# 3.0 MORPHOMETRIC RELATIONSHIPS OF KEY TARGET SPECIES TO PREDICT APPROPRIATE MESH SIZES

## 3.1.0 Introduction

Owing to temporal and spatial variables, commercial seining operations may engage juvenile fish in the herding process; consequently the majority are forced to penetrate or contact the meshes in order to attempt escape from the gear. Studies on seining gears completed in South Africa (Jones, G.K. 1982), South Australia (Lamberth et al., 1995), Turkey (Tosunoğlu, Z., 2003) and in NSW estuaries (Gray et al., 2000; Kennelly and Gray, 2000), all described the inappropriateness of the mesh size configurations currently legislated.

It is well recognised that most mobile fishing gears function without optimal selective performance, and for many towed gears the selection of fish is a direct function of their transverse morphology in relation to available mesh openings (Wileman et al., 1996; Stergiou and Karpouzi, 2003; Broadhurst et al., 2006a).

Most research examining the utility of different mesh sizes and configurations have mainly involved trial and error, and are influenced by the commercial availability of materials and mesh sizes (Broadhurst and Kennelly, 1995; Broadhurst et al., 2004b). Utilising data that examine relationships between various morphological parameters, can alleviate the trial and error process, and provide predictions of appropriate mesh sizes and shapes that minimise bycatches without affecting the capture of the targeted species (Konstantinos and Vasiliki, 2003; Broadhurst et al., 2006a; Santos et al., 2006).

It is also important to recognise the material structure of the nets used and associated differences in buoyancy, maintenance of shape and mesh openings, fish behavioural responses, and the potential of different materials/ components of the gear to entangle and/or gill various species of fish.

### 3.1.1 Aims

Given the above, the main aims in this chapter are to (i) quantify and collate morphological data for the primary target species captured in NSW beach seines and (ii) determine appropriate mesh sizes and configurations for various components of NSW beach seines.

## 3.2.0 Materials and methods

### 3.2.1 Collection and analyses of morphological data

Key fish species landed or targeted in NSW seine fisheries were collected from commercial seines, trawls, gill nets and line fisheries from South West Rocks to the Clarence River, between October 2003 and July 2005. The morphological data collected for all individuals are summarized in Fig. 8).

The ratio between maximum height and maximum width were used to determine the general body shape of key species (Fig. 9).

Morphological data were indexed against (TL) and plotted using simple linear regressions using the programs excel data analysis package and sigma plot and adobe illustrator (see Fig. 10). Where sex was identifiable, separate lines were fitted for males and females and comparisons made using analysis of co-variance (ANCOVA). Where relationships proved to have no significance in sexual dimorphism, or where sex was unidentifiable, data were either combined or pooled, respectively. Lines were fitted using raw data and indexed against (TL), with the exception of TL vs. MWt, which were log transformed, with weight as the dependent variable.

## 3.3.0 Results

### 3.3.1 Morphological data

A total of 1163 fish of 8 key species were measured between 22/10/03 and 27/07/05 within 40 hours of capture.

The species examined represent two general body shapes (Fig. 9): (i) fusiform: sea mullet, flat-tail mullet and sand whiting and (ii) ventrally compressed: tailor, bigeye trevally, silver trevally, luderick, yellowfin bream and tarwhine; determined by the ratio between maximum height and width. The relationship between these two variables denotes the mean transverse morphology of the species, and can help determine the optimum hanging ratio of the gear used (area open/ shape) and consequently the size of the mesh required to reduce the capture of juveniles.

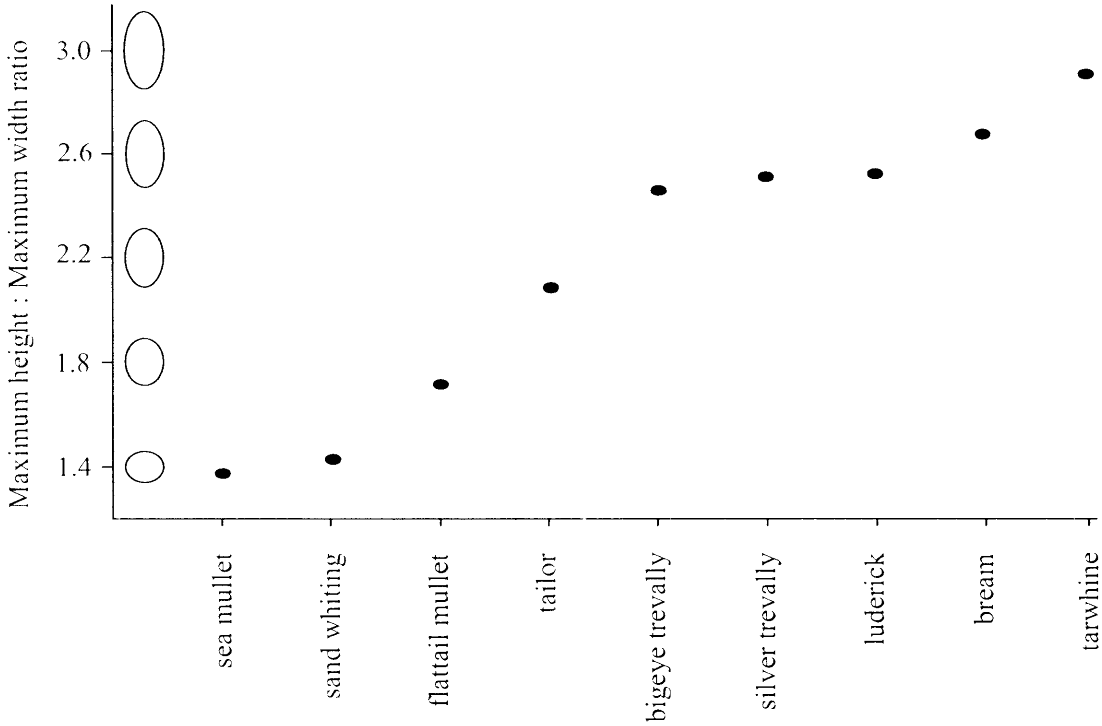

**Figure 9** Maximum height: maximum width ratio for key target species.

Significant linear relationships were detected between TL and the various morphometric measurements for all species (Tables 8 and 9). Coefficients of determination typically ranged between 0.75 and 0.99, indicating that most of the measures provide a reliable estimate of TL (and vice versa). The main exceptions included those variables describing the transverse morphology of male sea mullet ($r^2$ between 0.50 and 0.76, Table 8), male and female flat–tail mullet ($r^2$ between 0.32 and 0.72, Table 8), male and female luderick ($r^2$ between 0.36 and 0.73, Table 8), and silver trevally ($r^2$ > 0.70, Table 9) pooled across sexes. Fig. 10 illustrates the linear relationship between length and girth for the key species.

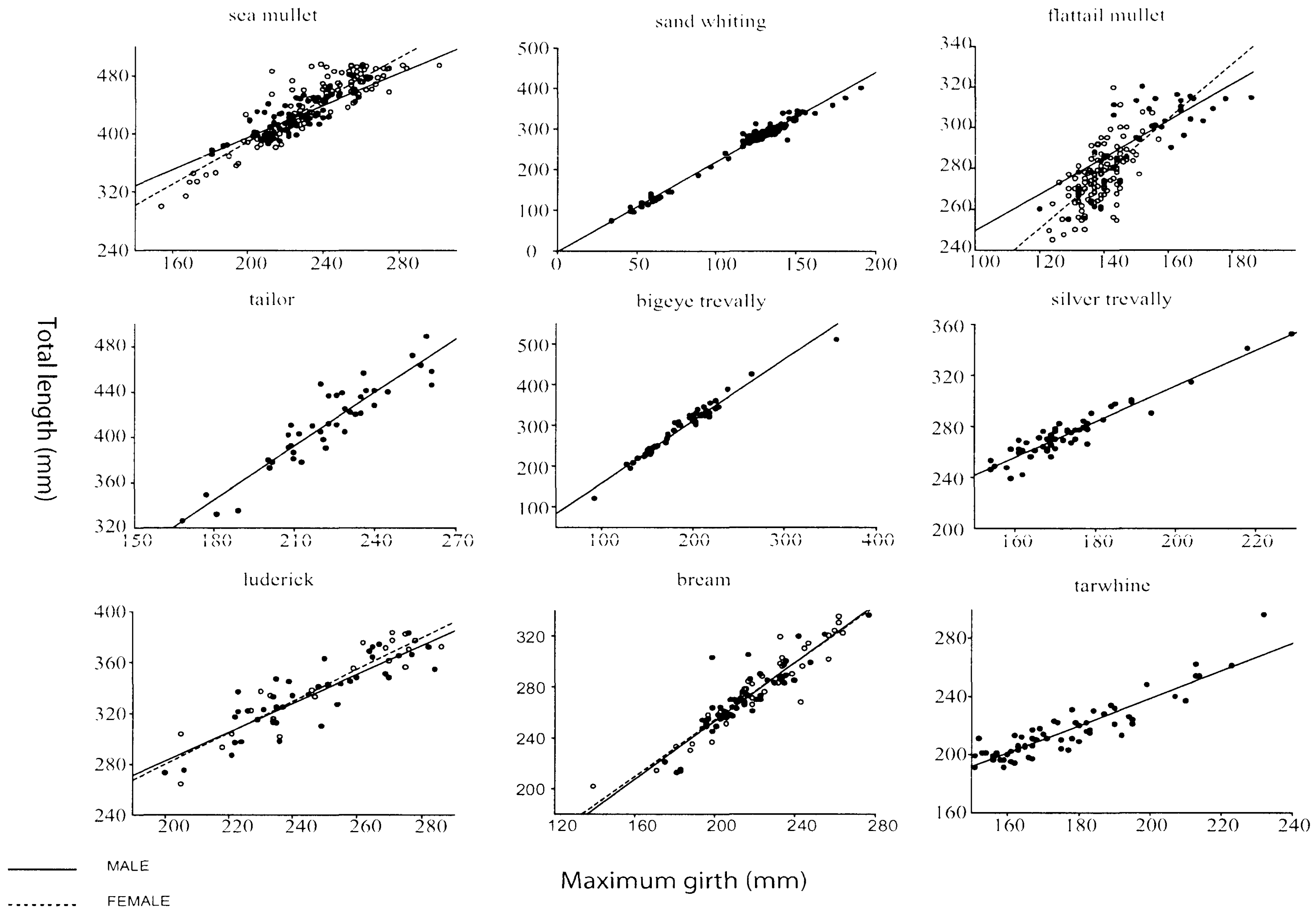

**Figure 10** Linear relationships (total length vs. girth) for key target species captured in the NSW beach seine fishery.

