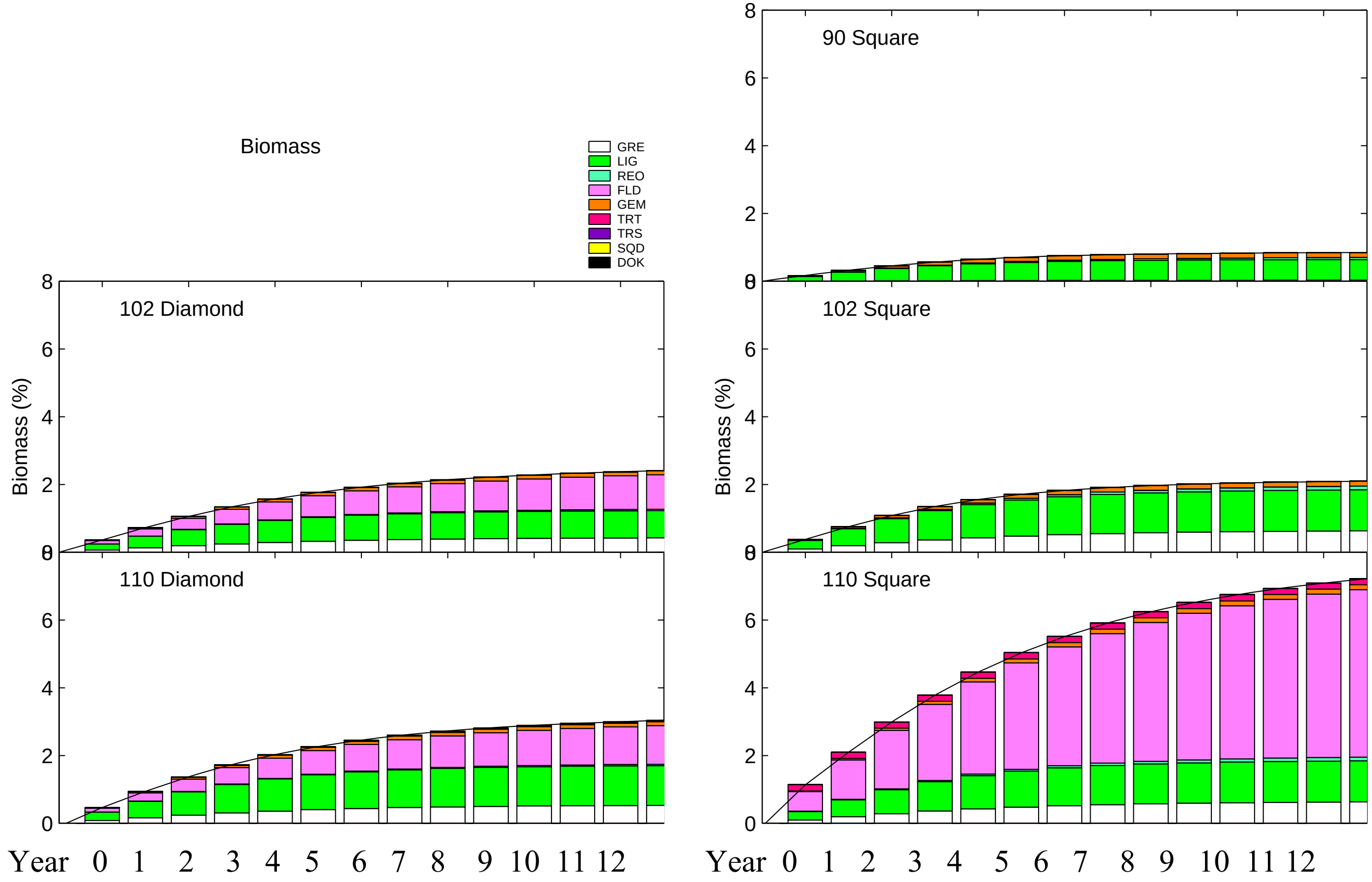
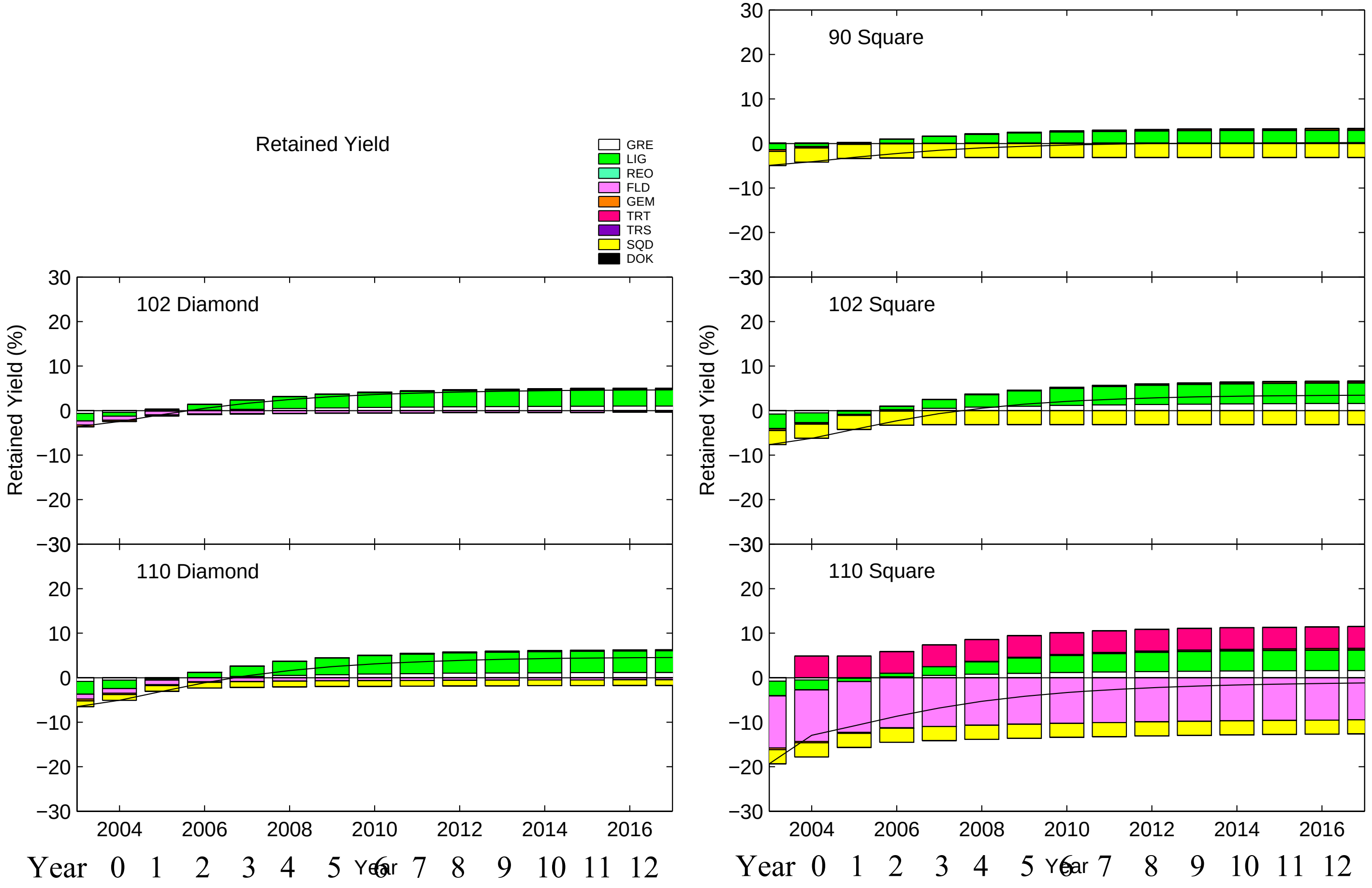
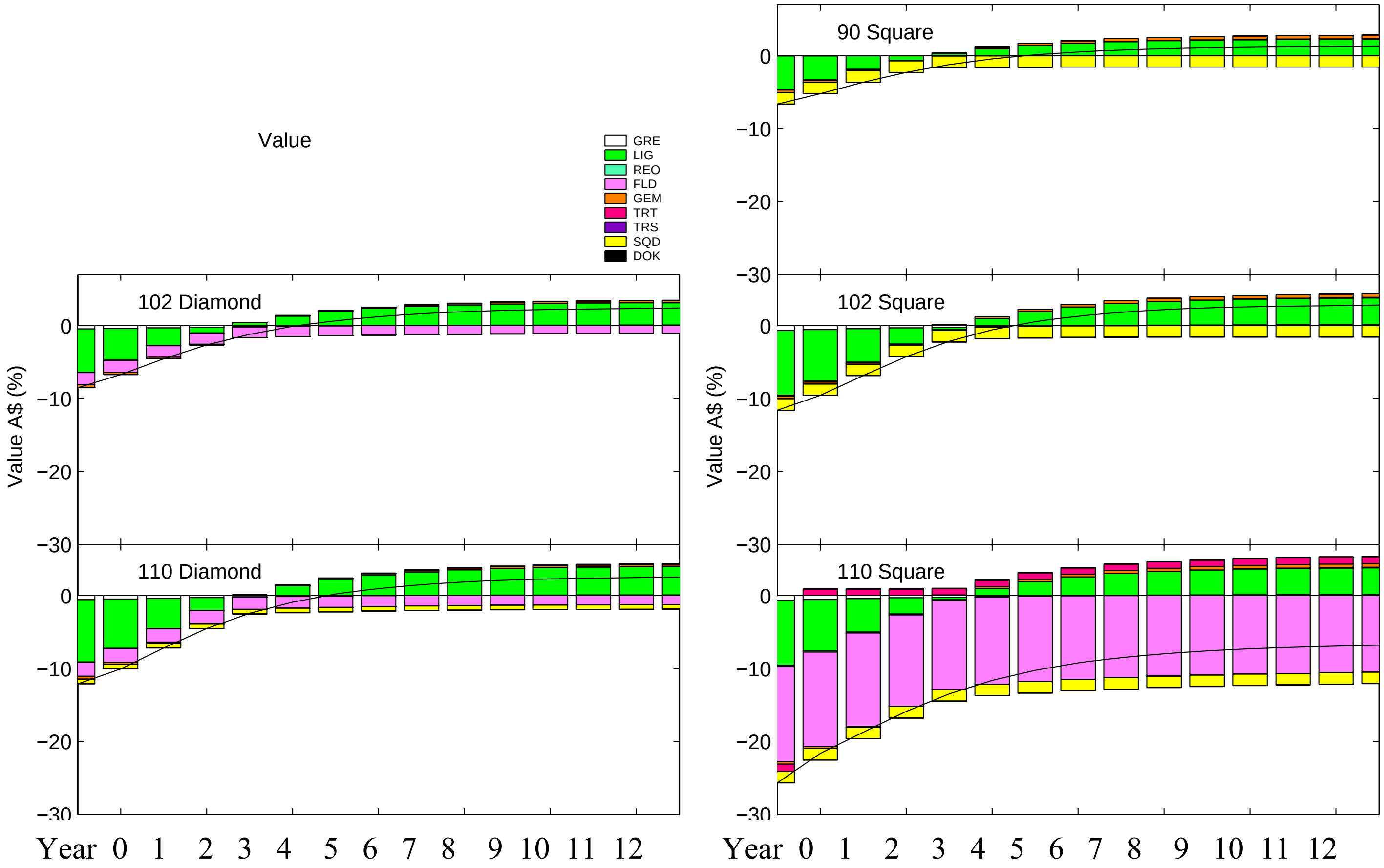


Figure 8-3 Effect on the fishery of changing to a modified gear type in the East. The difference in (i) stock biomass, (ii) retained yield, (iii) value of the catch, and (iv) discards for each gear type obtained by subtracting that for the standard gear. Results are shown for all species combined but note that some species will be missing from some plots because gear selectivities were not available for all combinations of species and gear.


Biomass
GRE
LIG
REO
FLD
GEM
TRT
TRS
SQD
DOK
90 Square
102 Diamond
102 Square
110 Diamond
110 Square
Biomass (%)
Year 0 1 2 3 4 5 6 7 8 9 10 11 12


Retained Yield
GRE
LIG
REO
FLD
GEM
TRT
TRS
SQD
DOK
90 Square
102 Diamond
102 Square
110 Diamond
110 Square
Retained Yield (%)
30
20
10
0
−10
−20
−30
2004
2006
2008
2010
2012
2014
2016
Year
Year 0 1 2 3 4 5 6 7 8 9 10 11 12


Value
GRE
LIG
REO
FLD
GEM
TRT
TRS
SQD
DOK
90 Square
102 Diamond
102 Square
110 Diamond
110 Square
Value A$ (%)
0
−10
−20
−30
Year 0 1 2 3 4 5 6 7 8 9 10 11 12

