Evaluation of selectivity in the South-East fishery to determine its sustainable yield

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OBJECTIVES:

1. Determine size (age) at capture for the main commercial species in the SEF that would maximize their biologic and economic yield, especially for the quota species.

2. Determine selectivity of the major fisheries in the SEF, taking account of the mix of gear types and areas fished.

3. Evaluate success of alternative gear mixes (type and configuration), maximising overall biologic and economic yield for selected fisheries.

4. Identify fisheries that contain mixes of gear types and species that lead to a grossly undesirable selectivity of some species, and that could profit from the development of specified selective techniques.

5. Help to coordinate and present results at SEFAG workshop to assess the potential of adapting selectivity of the SEF to promote sustainability and economic returns.

NON-TECHNICAL SUMMARY:

Fisheries assessments are typically performed species by species, and gear by gear, as though the species or fisheries existed in a vacuum. But fishing gears catch a variety of commercial and bycatch species and different industry sectors compete for some of the same species. Multi-species assessments hold out the promise of injecting some of the reality of a fishery into the vacuum of single species assessments.

Unfortunately, multi-species assessments are data hungry. Of the two principal multi-species approaches, biological multi-species interactions are the hardest to define and the most data hungry. Despite intensive sampling programs extending over decades in the US and Europe, there are only a few instances where results from biological multi-species assessments are used in fisheries management. Technical multi-species interactions – interactions due to fishing gears catching more than one species at a time – are easier to define and the data requirements are less. The primary approach used for estimating technical multi-species interactions is multi-species yield per recruit (MSYPR) and this is the approach used in this report. However, even the data requirements for MSYPR proved onerous for a complex multi-species, multigear fishery like the South East Fishery (SEF), where many species are not quantitatively assessed.

Biological data on relationships between length and weight, girth or gape were obtained for 14 quota species and 8 bycatch species. Growth data to supplement existing collections were obtained for 13 quota species. Market size categories and prices were obtained for 14 species. Most fish sampled during the present study came from the commercial fishery, which tends to

be biased as it selects against smaller fish. Developing an accepted method to correct for this bias should be a priority. Improving the quality of basic biological data for SEF species needs to be a priority if the increasing complexity of assessment models is to provide dividends.

A key relationship in yield per recruit analysis is the selectivity (by length) of the fishing gears. Gillnet selectivity data for shelf species were available from an earlier FRDC project (94/040) that used an experimental gillnet to fish different habitats. These data (and some earlier data from studies using the same net) were analyzed and the relationship between the 50% Selection Factor (length at 50% selection/mesh size) and the slope of the girth/length relationship defined so that the relationship could be extended to other species. Selectivity for the trawl was harder to find. Analyses of >3.9 million length frequency records from Australia and New Zealand were too noisy – too many factors in addition to mesh size affected selectivity. FRDC Project 98/204 collected selectivity data for six species using covered cod-end studies. These data, supplemented by earlier covered cod-end studies and some alternate haul work on a further eight species, were analyzed and the relationship between 50% Selection Factor and the slope of the length/girth relationship defined. An additional relationship between the Selection Range Factor (length between 25 and 75% selection/mesh size) and the slope of the length/girth relationship was identified. With these two relationships, selectivity could be estimated for the 14 quota and 8 bycatch species for which biological data had been collected.

The above data were sufficient to generate single species yield per recruit curves for 11 quota species. At current fishing mortalities, individual yield per recruit increases of up to 25 percent could be achieved with otter board trawl cod-end mesh sizes significantly larger than the 90mm used currently in the SEF, especially for ling, gemfish, jackass morwong, ocean perch (deep), blue warehou and spotted warehou. Yield per recruit could also be increased if larger mesh sizes were adopted by the Danish seine gear targeting eastern school whiting. Yield per recruit peaked at intermediate mesh sizes for tiger flathead, blue grenadier and redfish. Because larger fish are generally caught in deeper waters, yield per recruit for redfish could be increased slightly by concentrating all effort deeper than 60 m depth, for the current 90 mm mesh size. Maximum yields at larger mesh sizes (and greater depths) are only obtained with high fishing mortalities. For some species in the SEF these higher fishing mortalities may already be occurring. There is increased environmental and economic costs associated with these high fishing mortalities which may not be sustainable in the longer term. Larger mesh sizes reduce the biological and economic costs of excess fishing mortality. In all yield per recruit analyses, the slope of the yield vs effort slope was flatter at larger mesh sizes, indicating a reduced risk of overfishing at larger mesh sizes.

Extending single species yield per recruit analysis to multi-species yield per recruit analysis requires that relative recruitments be estimated. Relative recruitments were estimated from assessments for five species – redfish, tiger flathead, jackass morwong, blue warehou and spotted warehou. A relative recruitment estimate for school whiting was unrealistic and not used further. Results of the MSYPR will be sensitive to the assumptions and results of these fisheries assessments.

Multi-species yield per recruit analyses revealed that, at the current fishing mortality, increases in biomass and landed value of up to 10 percent could be achieved when trawl cod-end mesh size was increased to 128 mm from the current 90 mm. Alternatively, large reductions in fishing mortality would be required to achieve maximum yield per recruit at the current mesh size. The fishing effort required to maximize yield per recruit at the current 90 mm trawl mesh size was estimated at 20 percent of current fishing mortalities for biomass and only 12 percent for monetary yield. In practical terms it is likely that a combination of larger mesh size and reduced fishing mortality is required to achieve optimal yield per recruit in the trawl fishery.

Another option to optimize yield per recruit is to use an appropriate combination of different fishing gears. Single species yield per recruit analysis revealed that there is little gain to be made from increasing gillnet mesh size, but a reduction to 5 inch would improve yields of blue warehou and jackass morwong. Compared to a 90 mm trawl cod-end mesh, yield per recruit for blue warehou is lower when using a 6 inch (152mm) mesh gillnet, but egg production is increased 4-fold. Conversely, yield per recruit for jackass morwong is higher with a 6 inch gill net compared to a 90 mm trawl. If the gillnet mesh size were reduced to 5 inch, yields could be up to 20 percent higher than with the trawl at current mesh sizes.