**Table 8** Summaries of linear regressions for male and female fish, ANCOVA testing slopes (β) and elevations (α), respectively and where appropriate, common regressions. Wt = weight; TL = total length; FL = fork length; NL = natural length; SL = standard length; MH = maximum height; MW = maximum width; MG = maximum girth; DSL = dorsal standard length; ASL = anal standard length; $r^2$ = coefficient of determination. The number; size range; and mean TL ± SE (in mm) of specimens are provided in parentheses. All lengths in mm and weights in g. *significant $P < 0.05$; **significant $P < 0.01$.

| | Males | | Females | | | Ratios | Common | |
|---|---|---|---|---|---|---|---|---|
| | Equation | $r^2$ | Equation | $r^2$ | β | α | Equation | $r^2$ |
| Sea mullet | (75; 371 –480.5;419.35 ± 2.729) | | (112; 300 –496;442.75 ± 4.284) | | | | (335; 217 –593; 414.59 ± 3.66) | 0.99 |
| | lnWt = 2.668LnTL –9.458 | 0.82 | lnWt = 2.963LnTL –11.198 | 0.92 | 0.05 | 10.67 ** | | |
| | TL = 1.075FL + 21.361 | 0.97 | TL = 1.111FL + 5.109 | 0.99 | 2.03 | 14.07 ** | | |
| | TL = 0.933NL + 36.803 | 0.98 | TL = 0.985NL + 17.161 | 0.99 | 6.46 * | | | |
| | TL = 1.117SL + 36.203 | 0.96 | TL = 1.125SL + 32.582 | 0.99 | 0.04 | 0.69 | TL = 1.161SL + 19.582 | 0.99 |
| | TL = 2.651MH + 205.401 | 0.61 | TL = 4.015MH + 91.030 | 0.78 | 15.56 ** | | | |
| | TL = 4.843MW + 130.882 | 0.76 | TL = 6.216MW + 43.726 | 0.92 | 15.08 ** | | | |
| | TL = 1.113MG + 170.658 | 0.50 | TL = 1.450MG + 98.809 | 0.79 | 12.60 ** | | | |
| | TL = 1.776DSL + 90.197 | 0.89 | TL = 1.964DSL + 61.978 | 0.95 | 3.37 | 24.49 ** | | |
| | TL = 2.460ASL + 128.497 | 0.77 | TL = 3.088ASL + 66.889 | 0.89 | 8.57 ** | | | |
| Flattail mullet | (135;245–319.5;275.76 ± 1.137) | | (35;255–320;298.67 ± 2.873) | | | | (191;245–359.5;286.17 ± 1.725) | |
| | lnWt = 2.601lnTL –9.406 | 0.83 | lnWt = 3.177lnTL –12.601 | 0.89 | 8.96 * | | lnWt = 3.010lnTL –11.693 | 0.93 |
| | TL = 1.063FL + 15.973 | 0.91 | TL = 1.111FL + 4.460 | 0.97 | 1.02 | 1.77 | TL = 1.117FL + 3.114 | 0.98 |
| | TL = 1.009NL + 1.292 | 0.99 | TL = 1.022NL –1.271 | 0.98 | 3.71 | 5.45 * | | |
| | TL = 1.081SL + 36.491 | 0.91 | TL = 1.149SL + 21.583 | 0.95 | 1.69 | 1.12 | TL = 1.138SL + 24.055 | 0.97 |
| | TL = 2.874MH + 116.219 | 0.32 | TL = 2.597MH + 135.797 | 0.59 | 0.31 | 1.53 | TL = 3.676MH + 72.450 | 0.74 |
| | TL = 6.227MW + 71.368 | 0.58 | TL = 5.490MW + 98.498 | 0.72 | 0.08 | 1.86 | TL = 6.650MW + 60.053 | 0.70 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | TL = 1.343MG + 89.468 | 0.40 | TL = 0.977MG + 146.710 | 0.54 | 42.59 ** | | | |
| | TL = 1.663DSL + 100.543 | 0.63 | TL = 1.739DSL + 101.438 | 0.59 | 0.12 | 25.51 ** | | |
| | TL = 2.024ASL + 119.530 | 0.60 | TL = 2.149ASL + 122.731 | 0.50 | 0.17 | 50.10 ** | | |
| Luderick | (40; 273 –383; 332.96 ± 4.318) | | (24; 264 –383; 342.98 ± 6.724) | | | | (119; 218.5 –416; 325.71 ± 3.657) | |
| | lnWt = 2.793lnTL –9.907 | 0.89 | lnWt = 3.069lnTL –11.497 | 0.94 | 1.71 | 0.63 | lnWt = 2.979lnTL –10.987 | 0.99 |
| | TL = 1.080FL + 2.080 | 0.97 | TL = 1.090FL –4.108 | 0.98 | 0.05 | 5.76 * | | |
| | TL = 0.992NL + 9.454 | 0.97 | TL = 1.003NL + 4.670 | 0.99 | 0.13 | 1.14 | TL = 1.008NL + 3.995 | 0.99 |
| | TL = 1.126SL + 27.526 | 0.95 | TL = 1.041SL + 49.030 | 0.98 | 2.61 | 2.19 | TL = 1.141SL + 21.794 | 0.98 |
| | TL = 2.599MH + 57.830 | 0.75 | TL = 2.581MH + 59.888 | 0.84 | 0.01 | 0.01 | TL = 2.942MH + 20.721 | 0.90 |
| | TL = 5.193MW + 113.173 | 0.57 | TL = 4.494MW + 151.324 | 0.36 | 0.31 | 2.24 | TL = 6.385MW + 62.349 | 0.69 |
| | TL = 1.137MG + 55.081 | 0.73 | TL = 1.239MG + 32.295 | 0.85 | 5.45 * | | | |
| | TL = 1.328DSL + 72.600 | 0.86 | TL = 1.349DSL + 66.508 | 0.94 | 0.02 | 0.65 | TL = 1.473DSL + 42.420 | 0.95 |
| | TL = 2.003ASL + 92.257 | 0.80 | TL = 1.991ASL + 96.278 | 0.85 | 0.01 | 0.54 | TL = 2.315ASL + 54.613 | 0.90 |
| Bream | (53;212.5–336;268.97 ± 3.437) | | (40;201.5–335;279.33 ± 5.027) | | | | (291;59–382;189.77 ± 4.614) | |
| | lnWt =2.903lnTL –10.543 | 0.91 | lnWt = 2.849lnTL –10.218 | 0.95 | 0.11 | 1.66 | lnWt = 2.948lnTL –10.808 | 0.98 |
| | TL = 1.335FL –1.574 | 0.99 | TL = 1.127FL + 0.582 | 0.99 | 0.08 | 0.53 | TL = 1.130FL –0.631 | 0.99 |
| | TL = 1.001NL + 6.608 | 0.98 | TL = 1.032NL –2.252 | 0.98 | 1.24 | 0.21 | TL = 1.024NL + 0.792 | 0.99 |
| | TL = 1.214SL + 8.322 | 0.98 | TL = 1.218SL + 8.018 | 0.98 | 0.02 | 0.70 | TL = 1.235SL + 3.710 | 0.99 |
| | TL = 2.628MH + 26.794 | 0.89 | TL = 2.933MH –1.919 | 0.92 | 2.61 | 0.01 | TL = 2.945MH –3.766 | 0.99 |
| | TL = 5.994MW + 61.053 | 0.79 | TL = 5.776MW + 75.121 | 0.76 | 0.11 | 5.31 * | | |
| | TL = 1.143MG + 24.758 | 0.78 | TL = 1.114MG + 31.178 | 0.89 | 0.08 | 0.01 | TL = 1.278MG –6.095 | 0.98 |
| | TL = 1.547DSL + 38.354 | 0.90 | TL = 1.816DSL + 0.161 | 0.96 | 7.97 | 2.61 | TL = 1.784DSL + 3.542 | 0.99 |
| | TL = 2.773ASL + 43.137 | 0.80 | TL = 3.303ASL + 5.565 | 0.88 | 3.79 | 6.44 * | | |

**Table 9** Summaries of linear regressions for fish pooled across sexes. Wt = weight; TL = total length; FL = fork length; NL = natural length; SL = standard length MH = maximum height; MW = maximum width; MG = maximum girth; DSL = dorsal standard length; ASL = anal standard length; $r^2$ = coefficient of determination. The number; size range; and mean TL ± SE (in mm) of specimens are provided in parentheses. All lengths in mm and weights in grams.

| Tarwhine | | Silver trevally | | Bigeye trevally | |
|---|---|---|---|---|---|
| (77;66–296;198.17 ± 5.33) | | (56;233–352.5;272.90 ± 2.944) | | (62;120–510;291.32 ± 7.657) | |
| lnWt = 3.134lnTL –11.390 | 0.99 | lnWt = 2.927lnTL –11.020 | 0.91 | lnWt = 3.012lnTL –11.446 | 0.99 |
| TL = 1.152FL –2.392 | 0.99 | TL = 1.180FL –2.059 | 0.99 | TL = 1.185FL –1.054 | 0.99 |
| TL = 1.029NL + 0.677 | 0.99 | TL = 1.022NL + 1.040 | 0.98 | TL = 1.022NL + 4.962 | 0.99 |
| TL = 1.268SL + 2.333 | 0.99 | TL = 1.180SL + 9.155 | 0.97 | TL = 1.219SL + 0.848 | 0.99 |
| TL = 2.662MH + 11.344 | 0.96 | TL = 3.380MH + 16.186 | 0.84 | TL = 3.482MH –4.177 | 0.96 |
| TL = 7.048MW + 28.230 | 0.93 | TL = 6.863MW + 64.572 | 0.86 | TL = 7.770MW + 20.339 | 0.97 |
| TL = 1.142MG + 14.682 | 0.96 | TL = 1.304MG + 47.210 | 0.72 | TL = 1.517MG + 7.30 | 0.96 |
| TL = 1.859DSL + 1.016 | 0.97 | TL = 1.698DSL + 21.042 | 0.93 | TL = 1.825DSL + 2.430 | 0.99 |
| TL = 3.061ASL + 5.091 | 0.98 | TL = 1.698ASL + 73.243 | 0.72 | TL = 2.062ASL + 3.646 | 0.99 |

| Tailor | | Sand Whiting | |
|---|---|---|---|
| (45;80–489;384.16 ± 14.20) | | (123;73–401;263.95 ± 6.357) | |
| lnWt = 3.071lnTL –11.973 | 0.99 | lnWt = 2.866lnTL –11.011 | 0.94 |
| TL = 1.135FL –3.573 | 0.99 | TL = 1.091FL –4.294 | 0.99 |
| TL = 1.019NL + 0.126 | 0.99 | TL = 1.028NL –1.197 | 0.99 |
| TL = 1.173SL + 2.632 | 0.99 | TL = 1.169SL + 2.614 | 0.99 |
| TL = 4.569MH –4.860 | 0.97 | TL = 5.736MH + 12.557 | 0.98 |
| TL = 8.755MW + 24.171 | 0.94 | TL = 8.012MW + 20.335 | 0.96 |
| TL = 1.869MG –4.471 | 0.97 | TL = 2.202MG –1.505 | 0.98 |

| | | | |
|---|---|---|---|
| TL = 1.627DSL + 48.731 | 0.99 | TL = 1.812DSL –0.556 | 0.99 |
| TL = 2.570ASL + 2.297 | 0.98 | TL = 2.805ASL –13.142 | 0.99 |

**Table 10** Mean predicted minimum legal dorsal (DSL) and anal standard lengths (ASL) and maximum girths (MG) (± 99% CI) corresponding to minimum legal (MLTL) or commercial (MCTL) total lengths of the species examined, and the existing and predicted minimum mesh sizes and shapes. Where appropriate, means are provided for males, females or both sexes combined. All other estimates are for combined regressions. All lengths in mm. —, na, not appropriate; dia, diamond; squ, square.

| Species | MLTL or MCTL | MG | Existing minimum diamond mesh | Predicted mesh size and shape |
|---|---|---|---|---|
| Sea mullet | 300 | na | 50 | 48–70 dia or squ |
| males | | 94.48 | | |
| females | | 138.75 | | |
| Flattail mullet | 250 | na | 50 | 53–60 dia |
| males | | 119.53 | | |
| females | | 105.72 | | |
| Luderick | 250 | na | 50 | 86–88 dia |
| males | | 171.43 | | |
| females | | 175.71 | | |
| Sand whiting | 270 | 123.30 | 50 | 62 dia or squ |
| Yellowfin bream | 250 | 200.38 | 50 | 100 dia |
| females | | na | | |
| males | | na | | |
| Tarwhine | 200 | 162.27 | 50 | 81 dia |
| Silver trevally | 250 | 155.52 | 50 | 78 dia |
| Bigeye trevally | 250 | 159.99 | 50 | 80 dia |
| Tailor | 300 | 162.91 | 50 | 81 dia |

## 3.4.0 Discussion

### 3.4.1 Utility of morphological data to predict mesh size and shape

Use of the various sex–specific or combined relationships should be limited to the size ranges used to fit the models for each species. Further, because the parameters of the regressions between TL and Wt and transverse morphology probably vary spatially and temporally (according to fish condition and maturity), they should only be considered mean values for the sample period.

