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Effects of Trawling Subprogram - Improving the Efficiency of Prawn Capture: Refining Net Designs in Australian Prawn Fisheries to Reduce By-catch and Fuel Costs

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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Project No. 98/226

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98/226	Effects of trawling subprogram – Improving the efficiency of prawn capture: refining net designs in Australian prawn fisheries to reduce by-catch and fuel costs

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OBJECTIVES

1. By December 1998, develop two novel net body configurations using *spectra* 50 mm twine and *momoi* 60 mm twine.
2. By March 1999, complete trials and evaluations of the two novel net designs against a conventional rig. Assess relative levels of by-catch, size composition of prawns and fuel consumption to evaluate effectiveness of the net designs.

NON TECHNICAL SUMMARY

During October 1998 a series of net trials were undertaken in the Gulf St Vincent, South Australia. The trials were aimed at determining the influences on catches and by-catches due to an increase in mesh size and a reduction in twine diameter in the bodies of prawn trawls.

The conventional *gundry* mesh used in the fishery has an inside mesh opening of around 45 mm and a twine diameter of 1.7 mm. This mesh was compared with two other types of mesh with smaller twine diameters and larger inside mesh openings (*spectra* and *momoi*). The diameter of *spectra* mesh is 1 mm, with *momoi* being 1.7 mm in diameter.

For the sake of our analysis and discussion we were interested in determining measures of the material that were comparable. Manufacturers specifications are not necessarily comparable nor do they describe the characteristics of the net once fabricated and stretched. We chose to measure stretched mesh opening from a number of random measures taken from nets that had been fabricated and towed to put the material under strain. The netting material was also independently assessed by FRDC although the material measured had not been pre-stretched by towing. The following table gives a summary of the specifications of the three mesh types tested. The specifications given for each mesh type are the manufacturer's description, the average measure found in this study and the average measure from the independent assessor.

Mesh type	Manufacturers specifications		Our measure	Independent measure
	Centre knot to centre knot (mm)	Twine diam. (mm)	Stretched inside mesh (mm)	Stretched inside mesh (mm)
Gundry (orange)	45 (1¾ inch)	1.7	44.42	45.96
Spectra (white)	52 (2 inch)	1.0	52.43	49.93
Momoi (blue)	57 (2¼inch)	1.7	52.96	52.98

The importance of a standard measure is demonstrated by the results seen for the *spectra* material. The actual mesh opening is larger than one would expect if the manufacturer's centre knot to centre knot measure were simply converted to an inside knot measure. It was noted that the mean size of *spectra* mesh measured in our study and by the independent assessor are different. It is assumed that this difference is accounted for by the difference in treatment of the material measured (ie. ours was pre-stretched).

If ordering material, fishers should use the manufacturer's specifications to avoid confusion.

The trials were conducted using a chartered commercial prawn trawler using a triple rig gear configuration ie. towing three nets. Attached to each trawl was an identical composite square mesh codend. The control (*gundry*) net was always towed in the middle whilst the *momoi* and *spectra* nets were randomly altered between the port and starboard sides. The gear was towed under normal commercial conditions with a shot duration of 25 minutes at 3 knots over a combination of sandy and light coral bottoms. Over five nights a total of 15 replicate comparisons of each configuration were trialed.

Both the *spectra* and *momoi* trawl bodies retained fewer small prawns. Whilst the weight of the catch was maintained it was found that the number of prawns in the catch was reduced significantly (means reduced by 13.7% and 15.6%, respectively). Both the *spectra* and *momoi* also retained significantly less by-catch (a reduction of 29.3% and 20.3% respectively).

The results from this study showed that both new trawl bodies were effective in excluding under-sized prawns and large numbers of small fish, with no significant reductions in weights of targeted prawns. It is also likely that a reduction in twine area associated with the larger mesh size in both new trawl bodies allowed a faster release of water than did the control, possibly contributing to the escapement of some by-catch and smaller prawns.

Because there were no significant differences in the weights of prawns captured between the various trawls, a further increase in the size of mesh in the body (eg. 60 mm) warrants investigation. Alternatively, it may be feasible to examine the utility of trawl bodies comprising composite panels of larger mesh.

The improved net designs may also offer advantages from improved fuel efficiency due to lower drag. The operator of the vessel used in these trials estimated fuel savings of around 10% (J. Raptis pers. comm.).

As a result of this study a majority of commercial fishers in the Gulf St Vincent have adopted the larger meshed trawl bodies.

It is a clear conclusion of this study that the *spectra* and *momoi* mesh tested, significantly reduced the amount of by-catch and improved the selectivity of prawns in comparison to the mesh that was typically used in the fishery. The rapid adoption by industry of the outcomes of this project has resulted in a fleet that has adopted the use of larger mesh sizes. Our findings show that this initiative must provide direct benefits in terms of;

- sustainability of the prawn fishery by improving selectivity for large prawns, and by
- further reducing the impact of fishing on the environment by reducing by-catch.

BACKGROUND

The recently completed FRDC funded research in Gulf St Vincent resulted in the successful transfer of by-catch reduction technology to commercial fishers. The collaborative research demonstrated the benefits that can be derived through liaison and consultation with industry, incorporating their ideas into modifications to improve the selectivity of prawn trawls. The cooperative research effort produced a modified codend that achieved a by-catch reduction of more than 60% whilst at the same time increasing the catch and value of the commercially sized prawns.

Like the majority of the worlds trawl fisheries, South Australia's prawn trawl fisheries have the selectivities of their nets regulated by means of legally defined minimum mesh sizes. However, unlike most trawl fisheries, there have been no formal studies done to determine optimum mesh sizes for the body of the trawl. It was evident in the recent trials in the Gulf St Vincent that the current minimum mesh of 45mm in the body of the trawl is too small and that the trawls may still select large quantities of undersized prawns. Furthermore, experienced industry participants (eg. Les Lowe from Gulf Net Mending Pty. Ltd.) have suggested that the current net configuration creates unnecessary drag.

NEED

We believe that these are good reasons for extending the research already done in Gulf St Vincent to trial novel net designs based on improved *spectra* twine, a material that offers greater strength and less drag than conventional netting. Although it is proposed that the research be done in Gulf St Vincent, using commercial vessels engaged in the fishery, the results will have clear implications for other prawn fisheries such as the NPF. With a favourable result and strong industry endorsement, it is likely that the nets will be rapidly adopted in other prawn fleets around Australia.

OBJECTIVES

1. By December 1998, develop two novel net body configurations using *spectra* 50mm twine and *momoi* 60mm twine.
2. By March 1999, complete trials and evaluations of the two novel net designs against a conventional rig. Assess relative levels of by-catch, size composition of prawns and fuel consumption to evaluate effectiveness of the net designs.

METHODS

A paper detailing the methodology used in this project, the results, a discussion and a list of reference material is attached at Appendix 3.

RESULTS & DISCUSSION

A paper detailing the methodology used in this project, the results, a discussion and a list of reference material is attached at Appendix 3.

BENEFITS

Commercial fishers, seafood processors and the community will benefit directly as a result of the research undertaken. The novel net design resulted in a better quality product (in terms of size) being caught and processed. Larger prawns are in greater demand and sell for a higher price. Improved size at capture allows fishers to satisfy the market demand for larger prawns and also delivers a better price to fishers.

The significant reduction in by-catch achieved using the new net configurations and materials have a positive impact on the environment. The community, especially recreational anglers, divers and other user groups of our marine environment will benefit from this improved net selectivity.

The reduced drag of the new mesh delivers greater fuel efficiency and it is estimated that this may be in the order of 10%.

These benefits are not just restricted to the Gulf St Vincent prawn fisherman and Gulf St Vincent environment. It is anticipated that with the wider adoption of the outcome of this project, there will be similar benefits delivered to other Australian prawn fisheries.