Multi-species, multigear yield per recruit showed that a combination of trawl and gillnet led to slightly increased yields over that from either gear type alone at current mesh sizes. If gillnet mesh size were reduced from 6 inch to 5 inch, a 5 percent increase in yield was predicted. When multi-species yield per recruit was based on multiples of currently estimated fishing mortality (instead of a constant fishing mortality for all species), increased yields from the combined fishery (5 inch gillnet mesh and 90mm trawl mesh) approached 10 percent. The current level of fishing effort would be suitable to maximize yield per recruit at trawl mesh sizes of 140 mm and greater. If mesh size were chosen to match current fishing mortality yield per recruit would be increased by over 10 percent. Quota transfer between the trawl and gillnet sectors will lead to a changed fishing mortality and potentially impact the reproductive capacity of the stocks involved.

Although important to consider, yield per recruit is but one of a range of indicators that can be used to assess the status of a fishery. Numerous other factors need to be considered when assessing optimal management harvest strategies for a fishery. There are many aspects of the biology of the fish species, their interaction with the environment, and the behavior of fishers that will affect catches, recruitment, sustainability and fishery dynamics. Discard rates, total catch and ecological indices can be related to temporal (year, month), spatial (geographical and depth), and operational (primary species sought, cod-end mesh size, vessel size, tow duration, total catch, total discards) factors. In addition changing year class strengths of fish in a fishery will change many of the operational factors. Similarly, market prices, profitability and management arrangements will influence where, when and by what means fishers will harvest the available resource and respond to alternative management arrangements. All of these biological and socio-economic factors should be considered when determining the optimal harvest strategy for long term sustainability of a multi-species resource accessed by a multi-sector fishing industry such as the South East Fishery.

More sophisticated multi-species models need to be developed that can:

- use parameter estimates from robust assessments to aid low information assessments;
- include the dynamics of the fishing fleets in addition to the biological dynamics; and
- Include impacts of changes in TACs, and input controls (mesh size, quota transfer, spatial management of effort, ground gear, vessel size, etc.) on the dynamics of the individual species, market value, and environmental impacts (eg. bottom time, bycatch, fuel use).

More data need to be routinely collected to run these and current assessment models. The cost effectiveness of the increased data requirements and resources needed for more complex multi-species, multi-gear modeling of the fishery needs to be evaluated against other research and management priorities.

OUTCOMES ACHIEVED:

Biological data were collected for 22 species. Selectivity was estimated directly for 14 SEF species. A length/girth relationship was used to indirectly estimate selection curves for a further 13 species. Single species, multi-species, multi-species/multi-gear, and multi-species/multi-area models were developed for the shelf fisheries off southern NSW and eastern Victoria. Alternate mixes of gear, mesh size and area were tested and combinations that increased yield identified. Preliminary results were presented at a workshop on reducing discards in the SEF and have been widely used by assessment groups and AFMA.

KEYWORDS: Multi-species yield per recruit, selectivity, South-East Fishery, trawl, gillnet, mesh size

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1 BACKGROUND

The South East Fishery (SEF) is a complex multi-species fishery containing many commercial species (including 21 quota "species") and at least six types of gear. In the SEF there are distinct sub-fisheries in the different regions and depths fished, each targeting a subset of the total range of SEF species (Klaer and Tilzey 1994). Despite the diversity of fisheries, species and markets in the SEF, there is at present only one minimum mesh size for SEF otter-board trawlers fishing for all species and in all areas. This mesh size was adopted to maximize the yield per recruit of flathead caught by Danish seines in the 1950s. Over the past 40 years the SEF has changed; the fishing area that extended over shelf waters less than 250m now includes slope and deeper waters down to 1000m. Types of configurations of gear have also changed and the SEF has become a complex multi-species and multigear fishery supplying a variety of markets.

On a per-recruit basis, each species has a biological size at which it is best caught, depending on its rate of growth and expected longevity. Because fish of different size have different market value, the best size for each species on an economic basis may be different from the biological best size. The mesh size that maximized biological yield per recruit of flathead for Danish seines in the 1950s is unlikely to be the mesh size that would maximize economic yield of the species mix in the SEF today, especially as fishing practices have changed markedly.

Discarding of unmarketable bycatch in the SEF is high. Not only does the bycatch consist of non-commercial species but there is also significant bycatch of commercial species, including quota species such as redfish, mirror dory and tiger flathead (Knuckey and Liggins 1999). As well as varying by species, discard rates also vary by area and time. For example, discard rates of redfish in Ulladulla and Eden were estimated at 22 and 80 percent respectively by number in 1994 (FRDC Project 92/279). Overall discard rates for redfish increased from 23% in 2000 (Knuckey et al 2001a) to 40% in 2001 (Knuckey et al. 2002). Factors influencing discard rate are varied and include fish size, market forces and management regulations (Liggins and Knuckey 1999). The current minimum mesh size will not minimize unwanted catches across a range of species.

Defining the mesh size that would minimize discards and maximize returns to the trawl fishery is one aspect of multi-species yield per recruit. However, the SEF is more than a trawl fishery. Fishers also use gillnets, longlines, traps, droplines and Danish seines to catch SEF fish. The integration of the different sectors to manage the SEF as a single fishery raises questions about the effects of transferring quota between sectors.

One option is the free transfer of quota between sectors. However, because the different gears have different selectivities for the same species, the same quota may produce different catch rates from different gears (Bax and Laevastu 1987). For example, it has been suggested that catching blue warehou at a larger size with mesh nets, rather than at a smaller size with trawls, would provide economic benefits. However, the same tonnage of catch is a different proportion of the population when caught at different ages. In the case of blue warehou the mean age caught by mesh nets is 6-7 years, compared to 3-4 years for demersal trawls (Smith 1994). Preliminary analysis of yield per recruit indicates maximum biological yield to be at age 3-4; 1000t of fish caught at this age is equivalent (in simple biologic terms, omitting future recruitment) to only 470t of fish caught at age 6-7 years. This equivalence has important consequences for the free transfer of quota between sectors. Analysis of multi-species yield per recruit will determine these equivalences.

It has been suggested that minimum size limits be imposed on the SEF. Minimum size limits, for example on redfish and flathead, would reduce the number of smaller fish that are landed, but unless the selectivity of the gear is changed, the undersized fish may simply be dumped at sea. The impact of size limits on the biological and economic yield from a fishery can be estimated only with information on the selectivity of the fishery and the overall level of mortality (Marasco et al. 1991). This is the information that is developed from analysis of multi-species yield per recruit.