Notwithstanding the above, the regressions provide sufficient information to predict species-specific mesh sizes and shapes that may improve selection (Table 10). These predictions are based on the general shape and MG of fish and the assumption that the meshes in the codend or bunt are configured so that openings are sufficient for fish to penetrate. The mean MGs of all species corresponded to predicted optimal mesh sizes and/or shapes considerably different to existing regulations (Table 10). Specifically, for nearly all dorsally–and ventrally–compressed species, the minimum appropriate sizes of diamond mesh (assuming maximum lateral openings during fishing) were between 0.8 (flat–tail mullet) and 2.0 (yellowfin bream) times larger than the current minimum–legislated sizes.

The restrictions currently enforced on commercial beach seines were established in the 1940's according to the sizes of the targeted species and the mesh sizes commercially available at the time of determination. The appropriateness of these mesh sizes in selecting catches of legal sizes (MLTL or MCTL) has in essence been unknown due to the limited data available describing catch characteristics in NSW commercial beach seines. However, as described previously, published data describing the catches of commercial beach seines deployed in NSW estuaries (Gray et al., 2000; Kennelly and Gray 2000), indicate that a significant proportion of the landed catches may comprise juveniles of the targeted species.

Traditionally, field experiments examining increases in mesh sizes, to influence the selectivity of a gear for the enhancement of juvenile exclusion, have been based on trial and error. However, with knowledge regarding the key target species, and utilising data describing the relationships between various morphological parameters, (i.e., transverse morphology), estimates of suitable mesh sizes and shapes can be determined and further trialled to establish their suitability.

The current regulations enforced for beach seines have been assessed in terms of the transverse morphology of the targeted species in relation to the mesh openings of the current legislated mesh sizes. The linear relationships provided in Fig. 10 (total length vs. girth) for key target species captured in the NSW seine fishery, describe the predicted girth at various sizes. Corresponding with MLTL and/or MCTL for the key species, Table 10 describes the inappropriateness of the existing regulations and it is apparent that for nearly all species (with the exception of male sea mullet), the mesh sizes currently enforced are too small to allow juveniles to be selected out from catches during the hauling process. Improving selection is extremely important in working towards a sustainable future for the beach seine fishery.

Current legislation and gear restrictions on maximum mesh sizes used in NSW beach seines impact on the ability of commercial fisherman to reduce the capture of juveniles at times when species and/or their sizes are diverse. It is important to recognise the temporal and spatial variability in beach seine catches, and that the appropriateness of a mesh size may only be evident or beneficial at specific times of the year, or at certain locations. In order to reduce the capture of juveniles of the targeted species, it is important that commercial fishers have a range of mesh sizes available at their discretion to target and capture a range of species throughout various times and locations.

(Gray and Kennelly et al., 2003) indicates that different estuaries often have contrasting species compositions and abundances, both of which are dependent on species specific, temporal and seasonal variability. Due to the existence of these spatio–temporal interactions, during periods where visual identification of key species is achievable, (e.g. for mono–specific schools of sea mullet or yellowfin bream), it may be beneficial to allow fishers the use of species–specific mesh sizes, (i.e., 70– and 100–mm, respectively). This however results in the need for a complex management system and the development of estuary–specific management. Nonetheless, it is imperative that the gears used to catch commercial quantities of the targeted species have mesh sizes that minimise the retention of juveniles of key species. Without such changes, the fishery is likely to continue to be perceived as functioning in an unsustainable manner, maintaining conflict between the various users of the resource. Adopting mesh sizes that select only target sizes and species, should improve the sustainability of the targeted resource.

The following chapter (Assessment of conventional and modified estuary deployed beach seines) was submitted for publication to Fisheries Research – see Appendix B.)

# 4.0 ASSESSMENT OF CONVENTIONAL AND MODIFIED ESTUARY–DEPLOYED BEACH SEINES

## 4.1.0 Introduction

The starting point for improving selection in net–based fishing gears like beach seines is to (i) identify strategic areas where most of the selection occurs and then (ii) regulate mesh openings at these areas according to the sizes of the main targeted species.

To address each of these issues for beach seines, two experiments were done to examine the catches of gears configured with currently legislated mesh sizes, and of gears modified to improve selection. These field experiments were aimed at determining the effects on catches associated with changing mesh size in the posterior wings and bunt, respectively.

By separately examining the catches in the anterior, posterior wings and bunt, the aims were to (i) identify any species–specific selection mechanisms, and then use this information to (ii) provide a first step in determining appropriate modifications and their location for improving selectivity in estuary deployed beach seines, and furthermore provide suggestions for improving selectivity in oceanic deployed beach seines.

## 4.2.0 Materials and methods

Two experiments were done using a chartered estuarine seine crew in the Clarence River (29°26'S, 153°22'E) NSW, between September 2005 and March 2006. (Fig. 11)

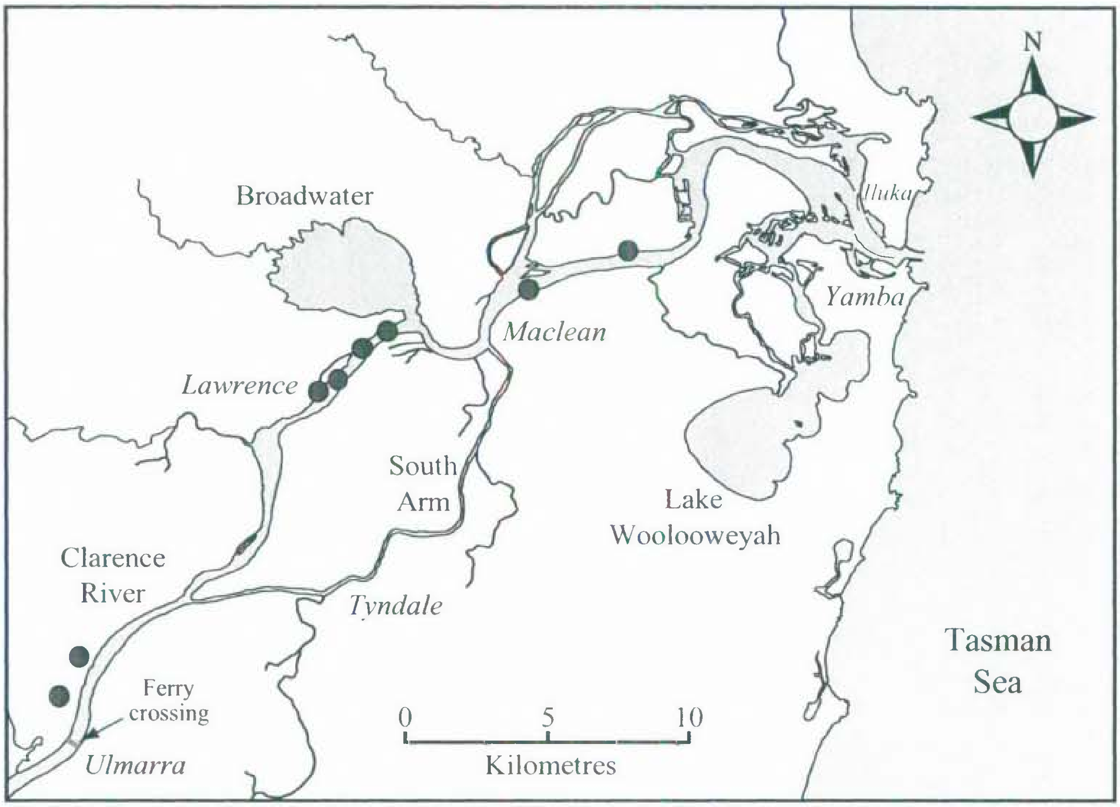

**Figure 11** Map of the Clarence River illustrating approximate locations of study sites.

The generic seine was categorised into three separate areas, namely i) anterior wings, ii) posterior wings and iii) the bunt and codend (Fig. 3). The respective total headline lengths for each individual component were 188, 30 and 12.5 m. The total headline length of all seine configurations measured 450 m.

Various sections of a beach seine were constructed (see Fig. 3; Fig. 12) and included one set of anterior wings made from 80–mm mesh (1.5–mm Ø, 10–strand PA), 3 pairs of posterior wings constructed from 57–, 63–and 80–mm mesh, respectively (1.5–mm Ø, 10–strand PA) and 4 bunt and codend sections (see below). Each of the gear components were equal in terms of the overall dimensions and materials used, (e.g. foot ropes 12–mm Ø 3–strand polypropylene –PP, head ropes (10–mm Ø 3–strand polyethylene –PE), hanging ratio (E= 0.5), netting material (knotted multi–strand polyamide –PA) and 20m hauling ropes (12–mm Ø 3–strand polyethylene –PE) attached to bridles, connected to the anterior wing–ends. Gears only differed in their respective mesh sizes.

Four bunt/codend configurations were constructed from various mesh sizes, all of knotted multi–monofilament polyethylene mesh. The first termed–control bunt, represented an existing design used by beach seine fishers in NSW estuaries and was constructed from 33–mm mesh (1 mm diameter–Ø) throughout (Fig. 12). The second, third and fourth configurations (termed the 45–, 65–and 80–mm bunts) were constructed from 45, 65 and 80 mm mesh (1.5 mm Ø), respectively (Fig. 12), with identical headline lengths (12.5 m) and total bunt and codend length (9 m) . Zippers were attached to the leading edges of the anterior and posterior wings to facilitate the exchange of the relevant gear components. (Details are provided in Section 2.1.1).