FURTHER DEVELOPMENT

The results of this study suggest that even further increases of mesh size in the trawl body (possibly 60 mm) warrants investigation. Alternatively, it may be feasible to examine the utility of trawl bodies comprising composite panels of larger mesh, particularly in the posterior section of the trawl.

CONCLUSION

The objective of assessing relative levels of by-catch, size composition of prawns and evaluating the effectiveness of the net designs has been met.

The *spectra* and *momoi* trawl bodies when compared to the *gundry* were found to be equally as effective in reducing the by-catches of a range of small fish with no significant reduction in the weight of prawns caught. These results indicate that the main factor is the increase in size of mesh.

There was no statistically significant differences between the two new trawl bodies in terms of the size of prawns retained, however both the *spectra* and *momoi* trawl bodies retained proportionally fewer smaller prawns.

A reduction in twine area associated with the increased mesh size in the new trawl bodies enabled a faster release of water, possibly facilitating the escape of smaller prawns and by-catch. Although there were no significant differences detected in the catching performance of the *spectra* (twine diameter 1 mm) and *momoi* (twine diameter 1.7 mm) trawl bodies, the *spectra* trawl body consistently produced a smaller percentage of by-catch.

As a result of this study most fishers operating in the Gulf St Vincent have adopted the larger meshed trawl bodies.

REFERENCES

Literature cited in Appendix 3 is referenced in that document. The following references relate to literature cited in the preceding text.

APPENDIX 1 - INTELLECTUAL PROPERTY

The FRDC's proportion of ownership of the project intellectual property, based on Part C of the application or unless otherwise justified, is 34.73%.

APPENDIX 2 - STAFF

The following staff were engaged on the project;

Simon Boxshall
Matt Broadhurst
Bryan McDonald
Paul McShane
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APPENDIX 3 – METHODOLOGY, RESULTS & DISCUSSION

Effects of twine diameter and a mesh-size increase in the body of prawn-trawls used in Gulf St Vincent, Australia

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Keywords: prawn trawl; selectivity; by-catch reduction; mesh size increase

Abstract

The influences on catches and by-catches due to (i) an increase in size of mesh and (ii) a reduction in twine diameter in the body of prawn trawls were investigated in Gulf St Vincent, Australia. Compared with a conventional trawl body (mesh size 45 mm) attached to a composite square-mesh codend, two new trawl bodies made with 53 mm mesh, but different twine diameters (1 and 1.7 mm, respectively) and each attached to identical composite square-mesh codends were equally effective in significantly reducing the by-catches of a range of small fish (by up to 67%) with no significant reduction in weights of prawns caught. These results, combined with no significant differences in selectivity parameters of both new trawl bodies, indicated that the main effect was the increase in size of mesh. The escape of large numbers of small fish and prawns is discussed in terms of their probable behavior in the body of the trawl and the extent to which this was influenced by the operational characteristics of the gear.

In many of the world's prawn-trawl fisheries, large numbers of organisms are taken incidentally to the targeted catch (collectively termed 'by-catch' - sensu Saila, 1983). This by-catch comprises a diverse assemblage of small fish, cephalopods and crustaceans, including prawns that are smaller than optimum size (for reviews see Saila, 1983; Andrew and Pepperell, 1992; Alverson et al., 1994). Concerns over the negative effects that the mortality of these individuals may cause on the yield of stocks has led to the application of various management strategies designed to minimize by-catches (Andrew and Pepperell, 1992). The most common and applied technique involves modifications to conventional trawls to reduce by-catch and improve overall selectivity. Depending on the sizes and species to be targeted and excluded, this has been achieved via changes to sizes and types of mesh used, and/or the application of physical modifications, collectively termed by-catch reducing devices (BRDs) (see Broadhurst, sub. ms. for review).

Inherent variabilities among the characteristics of different prawn-trawl fisheries has resulted in a range of modifications to conventional trawls. Regardless of design, however, the majority of functional modifications have been applied within or immediately anterior to the codend (e.g. Isaksen et al., 1992; Thorsteinsson, 1992; Broadhurst and Kennelly, 1997; Rogers et al., 1997). This is mainly due to observations that suggest most of the selection process for many species occurs in this area (Armstrong et al., 1990; MacLennan, 1992; Wileman et al., 1996), but also because codends often are fairly similar among different designs of trawls within a particular fishery (e.g. Broadhurst and Kennelly, 1997). Any modifications to improve selectivity, therefore, are more easily implemented, adopted and regulated throughout the fishery.

While alterations to codends have been successful in reducing various sub-sets of by-catch, there is also evidence to suggest that individuals of some species, and particularly prawns, escape from the bodies of prawn trawls (High et al., 1969; Sumpton et al., 1989; Vendeville, 1990). For example, High et al. (1969) attached various covers to this section of trawls to isolate areas that could be modified to passively separate fish from prawns (*Pandalus* sp.). While there was little evidence of fish escaping, large numbers of small prawns were retained in the covers, particularly in the posterior sections. Similarly, in one of the few studies examining the effects on catches due to changes in only the types of twine used in the body of trawls, Sumpton et al. (1989) showed that compared with multifilament twine (1.1 mm diameter), significantly more smaller-sized prawns (*Penaeus plebejus*, *Metapenaeus bennettae* and *Metapenaeopsis novaeguineae*) and squid (*Loligo* spp.) escaped through the bodies of trawls made with the same mesh size but from monofilament twine (0.9 mm diameter).

Despite the results from above and although nearly all prawn-trawl fisheries are regulated by means of legally-defined minimum mesh sizes (typically ranging from 40 to 50 mm stretched mesh - Vendeville, 1990), there is a paucity of information describing effects on selectivity due to different sizes of mesh used in the bodies of trawls. This is particularly the case in Australian prawn-trawl fisheries, where despite extensive research to develop BRDs (see Broadhurst sub.

ms), there have been no published studies quantifying these effects. In a recent experiment in Gulf St. Vincent, South Australia, (Broadhurst et al., 1999) we provided evidence to suggest, however, that the minimum size of mesh (45 mm) used throughout the trawls was too small. As a first step in addressing this issue, we investigated modifications to the codends and demonstrated that new designs comprising composite panels of different-sized square-shaped mesh (52 and 80 mm mesh hung on the bar) were effective in significantly reducing by-catches of under-sized western king prawns (*Penaeus latisulcatus*) and small fish with no reduction in weight of commercial catch.

These results, combined with the simplicity of the new codend led to the immediate and unanimous adoption of a design based on those tested. Encouraged by the performance of simple modifications to mesh size and type to improve selectivity, industry sought assistance to examine other refinements to their trawls. Given evidence to suggest that the size of mesh used in Gulf St. Vincent was inappropriate and that selection for some species may occur in body of prawn trawls, our aims in the present study were to quantify the influences on selection in this area due to (i) an increase in mesh size (from 45 mm to approx. 53 mm) and (ii) reduction in the diameter of twine used.

Materials and methods

This work was done in Gulf St. Vincent, South Australia (Fig. 1) in October, 1998 using a chartered commercial prawn trawler rigged to tow three trawls in a standard triple gear configuration (see Andrew et al., 1991 for details). Three different trawl bodies were examined. The first (termed the control) represented conventional trawl bodies (see Broadhurst et al., 1999 for specifications) and was constructed of 1.7-mm-diameter, 24 strand, polyethylene twisted twine with a mean mesh size (between the knots) of 44.42 mm (see results). The second and third trawl bodies (termed 'spectra 1 mm' and 'momoi 1.7 mm') had identical design, headrope and footrope length, rigging and tapers as the control but were made from 1-mm-diameter, polyethylene cabled twine (brand name 'spectra') and 1.7-mm-diameter, 30 ply, polyethylene twisted twine (brand name 'momoi'), respectively with mean mesh sizes of 52.43 and 52.96 mm (see results).