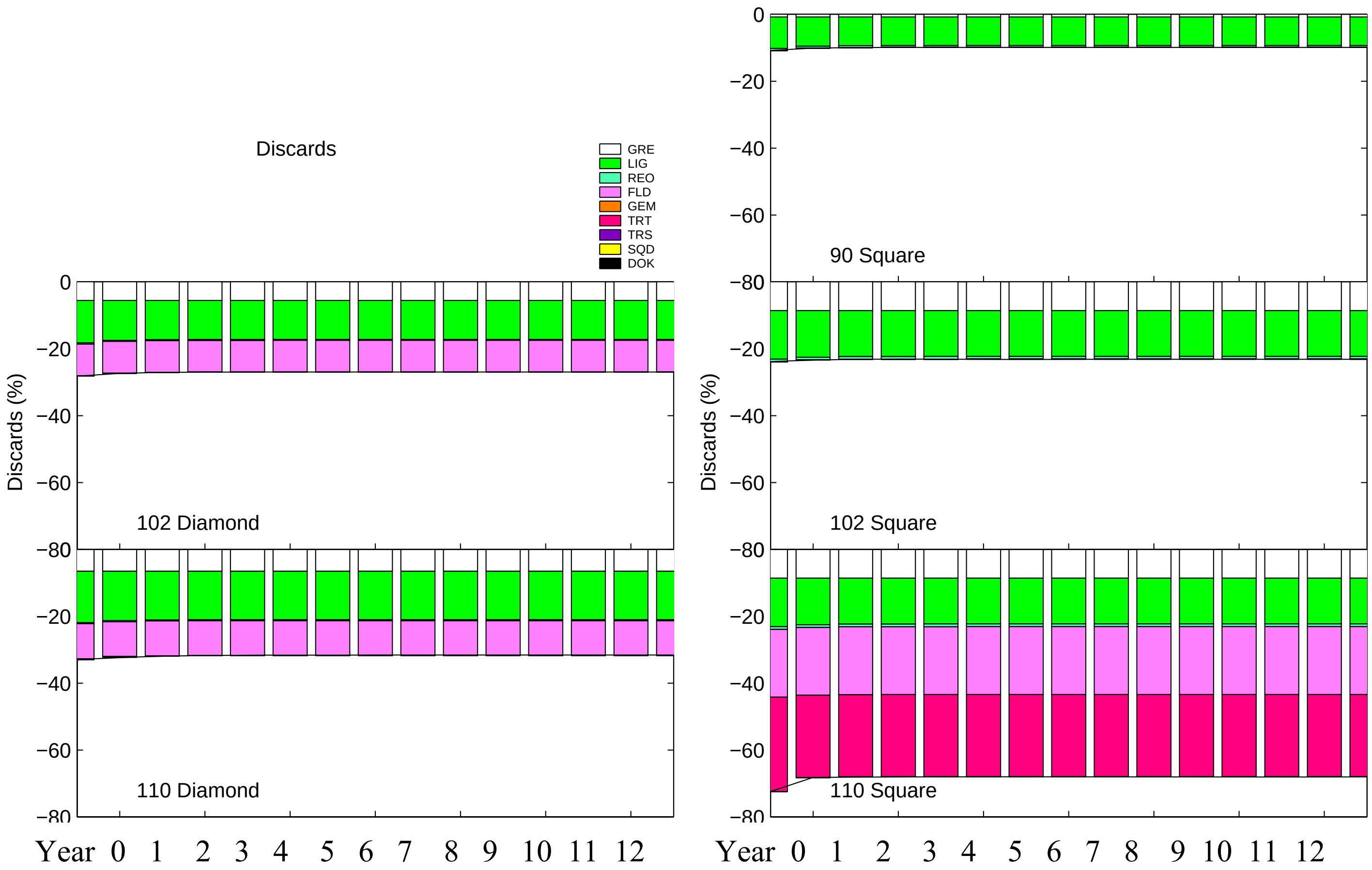
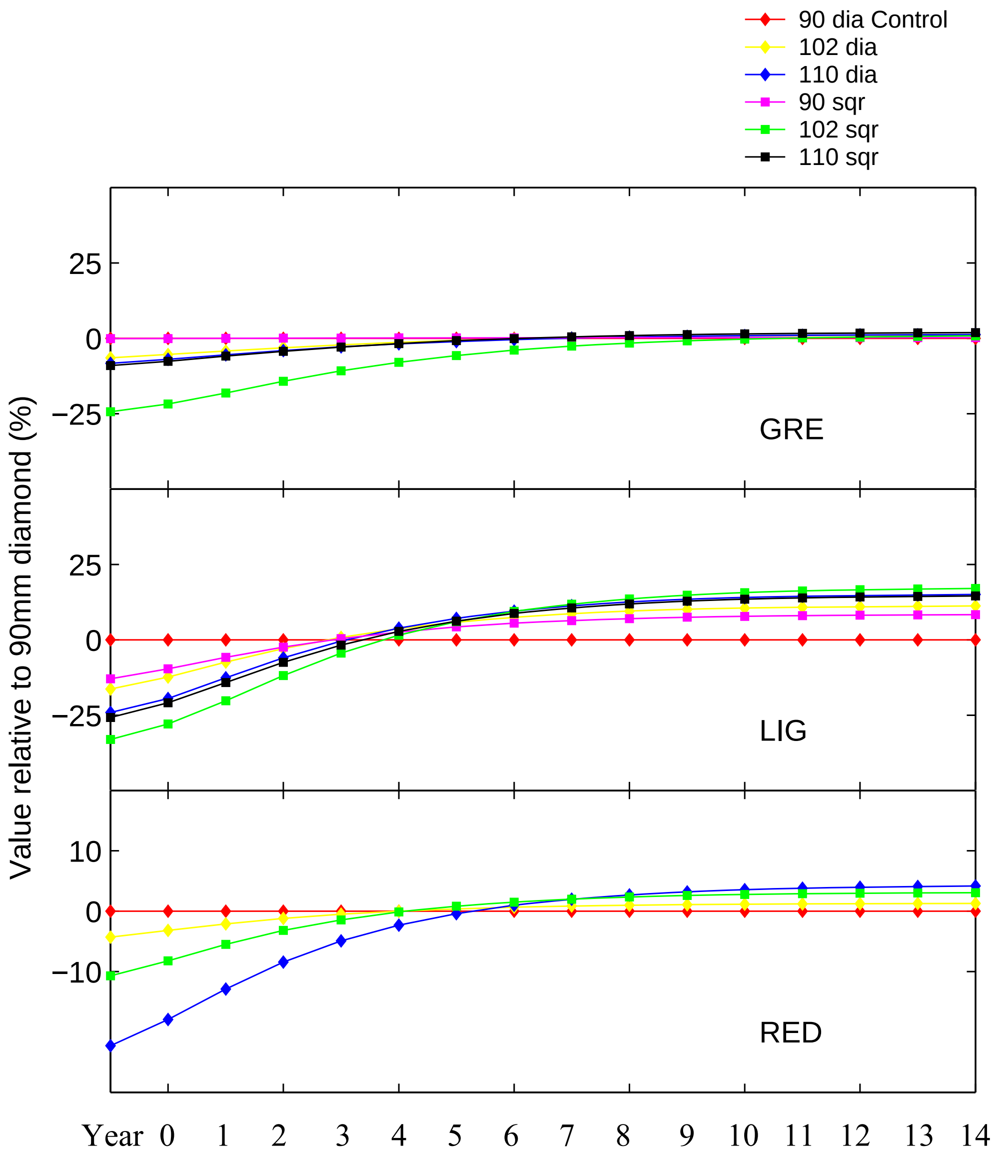
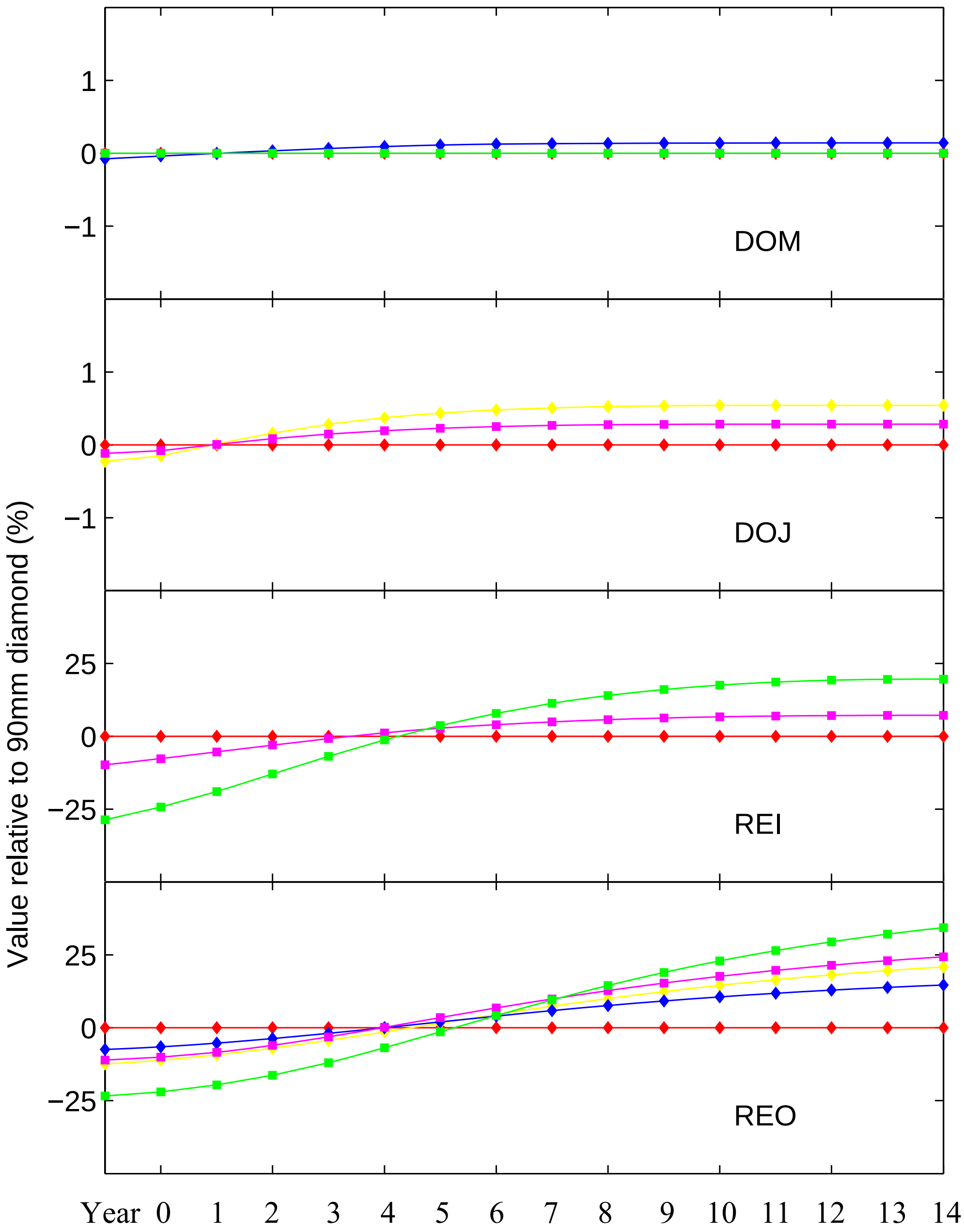


Figure 8-4 Effect on the fishery of changing to a modified gear type in the West. The difference in (i) stock biomass, (ii) retained yield, (iii) value of the catch, and (iv) discards for each gear type obtained by subtracting that for the standard gear. Results are shown for all species combined but note that some species will be missing from some plots because gear selectivities were not available for all combinations of species and gear.


90 dia Control
102 dia
110 dia
90 sqr
102 sqr
110 sqr
Value relative to 90mm diamond (%)
25
0
−25
GRE
25
0
−25
LIG
10
0
−10
RED
Year 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14


Value relative to 90mm diamond (%)
1
0
−1
DOM
1
0
−1
DOJ
25
0
−25
REI
25
0
−25
REO
Year 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

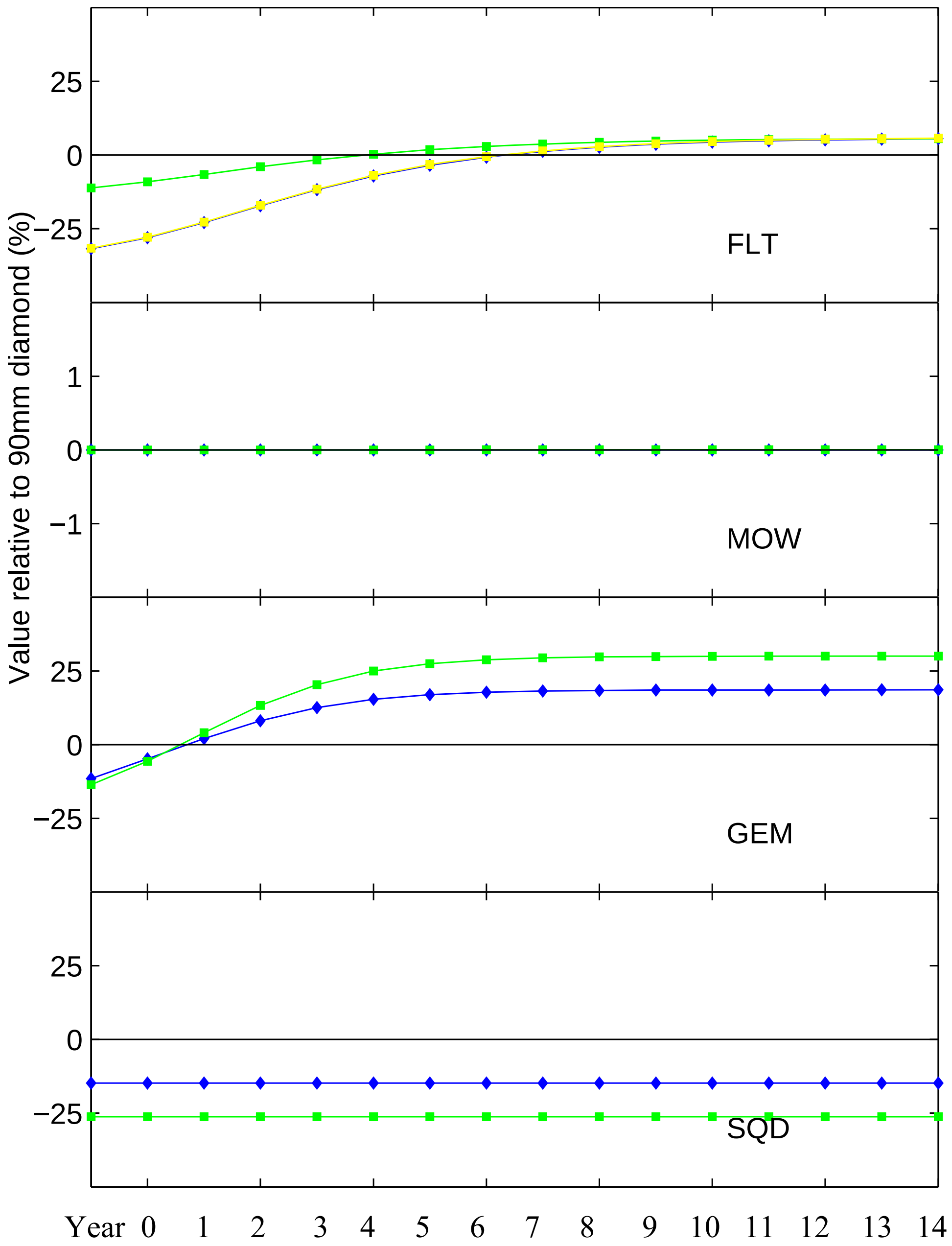
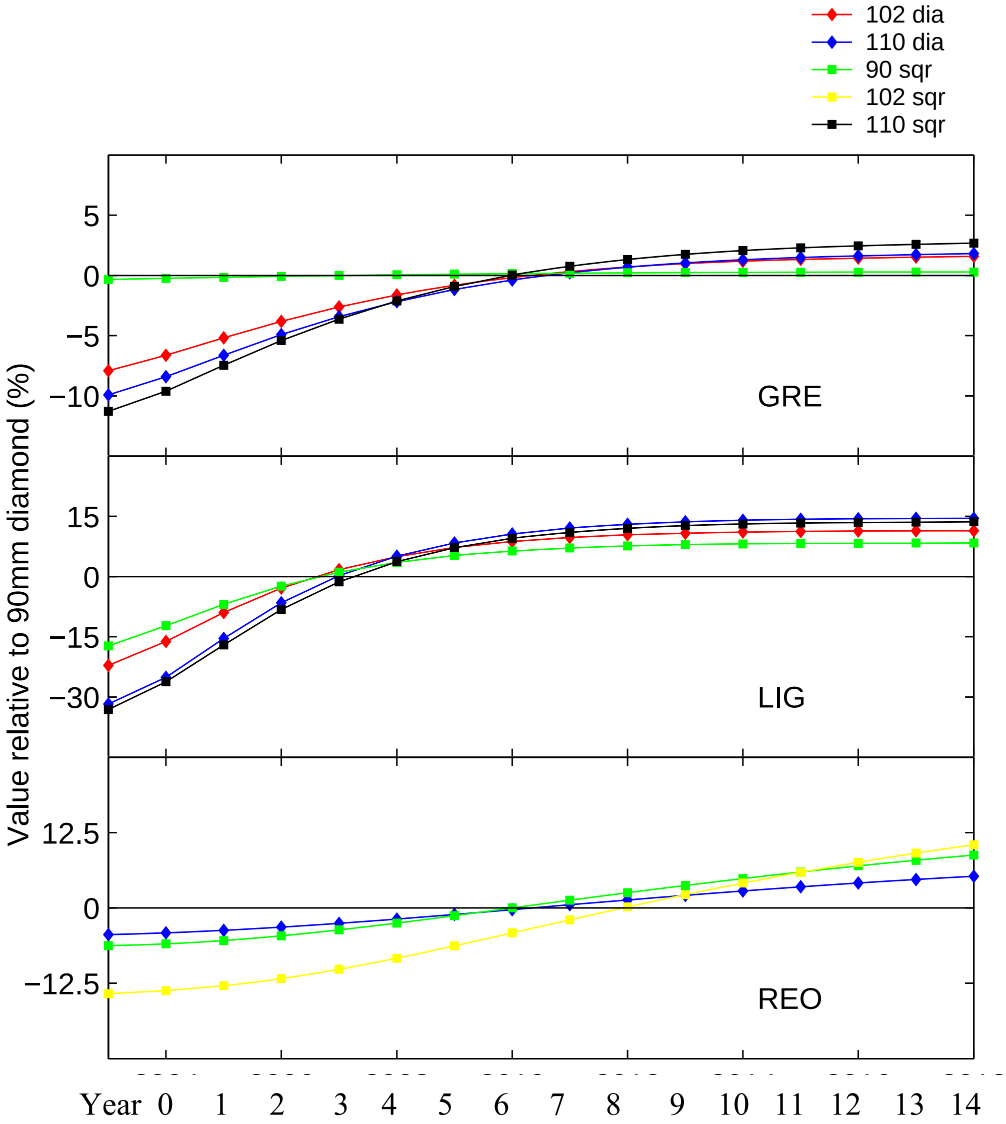
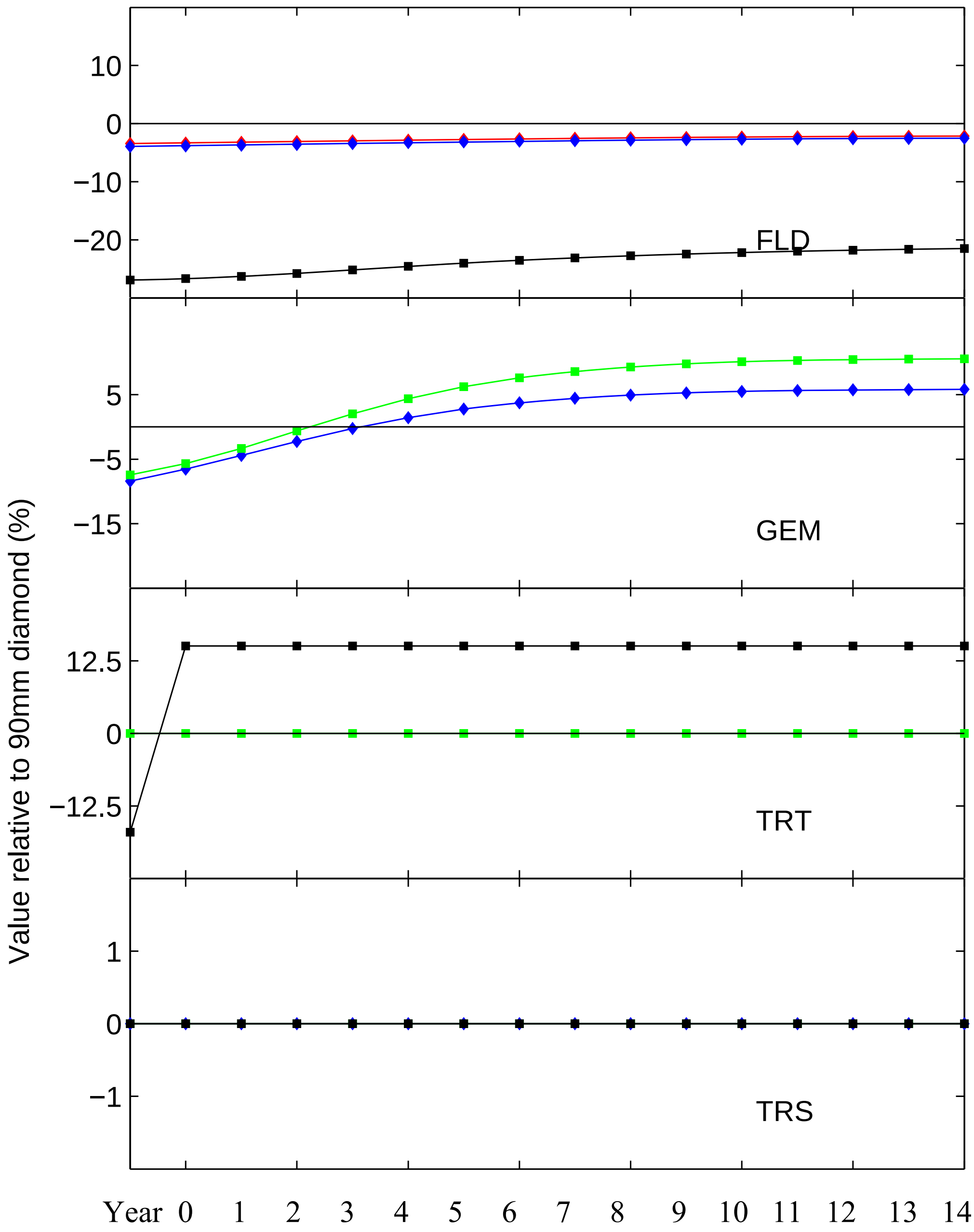