2 NEED

Developing methods of including more than one sector and multiple species in stock assessment, and of evaluating alternate options for taking the catch was identified as a priority in the Draft SEF Strategic Research Plan (1995-2000). Impacts of minimum mesh size and harvest strategy evaluation were the highest priorities of the SEF Assessment Group after routine data collection and stock assessment. Selective harvesting of wild fish stocks is integral to the ecologically sustainable development of fisheries and is required by national and international legislation.

The current South East Trawl (SET) mesh size was calculated to give the best yield per recruit for flathead caught by Danish seines in the 1950s. The minimum mesh size has not changed since, although the SEF has developed into a complex multi-species, multigear fishery. With the current mesh size, many species will not be caught at their best biologic or economic size. The effort necessary to fully exploit one species may be excessive for another species, potentially resulting in growth and recruitment overfishing. This could reduce productivity and profitability, and may reduce the stocks of some species to non-sustainable levels.

Techniques to improve the species selectivity of fishing gears have been and are still being developed in Australia and abroad. It is necessary to identify situations in the SEF where new or modified selective gears may increase returns from some species and ensure that other species in the same area are not overexploited.

3 OBJECTIVES

1. Determine size (age) at capture for the main commercial species in the SEF that would maximize their biologic and economic yield, especially for the quota species.

2. Determine selectivity of the major fisheries in the SEF, taking account of the mix of gear types and areas fished.

3. Evaluate success of alternative gear mixes (type and configuration), maximising overall biologic and economic yield for selected fisheries.

4. Identify fisheries that contain mixes of gear types and species that lead to a grossly undesirable selectivity of some species, and that could profit from the development of specified selective techniques.

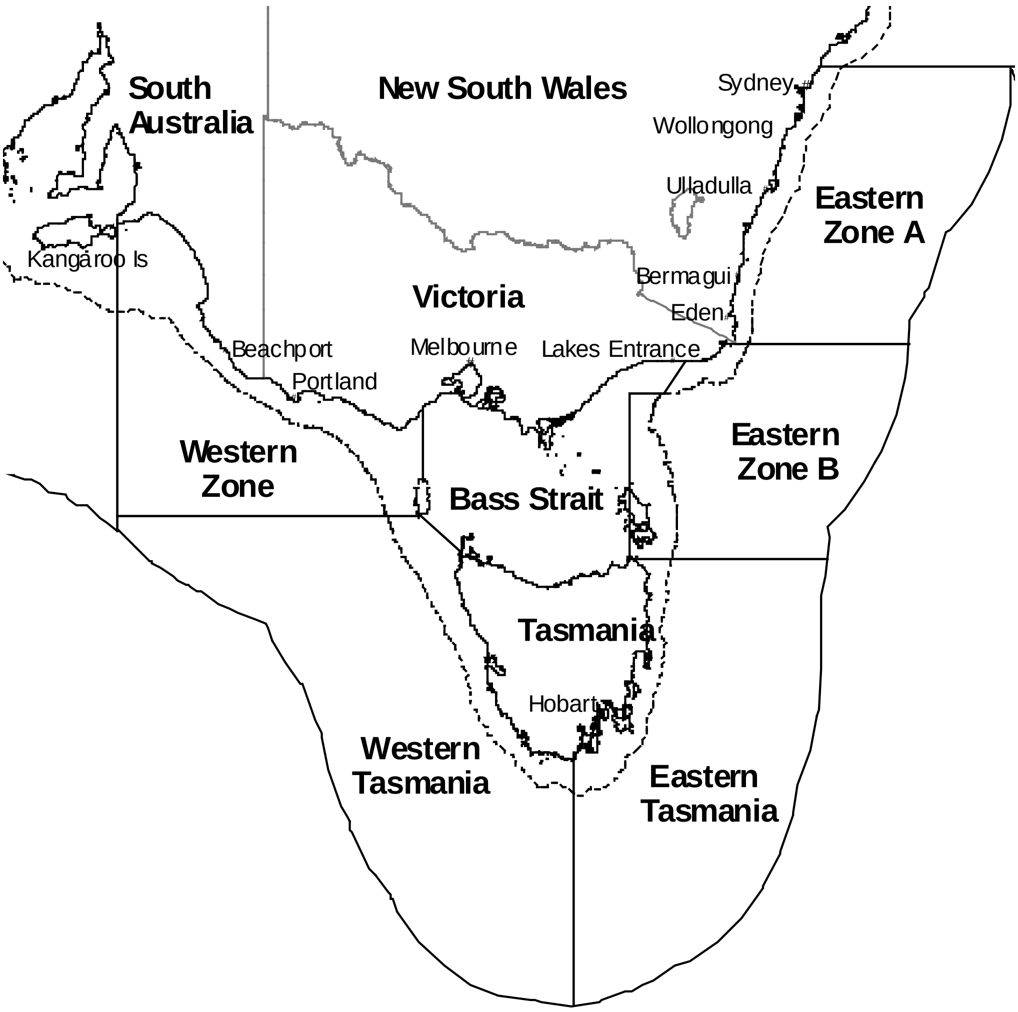
5. Help to coordinate and present results at SEFAG workshop to assess the potential of adapting selectivity of the SEF to promote sustainability and economic returns.

4 METHODS

4.1 Study area

The management boundaries of the SEF extend out to the 200 mile limit of the Australian Fishing Zone (AFZ) from a line east of Barrenjoey Point, Sydney, New South Wales to a line south of Cape Jervis, South Australia, and include waters around Tasmania and Victoria (Fig. 4.1.1). Klaer and Tilzey (1994) identified 6 major regions within the fishery: Eastern Zone A; Eastern Zone B; Eastern Tasmania; Western Tasmania; Western Zone and Bass Strait. Within these regions, various sub-fisheries have been identified based on the temporal and spatial assemblages of species landed by SEF vessels (Klaer and Tilzey 1994; Smith et al. 1997).