All three trawl bodies were attached to identical composite square-mesh codends (Broadhurst et al., 1999) consisting of two sections measuring 80 bars in circumference, 70 bars in length and constructed of 52 mm mesh (3-mm-diameter, braided polyethylene twine) cut on the bar (Fig. 2A). Each square-mesh section consisted of an upper and lower panel sewn together so that knot directions were opposite (Fig. 2A). A panel of 104 mm netting, measuring 6 bars x 10 bars, was inserted into the tops of the posterior sections of each square-mesh codend starting at the leading edge and ending approx. 1.3 m anterior to the last row of meshes (Fig. 2A, B). Lengths of 12-mm-diameter, polyethylene 3-strand rope (termed 'lastridge ropes) were firmly laced at a hanging ratio of 0.9 to each of the two lateral seams of the codends (to provide length-wise strength) (Fig. 2B).

Experimental procedure

Before the start of the experiment, all trawls were towed for a short period to allow knots and bindings to stretch. To obtain accurate information on sizes of mesh, a set of dial calipers was used to measure 30 randomly located meshes (stretched length in mm, between the inside knots) at four separate locations (starboard wing, footrope, headrope and posterior body) in each trawl body.

The spectra 1 mm and momoi 1.7 mm trawls were separately compared against the control trawl. In each paired comparison, the trawls being tested were shackled to the outside sweeps of the sleds and otterboards of the triple rigged gear and towed simultaneously. A conventional trawl body was used as the center net in all comparisons, but because it was not rigged identical to the outside nets, its catch was excluded from analysis. The triple gear was towed in normal commercial tows of 25-min duration at 3 knots (1.5 m/s) over a combination of sandy and light coral bottoms. Each of the outside trawls were randomly assigned after each tow (to eliminate any potential biases), so that 3 paired comparisons of each new trawl against the control trawl were done on each night (i.e. total of 6 tows per night). Over five nights, we completed a total of 15 replicate comparisons of each configuration.

After each tow, the catches from the two outside trawls were emptied onto a partitioned tray. Data collected from each tow were: the total weight of western king prawns and a subsample (100 prawns from each trawl) of their lengths (to the nearest 1-mm carapace length); the total number of prawns (estimated from the weight of the subsample); the weights of total discarded by-catch, discarded non-commercial by-catch; the weights and numbers of commercially and/or recreationally important by-catch species; and the sizes (to the nearest 0.5 cm) of commercially and/or recreationally important fish. A random sample of prawns (approx. 12 kg) from each trawl in each tow was separated and sent to 'A. Raptis & Sons PTY LTD' (seafood processing plant) in Adelaide for grading into 'commercial categories' (based on a system of numbers per pound) using a locally-built 'dynamic grading machine'.

Several commercially important species were caught in sufficient quantities to enable meaningful comparisons. These were western king prawns (*Penaeus latisulcatus*), blue swimmer crabs (*Portunus pelagicus*), sand trevally (*Pseudocaranx wrighti*), red mullet (*Upeneichthys porosus*), leatherjacket (*Thamnaconus degeni*), southern sand flathead (*Platycephalus bassensis*), small-toothed flounder (*Pseudorhombus jenynsii*) and southern calamari (*Sepioteuthis australis*). With the exception of western king prawns and southern calamari (which fishers are also legally permitted to retain), all remaining species comprised discarded commercial by-catch.

Analysis of mesh sizes

The mesh-size measurements collected from the trawl bodies were analyzed for heteroscedasticity using Cochran's test and then in a two-factor, balanced analysis of variance with trawl body and location of meshes considered fixed and random factors, respectively. Significant differences detected in these analyses were investigated by Tukey's multiple comparisons of means test.

Analysis of catch data

Catch data for all replicates that had sufficient numbers of each variable (i.e. 1 individual in at least 10 replicates) were analyzed with paired *t*-tests ($P \leq 0.05$). Except for the weights and numbers of blue swimmer crabs and small-toothed flounder (species that could not pass through the meshes in any of the trawls), all variables were analyzed using one-tailed tests, testing the hypothesis that the larger-meshed trawl bodies retained fewer individuals than the control. Catches of blue swimmer crabs and small-toothed flounder were compared using two-tailed tests. To examine the relative effectiveness of the spectra 1 mm and momoi 1.7 mm trawl bodies, differences in catches (between each trawl and their respective controls) for those variables that had data in all tows were analyzed using Cochran's test for homogeneity of variances and a balanced, two-factor analysis of variance. In these analyses, trawl-type and nights were considered fixed and random factors, respectively. Where there were sufficient data ($n > 25$ in each trawl, pooled across all tows), size-frequencies of commercially and/or recreationally important fish were plotted and compared with two-sample Kolmogorov-Smirnov tests ($P = 0.05$).

Analysis of prawn sizes

Size-frequencies of prawns retained in each of the three trawls were combined across all tows. Using an estimated split model (Millar and Walsh, 1992), logistic curves were fitted to these data by maximum likelihood method (Pope et al., 1975). Logistic curve parameters, associated standard errors and 95% confidence limits were calculated for each large-meshed trawl body. Model deviance values were determined for a goodness of fit hypothesis (i.e. to test H_o: that the curves were logistic). Size categories of commercially graded prawns from each trawl were plotted and analyzed using two-sample Kolmogorov-Smirnov tests ($P = 0.05$).

Results

Analysis of mesh sizes

There were significant differences detected in size of mesh between the three trawl bodies (Table 1). Tukey's comparison of means test showed no significant differences between the spectra 1 mm and momoi 1.7 mm trawl bodies (mean mesh sizes ± SE of 52.43 ± 0.08 mm and 52.96 ± 0.09 mm, respectively), however, the mean size of mesh in the control trawl was significantly less at 44.42 ± 0.13 mm. Mesh size was not significantly different among the various locations examined in the trawl bodies.

Analysis of catch data

Compared to the control, the spectra 1 mm and momoi 1.7 mm trawl bodies significantly reduced the numbers of western king prawns caught (means reduced by 13.7% and 15.6%, respectively), without significantly reducing their weights (although mean catch from the spectra 1 mm was 6.3% lower than the control) (Table 2; Fig 3A and B). The spectra 1 mm and momoi 1.7 mm trawl bodies also significantly reduced the weights of total discarded by-catch (by 29.3% and 20.3%);

numbers of leatherjacket (by 32.5% and 23.7%) and their weights (by 24.2% and 19.6%); numbers of sand trevally (by 56.2% and 40.4%) and their weights (by 52.8 % and 40.4%); and the numbers of southern sand flathead (by 59.8% and 40.2%) and red mullet (by 67.2% and 59.3%) (Fig. 3, C, E, F, G and I; Table 2). The spectra 1 mm trawl body also significantly reduced the weights of southern sand flathead (by 31.8%), red mullet (by 57%) and the numbers of southern calamari (by 33.6%) (Fig. 3, H, J and L; Table 2). ANOVA of the differences in catches between the new trawl bodies and their controls showed no significant interactions nor main effects for any of the variables examined (Table 3).

Two-sample Kolmogorov-Smirnov tests comparing the size-frequency distributions of fish measured from the control and new trawl bodies detected significant differences in the relative size-compositions of southern sand flathead retained by both new trawl bodies and sand trevally by the momoi 1.7 mm trawl body (the new trawl bodies retained proportionally fewer small-sized fish) (Fig. 4, A and B). There were no other significant differences detected.

Analysis of prawn sizes

The logistic length selection curves derived for each of the new trawl bodies are provided in Fig. 5. Model deviance indicated sufficient goodness of fit for both curves (Table 4). The 95% confidence limits of the selectivity parameters showed that there were no statistically significant differences between the two new trawl bodies (Table 4).

Significant differences were detected in Kolmogorov-Smirnov tests on the commercial size categories of prawns graded from the control and new trawl bodies (Fig. 6). Both trawls with the larger meshed bodies retained proportionally fewer smaller prawns.