Figure 8-5 Figure 7a. Estimated difference in value of future catches under steady future effort for all species for each of the modified gears in the East. The value of the catch using 90 mm diamond standard (control) gear is subtracted from the value for each modified gear.


102 dia
110 dia
90 sqr
102 sqr
110 sqr
Value relative to 90mm diamond (%)
5
0
−5
−10
GRE
15
0
−15
−30
LIG
12.5
0
−12.5
REO
Year 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14



Value relative to 90mm diamond (%)
10
0
−10
−20
FLD
5
−5
−15
GEM
12.5
0
−12.5
TRT
1
0
−1
TRS
Year 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

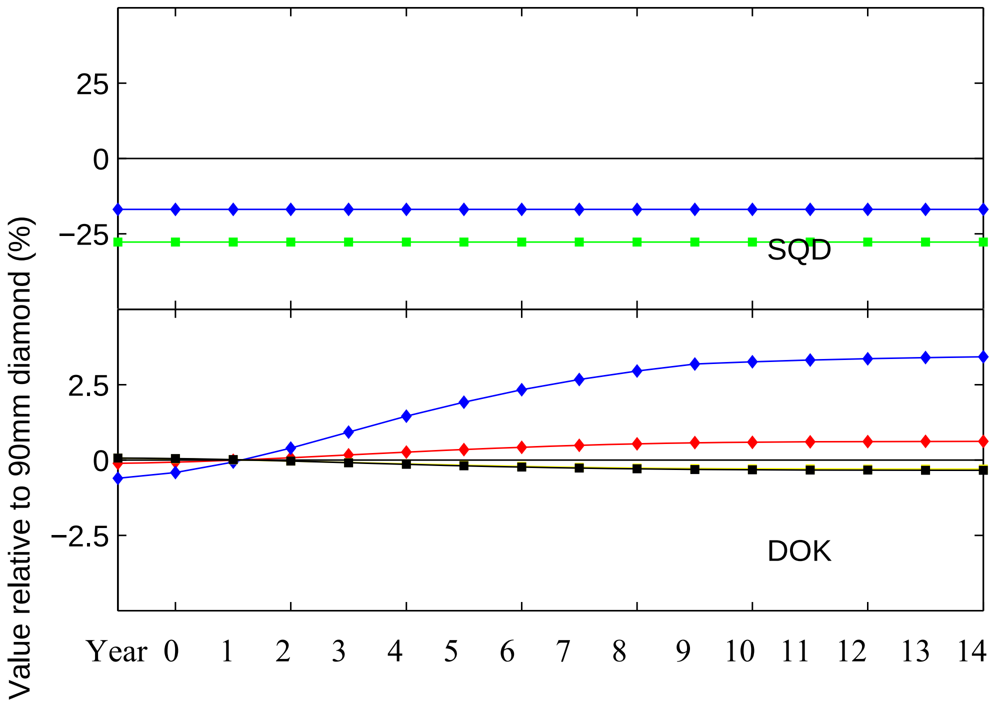


Figure 8-6 Estimated difference in value of future catches under steady future effort for all species for each of the modified gears in the West. The value of the catch using 90 mm diamond standard (control) gear is subtracted from the value for each modified gear.

9 EXTENSION

Over recent years, greater emphasis has been placed on the importance of a good extension program to support and communicate the information obtained in fisheries research projects (e.g. Kennelly 1997). A number of methods of relaying the project results to industry and wider stakeholder groups were deployed in the current project. One of the primary methods was to include the president of the peak industry body, the South East Trawl Fishing Industry Association (SETFIA) as a co-investigator in the project. Also, all of the research was conducted on industry vessels, so there was direct observation of the results of the covered codend and trouser trawl experiments by the skippers and crews of both vessels. Furthermore, the interest (and initial scepticism) generated by the project meant that crews of other vessels in the port discussed the work we were undertaking with both the research officers and crews involved in the project.

Apart from the industry liaison carried out by those directly involved in the project, we also tapped into a fishing industry extension service offered by “SeaNet”. SeaNet is a service for the Australian seafood industry that aims to provide easy access to information and advice about environmental best practice in our commercial fisheries. The service operates under the umbrella of the Fisheries Extension Network Australia (FENA) and is a coalition of the Australian Seafood Industry Council, the Australian Marine Conservation Society and OceanWatch Australia Ltd. The SeaNet extension officer helped to convey the project results to industry members not directly involved in the project and wider stakeholder groups.

In addition to the “one-on-one” communication provided by the researchers and extension officer, a newsletter was produced to communicate the objectives and results of the project to other industry members and stakeholder groups. The initial newsletter outlined the need for bycatch reduction in the fishery and the background to the project. It also introduced the project participants and highlighted that the research was being undertaken on industry vessels. Subsequent newsletters provided updates of the progress of the project and results of the covered codend and bycatch reduction work.

The final method of “letting the message get through” involved the production of a short video; a method that has proven successful in similar studies of other fisheries (Kennelly pers. comm.). Extensive video footage was collected while the covered codend experiments were being undertaken. This included footage of normal on-deck procedures as well as underwater footage of the operation of the covered codend and the behaviour of fish species encountering this gear. Further details of the underwater video equipment are given in Eayrs and Piasente (2000). At the end of the covered codend experiments, the footage was edited and a short video was produced. Like the initial newsletter, the video outlined the need for bycatch reduction in the fishery and provided the background to the project. It also conveyed general results of the covered codend experiments and indicated the future work that would be undertaken on gear modification to reduce bycatch in the fishery.

All parties associated with the project agree that direct industry participation in the research has ensured the success of the project regardless of the outcomes with respect to bycatch reduction. That the participation has occurred at two levels — with an industry member as co-investigator and with all research being undertaken on industry vessels — has been crucial for the overall acceptance of results.

At the higher level, the industry co-investigator has ensured that the direction and objectives of the bycatch reduction research were relevant to the needs of the fishery and were well aligned with other broad level strategic research being undertaken. This was also ensured through initial project evaluation by the South East Fishery Assessment Group and the South East Trawl Management Advisory Committee, both of which have participants from research, management, industry and environmental stakeholder groups. Furthermore, at a workshop held prior to project initiation, these stakeholders discussed the fishery's bycatch issues and focussed the project objectives on the most important issues (the discarding of small fish) and emphasised that gear modifications solutions should be augmented with options such as management changes and different types of bycatch utilisation.

By conducting the project on industry vessels, a more "hands-on" cooperation between industry members and project scientists has developed. The results of this have been evidenced in a number of different (and often unexpected) aspects of the project. One of the first to emerge was how the project handled the sale and quota management of fish. Sixteen of the species caught in the fishery, accounting for 90% of the value of the catch (Smith and Wayte 2000) were under Individual Transferable Quota (ITQ) management at the time of the project and, as the fishery moved towards the introduction of Statutory Fishing Rights, Industry was adamant from the outset that, in principle, additional quota should not simply be "made available" for the project above the allocated Total Allowable Catches (TACs). It was not introduced because catches were close to the TAC and therefore limiting quota availability. As such, it was agreed that catch of quota species during the project should be covered within the ITQ system and leased at market price from quota holders with first option given to the charter vessels. Another advantage of this system was that the quota holdings of the charter vessels, tailored to suit their annual fishing operations, would suffer minimal disruption by undertaking the charter. Because funding by the Fisheries Research and Development Corporation (FRDC) only covered half of the charter costs; the other half was met by proceeds from the sale of the fish caught during the project. These proceeds also covered costs of quota lease, icing, freighting and selling the fish.

The adoption of this system meant that the scientists became more aware of the need and practicalities of commercial aspects of fishing, and industry realised the costs (time and money) associated with correct scientific methods (e.g. replicated shots, unbiased sampling, data collection). Overall, this method of handling the quota and sale of fish has proved very successful, both in practice and in demonstrating that if scientists and industry are willing to work together, effective solutions to problems can be achieved. The reason for highlighting this aspect of the project was that it set the scene for future communication in the project and provided the first example of the real value in “letting the message get through”.

The next main message from the project was the size-selectivity (Knuckey *et al.* 2000) and escapement of fish from standard trawl codends (present study). The results of this research were presented to various stakeholder groups in a number of different forms. Of these, the production of a short video has probably been the most successful means of letting the message get through to the widest range of stakeholders. The wide access to video equipment (nearly all CTS vessels have video) and the ease by which people from a range of different backgrounds can assimilate information from this media ensured a high demand for copies of the video. The video was presented to large audiences at the launch of the SETFIA Code of Conduct by the Federal Minister and at the AFMA Environment Committee. Following these presentations, copies were requested by the Assistant Secretary of Environment Australia, the Director of Traffic Oceana, the Australian Conservation Foundation, numerous industry representatives and a number of public organisations (maritime museums, educational facilities etc). Overall, people believed the video provided an enlightening description of the bycatch issues facing the CTS and the ways they are being addressed.

The only real “scientific” information presented in the video was the graphs of weights and numbers of fish escaping from the codend (Figure 5-2) but the footage associated with this —

the cover full of small fish being emptied onto the deck and codend containing a mix of larger species — brought the message home in a far more effective manner. Elsewhere, the video presented footage of normal commercial fishing: fish being landed on the deck, sorted, discarded, or stored, unloaded and sold at the markets; and a significant amount of underwater footage showing fish being caught and escaping from trawl nets. Different aspects of these images captured the attention of different stakeholder groups: the general public and others not directly involved in the fishery (e.g. environmental groups) were interested in the general operations of the trawl fishery and how it was dealing with bycatch and discarding issues; fishery managers were eager to portray the work that was being undertaken with respect to ecologically sustainable development in the fishery; and fishers were particularly keen to view the video to see how fish behaved to trawl gear. Regardless of what attracted these people to view the video, it was through this attention that the underlying message of the video — the need for bycatch reduction in the fishery and the work we are doing to achieve this — was put across. Despite the success of the video in many respects, it did not meet the requirements of all stakeholder groups. Although the video had been produced months earlier, it was not until the results of the selectivity work was presented in one of the newsletters that a scientist not involved in the project commented “It is about time some real results came out of that project”. Thus, the importance of using different media to extend the results of the project was highlighted.

One of the most interesting and rewarding aspects of getting this information out to the different stakeholder groups was the change in attitudes that resulted, and the fact that, in general, most of the feedback from has been positive. A few examples from the different stakeholder groups are provided.

With increasing concerns about the ecological impacts of trawling and the general perception that trawls caught everything in their path, it was understandable trawl fishers were very concerned about the repercussions of releasing monitoring information that showed the extent of discarding in some parts of the fishery. Through their pro-active involvement in a project designed to reduce discarding in the fishery, industry gained a stronger position through which they could answer some of the criticisms being aimed at the fishing method. Furthermore, the results on fish escapement obtained by the project painted a far more realistic picture of what was actually occurring in fish trawls. Whilst trawling can not be generally considered the most selective of fishing methods, and “market fishing” in the CTS will probably never catch only targeted species, the high levels of escapement of some species from standard trawls indicated a higher level of selectivity towards larger fish than was generally perceived. This alone meant that the fishery was not "starting from scratch" with respect to improving selectivity and reducing levels of bycatch. This provided further encouragement for industry members to work towards the objectives of the project in a positive manner.