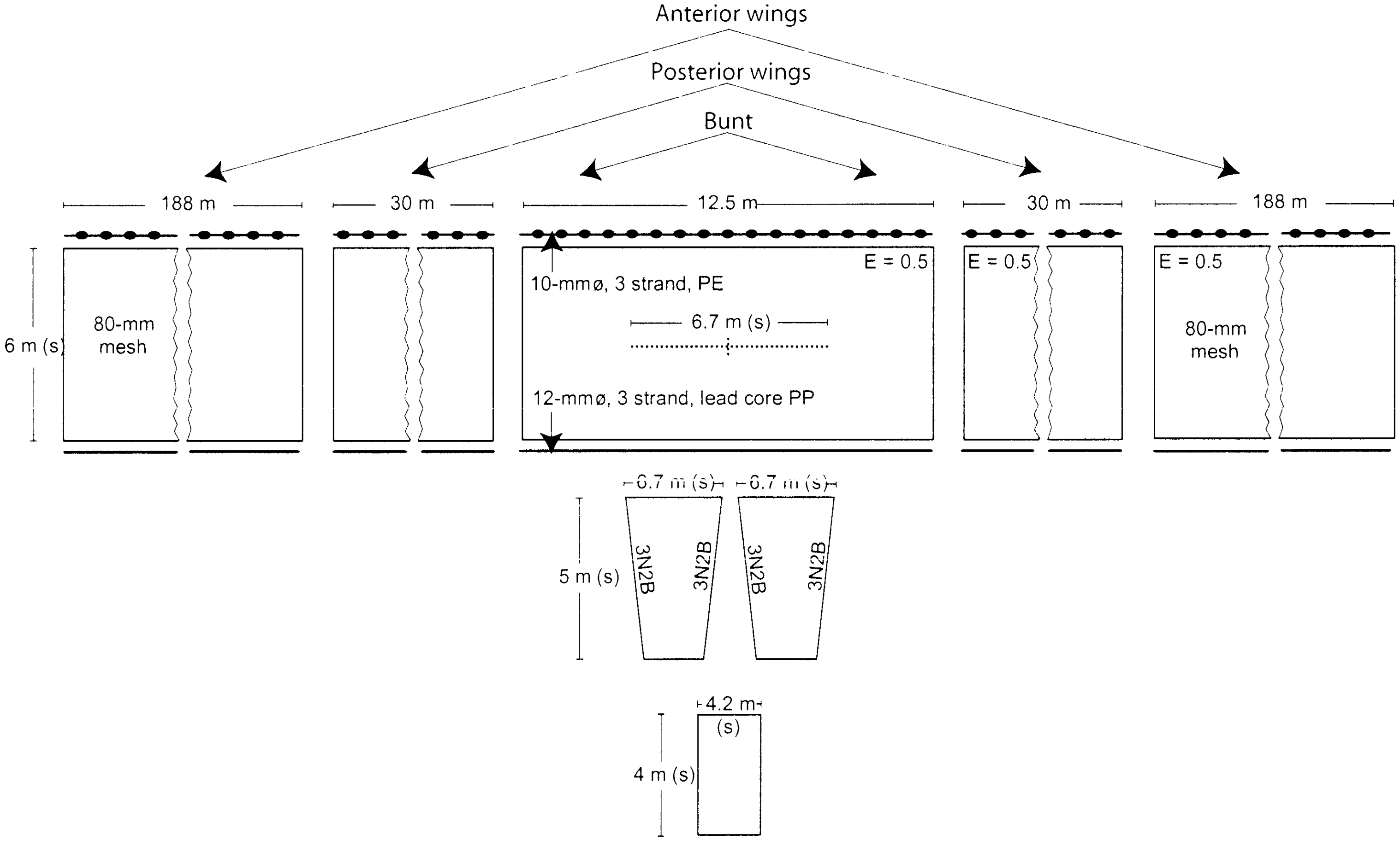

**Figure 12** Two–dimensional plan of the generic beach seine encompassing all mesh sizes used in the experiments –see section 4.21, 4.22. N, normals; B, bars; s, stretched mesh length; PE, polyethylene; PP, polypropylene; ø, diameter; E, hanging ratio.

In both experiments, each individual seine was deployed from a motored vessel during daylight, corresponding with times of minimal currents, (i.e. before either the flood or ebb tides). The basic methodology of the seine was comparable with normal commercial practices (Fig.13) (details are provided in section 2.1.0). Owing to tidal conditions and other fishing variables, a maximum of 3 individual deployments were possible on each sampling day. All seines were deployed in recognised commercial seining locations.

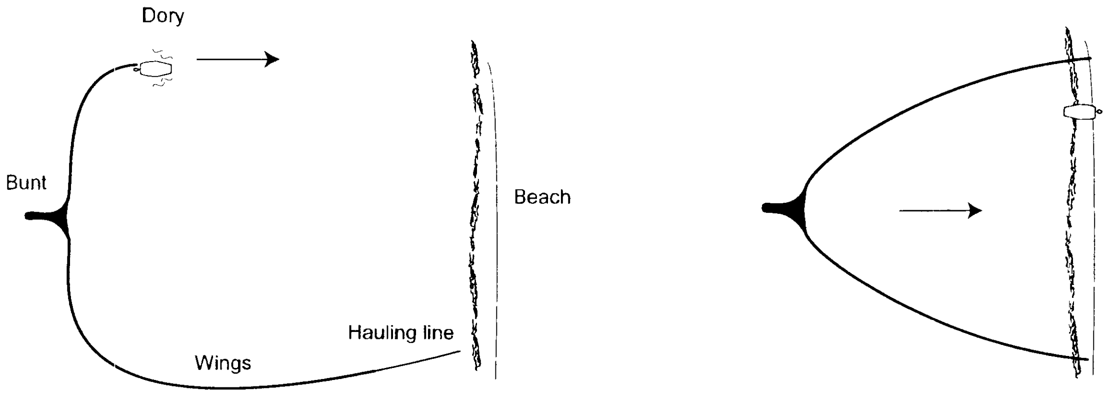

**Figure 13** Deployment of the estuary beach seine

### 4.2.1 Experiment 1.

The first experiment tested the hypothesis of no significant differences in catches between beach seines with the same anterior wings and bunt (80–and 45–mm, respectively) but with differing mesh sizes in the posterior wings. At the beginning of each sampling day, either the 57– or 80–mm posterior wings were zippered to the leading edges of the anterior wings and bunt and codend and loaded onto the deployment vessel and deployed according to normal conventional practices. Over 10 days between September and October 2005, a total of 15 replicate deployments of the 57–and 80–mm posterior wings were completed.

### 4.2.2 Experiment 2.

The second experiment tested the hypotheses of no significant differences in the (i) size selectivity of two treatment bunt and codends 63–and 80–mm, using the 33–mm bunt configuration as the control, and ii) catches between either of the three configurations. All configurations had identical anterior (80mm) and posterior wings (63mm), and were tested according to normal conventional practices. At the beginning of each sampling day, the control or particular treatment bunt/codend being tested was zippered to the posterior wings and loaded onto the commercial vessel ready for deployment. Over 23 sampling days, between October 2005 and March 2006, a total of 14 deployments of the 63–and 80–mm bunts, and 23 deployments of the 33–mm bunt were completed.

### 4.2.3 Data collected and statistical analyses

At the end of each deployment in experiments 1 and 2, catches in the pairs of anterior and posterior wings (i.e. fish that were always meshed or entangled) and the bunt (either meshed, entangled or otherwise) were separated on the beach (Fig. 14), and the following data recorded for each of the three sections of the seine: the numbers and weights of the total, retained and discarded catch, and the numbers of total, retained and discarded individual commercially–important species and their sizes (total length –TL to the nearest 0.5 cm for the entire catch or at least 100 randomly selected individuals of all species per seine deployment [1]).

For experiment 1, the size–frequency distributions of key species caught in (i) the pair of posterior wings and (ii) the entire beach seine configured with either the 57–or 80–mm posterior wings were combined across all deployments and compared with two–sample Kolmogorov–Smirnov tests.

**Figure 14** Removing the catch from a modified (63–mm) bunt and codend, used in Experiment 2.

For experiment 2, the size frequencies of individuals of key species were combined across only those deployments where the 33–mm bunt was fished on the same day as either of the two larger–meshed bunts. Using the seine configured with the 33–mm bunt as a control, logistic selection curves were fitted for each of the seines containing the larger–meshed bunts using the estimated–split SELECT model for alternate deployments and via maximum likelihood (Millar and Walsh, 1992). Converged models were corrected for over dispersion arising from between–haul variation using the replicate estimate of dispersion (Millar et al., 2004). Pairwise bivariate Wald statistics were used to test the hypothesis of no intra–specific differences in parameter vectors (size at 50% selection –$L_{50}$ and selection range –SR) between the seines containing the two larger–meshed bunts.

In both experiments, where there were sufficient data for the numbers and weights of variables (defined as at least one fish in each of 12 and 8 replicate deployments, respectively) in each section of the gear, these were ln(x+1) transformed, tested for heteroscedasity using Cochran's test and then analysed using balanced, one–nested factor analysis of variance (ANOVA), with seine configuration and days (nested factor) considered as fixed and random factors. Where homogeneity of variances was not established, ANOVA was done at $P = 0.01$ to reduce the probability of a type I error. The model used for experiment 1 included three replicate deployments day $^{1}$ of each of two seine configurations (57–and 80–mm posterior wings attached to the 80–mm anterior wings and 45–mm bunt) over five days. To provide a balanced analyses for experiment 2, two replicate deployments day $^{1}$ were randomly–selected for each of three seine configurations (33–, 63–, and 80–mm bunts attached to the 63–and 80–mm posterior and anterior wings) over four days. In both models, where the nested factor of days was non–significant at $P = 0.25$, it was pooled with the residual to increase the power for testing the main effect of seine configuration. Significant F–ratios detected for this latter factor were investigated using Student–Newman–Keuls (SNK) comparison of means tests. With the exception of the numbers of total, retained and discarded catches, only those significant differences detected between seine configurations for the numbers of variables were graphed. In all analyses, the null hypothesis was rejected at $P < 0.05$.

### 4.4.0 Results

A total of 28 305 fish, weighing 5.5 tonnes, were caught during the study. Catches comprised 23 species, although more than 85 and 95% of the total (by number) in experiments 1 and 2, respectively consisted of silver biddy (32 and 25%), sea mullet (21 and 25%), yellowfin bream (24 and 17%) and sand whiting (10 and 28%). The catch rates of these 4 key species by the conventional beach seine configurations were with in the ranges experienced during normal commercial operations. Irrespective of the configuration, fewer than 8% of any fish were meshed or entangled in the 188–m anterior wings. Typically, more of the remaining total catch was retained in the bunt (between 64 and 87%) than meshed or entangled in the posterior wings (between 11 and 40%), although the quantities of individual species of fish caught in either of these sections varied considerably (from 7 to 98%).

### 4.4.1 Experiment 1: effects of changing mesh size in the posterior wings

Kolmogorov–Smirnov tests detected significant differences in the size–frequency distributions of all four key species retained in the 57–and 80–mm posterior wings, and in the entire seine for each configuration ($P > 0.05$; Fig. 15).

Specifically, the 80–mm posterior wings meshed proportionally fewer small (undersize) yellowfin bream and sea mullet than the 57–mm posterior wings, which contributed towards lower catches of these sizes in the entire gear (Figs. 15a and d).

Few silver biddy and sand whiting of any size were meshed in the 80–mm posterior wings and proportionally fewer of their larger sizes were retained in the total seine (Figs. 15b and c).

Owing to variability in the temporal distribution of catches, the above observed differences in the sizes of fish retained did not translate into significant differences between seine configurations for the numbers and weights of total, retained and discarded catches in all sections of the gear, or any other variables in the bunt and total seine (Fig. 15a–e; Table 11).