Discussion

The results from this study showed that both new trawl bodies were effective in excluding under-sized prawns and large numbers of small fish (by up to almost 60%) with no concomitant reductions in weights of targeted prawns. These results provide evidence to suggest that simple changes to the body of prawn trawls can have a contributing effect on overall trawl selectivity. The escape of large numbers of small fish and prawns from this area may relate to their behaviors in the trawl and the extent to which these were influenced by the operational characteristics of the gear.

It is well established that fish exhibit specific responses to stimuli from trawls and attempt to avoid contact with the trawl body by maintaining position at the opening (Wardle, 1983; Watson, 1989). After some period, depending on species and size-specific swimming abilities (Wardle, 1975), fish invariably tire and turn towards the codend, allowing the trawl to pass around them (Watson, 1989) or alternatively, maintain swimming in the direction of the tow, but gradually fall back along the taper of the body panel towards the codend opening (Wardle, 1983). As the taper of the trawl body narrows and the density of fish increases, some may rise in the trawl and attempt escape through the meshes and/or pass into the codend and resume swimming immediately anterior to the catch (Wardle, 1983). In contrast, benthic invertebrates like prawns tend to display limited responses during capture. SCUBA observations by Watson (1976) showed that after contact with the leading edge of the trawl, penaeid prawns contracted their abdomens ventrally, propelling themselves backwards. This initial response was repeated three to five times, but because prawns are not capable of maintaining such activity, the flow of water quickly forced them against the meshes of the trawl body and they eventually tumbled down the net and into the codend.

Considering these behavioral patterns, gear-related factors such as the fast towing speed (1.5 m/s) and taper of the trawl body in the present study may have increased the probability of small fish and prawns being selected in this area. For example, the sizes of most of the fish encountered and particularly sand trevally, leatherjackets and small southern sand flathead (5 - 15 cm, [Fig. 4]) means that they would have been unable to maintain position in the moving trawls. Studies quantifying the swimming speeds of teleost fish suggest that while individuals 5 and 15 cm long may be expected to have burst speeds of 0.5 m/s and 1.5 m/s over very short periods, their normal maximum swimming performance (or maximum cruising speed - sensu Wardle, 1983) would be much less (Bainbridge, 1958; Beamish, 1978; Wardle; 1975; 1983). As a consequence, in the present study some fatigued individuals probably came in contact with meshes in the body panels as they were herded towards the codend opening. Further, the relatively steep tapers (i.e. 1N4B - see Broadhurst et al., 1999) of the trawl bodies used, (compared with those in most other prawn-trawl fisheries, FAO, 1972), probably contributed to contact of both fish and prawns with meshes in this section of the trawl. A combination of the above effects in the larger-meshed spectra 1 mm and momoi 1.7 mm trawl bodies may have facilitated the escape of smaller individuals.

It is also likely that a reduction in twine area associated with the larger mesh sizes in both new trawl bodies allowed a faster release of water than did the control (Harrington et al.[1]), possibly contributing to the effects discussed above. In partial support of this hypothesis and although no significant differences were detected between the spectra 1 mm and the momoi 1.7 mm trawl bodies for those variables examined (Table 3), compared to their respective controls, the narrower-twined spectra 1 mm trawl body consistently reduced a larger percentage of by-catch across a greater range of variables. These included the weights of southern sand flathead and red mullet and the numbers of southern calamari (Table 2; Fig 3). Further investigation, involving a greater number of replicate tows would be required, however, to validate the potential for this effect.

A contributing operational factor towards the escape of fish from both large-meshed trawl bodies may have been the period between when the vessel was slowed and the gear hauled to the surface (termed 'haulback') (Watson, 1989; Broadhurst et al., 1996). Watson (1989) showed that differences in geometry of the trawl and associated water flow during haulback caused fish (that were still swimming in the trawl) to become disorientated and attempt to escape through the surrounding meshes. More specifically, Workman and Taylor (1989) observed that numerous small individuals of schooling species such as Carangidae (e.g. *Trachurus lathami* and *Decapterus punctalus*) escaped during this period and that larger individuals were often gilled in the meshes of the body panels. In support of these effects in the present study, at the end of each tow we observed numerous individuals of southern sand flathead, leatherjackets and particularly larger sand trevally (10 - 15 cm) trapped in the meshes of the posterior sections of both large-meshed trawl bodies.

Although the results showed that significantly more smaller prawns escaped from the new trawl bodies than the control, the selectivity parameters and associated 95% confidence limits (Fig 5; Table 4) were within the range calculated in a previous study (Broadhurst et al., 1999) for a trawl comprising a body of 45 mm mesh attached to a similar design of composite square-mesh codend. During this work, the codend that showed the most appropriate size-selectivity for prawns tapered from a circumference of 70 bars at the start of the anterior section to 58 bars at the end of the posterior section. After extensive commercial testing, however, it was reported that the slight taper in this codend occasionally 'wedged' the catch in the posterior section, making it difficult to remove when the codend was retrieved and the draw-strings opened. To eliminate this problem, fishers widened the circumference to 80 bars throughout. While such an alteration solved the problems associated with build-up of catch in the codend (by allowing it to distribute more horizontally), it probably lowered the selectivity for prawns (Broadhurst and Kennelly, 1996). Any contributing effects on trawl selectivity due to the larger mesh in the spectra 1 mm and momoi 1.7 mm trawl bodies, may have been slightly negated by a reduction in overall selectivity of the composite square-mesh codends. This result illustrates the need for ongoing assessments of the influences on selectivity of trawls due to subtle modifications implemented to facilitate operational procedures.

Like the results from other related studies, the significant reduction in numbers of prawns caught, but not their weights, has shown that increases in mesh sizes and/or openings can facilitate an increase in catches of target-sized individuals (Walsh et al., 1992; Broadhurst and Kennelly, 1997; Broadhurst et al., 1999). Possible hypotheses to explain this effect include: (i) a faster release of water from the larger-meshed trawls resulted in prawns quickly passing into the trawl after initial contact, with less chance of escaping over the head rope and/or out through the mouth of the trawl or alternatively, (ii) less drag in the larger-mesh trawls, owing to less twine area and by-catch allowed an increase in spread, thereby covering more of the sea bed and capturing more prawns. Of these two hypotheses, the potential for an increase in spread is less likely, since there were no significant differences in the catches of blue swimmer crabs or small-toothed flounder (species that couldn't pass through either the trawl bodies or composite square-mesh codends) between any of the trawls examined.

Because there were no significant differences detected in the weights of prawns captured between the various trawls, a further increase in the size of mesh in the body (e.g. 60 mm) warrants investigation. Given the results presented here, this could facilitate a greater release of small fish and further improve size selectivity for the targeted prawns. Alternatively, it may be feasible to examine the utility of trawl bodies comprising composite panels of larger mesh, particularly in the posterior section, since it is apparent that as fish are herded together in this area their densities increase, resulting in random attempts at escape through the sides of the trawl (Wardle, 1983). In addition, any fatigued fish still swimming in the posterior section of the trawl during haulback may have an opportunity to escape through these larger meshes.

Although not mandated, the results from this study led to the use of the large-meshed trawl bodies by many of the fishers operating in Gulf St. Vincent. Combined with the contributing effects on by-catch reduction due to the composite square-mesh codend, this should result in a comparatively selective prawn-trawl fishery. For example, in a review of literature quantifying by-catches from prawn-trawl fisheries throughout the world, Andrew and Pepperell (1992) reported that typical by-catch to prawn ratios in similar temperate fisheries were in the order of 5:1. Using the mean catch per tow from the control and the new trawl bodies in the present study, discarded by-catch to prawn ratios were 1:1 for the spectra 1 mm and 1:1.3 for the momoi 1.7 mm trawl bodies. Ongoing monitoring is still required, however, to assess any potential effects on selectivity associated with operational refinements to the current trawl configurations.