Figure 4.4.1. Area of the South East Trawl Fishery, showing the six major regions defining subfisheries in the SETF (from Klaer and Tilzey 1994)



4.2 Biological data collection and analysis

Since 1994, on-board observers and port-based fish measurers have been deployed in the major ports to collect monthly samples of commercial catches. This was the primary source of biological data, catch composition and length-at-age information used in this study. Most data were collected from otter board trawlers and Danish seiners; more recently non-trawl vessels have been sampled. Length frequency samples of retained and discarded catches were collected onboard, while landed catches were more intensively sampled at the ports. Generally, sex was not identified in the length frequency data. Sub-samples of the major species were taken to collect sex-specific information on age and morphometry, including length (cm), weight (kg), girth1 (cm) - girth directly behind the operculum, girth2 (cm) - widest girth around the belly, gape (mm) - widest diameter of the mouth. While ageing data have been collected since 1994, morphometric data were collected from an intensive sampling period between October 1996 and April 1997. Additional samples were obtained from the CSIRO Shelf habitat study (FRDC Project 94/040), especially for smaller fish.

Additional length and girth data were analyzed to assist in generating the relationship between selection factor (mesh size/ length) and body shape. Data for gummy shark came from Ward and Gardner 1996; school shark from West (CSIRO, unpublished data); piked spurdog, red cod, snapper and red gurnard from Bax et al. 1999).

All morphometric data were regressed against the length (l) of the fish using a power curve for weight (w = al^b) and linear regression for all other dimensions. While small differences in growth and morphometric parameters were noted between the sexes, these were considered negligible with respect to the overall aim of the project, and all analyses were subsequently pooled over sex. Gemfish was the only exception due to the significant differences in the age and maximum length of males and females. Most quota species were aged using the standard technique of sectioning the sagittal otolith and counting the annuli.

Natural mortality was estimated from maximum observed age, although relationships between age at first maturity and natural mortality were also investigated. Estimation of maximum age required the reading of otoliths for those species for which age composition data were not already available.

4.3 Natural mortality estimates from life history parameters

Direct estimation of natural mortality requires an accurate age composition of the unfished stock (plus some assumptions of relative recruitment strengths of the year classes in the sample). These data are rarely available and several alternative techniques have been used to estimate natural mortality (summarised by Vetter 1988, Table 4.3.1).

Table 4.3.1 Methods and parameters that are used to estimate natural mortality (from Vetter 1988). T_{max} and T_{mature} are maximum age and age of maturity, respectively. k and L_∞ (and W_∞) are parameters of the von Bertalanffy growth equation. L_{mature} is length at maturity.

Method	T_{max}	T_{mature}	k	L_∞	L_{mature}	W_∞	Other
Beverton and Holt 1959	Y		Y	Y			Metabolic rate,
Beverton 1963	Y		Y	Y	Y		Reproduction
Ursin 1967						Y	
Alverson and Carney 1975	Y						Age at max biomass
Ware 1975							Growth rate
Jones and Johnston 1977					Y		Gonad size/condition
Blinov 1977	Y						
Gunderson 1980	Y	Y		Y			GI
Pauly 1980			Y	Y		Y	Water temperature
Hoenig 1983	Y						
Peterson and Wroblewski 1983							Weight
Roff 1986			Y	Y	Y		

The methods of Hoenig (1983), Pauly (1980) and Gunderson (1980) were applied to the collected data, depending on data availability. Results dependent on von Bertalanffy parameters should be treated with caution as the von Bertalanffy parameters might be biased from over representation of faster growing younger fish in samples subject to mesh selection.

Four natural mortality estimates were obtained using the equations described below.

Two natural mortality estimates were derived using Hoenig (1983), where t_{max} was considered to represent the maximum age of one percent ($M = -\ln(0.01) / t_{max}$) and five percent ($M = -\ln(0.05) / t_{max}$) of the population, the latter being more appropriate for stocks that have undergone significant exploitation.

The method of Pauly (1980) provided a natural mortality estimates relating to the ambient water temperature and the maximum length and growth rate of fish:

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

where: T is the water temperature in °C.

The final natural mortality estimate was obtained from Gunderson's (1980) method based on the ratio of gonad to body weight and natural mortality.

Where available, natural mortality estimates derived from integrated assessment on a few of the species were used.

4.4 Constituent fisheries of the SEF and sub-fisheries used in per-recruit analyses

Existing information on distribution of commercial species (for example the BRS analysis of logbook data) was used with geographical distribution of fishing ports and gears to determine the effective fisheries in the SEF (Smith et al. 1997). The following description comes from that analysis.

4.4.1 Trawl and Danish seine

For the period 1993-96, almost 80,000 tonnes was landed from 23,700 otter board trawler trips (Smith et al. 1997). Vessels from 34 ports were involved, although the top 15 ports contributed 96% of total landings. In order, the top 5 ports were Hobart, Eden, Portland, Ulladulla and Lakes Entrance, and they accounted for 73% of the total catch. Excluding orange roughy, these ports accounted for 72% of the catch, but Hobart had the fifth largest landings rather than the top.

Over the same period, Danish seine vessels, landed almost 8,000 tonnes from 5,600 landings. Lakes Entrance contributed almost 80% of total landings.

For most species, e.g. roughy, redfish, royal red prawns and flathead, the bulk of the catches are restricted to several zones. Smith et al. (1997) concluded that port and zone interactions provided natural fishery categories.

There is discarding of most quota species, however in the analysis by Smith et al. (1997) discarding was greater than 10% in only 5 species – redfish (66% by weight), mirror dory (52%), ocean perch (35%), tiger flathead (13%), and blue warehou (11%).

4.4.2 Non-trawl

The non-trawl sector catches significant quantities of blue eye trevalla, blue warehou and ling. Blue eye trevalla are taken predominantly by the drop line sector, with lesser amounts by gillnet and longline; catches are considerably greater than those by trawl sector. Blue warehou is caught by the gillnet sector and catches have declined sharply in recent years, most likely as a result of stock depletion. The non-trawl catch of ling is about 40% of the trawl catch, coming from bottom set long lines, gillnets, traps and smaller amounts by drop lines. More recently, there has been increased catches of ling by automatic longlines.

Other species caught by the non-trawl sector include gemfish and ocean perch (drop lines, longlines), spotted warehou, silver trevally, jackass morwong, blue grenadier and John dory (gillnet).

Discard rates for the various non-trawl methods are relatively low. In an observer study undertaken in 2000, the discard rate for the mesh-net fishery was 19% and discard rates for the dropline, trap and longline fisheries were 9%, 4% and 3% respectively (Knuckey et al 2001b).