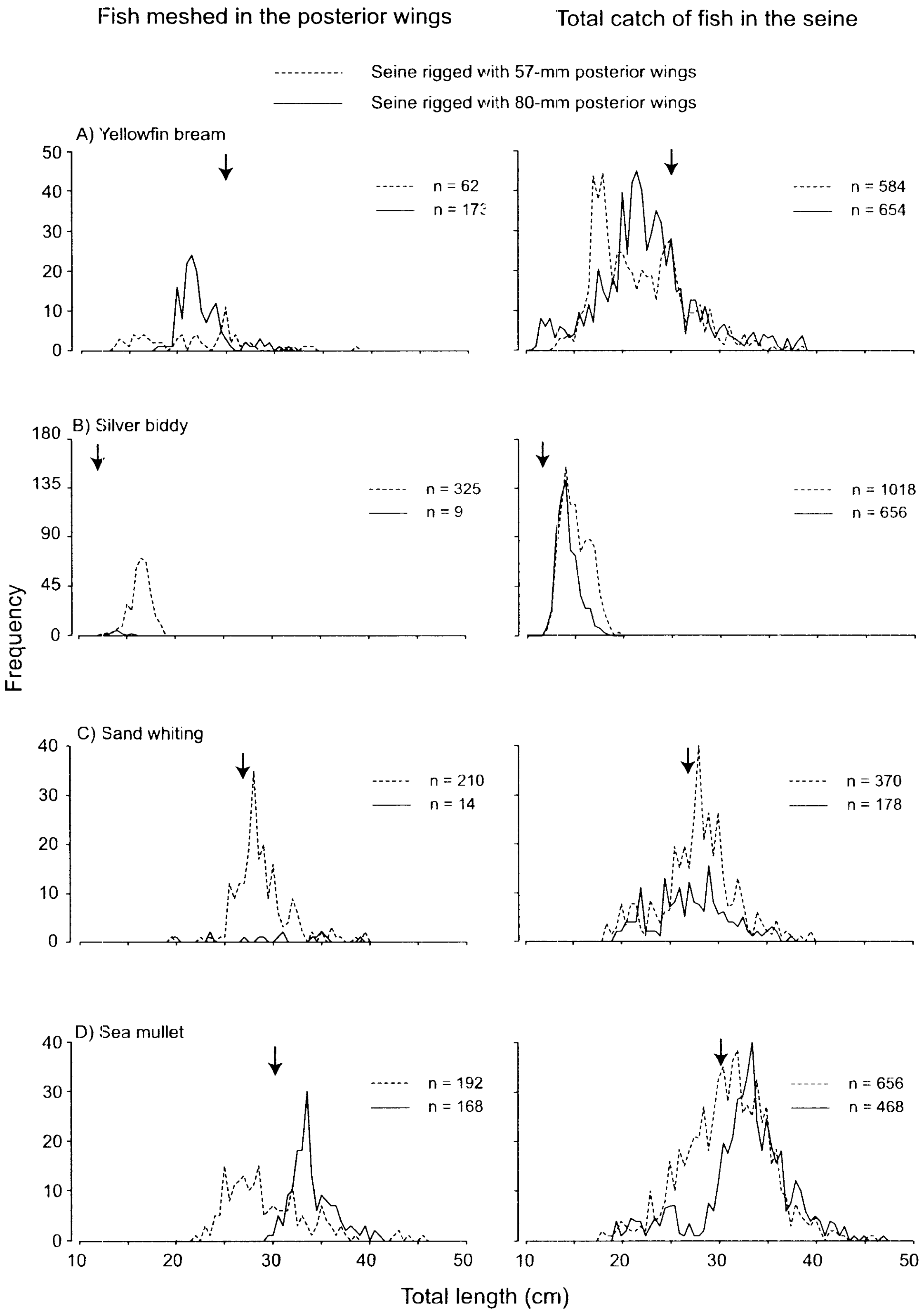

**Figure 15** Experiment 1: size–frequency distributions of (a) yellowfin bream, (b) silver biddy, (c) sand whiting and (d) sea mullet retained in the posterior wings and the total seine when either the 57–or 80–mm posterior wings were attached to the 80–mm anterior wings and the

45–mm bunt. The minimum commercial or legal total lengths are indicated by the arrows. All size–frequency distributions were significantly different between the treatment seine configurations (Kolmogorov–Smirnov tests, $P < 0.05$). n, number.

**Table 11** F–ratios from one–nested ANOVA to determine the effects on catches in different sections (anterior and posterior wings and bunt) and the total seine due to fishing with the 57–and 80–mm posterior wings. Each beach seine configuration was used three times day$^{-1}$ over 5 days. $^{**}P < 0.01$; $^{*}P < 0.05$; ret, retained; disc, discarded; SC, seine configuration; D, days. "Pld" indicates that the nested term of 'days' was non–significant at $P > 0.25$ and the sums of squares pooled with the residual. The degrees of freedom for SC were 1 and 8 for the full model and 1 and 28 for the pooled model. < and > indicate directions of differences in SC detected in Student–Newman–Keuls tests.

| | Anterior wings | | | Posterior wings | | | Bunt | | | Total seine | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | SC | D | SC differences | SC | D | SC differences | SC | D | SC differences | SC | D | SC differences |
| No of total catch | 0.99 | $1.35^{pld}$ | None | 0.31 | 2.99* | None | 0.28 | 2.91* | None | 0.06 | 3.23* | None |
| Wt of total catch | 1.21 | 1.99 | None | 0.19 | 4.98** | None | 0.22 | 2.64* | None | 0.39 | 3.97** | None |
| No of ret catch | 0.88 | $1.21^{pld}$ | None | 0.21 | 3.74** | None | 0.07 | 3.32 | None | 0.03 | 3.69** | None |
| Wt of ret catch | 1.53 | 1.48 | None | 0.48 | 6.22** | None | 0.05 | 3.36* | None | 0.38 | 3.91** | None |
| No of disc catch | 0.58 | $0.83^{pld}$ | None | 0.75 | 2.05 | None | 1.08 | $1.25^{pld}$ | None | 0.07 | 1.87 | None |
| Wt of disc catch | 0.19 | $1.26^{pld}$ | None | 0.51 | 3.19* | None | 0.63 | $1.39^{pld}$ | None | 0.01 | 2.54* | None |
| No of total yellowfin bream | — | — | — | 3.31 | 1.72 | None | 2.07 | 1.90 | None | 0.01 | 2.54* | None |
| Wt of total yellowfin bream | — | — | — | 4.71 | 2.66* | None | 0.94 | 2.41 | None | 1.27 | 2.74* | None |
| No of ret yellowfin bream | — | — | — | 5.49* | 2.01 | 80 > 57 | 0.22 | 3.56 | None | 0.32 | 3.32* | None |
| Wt of ret yellowfin bream | — | — | — | 4.74 | 2.37 | None | 0.19 | 2.80 | None | 0.36 | 2.77 | None |
| No of disc yellowfin bream | — | — | — | 2.27 | 1.57 | None | 2.33 | 1.47 | None | 1.81 | 1.84 | None |
| Wt of disc yellowfin bream | — | — | — | 3.65 | 2.34 | None | 1.00 | 1.58 | None | 1.38 | 2.01 | None |
| No of total silver biddy | — | — | — | 22.68** | 1.46 | 57 > 80 | 0.13 | 2.95 | None | 0.07 | 2.38 | None |
| Wt of total silver biddy | — | — | — | 11.70** | 1.85 | 57 > 80 | 0.03 | 3.31* | None | 0.64 | 3.14* | None |
| No of ret silver biddy | — | — | — | — | — | — | 0.13 | 2.98 | None | 0.07 | 2.40 | None |
| Wt of ret silver biddy | — | — | — | — | — | — | 0.03 | 3.33* | None | 0.64 | 3.14* | None |
| No of total sand whiting | — | — | — | — | — | — | 1.42 | 2.22 | None | 0.03 | 3.70** | None |
| Wt of total sand whiting | — | — | — | — | — | — | 0.65 | 2.77 | None | 0.01 | 4.16* | None |
| No of ret sand whiting | — | — | — | — | — | — | 1.19 | 2.64 | None | 0.01 | 4.64** | None |
| Wt of ret sand whiting | — | — | — | — | — | — | 0.46 | 2.90 | None | 0.01 | 4.36** | None |
| No of disc sand whiting | — | — | — | — | — | — | 0.66 | 1.95 | None | 0.02 | 2.49* | None |
| Wt of disc sand whiting | — | — | — | — | — | — | 0.30 | 1.98 | None | 0.01 | 2.76 | None |
| No of total sea mullet | — | — | — | — | — | — | 0.24 | $1.05^{pld}$ | None | 0.01 | $1.00^{pld}$ | None |
| Wt of total sea mullet | — | — | — | — | — | — | 0.57 | $1.01^{pld}$ | None | 0.02 | $0.93^{pld}$ | None |
| No of ret sea mullet | — | — | — | — | — | — | 0.50 | $1.07^{pld}$ | None | 0.03 | $1.13^{pld}$ | None |
| Wt of ret sea mullet | — | — | — | — | — | — | 0.62 | $1.00^{pld}$ | None | 0.02 | $1.05^{pld}$ | None |
| No of disc sea mullet | — | — | — | — | — | — | — | | — | 1.24 | $1.23^{pld}$ | None |
| Wt of disc sea mullet | — | — | — | — | — | — | — | — | — | 2.64 | $1.29^{pld}$ | None |

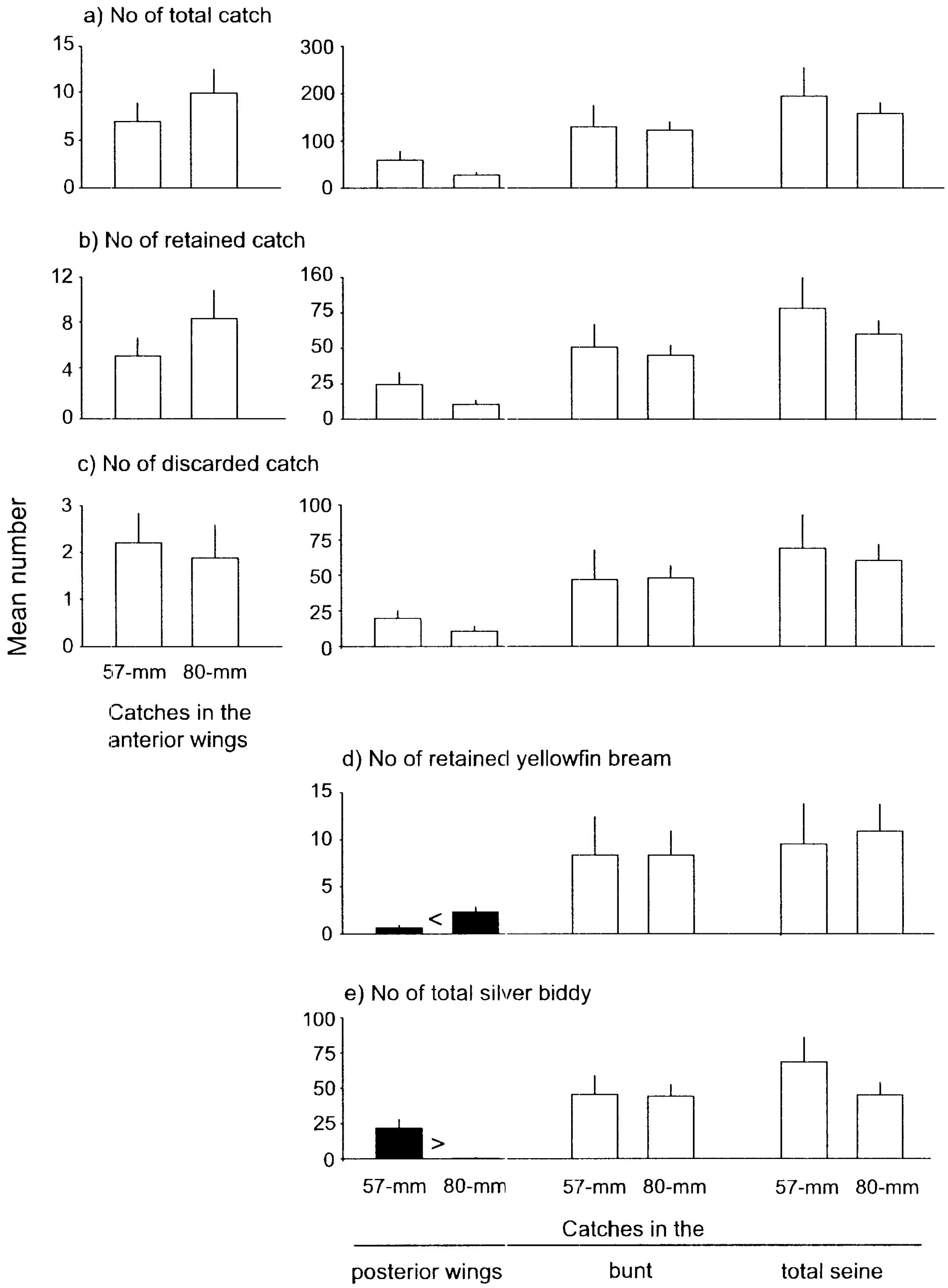

**Figure 16** Experiment 1: differences in mean numbers of catch (± se) deployment [1] in each of the three sections of the seine (anterior and posterior wings and bunt) and total seine when either the 57–or 80–mm posterior wings were attached to the 80–mm anterior wings and the 45–mm bunt for (a) total, (b) retained and (c) discarded catch, (d) retained yellowfin bream and (e) total silver biddy. Black histograms represent significant F–ratios, with the directions of significant differences detected in Student–Newman–Keuls tests illustrated by < and >.