One of the most obvious change in attitudes has resulted from the "hands on" work conducted between scientists and industry on the industry vessels. The benefits of conducting gear modification research on industry vessels are well recognised (Kennelly and Broadhurst 1996) and many recent research projects in Australia have operated in this manner (e.g. Broadhurst and Kennelly 1994; Broadhurst *et al.* 1999b; Gray *et al.* 2000). Not only can it be a cheaper option than maintaining and operating a specialised research vessel, such a process utilises the local knowledge of the fishers, provides standard gear against which modifications can be tested, and ensures the interest and involvement of the rest of the fleet (Kennelly 1997; Kennelly and Broadhurst 1996). In the present project, industry and scientists have definitely benefited from a better understanding of the other. This statement does not mean to imply that this process has not had its problems, there have been many instances where arguments and misunderstandings have needed to be resolved. But, the process itself, and the outcomes in terms of understanding and collaboration, have been positive. This has also been extended to the wider industry, not just through the formal extension services offered by SeaNet, but through informal talks (often over a cold beer) with other fishermen in the port or interested onlookers. Importantly, the resulting benefits of this process are not restricted to within the project. The mutual respect and understanding that has developed is pervading the many other forum where industry and scientist must work closely together.

The other apparent change in attitude has been amongst the environmental groups (both government and non-government) involved in the fisheries area and the general public. Most have had little, if any, first-hand experience working with trawlers. The video has provided an insight into trawling in the CTS and a general understanding of the bycatch and discarding issues in the fishery. Moreover, they now have evidence that trawling is not entirely non-selective, and that work is being done to improve the selectivity and reduce discarding. With this knowledge, we have noticed that individuals are more willing to be involved in the process of working with industry to help improve the situation, rather than just remaining outside the process and being critical.

10 BENEFITS AND ADOPTION

This report describes the results of escapement from standard trawls and highlights how the extension of these results to industry and wider stakeholder groups has resulted in positive changes in attitudes to bycatch reduction in the fishery.

Robust fisheries stock assessments requires the input of estimates of variables such as growth rates, fishing effort and selectivity. Selectivity estimates were lacking for some CTS quota species, and there was a need to gain such information. Covered codend experiments provided an opportunity to calculate values for 90 mm diamond double braid codends for a number of common quota and bycatch species. These data were passed on to stock assessment scientists.

Video observations of fish behaviour revealed that different species behave in a variety of ways in response to trawl gear, and that behaviour varies according to their location in the net. Interspecific variation in escape response related to swimming behaviour could be utilised in designing more selective trawl gear. In this way, capture of commercial target species could be increased and the capture of unwanted species, including undersized commercial species reduced.

Comprehensive extension of results of this research was been recognised as an essential part of the project. Various methods of “letting the message get through” to a range of different stakeholders were trialled and evaluated, and one of the most important of these was that the research was designed and conducted with full industry collaboration. Use of video footage was also been very successful, both as a mechanism to explain the need for bycatch reduction in the fishery and to help breakdown the wider community’s pre-conceived ideas about CTS bycatch issues. 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.

11 FURTHER DEVELOPMENT

If gear modifications are designed to reduce the capture of non-marketable fish species rely on behavioural differences between the targeted and non-targeted fish species, then further work is required to establish the specific factors that trigger particular behaviours. This would allow more refined modifications to be made that reduce unwanted losses of commercially valuable fish.

As the focus on reducing bycatch increases, and new gear technologies are developed, there is an increasing need to assess their effectiveness. This project has set a precedence in the CTS for such projects to be conducted, with close cooperation and support from Industry. Two recent examples are trials of a ‘high lift net in the CTS (Koopman *et al.* 2009) and a T-90 net in the Great Australian Bight Trawl Fishery (Knuckey *et al.* 2008).

Realised benefits to fish populations through increased escapement resulting from changing codend mesh size or shape depend entirely on survival rates of escapees. While this has not been quantified in the CTS, suitable methods are available (e.g. Lehtonen *et al*. 1998; also see Broadhurst *et al.* 2006b and references therein).

12 PLANNED OUTCOMES

This project has highlighted the potential benefits of modifying trawl gears to reduce discarding in the CTS. Since this project, SESSF operators have been proactive in the trial of gear modifications to reduce bycatch (e.g. Knuckey *et al.* 2008; Koopman *et al.* 2009), and many modified gears are routinely used in everyday fishing practices. SETFIA have realised the benefits demonstrated in this project and state in their Code of Practice “Selective fishing gear and practices shall be further developed and applied in order to foster biodiversity and the population structure and to conserve ecosystems and fish quality.”

Quantifying the effects of potential gear changes on discards is difficult because of the numbers of confounding factors influencing discarding (i.e. stock abundance/availability, market influence and quota availability to name a few), and the lack of detail of gear modifications in logbook and observer records, however gross comparisons of changes in discards over time do show declining patter. During 2000 and 2001, an average of 1,854 t of quota species and 13,232 t of non-quota species were discarded by the CTS (see Knuckey *et al.* 2001 and Knuckey *et al.* 2002), while during 2005 and 2006, the average weight of quota and non-quota species discarded were 1,386 t and 11,406 t respectively (see Koopman *et al.* 2006 and Koopman *et al.* 2007). It is expected that at least some of this reduced discarding of observed is due to modifications to gears that were made as an outcome of this project.

13 CONCLUSION

13.1.1 Net selectivity

The first phase of the project was to undertake covered codend experiments to determine the selectivity of standard trawl codends. There was a need to gain this type of information for stock assessment of CTS quota species (Cui *et al.* 2001). While conducting the selectivity research, we were also able to quantify the number and weight of organisms that escape from these trawls. This paper reports the results of escapement from standard trawls and highlights how the extension of these results to industry and wider stakeholder groups has resulted in positive changes in attitudes to bycatch reduction in the fishery.

Small-mesh codend covers were placed on standard commercial nets used in the CTS. The quantity and species composition of organisms caught in the cover was compared to that in the codend. About 70% of the organisms in the total catch escaped through the codend and were caught in the cover; this represented about 30% of the catch by weight. The codend catch consisted mainly of teleosts (79% by weight), elasmobranchs (15%), cephalopods (4%) and crustaceans (2%). In contrast, nearly all (96%) of the cover catch consisted of small teleosts, the most common of which were small non-commercial species including toothed whiptails, grey whiptails, threespine cardinalfish and blacktip cucumberfish. Only low proportions of crustaceans (2%), cephalopods (1%) and elasmobranchs (1%) were in the cover. Although quota species only comprised 7% of the weight of fish caught in the cover, this was evidence that some of these species (ocean perch, gemfish, flathead, pink ling and redfish) were escaping through the codend. The implications of these results for management of the fishery and implementation of the Bycatch Action Plan are discussed.

13.1.2 Fish behaviour

In situ examination of the swimming behaviour of commercially important fish species was undertaken with underwater cameras positioned at various locations on demersal trawl gear employed in the CTS. Behavioural categories quantified included various swimming states and velocities within sections of the trawl net revealing differences among and within the species examined. Sources of variation in swimming behaviour included net position (mouth, body, extension and codend) and species.

Blue grenadier, pink ling and whiptail species were observed to swim in an anguilliform mode in which the posterior half of the body is flexed laterally. All other species observed were seen to have a carangiform swimming mode where the posterior portion of the body and tail oscillate. Tiger flathead and ocean perch were found to show high activity response to the trawl net compared with generally passive activity in whiptails, New Zealand dory, and jackass morwong. However, when in the body of the trawl, gemfish were seen to be most active with generally passive activity shown for ocean perch, whiptails and New Zealand dory.

Some blue grenadier, ocean perch and whiptails escaped capture by passing through open mesh in the trawl mouth whereas tiger flathead were seen to pass under the ground gear. In the trawl body small numbers of blue grenadier were observed passing through open meshes in the top panel whereas large numbers of silver warehou were observed swimming faster than the tow speed, presumably escaping capture by swimming forward of the trawl path. Interspecific variation in escape response related to swimming behaviour could be utilised in designing more selective trawl gear. In this way, capture of commercial target species could be increased and the capture of unwanted species, including undersized commercial species reduced.

13.1.3 Bycatch reduction

Ways of reducing discards were investigated by testing codends constructed of different mesh sizes and/or shapes against the standard (control) 90 mm diamond mesh codend using trouser trawl experiments. Four different configurations were trialled off Bermagui and off Portland, and the differences in the catch composition and size frequency quantified. Before experimental codends were trialled, the trouser trawl was extensively tested both in the flume tank and at sea reduce potential biases. Initial flume tank tested revealed a narrowing of the extension sections at their centres. To avoid possible problems with blockage, the 33 mesh extensions were reduced to 16 meshes in length, and 20 mesh sections of lighter material (2.5 mm diameter) substituted at the back of the trouser. No significant differences in flow between the sides of the trouser were detected which supported the visual observation that the trouser construction was symmetrical.

Despite the apparently symmetrical shape of the trouser trawl, catches were consistently biased to one side during initial sea tests. A video camera mounted in various positions in the net failed to show any twisting, blockage or lack of symmetry. The bias in the catch to one side of the trouser was effectively rectified by a relatively minor change to the rig which reduced the differences between the codends to within normal experimental variability. This was achieved by joining the legs and extension sections of the trouser based on the experience of the fishers involved in the project.

Increasing mesh size and/or using square mesh reduced catches of many species, particularly small non-commercial species, but also in some cases of discarded and retained commercial species. Impacts on commercial retained catch were particularly evident in deepwater off Bermagui, in particular of pink ling, Gould's squid and offshore ocean perch.

Spatial variability in performance of modified codends was observed. Modified codends, and in particular the 110 mm diamond codend, greatly reduced catches of non-commercial and commercial discards in shallow water off Bermagui but also resulted in a significant reduction of commercial retained catches. Use of larger mesh gear had a lot less impact in deep water. The 90 mm square codend was the only test mesh to reduce the weight of discards, but not of commercial retained catch in deep water off Bermagui. Although producing a long-term improvement in yields, catch value and stock biomass, all of the test gears resulted in an initial drop in catch value in the east. For 90 square and 102 diamond, this was only about a 5% drop but for the larger mesh configurations it was about a 15% loss. The catch value was not predicted to return positive figures until a 4-6 year time horizon.

Apart from the 110 mm diamond codend, none of the test codends affected the weight of catches of commercial retained species off Portland in either shallow or deep areas sampled, but they also had little impact on reducing discards of commercial species. Only the 102 mm diamond and 110 mm square codends reduced the weight of catches of commercial discards off Portland. All test codends (apart from the 102 mm square codend fished in shallow water) did however reduce the numbers of non-commercial discards.

Modelling showed that there was an initial decrease in the value of retained catches using the test codends, but in most cases, the value returned to and bypassed the reference level, resulting in an overall long-term improvement in catch value. Off Bermagui, the greatest improvement in overall catch value was observed for 110 mm diamond codend which increased to about 4% above the reference level. This increase was largely due to an increase in the value of pink ling and tiger flathead, and a comparatively small decrease in value of Gould's squid catches. Off Portland, both the 110 mm diamond and 102 mm square resulted in a 3% increase to catch value, both due to large increase in the value of pink ling catches. The 110 mm square codend was the only test mesh that resulted in a long-term decrease in catch value. Importantly, all discards of commercial species would be significantly reduced using any of the test codends.

Extension of this project was carried out through a number of channels. A SeaNet extension officer and published newsletter helped to convey the project results to industry members not directly involved in the project and wider stakeholder groups. Extension of results was enhance by the production of a short video that was distributed to stakeholders. Probably the most important and unexpected aspect of extension of this project occurred through collaborating with industry. Being involved in the research, and seeing the results for themselves, industry members conveyed their observations to their peers leading to a greater knowledge and acceptance of results.

13.1.4 Potential for adoption

At the time that the result of this project became available for industry, the CTS was in difficult financial times. Costs were increasing due primarily to increasing fuel prices and repairs and maintenance costs for the ageing fleet. In addition, operators faced stable or falling real prices of fish and reductions in TACs were being implemented. The cost of management levies, quota leasing costs and other non-fishing regulatory costs such as workers compensation and payroll tax exacerbate the situation. In 2001/02, the GVP of the fishery was about $70 million, but net returns to industry were only $0.5 million, yet it was under significant pressure to improve its ecological credentials.

Given the above, it was a very difficult time for industry to accept the need for codend modifications to reduce bycatch that would come at an initial cost in lost value of the catch, regardless of the fact that there were potential long-term gains in stock biomass, yield, and catch value. Immediate implementation of such measures would have had significant financial implications for many fishing businesses. It was acknowledged that there was a definite need for uptake, but a lot of work needed to be done with industry to facilitate this. As a result, FRDC supported a project 2001/006 – Promoting industry uptake of gear modifications to reduce bycatch in the South East Trawl Fishery. Through this project and ongoing work by SETFIA, larger and/or rotated mesh panels were introduced into most trawls in the SESSF and were ultimately mandated.

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15 APPENDIX 1: INTELLECTUAL PROPERTY

There is no intellectual property associated with this project.

16 APPENDIX 2: STAFF

Name	Organisation	Project Involvement
Ian Knuckey	Fishwell Consulting	Principle Investigator
Gail Richey	SETFIA	Co-Investigator
Xi He	CSIRO	Co-Investigator
Steve Eayrs	AMC	Co-Investigator
Ken Graham	NSW Fisheries	Co-Investigator
Crispian Ashby	Fisheries Research Branch (Fisheries Victoria)	Field scientist
Matt Piasente	AMC	Field scientist
Sally Wayte	CSIRO	Modelling
Robin Thompson	CSIRO	Modelling

17 APPENDIX 3: LOG OF CAMERA POSITION IN DEMERSAL TRAWL NETS

Table 17-1. Camera systems used and their position and direction during footage collection of fish behaviour within demersal trawl nets off Portland and Bermagui. Camera system B* denotes camera system B arrangement 2.

Date	Region	Location	Camera system	Ave. depth (m)	Camera position	Camera direction	Start time recording	End time recording	Total record time (min)
26/08/1999	Bermagui	Codend	A	90	Centre of top panel	Aft	12:30	14:00	90
28/08/1999	Bermagui	Codend	A	270	Centre of top panel	Forward	12:00	13:30	90
17/11/1999	Portland	Codend	B	320	Centre of top panel	Aft	1:00	1:30	90
19/11/1999	Portland	Codend	B	215	Centre of top panel	Aft	6:30	8:00	90
01/09/1999	Bermagui	Extension	A	414	Centre of top panel	Aft	12:30	14:00	90
09/10/2001	Portland	Extension	B*	327	Centre of top panel	Forward	21:00	0:00	180
10/10/2001	Portland	Extension	B*	360	Centre of top panel	Forward	1:15	4:15	180
10/10/2001	Portland	Extension	B*	657	Centre of top panel	Forward	6:20	9:20	180
10/10/2001	Portland	Extension	B*	630	Centre of top panel	Forward	12:45	15:45	180
12/03/2000	Portland	Body	B	450	Centre of top panel	Aft/down	12:00	15:00	180
16/03/2000	Portland	Body	B	198	Centre of top panel	Aft/down	7:45	10:45	180
17/05/2000	Portland	Body	B	432	Centre of top panel	Aft/down	16:40	19:40	180
18/06/2000	Portland	Body	B	450	Centre of top panel	Aft/down	12:00	15:00	180
18/06/2000	Portland	Body	B	450	Centre of top panel	Aft/down	16:00	19:00	180
19/06/2000	Portland	Body	B	216	Centre of top panel	Aft/down	7:00	10:00	180
19/06/2000	Portland	Body	B	306	Centre of top panel	Aft/down	11:00	14:00	180
19/06/2000	Portland	Body	B	468	Centre of top panel	Aft/down	15:30	18:30	180
17/11/1999	Portland	Mouth	B	432	Centre of headline	Aft/down	11:00	14:00	180
11/03/2000	Portland	Mouth	B	378	Right wingend	Forward/down	12:00	15:00	180
11/03/2000	Portland	Mouth	B	450	Right wingend	Forward/down	7:30	10:30	180
15/03/2000	Portland	Mouth	B	288	Left wingend	Centre of mouth	8:00	11:00	180
15/03/2000	Portland	Mouth	B	648	Left wingend	Centre of mouth	15:30	18:30	180

Date	Region	Location	Camera system	Ave. depth (m)	Camera position	Camera direction	Start time recording	End time recording	Total record time (min)
16/03/2000	Portland	Mouth	B	468	Right wingend	Aft	12:15	15:15	180
17/03/2000	Portland	Mouth	B	198	Centre of headline	Aft/down	7:00	10:00	180
18/05/2000	Portland	Mouth	B	360	Centre of headline	Aft/down	10:30	13:30	180
14/06/2000	Portland	Mouth	B	450	Right wingend	Forward/down	14:00	17:00	180
13/12/2000	Bermagui	Mouth	B	90	Centre of headline	Aft/down	14:00	17:00	180
14/03/2001	Portland	Mouth	B	270	Centre of headline	Aft/down	20:30	23:30	180
28/03/2001	Portland	Mouth	B	288	Centre of headline	Aft/down	6:30	9:30	180
29/03/2001	Portland	Mouth	B	414	Centre of headline	Aft/down	6:30	9:30	180
14/3/2001	Portland	Mouth	B	450	Centre of headline	Aft/down	6:15	9:15	180
29/3/2001	Portland	Mouth	B	324	Centre of headline	Aft/down	6:30	9:30	180

Table 17-15. Camera systems used and their position and direction during footage collection of assessments of modifications made to the standard demersal trawl nets off Portland and Bermagui.