4.4.3 Sub-fisheries

In designing a stratification scheme for the Scientific Monitoring Program, Smith et al. (1997) proposed 14 sub-fisheries (plus line and gillnet) based on gear, species, port group and vessel catch rate. For this study we were only interested in fishery stratifications that could affect selectivity. Consequently we omitted stratification by port group and vessel catch rate. This left 7 sub-fisheries (plus line and gillnet) (Table 4.4.3.1).

Table 4.4.3.1 Sub-fisheries of the SEF (from Smith et al. 1997)

Stratum code	Gear	Area	Defining species	Trips (1992-1996) # p.a.	length(d)
OR	Trawl	SW, TAS	Orange roughy	2439	5.7
SBG	Trawl	SW, TAS	Blue grenadier (spawning)	466	2.8
OTHER	Trawl	SW, TAS	All species excl. roughy and spawning grenadier	3996	4.5
OFFSHELF	Trawl	EDEN, LE, NSW	Blue grenadier (non-spawning), gemfish, ling, ocean perch, mirror dory	4156	1.1
INSHORE	Trawl	EDEN, LE, NSW	Spotted warehou, blue warehou, tiger flathead, jackass morwong, silver trevally, John dory, redfish	20569	1.3
RRP	Trawl		Royal red prawn	3042	2
DS	D. Seine		School whiting	4886	1.3
LINE	Line		Blue eye trevalla, ling	NA	NA
NET	Gillnet		Blue warehou, ling, blue eye trevalla	NA	NA

For the purpose of the current project, we omitted those sub-fisheries that targeted single species and where bycatch (of other fish species) was less of a concern. This left the Offshore and Inshore trawl fisheries off Eden, Lakes Entrance and New South Wales, plus the Danish seine, line and net fisheries that target some of the same species. We chose to concentrate on the inshore fisheries in this study, as trawl mesh selectivity data were available for most of the species from the FRDC Bycatch study (FRDC Project 98/204). Insufficient data were available to treat the Other category at a similar level of resolution to the inshore fisheries and this category was omitted from further analyses.

Catch composition is determined by the selectivity of the fishing gear and the availability of the fish (species and size) on the fishing grounds. Recent studies on the shelf off Eastern Victoria and New South Wales have shown that fish populations in that area are structured by latitude and depth (Graham et al. 1995, 1996, Bax and Williams 2000, Williams and Bax 2001). Based on these studies, we further divided the inshore fisheries by latitude and depth to examine the effect of fish availability on catch composition, selectivity and discards (Table 4.4.3.2).

Table 4.4.3.2 Distinct areas of species composition, size composition and fish catches as defined by latitude, longitude and depth.

	Northern extent	Southern extent	Western extent (or min. depth)	Eastern extent (or max. depth)
SOUTH50	37.50°S	40.75°S	>146.37°W	50 m
SOUTH150	37.50°S	40.75°S	51 m	150 m
SOUTH300	37.50°S	40.75°S	151 m	300 m
SOUTH600	37.50°S	40.75°S	301 m	600 m
NORTH50	33.58°S	37.50°S	0 m	50 m
NORTH150	33.58°S	37.50°S	51 m	150 m
NORTH300	33.58°S	37.50°S	151 m	300 m
NORTH600	33.58°S	37.50°S	301 m	600 m

4.5 Abundance estimates

A key advantage of single species yield per recruit is that recruitment estimates are unnecessary for the per recruit calculations - recruitment is assumed to remain constant. Multi-species yield per recruit (MSYPR) requires relative recruitment multipliers for each species, as it is unlikely that recruitment levels are the same for each species. Relative recruitments of individual species in a multi-species fishery will not be constant over time. MSYPR attempts to account for variability in relative recruitment levels by estimating the long-term equilibrium yield; therefore relative recruitment multipliers are best estimated from average recruitment to the stocks over long time period. If one or two species are particularly important (economically or due to high discarding rates) it may be useful to simulate low and high relative recruitment levels for these species. One example in the SEF shelf fishery is redfish which has variable recruitment and highly variable discard levels - >50% discard rate on average in 1993-1995 in Eastern Sector A, declining to 19% in 1999 (Liggins 1996; Smith and Wayte 2001) when the smaller fish were used in the surimi market and increasing again to 50% in 2003 when there was no surimi processors for smaller redfish (Talman et al. 2004).

Relative recruitment multipliers may be estimated from fishery-dependent data (ie. stock assessments) or fishery-independent data (eg. research survey catch per tow corrected for availability and vulnerability of individual species to the sampling gear) (Murawski 1984). Given probable biases in any of these methods, it is important that a consistent method be used for the different species. This restricted our choice of method to fishery-dependent data.

Populations are assumed to be at equilibrium in per-recruit analyses and therefore the catch of all age classes in a given year is equal to the total catch of a given age class over its entire life (equilibrium yield). Given this assumption, recruitment (N_r) can be estimated from actual catch, divided by expected catch per recruit at the observed fishing mortality. Fishing mortality (F) was taken directly from assessments or estimated as the difference between total mortality and natural mortality given in assessments. In one case the number of 1 year-olds recruiting to the fishery from an integrated assessment was used for simplicity.

Estimates for most species are quite speculative. Despite sound integrated assessments being available for some of the species that provide believable representations of relative year class strengths within a species (eastern gemfish, orange roughy, blue grenadier), there is little confidence among assessment group members that the other current assessments accurately portray abundance or exploitation rates for spotted warehou, redfish, blue warehou or school whiting. Formal assessments are not available for any of the other quota species.

John Dory and silver trevally were not included in the per-recruit analyses as limited data are available for natural and/or fishing mortality.

4.6 Size composition and availability

Catch composition is determined by the selectivity of the fishing gear and the availability of the fish (species and size) on the fishing grounds. We included latitude and depth as factors in the per-recruit analyses (Table 4.4.3.2) based on Graham et al. 1995, 1996, Bax and Williams 2000 and Williams and Bax 2001.

Size compositions by depth were determined from recent trawl surveys off New South Wales and eastern Victoria by NSW Fisheries (Graham et al. 1995, 1996) and CSIRO (Bax and Williams 2000). All length frequency data for the relevant species from surveys between (1993 and 1994 (NSW Fisheries) and 1993 and 1996 (CSIRO) were included in the analysis. All sample data were weighted by the estimated number of fish in the catch.