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Table 1

Summaries of *F* ratios from two-factor analysis of variance to determine differences in size of mesh in the trawls and at various locations and results of Tukey's comparison of means test for the significant difference detected in size of mesh between trawls. Data were treated in the raw form. In all tables $^{*}P < 0.05$; $^{**}P < 0.01$.

Treatment	d.f.	Mesh size (mm)
Trawls (T)	2	2494.7**
Location in trawl (L)	3	0.85
T x L	6	1.4
Residual	346	

spectra 1 mm = momoi 1.7 mm > control

Table 2

Summaries of paired *t*-tests comparing control and new trawl bodies. Weights and numbers of blue swimmer crabs and small-toothed flounder were analysed using two-tailed paired *t*-tests while the remaining variables were analysed using one-tailed paired *t*-tests. pt-v = paired *t*-value; *n* = number of replicates; disc = discarded; n-comm = non-commercial.

	Spectra 1 mm v control			Momoi 1.7 mm v control		
	pt-v	*P*	*n*	pt-v	*P*	*n*
No. of prawns	-2.368	0.016*	15	-2.389	0.016*	15
Wt of prawns	-1.755	0.051	15	-0.044	0.483	15
Wt of total disc by-catch	-4.127	0.0005**	15	-2.662	0.009**	15
Wt of disc n-comm by-catch	-1.709	0.055	15	-1.38	0.095	15
No. of leatherjacket	-3.627	0.001**	15	-2.447	0.014*	15
Wt of leatherjacket	-4.542	0.0002**	15	-2.181	0.023*	15
No. of sand trevally	-1.987	0.033*	15	-2.491	0.013*	15
Wt of sand trevally	-1.960	0.035*	15	-2.253	0.020*	15
No. of southern sand flathead	-3.516	0.002**	14	-2.939	0.006**	14
Wt of southern sand flathead	-2.994	0.005**	14	0.445	0.668	14
No. of red mullet	-3.116	0.004**	15	-2.610	0.013*	11
Wt of red mullet	-2.157	0.024*	15	-0.882	0.199	11
No. blue swimmer crab	1.505	0.156	14	0.725	0.482	13
Wt of blue swimmer crab	1.524	0.152	14	1.462	0.169	13
No. of small-toothed flounder	-0.395	0.699	13	-1.977	0.068	15
Wt of small-toothed flounder	-0.082	0.936	13	-0.150	0.883	15
No. of southern calamari	-2.210	0.022*	15	-0.846	0.206	15
Wt of southern calamari	0.026	0.510	15	-0.837	0.208	15

Table 3

Summaries of F ratios from two-factor analyses of variance to determine effects on variables due to fishing with different trawl bodies on different nights. The transforms used to stabilize the variances where required are listed. N-comm = non-commercial, disc = discarded.

				By-catch (wt)							
		Prawns		Total	N-comm	Leatherjacket		Trevally		Southern calamari	
Treatment	df	no.	wt.	disc	disc	no.	wt.	no.	wt.	no.	wt.
		1/(x+1)				ln(x+1000)					
Trawl bodies (T)	1	0.01	3.97	0.64	0.44	0.64	0.64	1.36	1.36	1.15	1.31
Nights (N)	4	1.50	1.79	0.40	0.41	0.40	0.42	0.72	0.72	1.47	0.18
T x N	4	1.00	0.48	0.86	1.27	0.86	0.23	0.73	0.29	2.20	0.36
Residual	19										

Table 4

Computed selectivity parameters for prawns (carapace length in mm) from the two new trawl bodies and deviance values for logistic curve goodness of fit. Standard errors are given in parentheses. a, b = logistic parameters (Pope et al., 1975). P = split proportion from estimated split model (Millar and Walsh, 1992).

	Momoi 1.7 mm		Spectra 1 mm	
a	-8.99		-13.00	
b	0.26		0.39	
P	0.59		0.56	
		95% confidence limits		95% confidence limits
25% retention (L_{25})	30.26 (0.67)	25.43 - 34.91	29.92 (0.49)	26.72 - 32.92
50% retention (L_{50})	34.47 (0.92)	32.93 - 37.06	32.68 (0.57)	31.69 - 34.13
75% retention (L_{75})	38.68 (1.56)	34.11 - 45.51	35.44 (0.92)	32.46 - 39.55
Selection range (SR)	8.42 (0.44)	5.48 - 11.42	5.52 (0.16)	3.71 - 7.33
Deviance	22.58		29.49	
df	34		32	
p-value	0.932		0.594	

Captions to figures

Figure 1. Location of Gulf St. Vincent, South Australia.

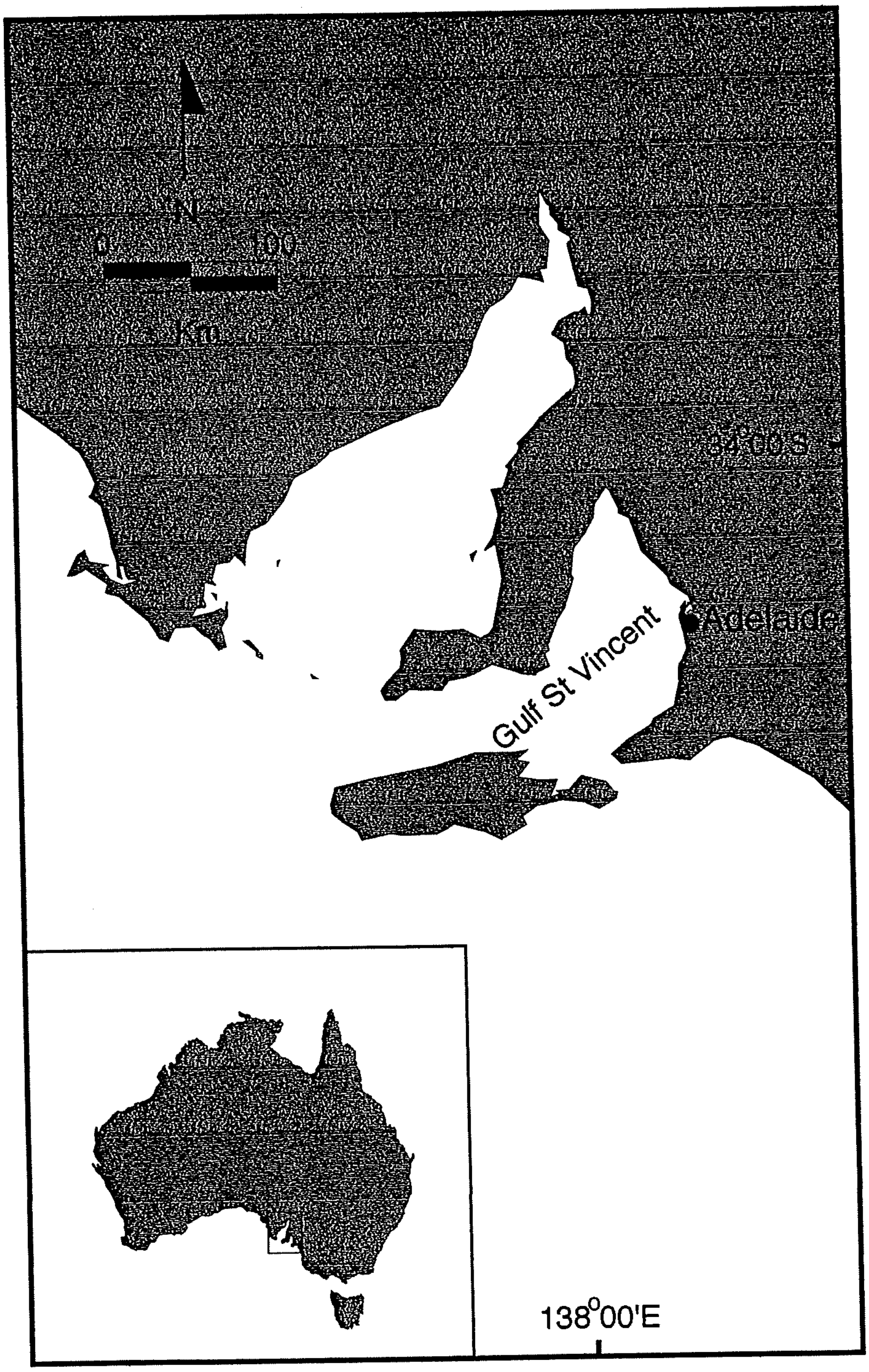
Figure 2. Diagrammatic representation of (A) panels and sections of the composite square-mesh codend, (B) completed composite square-mesh codend, and (C) prawn-trawl body and codend used in the study. B = bars.