Date	Region	Camera system	Gear modification assessed	Ave. depth (m)	Camera position	Camera direction	Start time recording	End time recording	Total record time (min)
26/08/1999	Bermagui	A	Covered codend	100	Centre of top panel of cover before first hoop	Aft	7:00	8:30	90
01/10/1999	Bermagui	A	Covered codend	100	Centre of top panel of cover before first hoop	Aft	7:00	8:30	90
28/02/2000	Bermagui	A	Square mesh panel	100	Centre of top panel, end of extension section	Aft	7:00	8:30	90
29/02/2000	Bermagui	A	Square mesh panel	100	Centre of top panel, end of extension section	Aft	7:00	8:30	90
15/02/2000	Bermagui	A	Lastridge rope system	400	Centre of top panel, end of extension section	Aft	8:30	10:00	90
17/02/2000	Bermagui	A	Lastridge rope system	400	Centre of top panel, end of extension section	Aft	8:30	10:00	90
17/04/2000	Bermagui	B	Trouser trawl design	200	Before separator panel	Aft/down	7:00	10:00	180
18/04/2000	Bermagui	B	Trouser trawl design	200	Before separator panel	Aft/down	7:00	10:00	180
02/05/2000	Bermagui	B	Trouser trawl design	400	Before separator panel	Aft/down	8:20	11:00	180
02/05/2000	Bermagui	B	Trouser trawl design	400	Before separator panel	Aft/down	12:05	15:05	180
03/05/2000	Bermagui	B	Trouser trawl design	400	Before separator panel	Aft/down	8:30	11:30	180
16/05/2000	Portland	B	Trouser trawl design	300	Before separator panel	Aft/down	7:00	10:00	180
17/05/2000	Portland	B	Trouser trawl design	210	Before separator panel	Aft/down	21:00	0:00	180
18/05/2000	Portland	B	Trouser trawl design	360	Before separator panel	Aft/down	10:25	13:35	180
18/05/2000	Portland	B	Trouser trawl design	360	Before separator panel	Aft/down	15:10	18:15	180
03/10/2000	Portland	B	102-mm Square mesh codend	400	Centre of top panel, end of extension section	Aft	7:00	10:00	180
29/03/2001	Portland	B	110-mm Diamond mesh codend	400	Centre of top panel, end of extension section	Aft	13:15	16:15	180
22/05/2001	Portland	B	110-mm Square mesh codend	400	Joining seams of the extension sections, before codends	Aft	16:00	19:00	180
31/05/2001	Portland	B	110-mm Diamond mesh codend	400	Centre of top panel, outside of extension before 110-mm codend	Aft	11:15	14:15	180

18 APPENDIX 4: NOTES ON FIT OF MODELS TO EACH SPECIES & MODEL DIAGNOSTICS

18.1.1 EAST:

18.1.1.1 Blue grenadier

More sophisticated stock assessment (Tuck and Thomson 2003) than the crude method applied here showed that the stock is dominated by a very large recruitment event which occurred in 1994. The method used here assumes constant recruitment. Nevertheless the model was able to match the data well although the estimated female spawning biomass is much smaller than that estimated by Tuck and Thomson (2003) for the east and west regions combined. This could be explained to some extent because only the east portion of the stock is estimated here and most of the catches actually come from the west.

18.1.1.2 Pink ling

It was necessary to reduce the availability of 1-year old fish by multiplying the gear selectivity for one-year olds by a value between 0 and 1. This value was estimated, as an additional model parameter, to be 0.04. Stock size is much smaller than that estimated by Klaer (2003). The model, in order to fit the observed age distribution, estimates a quite depleted stock.

18.1.1.3 Redfish

Observed catch-at-age for redfish is quite variable. This was not well captured even in a full-stock assessment (see Thomson 2002a) and is poorly captured by this model. The ALKs for this species are not well sampled (Thomson 2002a). The estimated stock size (Table 3a) is double that estimated by a full assessment Thomson (2002a). The model can’t reproduce the fluctuations in observed yield and doesn’t attempt to fit the recent drop in yield taken from deeper water. This could not be reproduced without the numbers-at-age in the population becoming negative at times. The model needed to keep the biomass high in order to prevent this. The poor fit for this species is likely due to a high degree of natural variability in stock availability.

18.1.1.4 Mirror dory

The fits to the data are reasonably good. Catches of 2-year olds were being overestimated so a multiplier was estimated (=0.06) and applied to the selectivity of both 1- and 2-year olds. One year olds were not overestimated because their selectivity was low to start with, but the multiplier was applied to both for consistency. Hall (2002) assessed mirror dory in the east using a surplus production model. He estimated a biomass of approximately 1000 t in the east. This should probably be compared with available biomass from this model (Table 3a), which is roughly twice Hall's estimate.

18.1.1.5 John Dory

Catches of 1- and 2-year olds were being overestimated so a multiplier was estimated (=0.5) and applied to both age classes. The model is able to reproduce the fluctuations in yield well. Although there is no stock assessment with which to compare our results, the estimated spawning biomass is unrealistically low (Table 3a).

18.1.1.6 Inshore ocean perch

Only one age composition is available for catches and one for discards. These are not well estimated. Yield is well estimated but the stock size is unrealistically low (Table 3a). The model was unable to match the observed discarding rate of 66%. Discarding of this species might be market related, not just size-based.

18.1.1.7 Offshore ocean perch

Fits are reasonably good and the estimated stock size does not seem unrealistic. The stock is estimated to be depleted to 13% of its pristine level, which is below the range of 20-40% assumed for all stocks.

18.1.1.8 Tiger flathead

An availability parameter (=0.32) had to be estimated for 1- and 2-year fish as these were overestimated in both the catches- and discards-at-age. Estimated spawning biomass in 2003 is close to a quarter of that estimated by Cui *et al*. (2003) for east and west together.

18.1.1.9 Jackass morwong

Observed morwong discards have been small (4%) and it was difficult to fit the single observed discard-at-age so discarding was ignored. In order to fit the observed age data availability for ages 1-3 had to be was dropped to zero, this results in a selectivity/availability curve that is similar to that estimated by Fay (2004). Fay (2004) estimated morwong spawning biomass in 2003 of 10 000t which is roughly double the female spawning biomass estimated here. The estimated stock size relative to pristine is not dissimilar to the current stock assessment.

18.1.1.10 Gemfish

The eastern gemfish fishery was closed to targeted fishing in 1993, a small bycatch quota was allocated. The estimated recruitment for this species can be taken to be the average over the post-closure period and is consequently low. Recruitment is kept constant in future projections which consequently does not allow for recovery. The estimated available biomass is in 2003 is lower than the range estimated by Punt (1999).

18.1.1.11 Gould's Squid

The model seems to track the observed yield fairly well, relative population size (*R)* is similar in shallow and deep waters which seems realistic.

18.1.2 WEST:

18.1.2.1 Blue grenadier

Most blue grenadier caught in the west are taken during their spawning aggregation so it is not surprising that the model predicts much younger (smaller) fish than are seen in the catches. For this reason estimated discarding is higher than that observed. Also, there has been at least one large recruitment event in the mid-90s which violates the assumption that recruitment has been constant. The estimated stock size is roughly a third of that estimated by Tuck and Thomson (2003) for the east and west regions combined.

18.1.2.2 Pink ling

The availability of 1 year olds is multiplied by 25%. Estimated stock size is lower than that found by Klaer (2003).

18.1.2.3 Offshore ocean perch

The age composition data seem to be quite poorly estimated. Estimated stock size is very low.

18.1.2.4 Deepwater flathead

Yields of deepwater flathead are of similar magnitude in shallow and deep water but effort in the west is much lower in shallow water. An attempt to fit to these data by estimated separate q values in deep and shallow failed. Data from the two depth zones were pooled and a single joint q estimated. There were no consistent differences between the catch-at-age compositions from deep and shallow so the deep ones were used as they were based on greater and more numerous sample sizes. This was more successful than the previous attempt but it was still not possible to achieve a good fit to both yield and catch-at-age simultaneously. There are zeros in the yield series which could not be estimated. These were excluded but the low yields in the middle of the series continued to cause problems. Estimated population size is clearly far too low, particularly when compared with that estimated by Wise and Tilzey for the GAB.

18.1.2.5 Gemfish

The observed discard rate is low and there was no discard-at-age data from deep water so discarding was ignored. Observed landed catches include a higher proportion of 1-year olds than was estimated (and than is usual in the CTF). The variability in the yield was not well captured. The estimated population size seems low.

18.1.2.6 Blue warehou

The availability of 1 and 2 year old fish had to be reduced by a factor estimated at close to zero. The estimated size is high relative to pristine (60%) whereas Punt and Smith (2004) shows that the stock is depleted to 30% in the west. This is surprising and perhaps indicates lack of contrast in the catch-at-age data, which seems to be reasonably well estimated. The estimated stock size is, nevertheless, clearly low.

18.1.2.7 Silver warehou

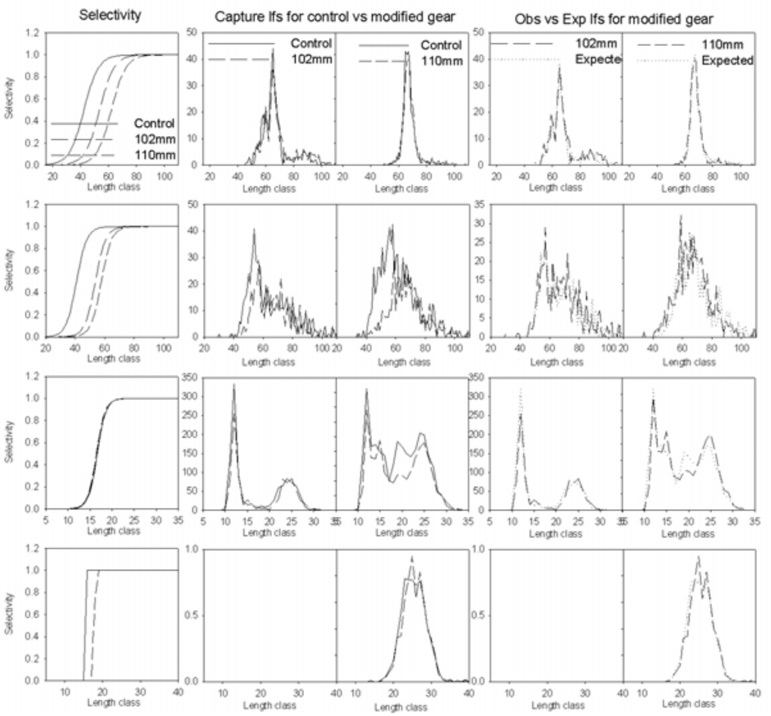
Recruitment has obviously not been constant (see also Thomson 2002b). Yield increases more than is expected, probably because of greater targeting by the blue grenadier spawning fishery (Wayte and Smith 2002). The biomass and estimated depletion found here are not overly dissimilar with the full stock assessment of Thomson (2002b) which covered the east and west.

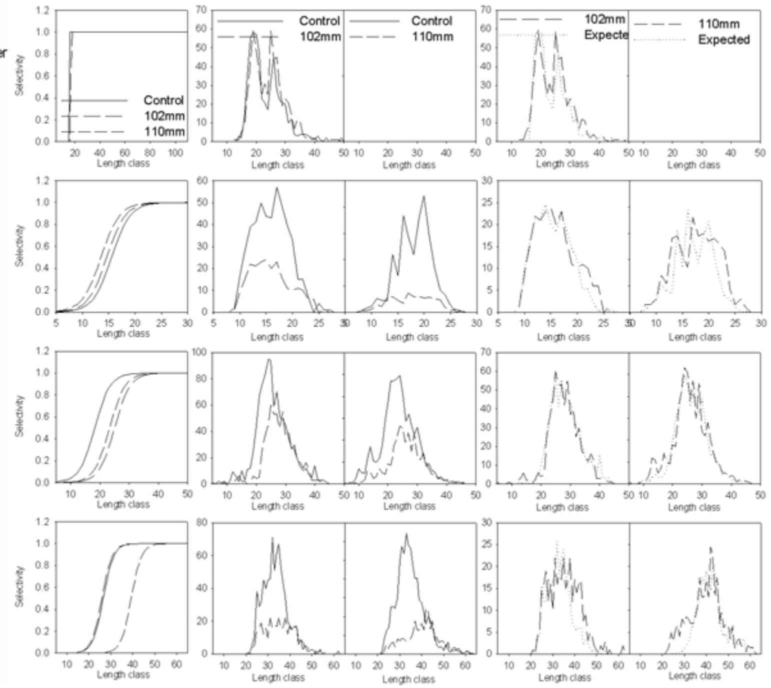
18.1.2.8 Gould's squid

The model seems to track the observed yield fairly well. *R* in shallow water is much greater than that in deep which indicates targeting of Gould's squid in shallow water.

18.1.2.9 King dory

King dory don't appear in the landed age composition until they are 9 or 10 years old. The only discard age composition available shows animals aged 4 and 5. The gear selectivity curve for this species rises steeply after age 3 and almost reaches 1 by age 4. Consequently, the estimated discard rate is high. When unconstrained it was over 60%. Given the paucity of discard composition data it is not possible to estimate an availability function. The model is unable to estimate both the drop in yield during the late 90s and the rise during the 2000s. It can estimate a recent decline in yield or a recent drop but not both.