ANOVA did return significant F–ratios for the number of retained yellowfin bream and the number and weight of total silver biddy meshed in the posterior wings (Fig. 16d and e, Table 11). Compared to the 57–mm mesh, significantly more (mean increase of almost threefold) retained yellowfin bream and fewer (mean reduction of 97%) silver biddy were meshed in 80–mm posterior wings (Fig. 16d and e). There were no other significant effects of seine configuration, although several variables in the catches were significantly different among days (Table 11).

### 4.4.2 Experiment 2: effects of changing mesh size in the bunt

Sufficient quantities and sizes of yellowfin bream and sea mullet were caught in all configurations and sand whiting in the beach seine configured with the 33–and 63–mm bunts to enable attempts at modelling selectivity for the seines with the larger–mesh bunts (Table 12, Fig. 17).

**Table 12** Total lengths (in cm) at 50% probability of retention ($L_{50}$), selection ranges (SR) and relative fishing efficiencies (P) for the key species caught by the beach seine configured with either the 63–or 80–mm bunts. Standard errors are given in parentheses. $n^t$ and $n^c$, number of treatment and control (33–mm bunt) deployments used in the model; —, insufficient data or unable to converge model, ns, non–selective for the sizes caught.

| Species and bunt | $n^t$ | $n^c$ | $L_{50}$ | SR | p |
|---|---|---|---|---|---|
| *Silver biddy* | | | | | |
| 63–mm | 12 | 12 | — — | — | |
| 80–mm | 12 | 9 | — — | — | |
| *Sea mullet* | | | | | |
| 63–mm | 14 | 10 | 20.98 (1.07) | 4.49 (1.26) | 0.70 (0.01) |
| 80–mm | 12 | 9 | 26.42 (0.85) | 7.84 (1.65) | 0.49 (0.02) |
| *Yellowfin bream* | | | | | |
| 63–mm | 12 | 10 | ns ns | ns | |
| 80–mm | 12 | 9 | 20.81 (0.82) | 4.12 (0.94) | 0.5 (0.04) |
| *Sand whiting* | | | | | |
| 63–mm | 12 | 12 | 33.87 (1.16) | 5.94 (0.40) | 0.79 (0.06) |
| 80–mm | 12 | 9 | — — | — | |

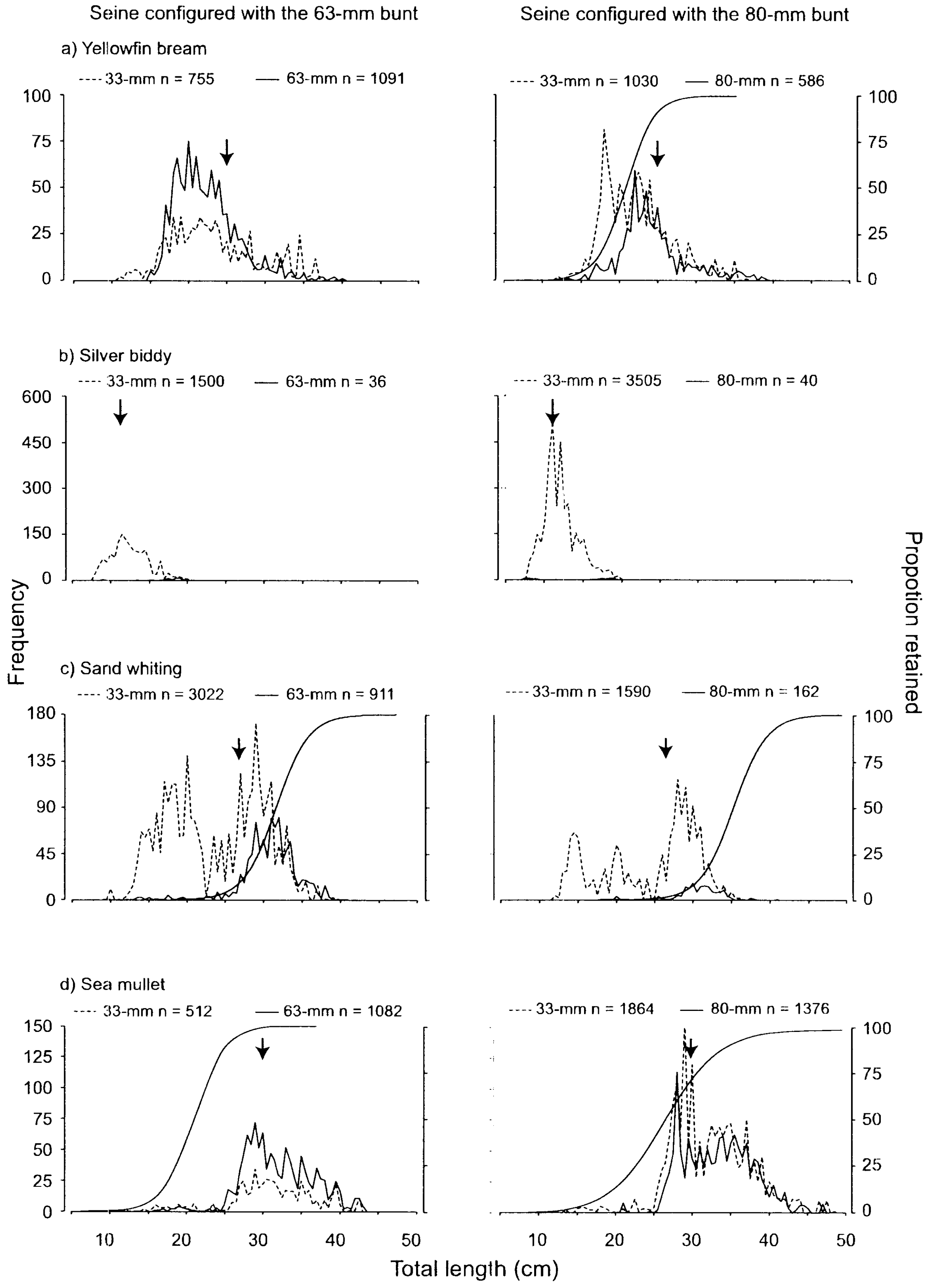

**Figure 17** Experiment 2: size–frequency distributions and, where converged, selection curves for (a) yellowfin bream, (b) silver biddy, (c) sand whiting and (d) sea mullet for the seine configured with the 63–and 80–mm bunts. The 33–mm bunt was used as a control. The minimum commercial or legal total lengths are indicated by the arrows. n, number.

Logistic models were converged for these species, although the curve for yellowfin bream from the 63–mm bunt was not significantly different from the null model ($P > 0.05$) and was not presented.

Pairwise bivariate Wald tests detected significant differences between the treatment configurations for sea mullet ($P > 0.05$).

ANOVA did not detect any significant effects of seine configuration (i.e. the three different bunts) or days for the numbers or weights of fish meshed in either the anterior or posterior wings (Table 13, Fig. 18).

**Table 13** F–ratios from one–nested ANOVA to determine the effects on catches in different sections (anterior and posterior wings and bunt) and the total seine due to fishing with the 33–, 63–and 80–mm bunts. Each beach seine configuration was used twice daily on four separate days. $^{**}P < 0.01$; $^{*}P < 0.05$; ret, retained; disc, discarded; SC, seine configuration; D, days. "Pld" indicates that the nested term of 'days' was non–significant at $P > 0.25$ and the sums of squares pooled with the residual. The degrees of freedom for SC were 2 and 9 for the full model and 2 and 21 for the pooled model. <, > and 'not clear' indicate directions of differences for SC detected in Student–Newman–Keuls tests.

| | Anterior wings | | | Posterior wings | | | Bunt | | | Total seine | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | SC | D | SC differences | SC | D | SC differences | SC | D | SC differences | SC | D | SC differences |
| No of total catch | 0.28 | $1.30^{pld}$ | None | 3.93 | 2.39 | None | 4.43* | 2.32 | Not clear | 2.75 | 2.39 | None |
| Wt of total catch | 0.13 | 1.80 | None | 2.55 | 2.77 | None | 0.34 | $1.15^{pld}$ | None | 0.21 | $1.34^{pld}$ | None |
| No of ret catch | 0.17 | 1.89 | None | 3.43 | 1.63 | None | 3.56* | $0.97^{pld}$ | Not clear | 0.81 | $1.46^{pld}$ | None |
| Wt of ret catch | 0.15 | 2.33 | None | 2.86 | 1.72 | None | 0.21 | $0.68^{pld}$ | None | 0.22 | $1.13^{pld}$ | None |
| No of disc catch | 0.37 | $1.06^{pld}$ | None | 1.91 | $1.47^{pld}$ | None | 3.93 | 3.52* | None | 3.56 | 3.62* | None |
| Wt of disc catch | 0.52 | $1.38^{pld}$ | None | 0.57 | 1.65 | None | 0.28 | 3.26* | None | 0.01 | 2.76 | None |
| No of total yellowfin bream | — | — | — | 2.81 | $0.41^{pld}$ | None | 0.27 | 5.98** | None | 0.44 | 4.63** | None |
| Wt of total yellowfin bream | — | — | — | 2.18 | $0.52^{pld}$ | None | 0.56 | 3.77* | None | 0.61 | 3.94* | None |
| No of ret yellowfin bream | — | — | — | 0.88 | $0.84^{pld}$ | None | 0.88 | 2.06 | None | 0.86 | 1.88 | None |
| Wt of ret yellowfin bream | — | — | — | 0.88 | $0.75^{pld}$ | None | 0.86 | 1.56 | None | 0.74 | 1.63 | None |
| No of disc yellowfin bream | — | — | — | 3.26 | $0.36^{pld}$ | None | 0.11 | 7.28** | None | 0.27 | 4.41** | None |
| Wt of disc yellowfin bream | — | — | — | 3.28 | $0.42^{pld}$ | None | 0.21 | 5.99** | None | 0.42 | 6.02 | None |
| No of total sand whiting | — | — | — | 1.00 | 2.54 | None | 13.99** | 2.21 | 33 > 63 > 80 | 2.83 | 3.02* | None |
| Wt of total sand whiting | — | — | — | 1.34 | 2.34 | None | 4.92* | 2.26 | Not clear | 0.95 | 2.33 | None |
| No of ret sand whiting | — | — | — | 1.01 | 2.60 | None | 5.93** | $1.22^{pld}$ | 33 = 63 > 80 | 1.03 | 2.06 | None |
| Wt of ret sand whiting | — | — | — | 1.35 | 2.37 | None | 3.98* | $1.11^{pld}$ | 33 = 63 > 80 | 1.03 | 1.73 | None |
| No of disc sand whiting | — | — | — | — | — | — | 26.01** | 2.97* | 33 > 63 = 80 | 18.73** | 2.49 | 33 > 63 = 80 |
| Wt of disc sand whiting | — | — | — | — | — | — | 7.05 | 4.10 | None | 5.89* | 3.51* | 33 > 63 = 80 |
| No of total silver biddy | — | — | — | — | — | — | 65.17** | $1.18^{pld}$ | 33 > 63 = 80 | 24.99** | $0.72^{pld}$ | 33 > 63 = 80 |
| Wt of total silver biddy | — | — | — | — | — | — | 18.33** | 2.08 | 33 > 63 = 80 | 19.27** | $1.41^{pld}$ | 33 > 63 = 80 |
| No of ret silver biddy | — | — | — | — | — | — | 55.70** | $0.76^{pld}$ | 33 > 63 = 80 | 24.45** | $0.90^{pld}$ | 33 > 63 = 80 |
| Wt of ret silver biddy | — | — | — | — | — | — | 21.88** | $1.02^{pld}$ | 33 > 63 = 80 | 9.51** | $0.93^{pld}$ | 33 > 63 = 80 |
| No of disc silver biddy | — | — | — | — | — | — | 31.64** | 1.59 | 33 > 63 = 80 | 23.22** | $1.36^{pld}$ | 33 > 63 = 80 |
| Wt of disc silver biddy | — | — | — | — | — | — | 5.92 | 15.44** | None | 5.72 | 14.42** | None |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No of total sea mullet | — | — | — | — | — | — | 8.68** | $0.78^{pld}$ | 33 > 63 = 80 | 1.42 | 2.02 | None |
| Wt of total sea mullet | — | — | — | — | — | — | 3.11 | $1.00^{pld}$ | None | 0.72 | 1.74 | None |
| No of ret sea mullet | — | — | — | — | — | — | 1.69 | $0.89^{pld}$ | None | 0.26 | 1.51 | None |
| Wt of ret sea mullet | — | — | — | — | — | — | 1.43 | $1.02^{pld}$ | None | 0.30 | 1.57 | None |
| No of disc sea mullet | — | — | — | — | — | — | 36.89** | $1.49^{pld}$ | 33 > 63 > 80 | 2.99 | 3.15 | None |
| Wt of disc sea mullet | — | — | — | — | — | — | 14.06** | $1.42^{pld}$ | 33 = 63 > 80 | 1.67 | 2.44 | None |