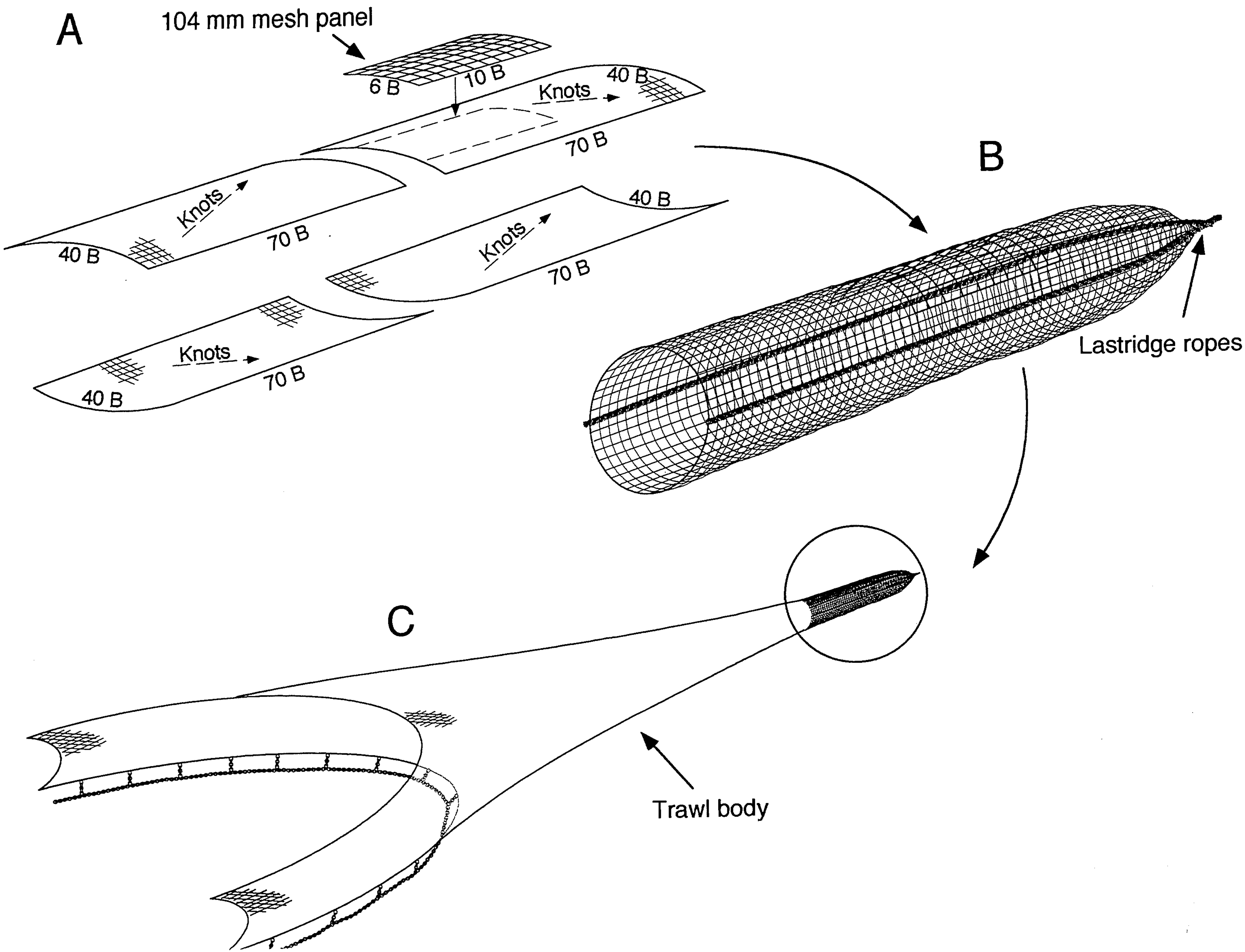
Figure 3. Differences in mean catches (per 25 min tow ± SE) between the new trawl bodies and control for the (A) numbers and (B) weights of king prawns (*Penaeus latisulcatus*); the weights of (C) total discarded by-catch and (D) discarded non-commercial by-catch; the numbers of (E) leatherjackets (*Thamnaconus degeni*), (F) sand trevally (*Pseudocaranx wrighti*) and (G) southern sand flathead (*Platycephalus bassensis*); the weights of (H) southern sand flathead; the numbers (I) and weights (J) of red mullet mullet (*Upeneichthys porosus*); the numbers of (K) blue swimmer crabs (*Portunus pelagicus*); the numbers (L) and weights of (M) southern calamari (*Sepioteuthis australis*); and the numbers of small-toothed flounder (*Pseudorhombus jenynsii*). Significant differences are indicated by shaded histograms.

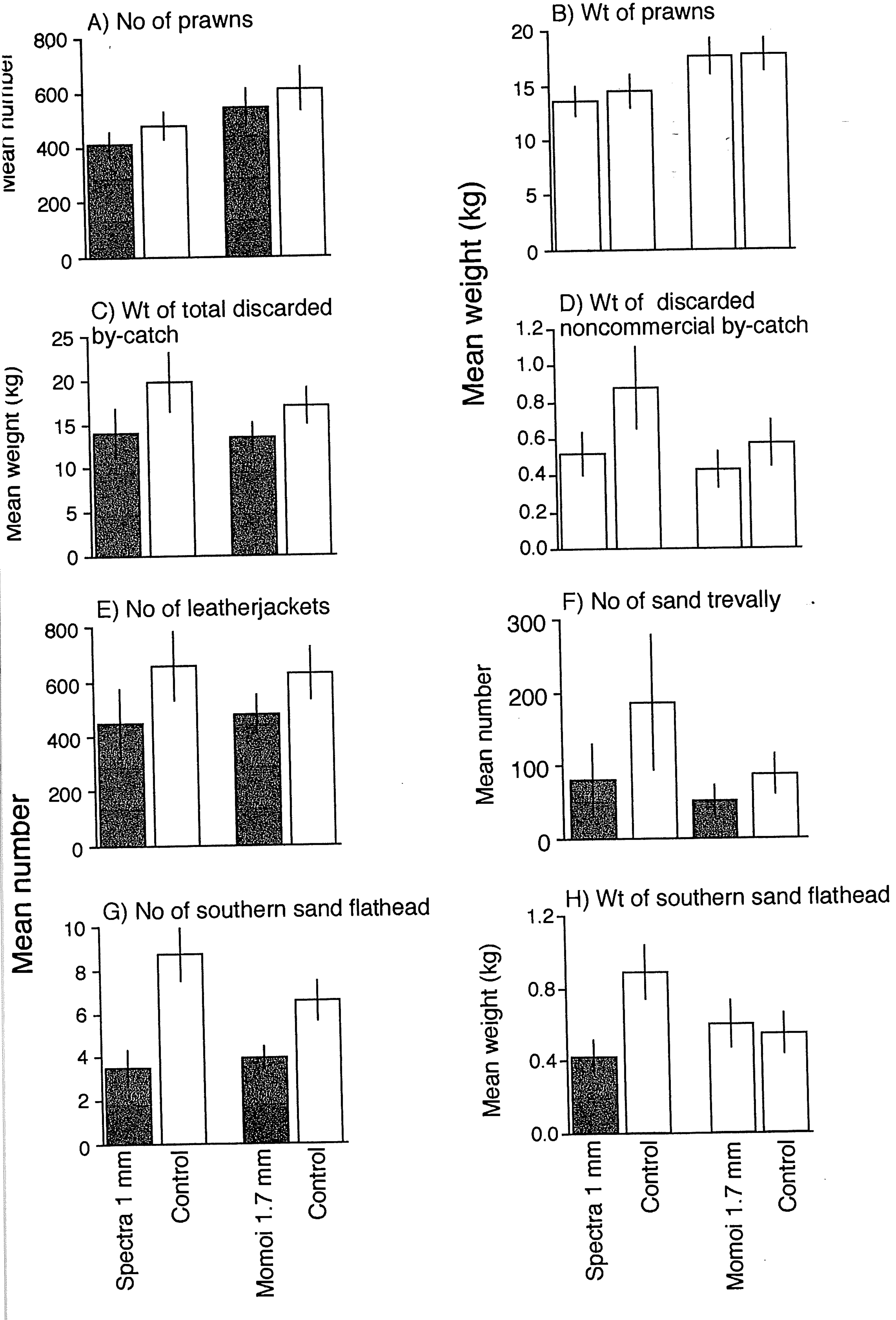
Figure 4. Size-frequency distributions of the new and control trawl bodies for (A) southern sand flathead (*Platycephalus bassensis*), (B) sand trevally (*Pseudocaranx wrighti*) and (C) leatherjacket (*Thamnaconus degeni*).