Selectivity
Capture lfs for control vs modified gear
Obs vs Exp lfs for modified gear
Control
102mm
110mm
Expected
Selectivity
Length class


Blue Grenadier
Ling
Redfish
Mirror Dory
John Dory
Inshore Ocean Perch
Offshore Ocean Perch
Tiger Flathead
Control
102mm
110mm
Expected
Selectivity
Length class

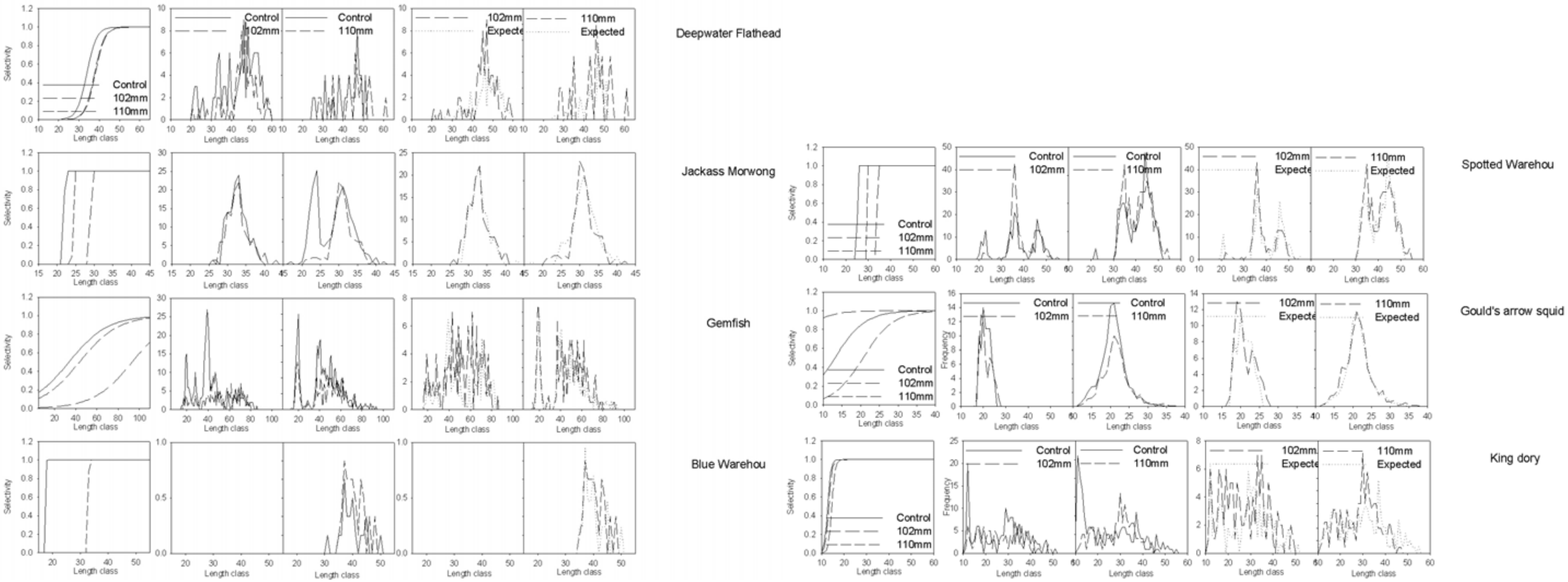
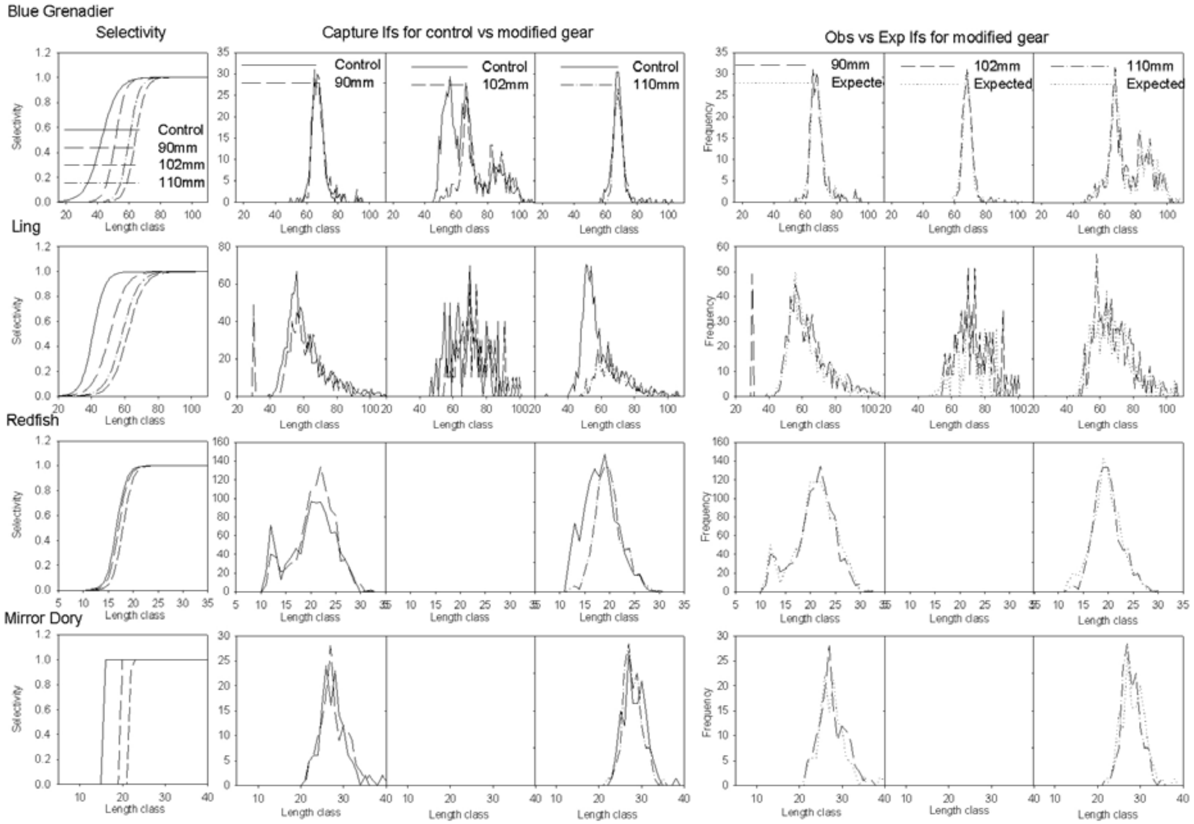
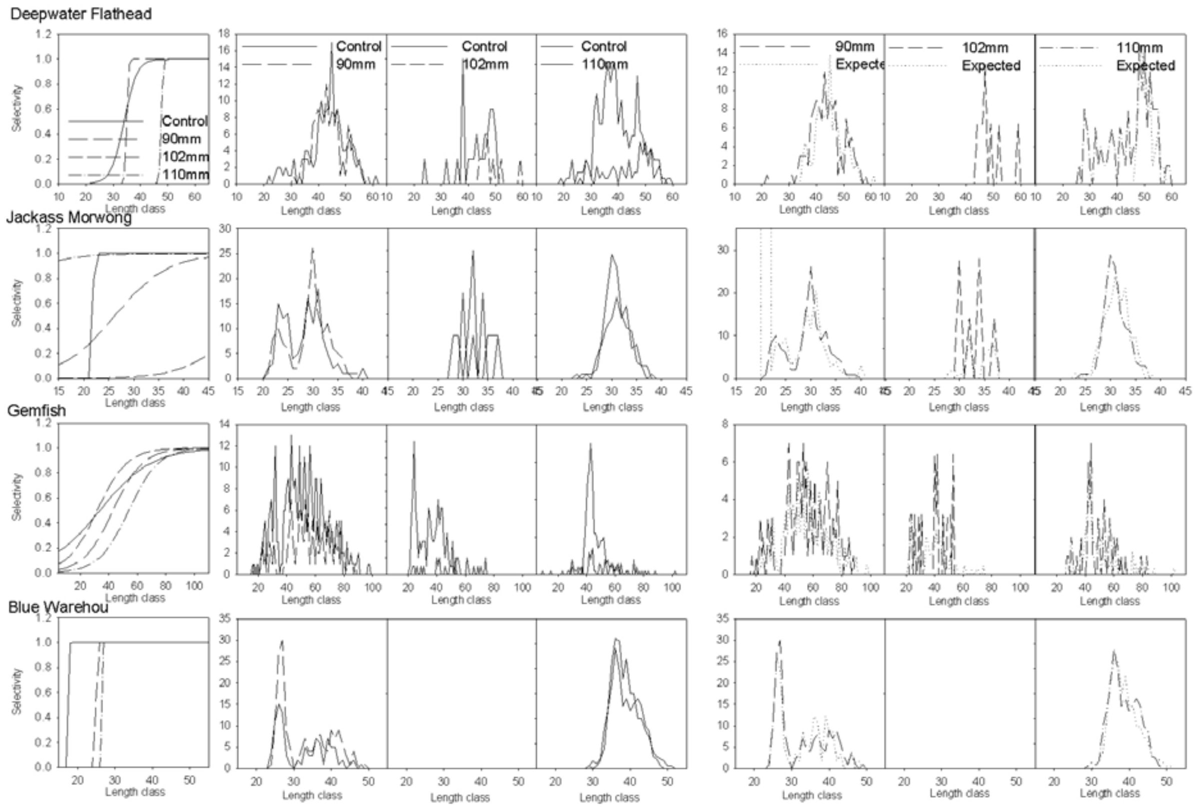


Figure 18-1. Fig 1a Calculated gear selectivity for the 102-mm and 110-mm diamond gears (first column). The observed catch length frequency for the control gear (when towed with the modified gear) and the modified gear is shown (second and third columns), with the model fits to the observed length frequencies (fourth and fifth columns). Each row pertains to a particular species.


Blue Grenadier
Selectivity
Capture lfs for control vs modified gear
Obs vs Exp lfs for modified gear
Control
90mm
102mm
110mm
Expected
Ling
Redfish
Mirror Dory
Selectivity
Frequency
Length class


Deepwater Flathead
Jackass Morwong
Gemfish
Blue Warehou
Selectivity
Length class
Control
90mm
102mm
110mm
Expected

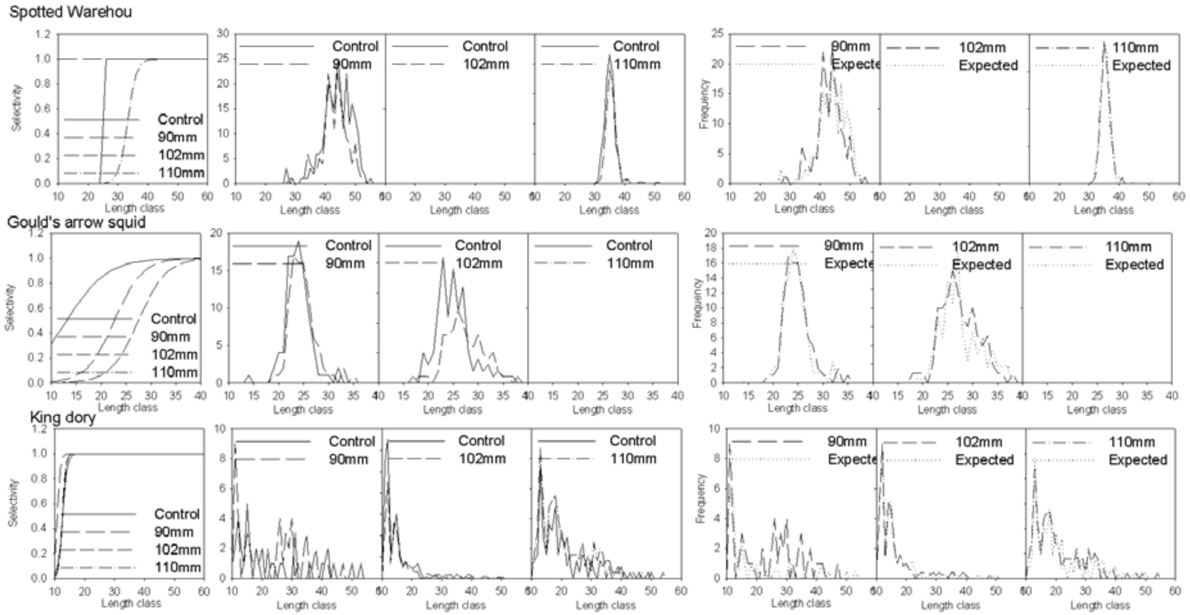


Figure 18-2 Figure 1b. Calculated gear selectivity for the 90 mm, 102 mm and 110 mm square mesh gears (first column). The observed catch length frequency for the control gear (when towed with the modified gear) and the modified gear is shown (second, third and fourth columns), with the model fits to the observed length frequencies (fifth to final columns). Each row pertains to a particular species.

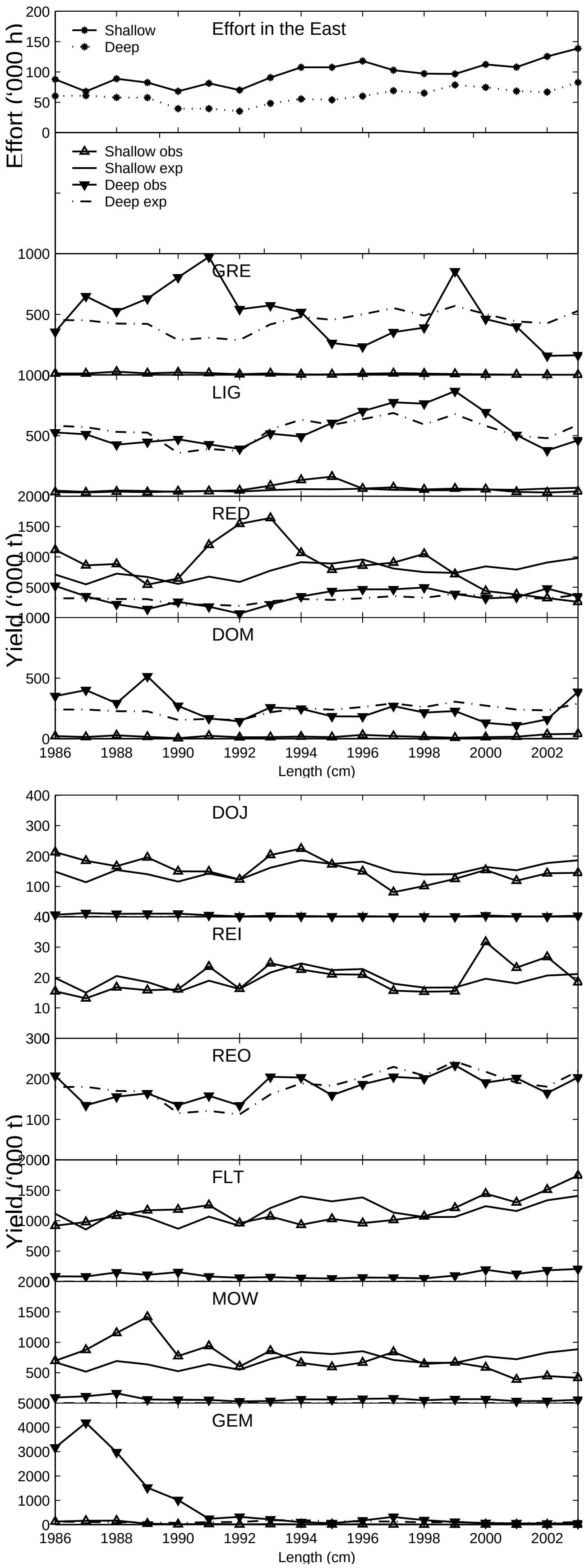


Figure 18-3 Figure 3a Model fit to the annual yield for each species in the east. The same effort series (in 1000s of trawl hours) was used for all species in the east.