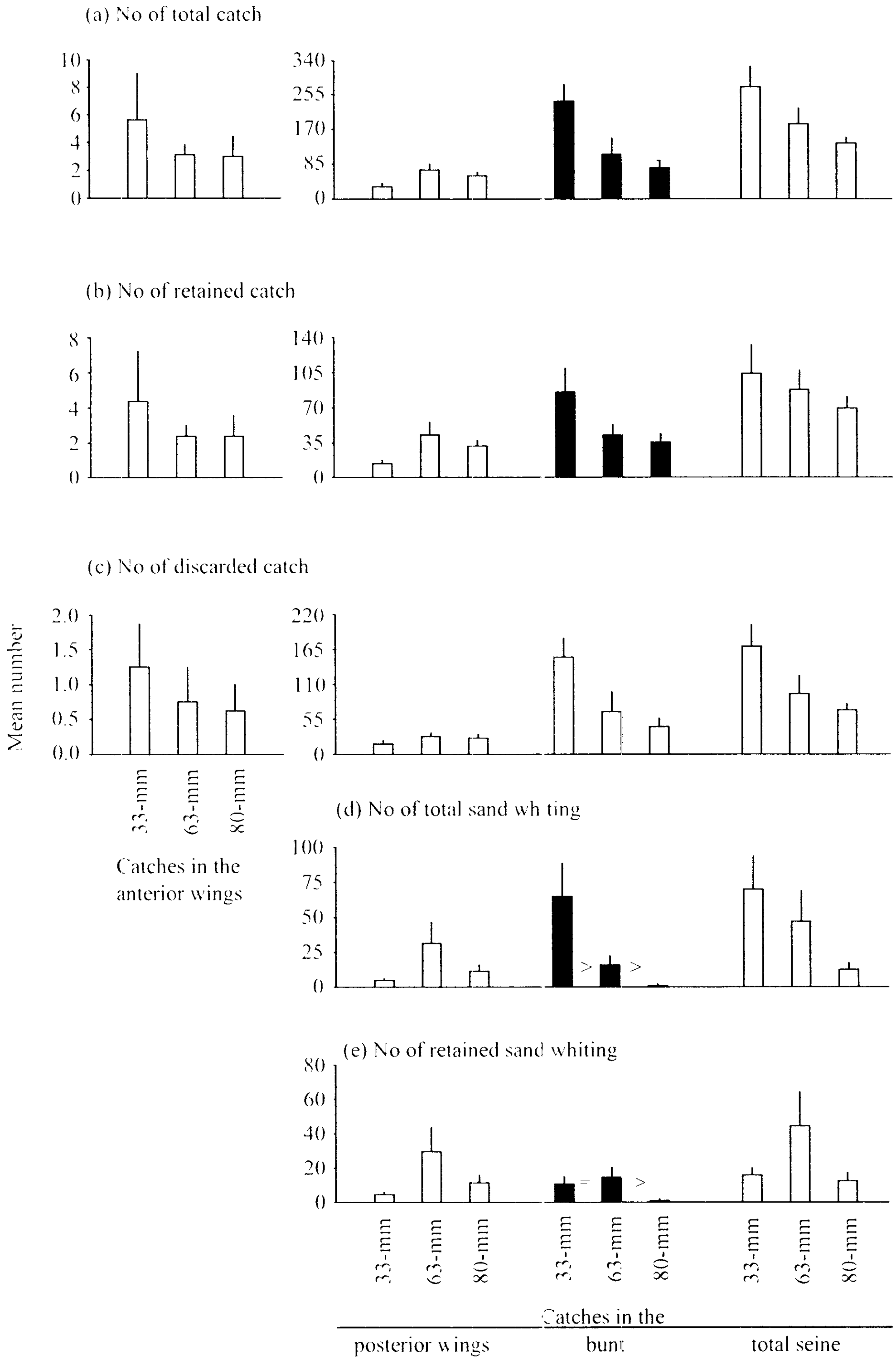

**Figure 18** Experiment 2: differences in mean numbers of catch (± se) deployment[1] in each of the three sections of the seine (anterior and posterior wings and bunt) and total seine when either the 33–, 63–or 80–mm bunts were attached to the 80–mm anterior wings and 63–mm posterior wings for (a) total, (b) retained and (c) discarded catch, (d) total, (e) retained, and

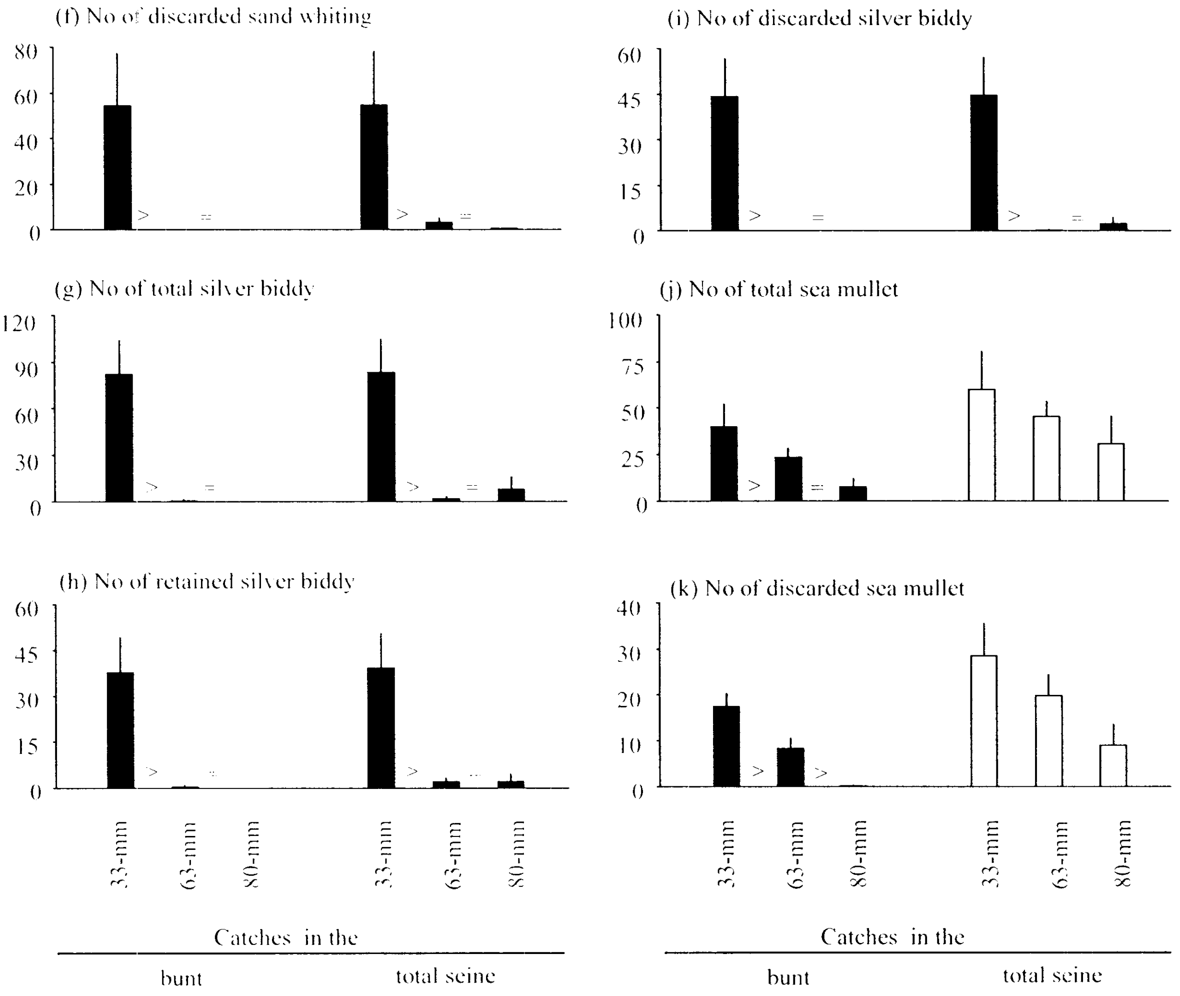

**Figure 18 continued**: (f) discarded sand whiting, (g) total, (h) retained and (i) discarded silver biddy, and (j) total and (k) discarded sea mullet. Black histograms represent significant F–ratios, with the directions of significant differences detected in Student–Newman–Keuls tests illustrated by < and >.

Similarly, there were no significant effects of seine configuration on the numbers or weights of total, retained and discarded catch in the total seine, although the numbers of total and retained catch were significantly different among bunts (Table 13, Fig. 18a–c). While these mean catches showed a negative relationship with mesh size, SNK tests failed to elucidate definitive differences (Table 13, Fig. 18a–b). Seine configuration also had significant effects on the numbers and weights of discarded sea mullet, total and retained whiting and silver biddy and the numbers of discarded sand whiting, silver biddy and total sea mullet retained in the bunts (Table 13).

SNK tests of these differences showed that compared to the conventional 33–mm mesh bunt, both the 63–and 80–mm bunts retained significantly fewer catches of most categories of silver biddy (by between 95 and 100%), and numbers of discarded sand whiting (98 and 100%, respectively) and total sea mullet (41 and 81%, respectively) (Table 13 and Figs. 18d, f, g and i–k). The 80–mm bunt also had significantly fewer numbers and weights of retained sand whiting (by between 90 and 85%) and weights of discarded sea mullet (by 98 and 99%, respectively) than either the 63–or 33–mm bunts (Table 13, Fig. 18e). The number of total sand whiting and discarded sea mullet were incrementally reduced by the two larger–meshed bunts (by between 50 and 99% –Table 13 and Figs. 18d and k). No definitive order of differences was detected for the weight of total sand whiting, although the 33–mm bunt retained more than the larger–meshed bunts (Table 13, Fig. 18h). Several catch variables were significantly different among days (Table 13).