Figure 5. Plots of the selection curves of western king prawns (*Penaeus latisulcatus*) for the spectra 1 mm and momoi 1.7 mm trawl bodies.

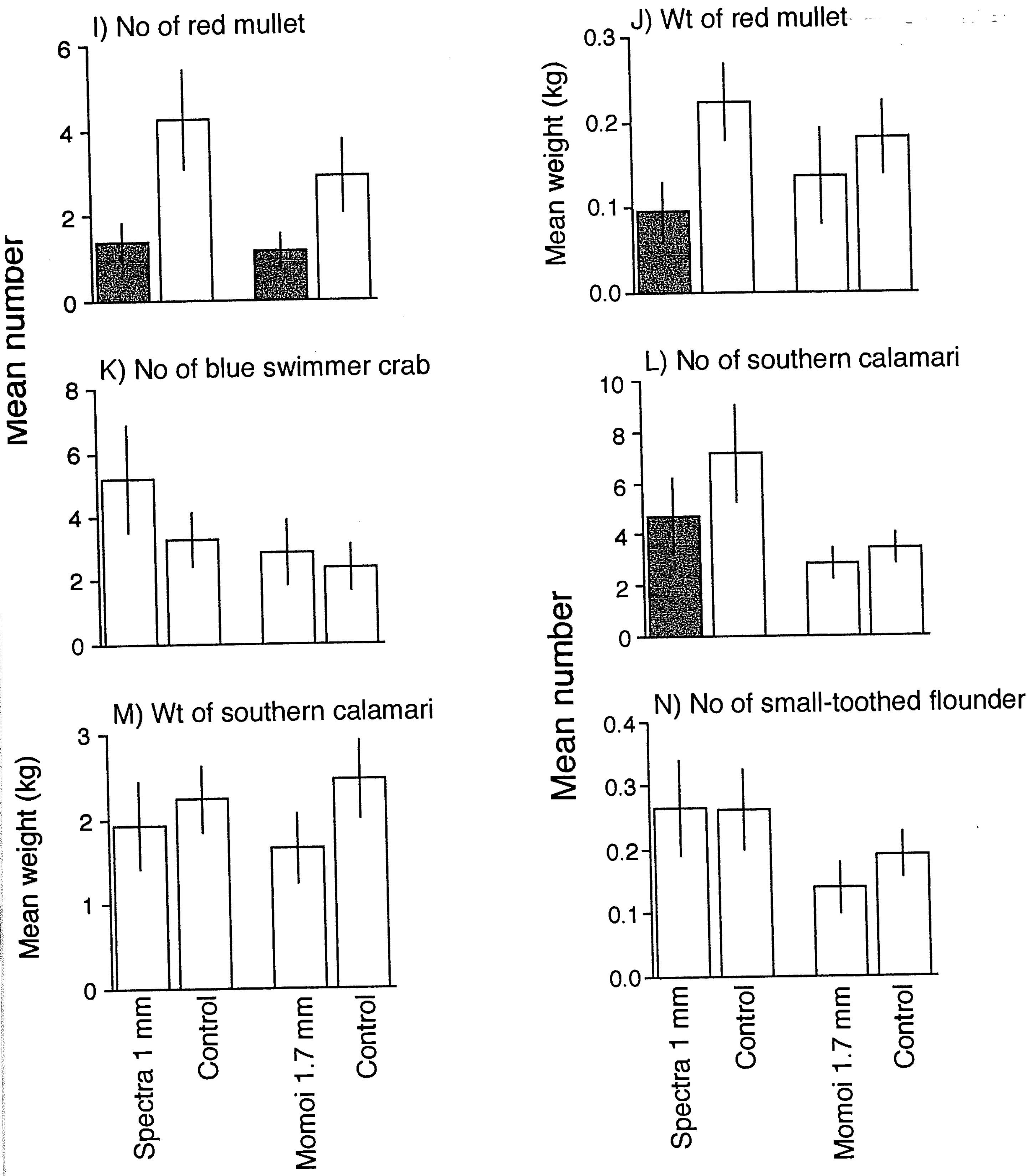
Figure 6. Commercial size-categories of western king prawns (*Penaeus latisulcatus*) caught with the (A) spectra 1 mm and control trawls and (B) momoi 1.7 mm and control trawls (u = under).