NSW Fisheries data were collected seasonally (4 times per year) in 1993 and 1994 from three inshore (30-60 m depth), three mid-shelf (100-125 m depth) and three outer-shelf (130-150 m depth) grounds randomly selected from available grounds between Port Stephens and Cape Howe (Graham et al. 1995). Each ground was surveyed for two days each season with four 3 knot, 60 minute tows each day – two before and two after daybreak. Fishing occurred from the *RV Kapala* with a 56 m headline Engel balloon trawl with 180 m sweeps, 45 m bridles and 2.4 m Vee doors. The cod-end was lined with a 45 mm mesh liner.

CSIRO data were collected from winter 1993 and 1994, summer and autumn 1996 at five depths (25, 40, 80, 120 and 200 m) on seven cross-shelf transects between Wilsons Promontory and Bermagui. There was one 3 knot, 30 minute trawl sample at each station. Fishing occurred from the *RV Southern Surveyor* using a commercial trawl, designed and made by McKenna net-makers of Hobart, Tasmania. The net is a demersal two-panel design with a total length of ~54 m, a headline of 37.6 m buoyed by 56 x 200 mm diameter floats, and a footrope of 41.3 m with ~150 mm diameter punched-disc rubber rollers. Its mesh sizes decreased from ~220 mm in the wings, square and belly to 40 mm in the cod-end liner. In operation the net had a wingspread of ~20 m and headline height of ~3 m and was fished from twin warps behind Polyvalent trawl doors.

Seasonal variation in availability of fish on the fishing grounds was not included as a factor in the analyses, although they are known to occur. For example in 1993 and 1994, redfish were most abundant during winter on NSW outer-shelf grounds, tiger flathead were most abundant during spring and summer on inshore grounds, but more abundant during winter on mid and outer shelf grounds (Graham et al. 1996). Blue and spotted warehou were almost entirely caught during late autumn and winter, after moving into NSW waters from further south.

In this study we averaged length frequency compositions from all the above survey data. All data were specific to the latitude and depth cells given in Table 4.4.3.2.

4.7 Commercial discards

Information on the discarded portion of the SEF catch was gathered by the Integrated Scientific Monitoring Program (ISMP) based at MAFRI in Victoria. Field scientists sampled the retained and discarded catches onboard selected SEF trawlers. Discarding can vary between different areas of the fisheries and between years. An example of overall discards for Eastern Sectors A and B is provided (Fig. 4.7.1).

In this study, we averaged discard proportions and length frequency compositions from 1996 to 1999. All data were specific to the latitude and depth cells given in Table 4.4.3.2. Data were only available for trawl-caught fish and the data were not disaggregated temporally.

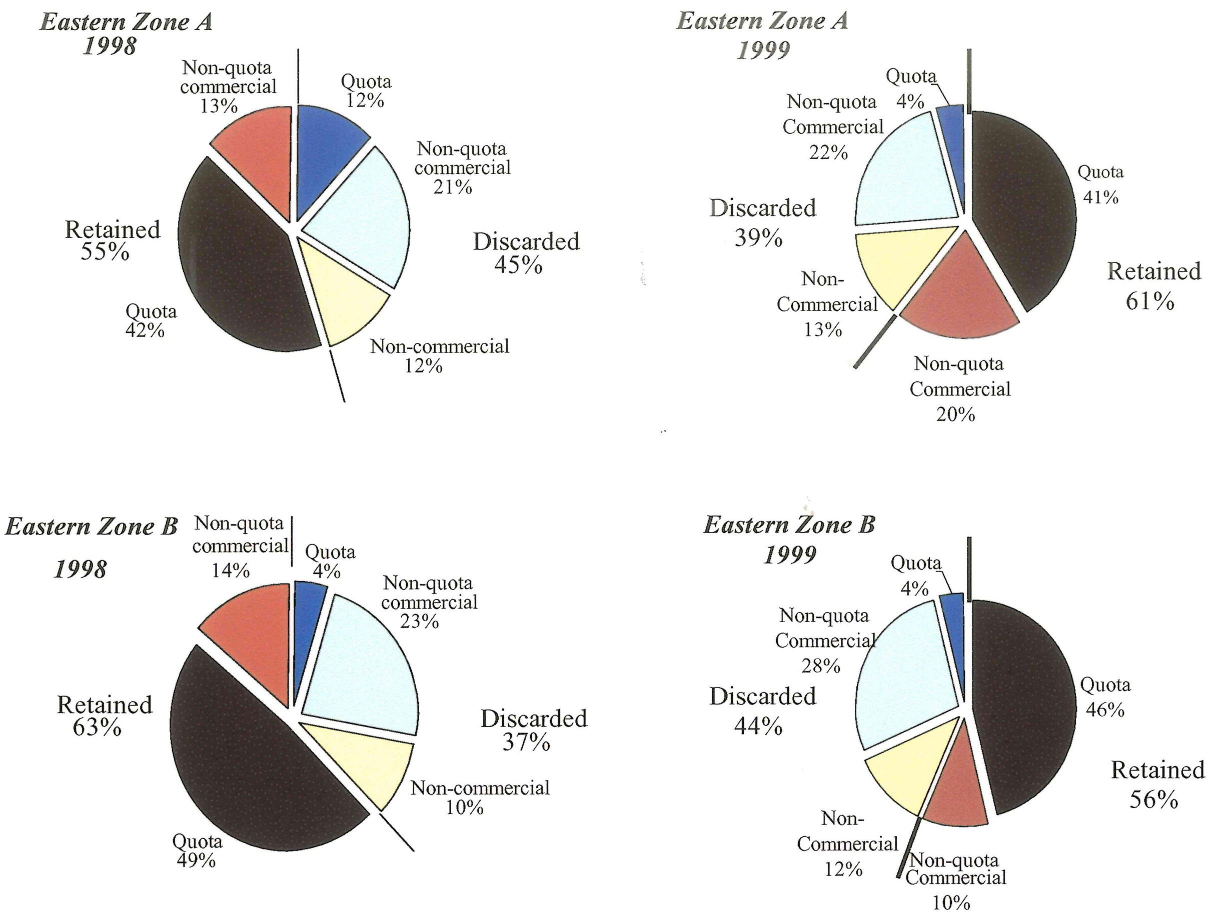


Fig. 4.7.1 **Composition of the total catch, retained and discarded by weight during 1998 and 1999 for Eastern zones A and B of the trawl sector (Original figure from Smith and Wayte 2001 using ISMP data)**

4.8 Estimating mesh selectivity

Mesh selectivity and its variation with fish length determine the size (age) of recruitment of fish to a fishery of defined gear type and net size. Estimating mesh selectivity, therefore, is an important component of yield per recruit analyses.