Although most of the above general trends in catches retained in the bunts were reflected in the total seine, in more than half the cases these were not sufficient to result in significant differences (Table 13, Fig. 18). Specifically, only the numbers and weights of discarded sand whiting, total and retained silver biddy and number of discarded silver biddy returned significant F–ratios (Table 13). Subsequent SNK tests identified the same patterns as in the bunt, with both seines rigged with the larger–meshed bunts retaining fewer catches of these variables (by between 63 and 99%) than the conventional seine configuration with the 33–mm bunt (Table 13, Figs. 18f–i).

### 4.5.0 Discussion

The data presented here support the few relevant previous studies on beach seines which have indicated a broad, species–specific influence of the posterior sections of these gears on their selection (Lamberth et al., 1995; Gray et al., 2000; Kennelly and Gray, 2000). By examining larger mesh sizes in the posterior wings and bunt, we have also identified that the current configurations of NSW beach seines are inappropriate for maximizing size selectivity of nearly all of the retained species, but that the morphology and behaviour of some of the main targets can be used as a first step in predicting appropriate mesh sizes (Broadhurst et al., 2006a).

Irrespective of the species or their sizes, very few individuals were meshed in the anterior wings (< 8%) of any of the beach seine configurations, with most retained in the posterior wings and bunt. The strong contributory influence of these latter sections, and especially the bunt, on selection is clearly illustrated by the partitioning of catches in the two experiments. During experiment 1, increasing the mesh size in the posterior wings from 57 to 80 mm had a significant effect on the numbers of retained yellowfin bream and total silver biddy meshed at that section but, owing to proportionally greater catches in the 45–mm bunt, this did not translate to any significant differences in catches by the entire seine (Table 11). By comparison, changing the mesh size in the bunt in experiment 2 resulted in 15 significant F–ratios for different variables at that section; however the influence of the posterior wings reduced these differences to 7 significant F–ratios for the total seine (Table 13).

Such an apparent broad area of selection in beach seines contrasts with towed fishing gears, where this process mostly occurs in the codend (Wileman et al., 1996), and can be attributed to their operational characteristics as well as the morphology and behaviour of the targeted species. During the slow retrieval (0.25 ms$^{-1}$) of the gear, fish were observed to easily swim away from the anterior wings and towards the posterior sections and deeper water. As the bunt approached the beach and the area between the anterior wings decreased, some fish made random attempts at escape through the posterior wings, where the meshes were mostly open and often orientated perpendicular to the direction of hauling. For many fish, selection in this section appeared to depend on their girth in relation to mesh size. For example, fish that were meshed in large quantities in the posterior wings during experiment 1 showed well–defined cohorts, similar to those typically observed for gillnets (Hamley, 1975). Applying regressions between total length and girth calculated by Broadhurst et al. (2006a), it is evident that the modal total length (TL) of these cohorts closely corresponded to the mesh size (Fig. 19).

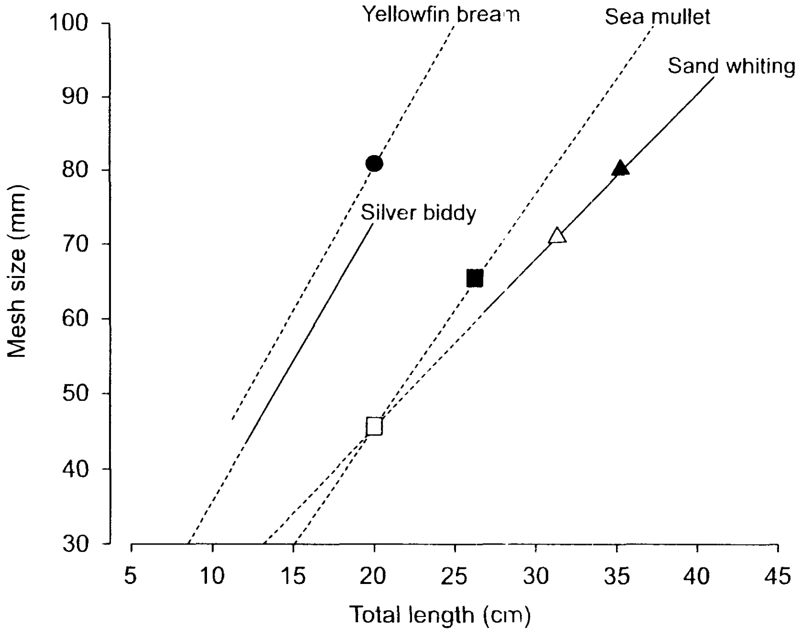

**Figure 19** Linear regressions between total length and mesh size corresponding to maximum girth calculated by Broadhurst et al. (2006) for the size ranges of the key species caught during the present study. The dashed lines refers to undersized individuals, while the open and closed symbols indicate the 50% lengths of retention (L50) of successfully converged selection curves for the seine rigged with the 63-and 80-mm bunts, respectively.

Presumably, most individuals with maximum girths smaller than the mesh perimeter were able to escape though the posterior wings, although the large numbers of small fish retained in the bunt for all seine configurations indicate that many did not encounter this section. Selection probably was less defined for many of these fish once they entered the posterior bunt, since this typically occurred when the gear was close to the beach at the end of retrieval and the lack of forward movement caused meshes to become convoluted, with variable lateral openings (Gray et al., 2000).

In addition to the general patterns observed above, there were more discrete species-specific differences in selection mechanisms. In particular, where selectivity curves were converged in experiment 2, only the $L_{50}$ for yellowfin bream in the seine rigged with the 80-mm bunt corresponded to the predicted girth for this mesh size (Fig. 19). Furthermore, this selection occurred across the narrowest selection range (SR) (Table 12). Sea mullet and sand whiting had $L_{50}$s that were substantially smaller and greater, respectively than the mesh sizes in the bunt (Fig. 19) and relatively wider SRs. These differences might be related to the escape responses of these species. For example, during seine retrieval, many yellowfin bream were observed to actively penetrate meshes in the anterior bunt, either individually or in small schools and then, depending on their size, push through and escape or be retained. Some yellowfin bream were observed to orient themselves in a horizontal plane and escape under the leadline, utilising deviances in the substrate. In contrast, sea mullet almost always swam in schools around the posterior section of the seine and often randomly charged meshes with many individuals, including those with girths smaller than the mesh perimeter, failing to penetrate and becoming entangled (Gray et al., 2000). Conversely, the estimated $L_{50}$ and corresponding girth of sand whiting in the seine with the 63–mm posterior wings and bunt were greater than the mesh size, indicating that larger than expected individuals were able to escape from this configuration (Fig. 19). Like Gray et al., (2000), we observed that this species swam quite quickly and actively attempted to escape though various sections of the seine. It is also possible that some larger individuals were able to swim back and escape through the anterior wings, or alternatively, force their way under the footrope of the larger–meshed configuration. For example, some fish were also observed to bury themselves in the substrate, allowing the footrope to pass over them.

The above observations provide some direction for the future refinement of beach seines. Because of the close correlation between fish length and selection in the posterior wings, conventional diamond–shaped meshes in this area should be regulated according to the transverse morphology of the sizes of the smallest desired species. Further, it might be possible to improve the probability of fish encountering meshes, and therefore being selected, in the posterior wings by reducing the area of the bunt. One potential problem however, is that an increase in the number of fish being meshed in the posterior wings would increase the time required to sort catches and possibly lower their value (owing to damaged fish). Since most fish eventually enter the bunt, it seems logical that this area would benefit most from modifications and more specifically, some mechanism of maintaining mesh geometry during the entire deployment of the seine. One option might be to construct meshes from other types of twine or semi–rigid materials that have minimal elasticity and also maintain their shape. Alternatively, the use of square–shaped meshes in the posterior bunt may warrant investigation, since these are less likely to have variable lateral openings during fishing and have been demonstrated to improve selection in a range of towed gears (Suuronen and Millar, 1992; Stergiou, 1999; Macbeth et al., 2005b).

Notwithstanding the above, it is also clear that simply increasing mesh size throughout the bunt of the existing conventional beach seines used here is an appropriate strategy for significantly improving the size selection of some species and reducing unwanted bycatch. Given the results from experiment 2, the minimum mesh size in estuarine beach seines in NSW could be doubled without significantly reducing the total retained catch. While such an increase would result in a loss of nearly all silver biddy, this species is worth considerably less than the other key targets (e.g. < 4% of the total value of the fishery) and probably insufficient to justify the use of such a small mesh size –given the potential for large concomitant bycatches of the juveniles of the other key species. Regulating the minimum mesh size between 57 and 63 mm seems more appropriate and would also allow many undersize sea mullet to escape.

Although Kennelly and Gray (2000) suggested that larger mesh sizes in the bunt could result in greater meshing of undersize individuals of key species, including yellowfin bream and sea mullet, the potential for such effects are more than compensated for by the escape of more conspecifics. For example, in addition to sand whiting, the catches of undersized sea mullet were incrementally reduced in the larger–meshed bunts, and the selectivity for yellowfin bream significantly improved in the entire seine configured with the 80–mm bunt. Given the influence of the posterior wings on catches, it is likely that the numbers of undersized sea mullet would have been virtually eliminated if these were rigged with 80–instead of the 63–mm mesh used in experiment 2.

No published data are available on the fate of juveniles of the key species after escaping beach seines, but laboratory experiments by Broadhurst et al. (1997) and (1999) revealed few mortalities (< 3%) to similar–sized yellowfin bream and sand whiting after fatigue and simulated escape through a Nordmøre–grid guiding funnel and square mesh codends, respectively. These studies did not incorporate the full range of factors potentially affecting mortalities, however, it is clear from other work with mobile gears that organisms which escape during fishing typically have greater survival than those that are discarded after being landed (Davis, 2002; Broadhurst et al., 2006b). Further examination of the physiological and physical damage associated with escape through the meshes of a seine by juveniles is provided in Chapter 6. In the absence of further data, these results support pursuing a strategy of regulating selectivity in beach seines as a means for reducing unwanted fishing mortalities.

### 4.6.0 Conclusions

During the first experiment, increasing the mesh size from the conventional 57 to 80 mm in the posterior wings allowed some small fish to escape at this section, but owing to maintenance of catches in the bunt (45 mm mesh size), there were no effects on catches in the total seine. By comparison, maintaining mesh size in the posterior wings (63 mm) while increasing mesh sizes in the bunt (from the conventional 33 to 63 and 80 mm) in experiment 2 significantly reduced the catches of undersized individuals of some species in the bunt. However, similar catches in the posterior wings meant that less than half of these differences were detected for the entire seine. Such broad effects of the posterior section of the gear were attributed to the operational characteristics and species–specific differences in selection mechanisms. Owing to the orientation of meshes in the posterior wings, size selection for many species was considerably more defined than in the bunt. But because most fish were eventually directed into the bunt, this area demonstrated the greater potential for improving selection.

Based on the results from this work it was determined (i) the entire posterior sections of conventional beach seines (i.e. up to 90 m) have an important influence on what escapes or is retained and (ii) the mesh sizes used in these areas of estuarine beach seines are entirely inappropriate and should be increased from a maximum and minimum of 30 and 57 mm, respectively to between at least 57 and 100 mm. Further, because many of the species targeted in estuaries are also caught off ocean beaches, mesh sizes for these gears could also be similarly increased. The following chapter examines modifications made to the bunt and codend in ocean deployed beach seines and examines the effectiveness in reducing the capture of juvenile target species and in particular, yellowfin bream.