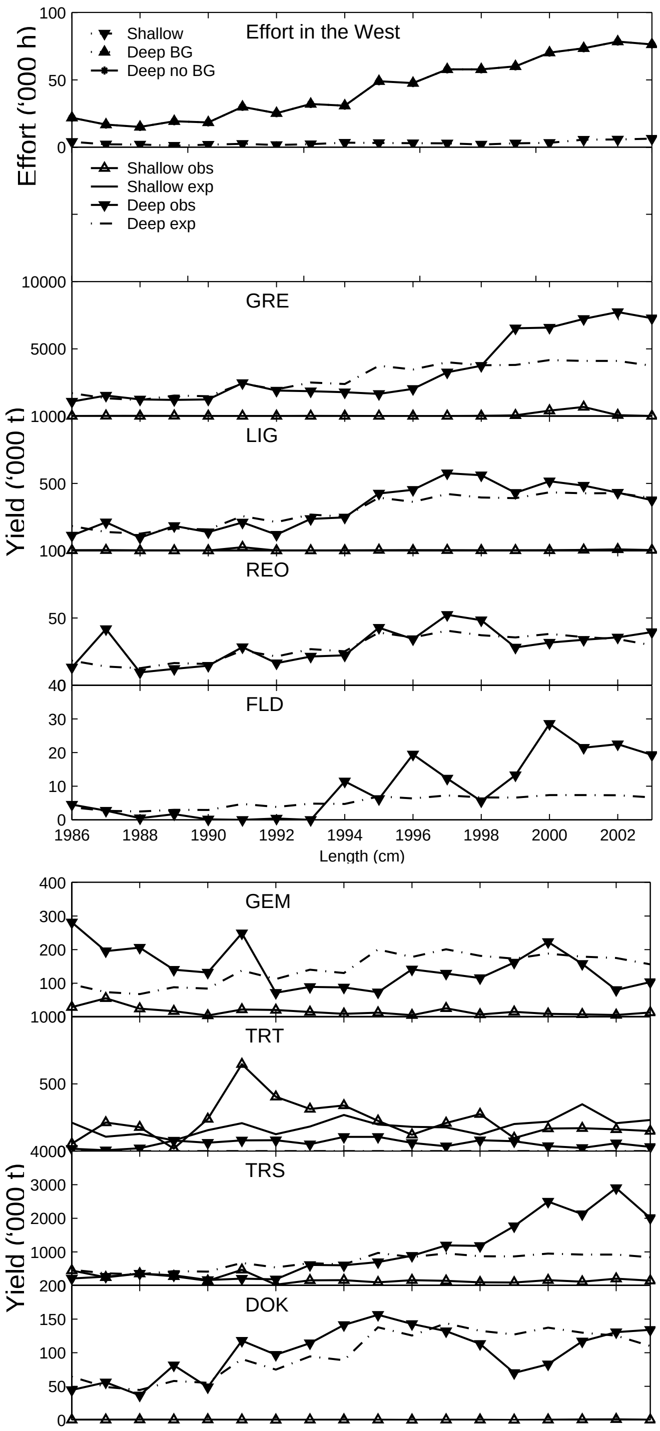
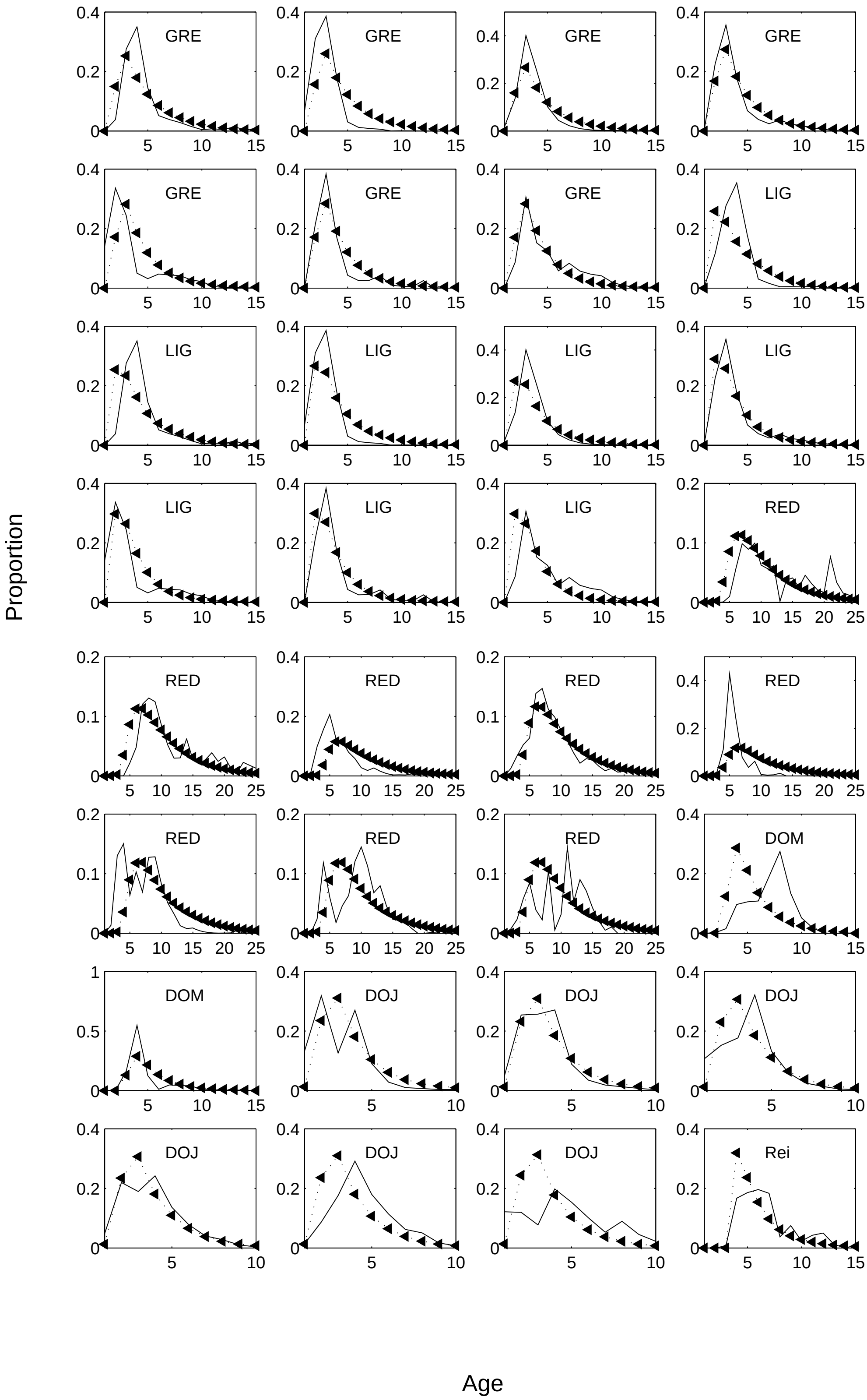


Figure 18-4 Figure 3b Model fit to the annual yield for each species in the west. The same effort series (in 1000s of trawl hours) was used for all species in the west.


GRE
LIG
RED
DOM
DOJ
Rei
Proportion
Age

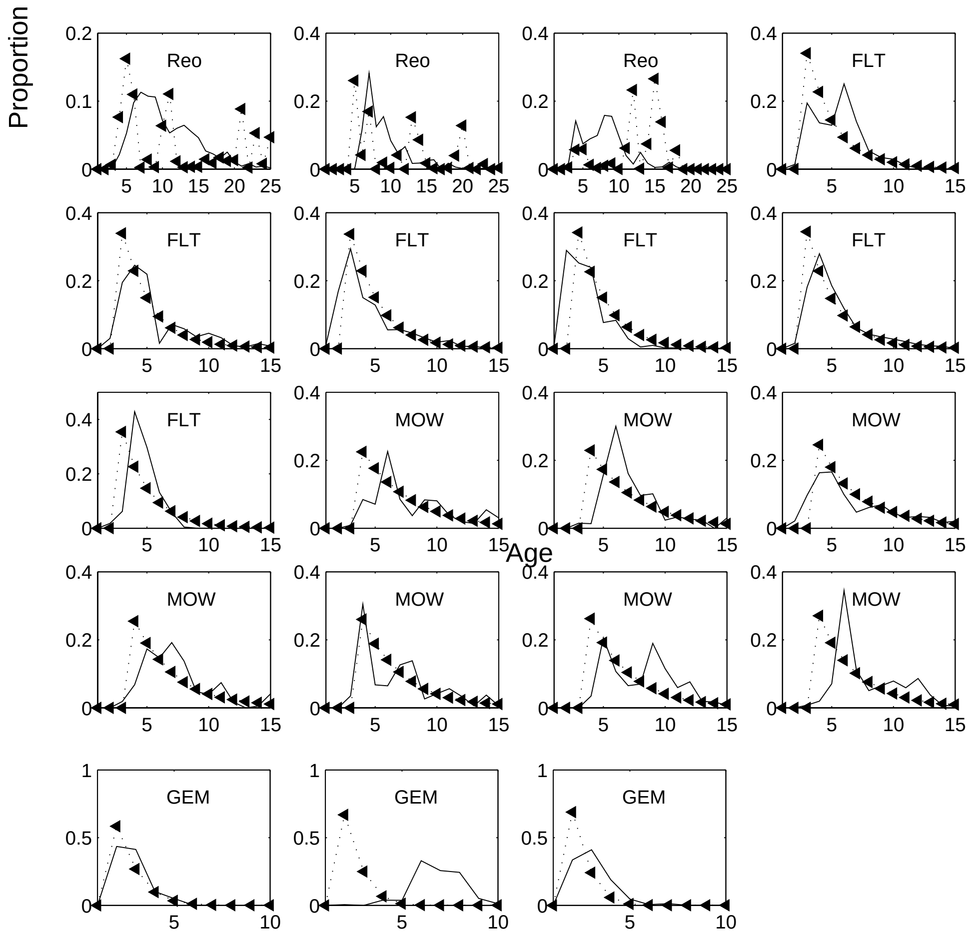


Figure 18-5 Figure 4ai. Observed (solid line) and expected (dotted line) catch-at-age compositions in the east.

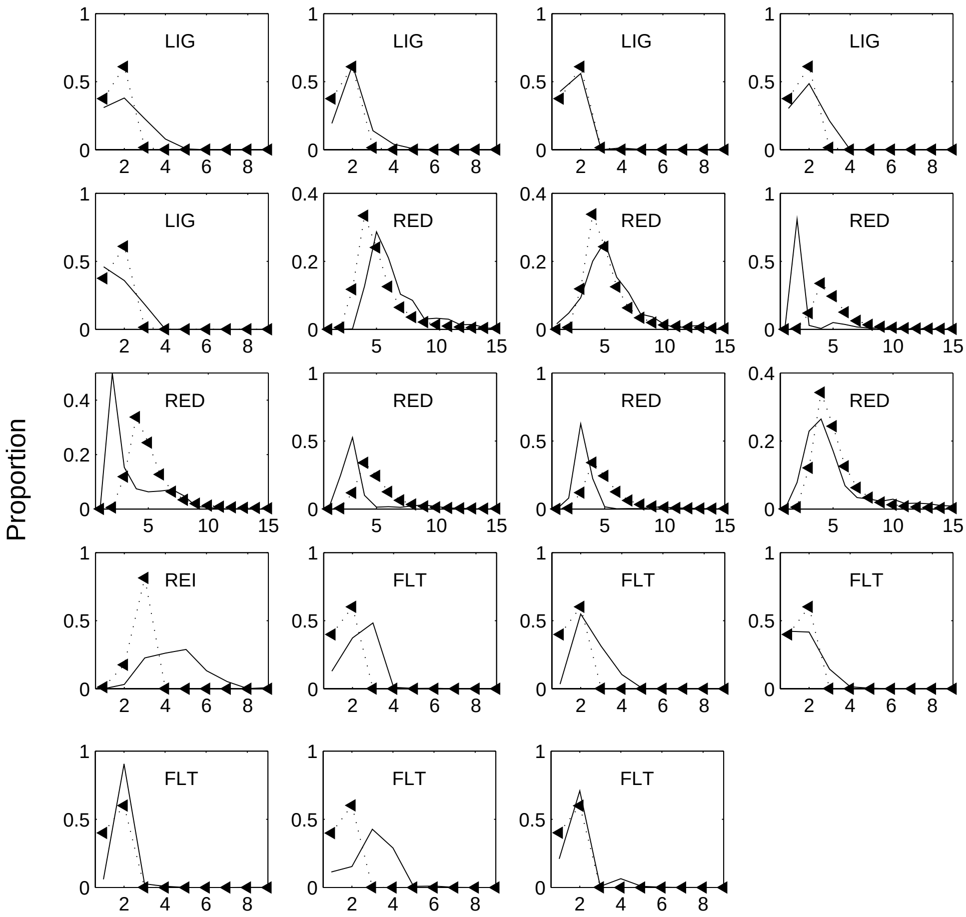


Figure 18-6 Figure 4aii. Observed (solid line) and expected (dotted line) age compositions in the east for shallow discards.