Selectivity by a particular mesh (or hook size) can be estimated as absolute or relative. Following Kirkwood and Walker (1986) we use the following definitions:

Absolute selectivity: the probability that if a fish of particular size encounters a net it is captured and retained in that net;

Relative selectivity: the probability that if a fish of a particular size encounters a net it is caught relative to the maximum probability of capture for a fish of any size.

Previous studies on multi-species yield per recruit (Murawski 1984, Pikitch 1987) have used absolute mesh selectivities derived from published covered cod-end experiments, or from a published linear relationship between size at (knife-edge) recruitment and mesh size (Sainsbury 1984). In this study we have used both relative and absolute methods depending on data availability.

4.8.1 Relative selectivity – Gillnet-caught fish

4.8.1.1 Data

Selectivity patterns for eight SEF species – seven quota species and one non-quota species – caught using experimental gillnets were modeled (Cui et al. 2001). The data were collected between Point Hicks and Disaster Bay in April 1996 (depths less than ~100 m) and January 1997 (depths greater than ~100 m) (Bax and Williams 2000). One gillnet was set at sunrise and retrieved one to two hours before sunset and another gillnet was set just after dark and retrieved prior to sunrise. Sampling locations were chosen to represent different depths and microhabitats, as determined from acoustic and video sampling (Bax and Williams 2000).

Each gillnet consisted of two fleets of six panels (one panel for each of the six mesh sizes considered in the study - 50, 76, 100, 125, 150, and 175 mm; 2- to 7-inches). The order of the panels was random but the same between sets. The panels had a hanging ratio of 0.5, and a hanging coefficient of 0.87. The monofilament line sizes were 0.62, 0.62, 0.81, 0.9, 0.9, 1.05 mm for the six mesh sizes respectively. Each panel measured 90 x 2.8 m and was separated by a 40 m gap giving the net a total length of ~1.5 km. The ground line was heavily weighted (38 kg per panel) and the float line buoyant (11.4 kg per panel) due to the fast currents expected in some areas. For the same reason, 20 kg grapples were used to anchor the centre and each end of the net fleet. Two net fleets were rotated and damaged mesh was mended or replaced between sets.

The numbers and weights of all species were recorded from each sample. Lengths were measured for all species with greater than five individuals caught per set. Fish lengths were measured from the tip of the snout to the tip of the medial caudal-fin ray, with the caudal fin in its natural position, and recorded as Fork Length (FL). Shark and ray species were measured from the tip of the snout to the upper caudal-fin lobe, with the caudal-fin in an extended position, and also recorded as Total Length (TL).

The spatial distribution of shots during the experiment can be categorised according to two variables: habitat and depth (Table 4.8.1.1). Three distinct habitats were identified: rough/reef, hard/close to reef, and soft/away from reef, while the data are stratified into four depth strata: A (<40m), B (40–69m), C (70–99m), and D (100-139m). Analysis of community composition data (Williams and Bax 2001) indicates that it is possible to categorise data from hard habitats as either soft or rough depending on area and this has been done in this study.

Table 4.8.1.1 Catches during the experiment by depth zone and habitat type and the width assumed for the size-classes when fitting the model used to estimate selectivity.

Species name	Catch by depth zone				Catch by habitat type		Total	Size-class width
	A	B	C	D	Rough	Soft		
Quota species								
Mustelus antarcticus (Gummy shark)	5	60	190	9	30	234	264	100
Seriolella brama (Blue warehou)	0	58	172	276	267	239	506	30
Centroberyx affinis (Red fish)	0	26	11	172	100	109	209	30
Genypterus blacodes (Ling)	0	5	2	80	69	18	87	100
Helicolenus percoides (Ocean perch)	0	13	38	197	176	72	248	25
Neoplatycephalus richardsoni (Tiger flathead)	0	60	9	174	45	201	243	50
Nemadactylus macropterus (Jackass morwong)	0	5	75	497	432	145	577	30
Non-quota species								
Squalus megalops (Spiny dogfish)	31	312	205	2199	1084	1663	2747	20

4.8.1.2 Modeling approach

An indirect method was used to estimate the selectivity function because the size-structure of the underlying populations cannot be determined directly (Cui et al. 2001).

Following Hamley (1975), Reiger and Robson (1966) and Kirkwood and Walker (1986), the expected catch in number of fish in size (length) class *j* by mesh-size *i*, $N_{i,j}$, is given by:

$$N_{i,j} = S_{i,j}\, q_i\, E_i\, \mu_j \qquad (1)$$

where $S_{i,j}$ is the relative selectivity of gear-type *i* on fish in size-class *j*, E_i is the fishing effort for gear-type *i*, μ_j is the expected number of fish in size-class *j* available to any of the gear-types, and q_i is a constant of proportionality (the "catchability") for mesh-size *i*. Equation (1) defines the product $S_{i,j}\, q_i$, but not its component terms. This ambiguity is removed by specifying that the maximum (over size-classes *j*) $S_{i,j}$ for each gillnet *i* is 1 - hence the term "relative" selectivity. Table 4.8.1.1 lists the widths of the size-classes considered for the analyses of this paper. The choices in Table 5.8.1.1 are based on avoiding having size-classes with insufficient data.

The general model is simplified as follows:

Fishing power is assumed to be independent of mesh-size, i.e. $q_i = q$;

Fishing effort is assumed to be independent of mesh-size, i.e. $E_i = E$ - this assumption is valid for the current study because all of the mesh-sizes were used during each shot;

Selectivity can be represented by a simple function of the mesh-size, m_i, and the mean size of a fish in size-class *j*, L_j.

The selectivity function

The selectivity function, $S_{i,j}$, can be modeled using a variety of functional forms (see, for example, the review by Miller and Fryer (1999)). However, for the purposes of this study, we follow Kirkwood and Walker (1986), Henderson and Wong (1991) and Pierce *et al.* (1994) and base the analysis on the assumption that $S_{i,j}$ can be represented using a gamma function, i.e.:

$$S_{i,j} = \left(\frac{L_j}{a_i\, b_i} \right)^{a_i} e^{a_i - L_j / b_j} \tag{2}$$

where a_i, b_i are parameters that determine the selectivity pattern for mesh-size *i*.