N
0
100
Km
34°00'S
Adelaide
Gulf St Vincent
138°00'E

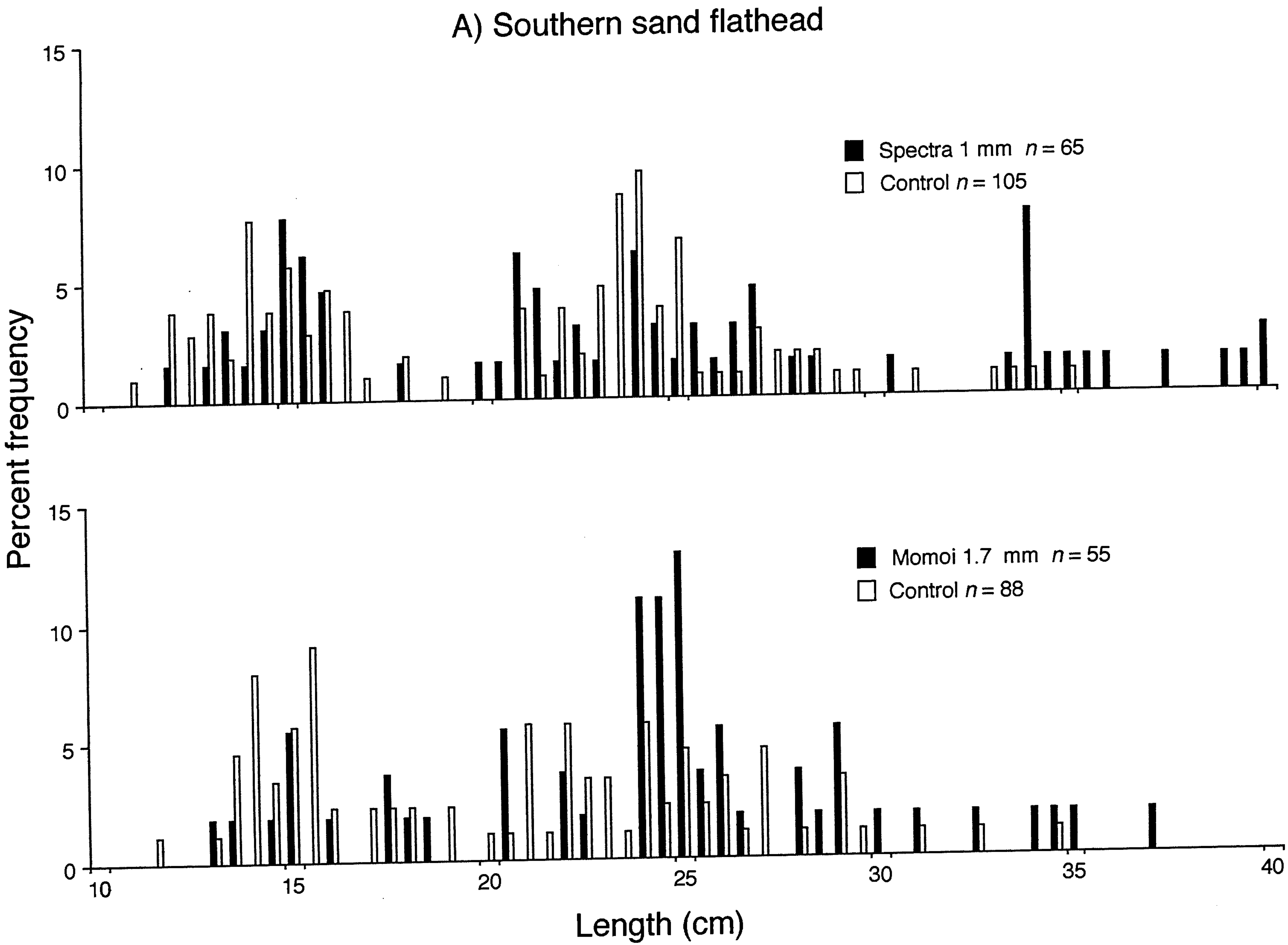

A
104 mm mesh panel
6 B
10 B
40 B
Knots
70 B
Knots
40 B
70 B
40 B
Knots
70 B
Knots
40 B
70 B
B
Lastridge ropes
C
Trawl body



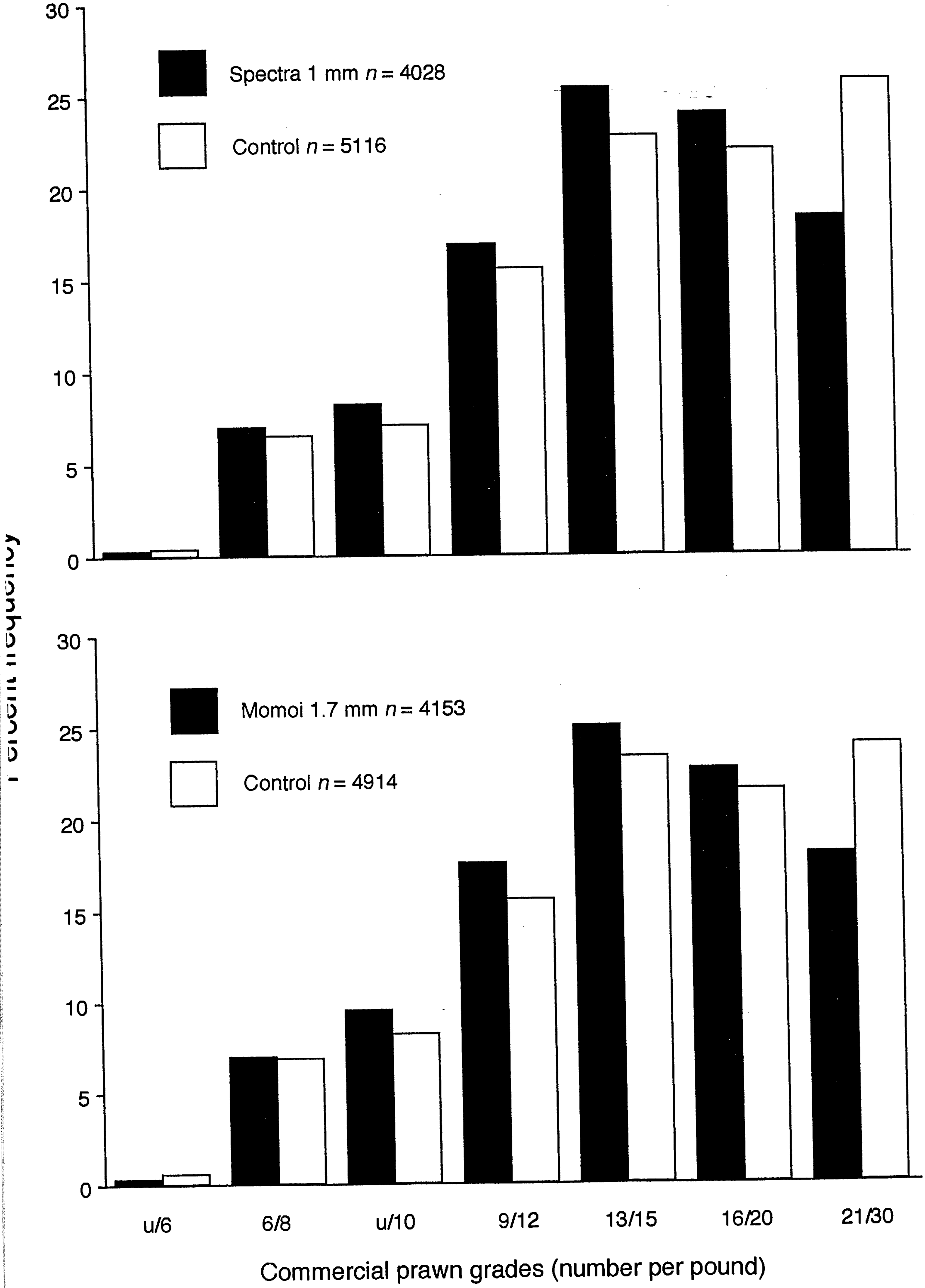
A) No of prawns
Mean number
800
600
400
200
0
B) Wt of prawns
20
15
10
5
0
Mean weight (kg)
C) Wt of total discarded by-catch
Mean weight (kg)
25
20
15
10
5
0
D) Wt of discarded noncommercial by-catch
1.2
1.0
0.8
0.6
0.4
0.2
0.0
E) No of leatherjackets
800
600
400
200
0
Mean number
F) No of sand trevally
Mean number
300
200
100
0
G) No of southern sand flathead
10
8
6
4
2
0
H) Wt of southern sand flathead
Mean weight (kg)
1.2
0.8
0.4
0.0
Spectra 1 mm
Control
Momoi 1.7 mm
Control
Spectra 1 mm
Control
Momoi 1.7 mm
Control



I) No of red mullet
J) Wt of red mullet
K) No of blue swimmer crab
L) No of southern calamari
M) Wt of southern calamari
N) No of small-toothed flounder
Mean number
Mean weight (kg)
Mean number
Mean weight (kg)
Mean number
Spectra 1 mm
Control
Momoi 1.7 mm
Control
Spectra 1 mm
Control
Momoi 1.7 mm
Control



A) Southern sand flathead
Spectra 1 mm n = 65
Control n = 105
Momoi 1.7 mm n = 55
Control n = 88
Percent frequency
0
5
10
15
10
15
20
25
30
35
40
Length (cm)



Percent frequency
Spectra 1 mm $n = 4028$
Control $n = 5116$
Momoi 1.7 mm $n = 4153$
Control $n = 4914$
0
5
10
15
20
25
30
u/6
6/8
u/10
9/12
13/15
16/20
21/30
Commercial prawn grades (number per pound)

Footnotes

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