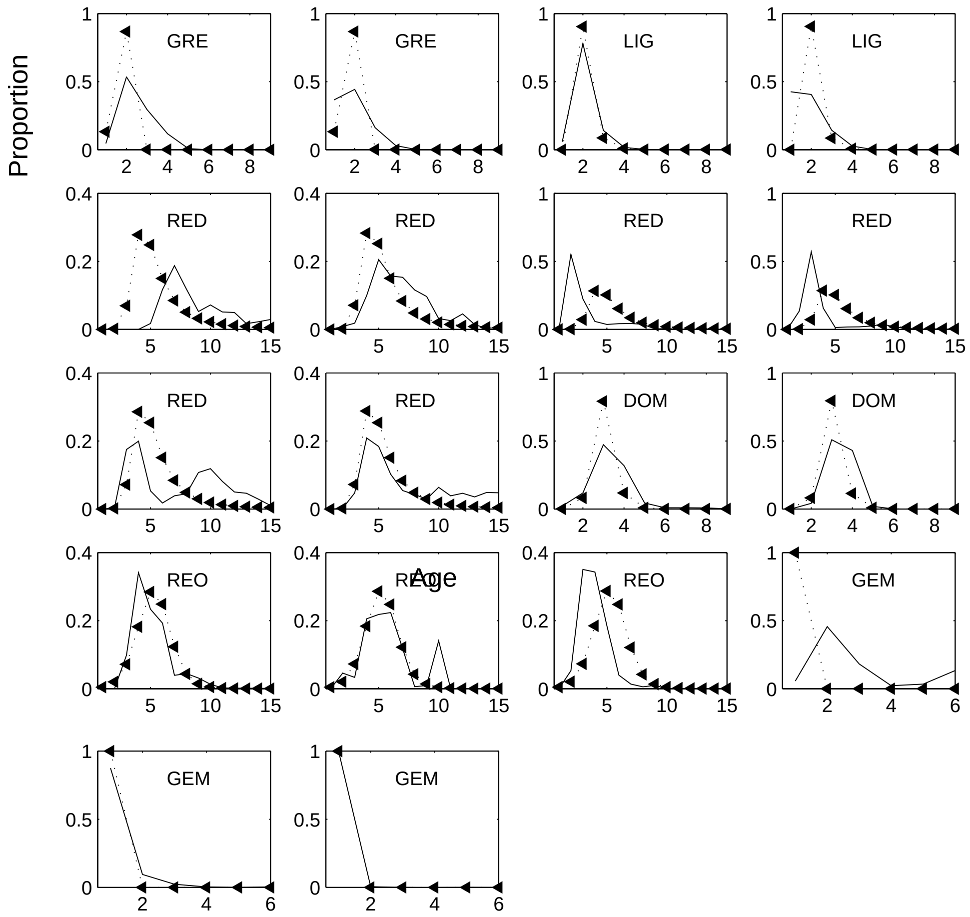
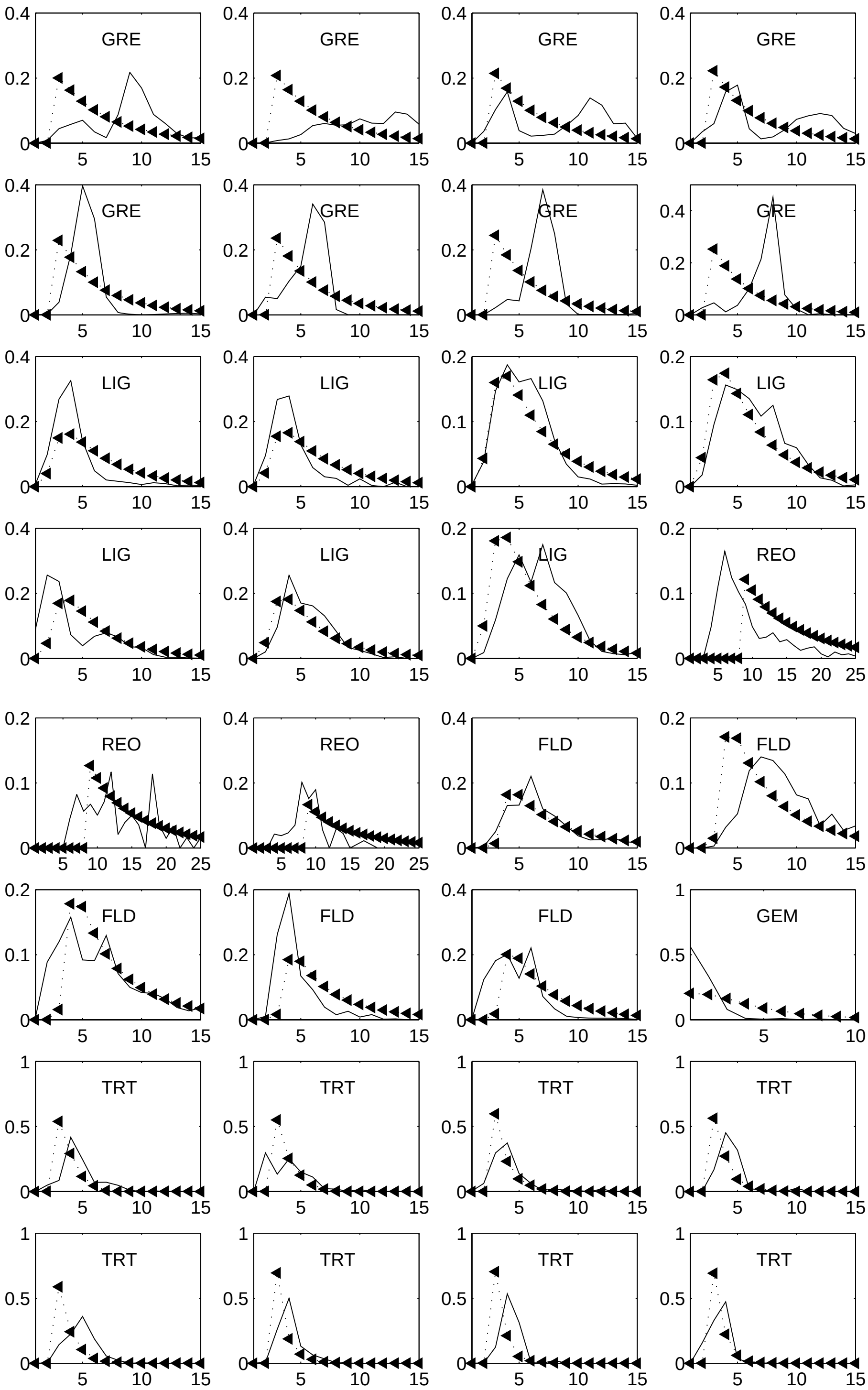


Figure 18-7 Figure 4aiii. Observed (solid line) and expected (dotted line) age compositions in the east for deep discards.


GRE
GRE
GRE
GRE
GRE
GRE
GRE
GRE
LIG
LIG
LIG
LIG
LIG
LIG
LIG
REO
REO
REO
FLD
FLD
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TRT

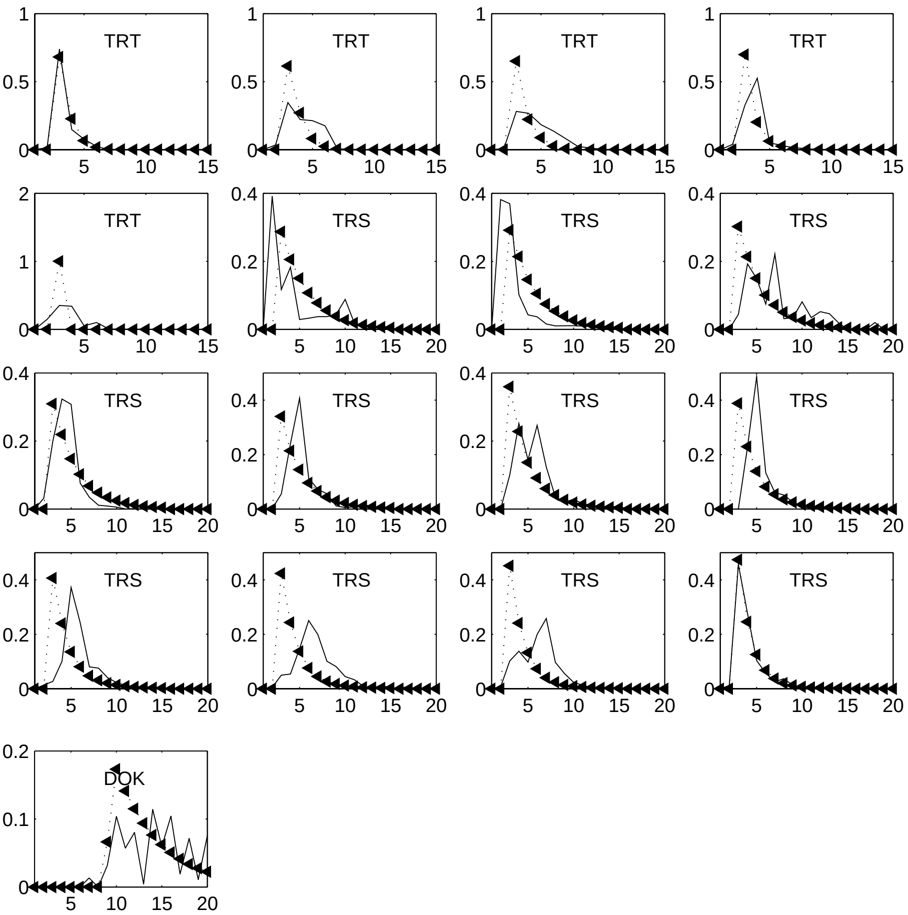

Figure 18-8 Figure 4bi. Observed (solid line) and expected (dotted line) catch-at-age in the west.

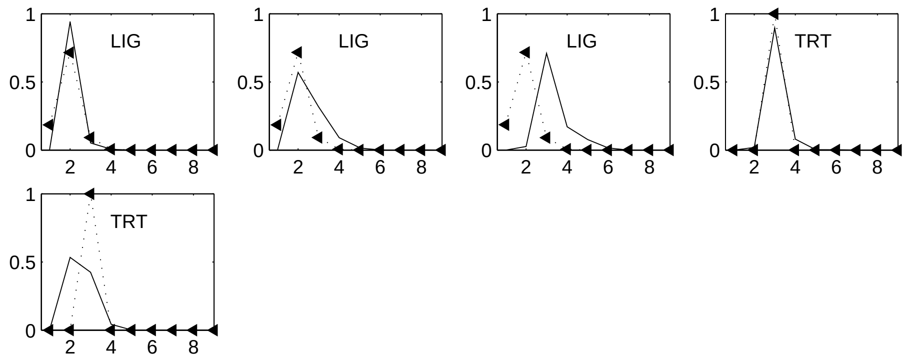

Figure 18-9 Figure 4bii. Observed (solid line) and expected (dotted line) discards-at-age in shallow water in the west.

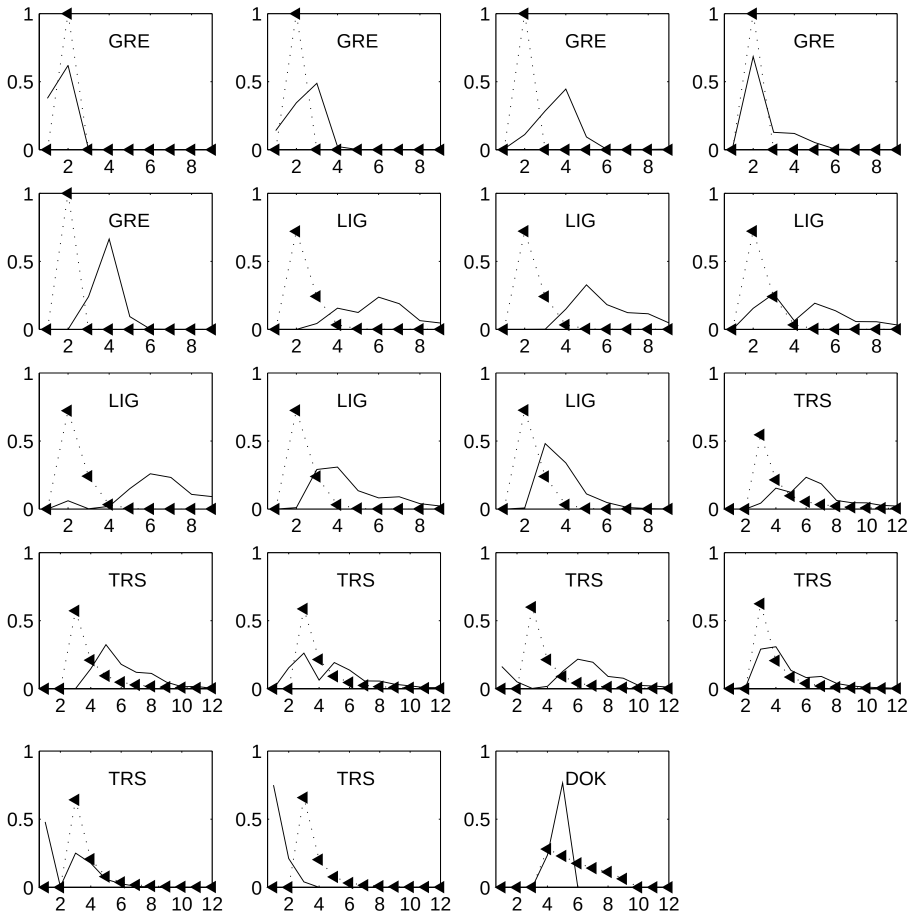

Figure 18-10 Figure 4biii. Observed (solid line) and expected (dotted line) discard-at-age in deep water in the west.

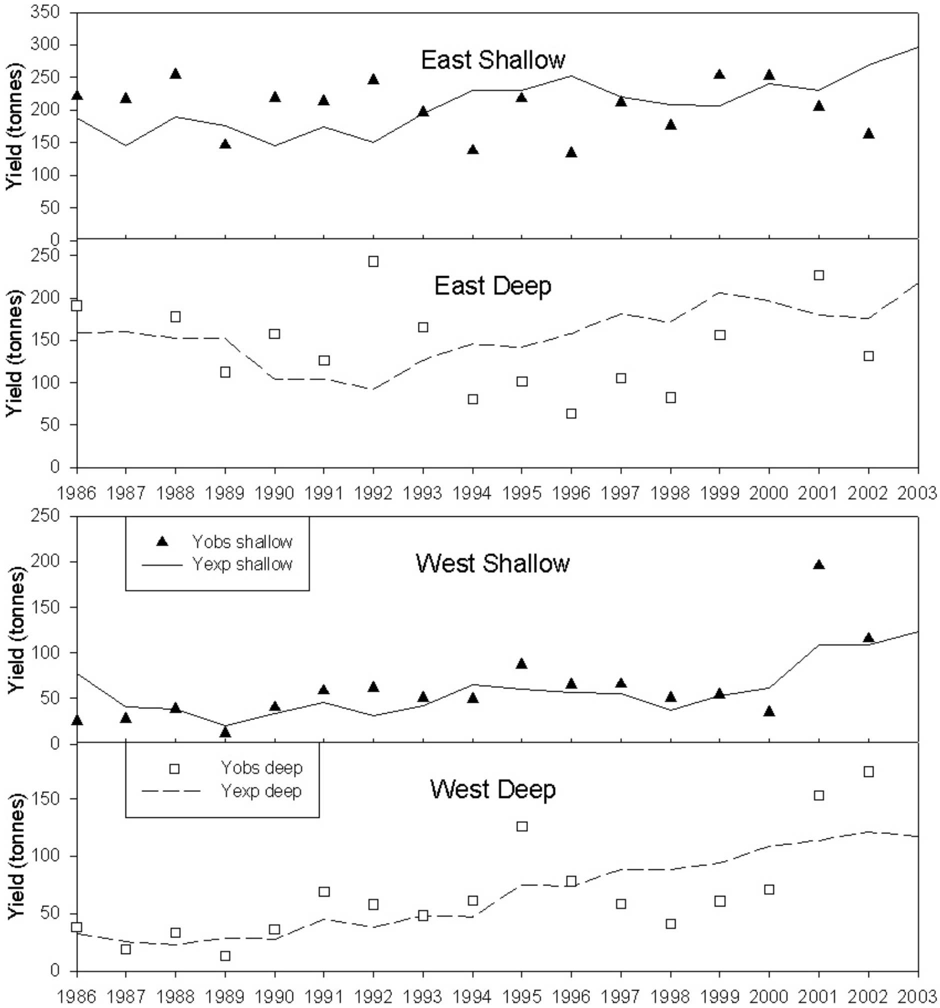

Figure 18-11 Figure 5a. Observed and expected Gould's squid yield in deep and shallow water in the East and in the West. The effort series used are shown in Figure 3.

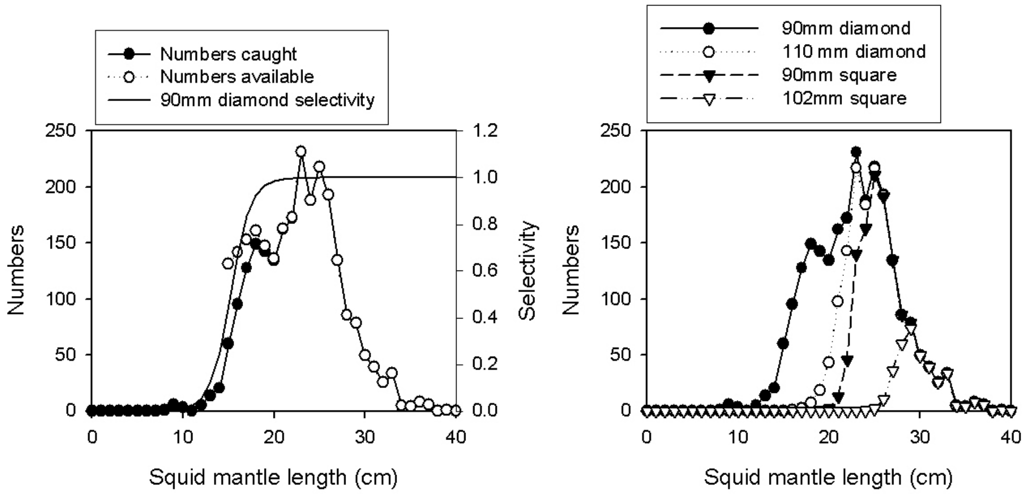

Figure 18-12 Figure 5b. (left plot) Observed Gould's squid length frequency in the east when using 90-mm diamond gear, and 90-mm diamond selectivity. (right plot) Observed Gould's squid length frequency for 90-mm diamond gear and expected length frequencies for modified gears.