It is assumed further (following Kirkwood and Walker (1986)) that the size at maximum selectivity for mesh size *i* is linearly proportional to the mesh size, m_i, and that the variance of the selectivity function is independent of mesh-size. This permits the number of parameters needed to model selectivity to be reduced from two for each mesh-size to two in total (θ_1 and θ_2):

$$a_i\, b_i = \theta_1\, m_i \qquad\qquad b_i = -0.5[\theta_1\, m_i - \sqrt{\theta_1^2\, m_i^2 + 4\theta_2}\,] \tag{3}$$

Parameter estimation

It is assumed that the catches in number (by mesh-size and size-class) are independent random variables drawn from a pre-specified probability distribution. This assumption leads to the following likelihood function:

$$L(\mathbf{N} \,|\, \underline{\theta}) = \prod_{i,j} P(N_{i,j} = n_{i,j} \,|\, \underline{\theta}) \tag{4}$$

where $n_{i,j}$ is the observed catch of animals in size-class *j* by mesh-size *i*, and $\underline{\theta}$ is the vector of model parameters.

The likelihood function (Equation 4) can be generalized to allow for more than one data set. For example, for the case of two data sets:

$$L(\mathbf{N} \,|\, \underline{\theta}) = L(\mathbf{N}_1 \,|\, \underline{\theta}_1)\, L(\mathbf{N}_2 \,|\, \underline{\theta}_2) \tag{5}$$

where $\mathbf{N}_1$ is the first data set, $\mathbf{N}_2$ is the second data set, $\underline{\theta}_1$ is the parameter vector for the first data set, and $\underline{\theta}_2$ is the parameter vector for the second data set. It is straightforward to extend Equation (5) to handle three or more data sets.

The hypothesis that the values for parameters associated with the first data set are the same as those associated with the second data set can be tested using the likelihood ratio test (Mood *et al.*, 1974). This test is used in this study to examine whether selectivity (represented by the parameters of the function *S*) and / or population size-structure (represented by the μ parameters) differ among depth zones and habitat types.

Choosing a probability model

The Poisson distribution is a natural first choice for modeling discrete random variables because it is able to approximate skewed and normal-shaped distributions. It has been used in several previous studies of the selectivity of gillnets and hooks (e.g. Kirkwood and Walker, 1986; Millar and Walsh, 1992; Punt *et al.*, 1996). However, the assumption underlying the choice of the Poisson distribution, that the variation in catches about the model predictions is due solely to sampling error, is unlikely to be valid in many cases. Some account can be taken of this 'additional' variability by assuming that the mean of the Poisson distribution varies according to some (pre-specified) distribution.

For the purposes of this study, it is assumed that the mean of the Poisson distribution varies according to a gamma distribution. It can be shown (Johnson and Kotz, 1969; McConnell and Horn, 1972) that these assumptions lead to the following (negative binomial) distribution:

$$P(N_{i,j} = n_{i,j} \mid \theta_1, \theta_2, \alpha, \mu_j) = \binom{\alpha - n_{i,j} - 1}{\alpha - 1} \left(\frac{\mu_j \, S_{i,j}}{\alpha + \mu_j \, S_{i,j}} \right)^{n_{i,j}} \left(\frac{\alpha}{\alpha + \mu_j \, S_{i,j}} \right)^{\alpha} \quad (6)$$

The variance of the negative binomial distribution, $Var(N_{i,j})$, is given by:

$$Var(N_{i,j}) = \mu_j \, S_{i,j} \left(1 + \frac{\mu_j \, S_{i,j}}{\alpha} \right) \quad (7)$$

The parameter α determines the extent of heterogeneity in the mean of the Poisson distribution. $Var(N_{i,j})$ converges to $\mu_j \, S_{i,j}$, the mean of the Poisson distribution, as $\alpha \to \infty$ (Johnson and Kotz, 1969; Cui *et al.*, 1999). Therefore, as expected, the assumption that the observations are distributed according to Poisson distribution is a special case of the general model outlined here. The choice for this study that the mean of the Poisson distribution varies according to the gamma distribution is primarily for numerical convenience and future work should consider the merits of alternatives.

There are therefore three parameters to represent selectivity (θ_1, θ_2, α) and one μ parameter for each of the *J* size-classes for a total of 3+*J* parameters.

Goodness of fit testing

The standard χ^2 test can be used to examine the goodness of fit of alternative models. However, it is necessary to first transform the negative binomial distribution into a form that is approximately normal (Johnson and Kotz, 1969; Cui *et al.*, 1999):

$$\chi^2_{n-J-3} = 4\sum_{i,j}[Y_{i,j} - E(Y_{i,j})]^2 \tag{8}$$

where $Y_{ij} = \sqrt{\alpha - \frac{1}{2}} \cdot \sinh^{-1}\sqrt{\dfrac{N_{ij} + \frac{3}{8}}{\alpha - \frac{3}{4}}}$ and $E(Y_{ij}) = \sqrt{\alpha - \frac{1}{2}} \cdot \sinh^{-1}\sqrt{\dfrac{E(N_{ij}) + \frac{3}{8}}{\alpha - \frac{3}{4}}}$

Under the assumption that the $N_{i,j}$ are independent random samples from the negative binomial distribution defined by Equation (6), the statistic χ^2_{n-J-3} should be a random sample from a χ^2 distribution with *n*-*J*-3 degrees of freedom. The hypothesis that the $N_{i,j}$ are independent random samples from a Poisson distribution can be tested by noting that the Poisson distribution is a special case of the negative binomial distribution when $\alpha \to \infty$. The degrees of freedom for a test of the adequacy of the Poisson distribution is *n*-*J*-2.

4.8.1.2 Extension to other species

Parameter estimates derived from the experimental gillnet data in Section 4.8.1.2 were used to develop a relationship between selectivity, length and body shape. This relationship was then used to extend the experimental results to other species of interest.

4.8.2 Relative selectivity – Trawl-caught fish

Our first attempt at estimating selectivity for trawl-caught fish was to estimate relative selectivity from available (but dispersed) trawl survey records. An extensive database (>3.9 million individual lengths) of length frequency data from varied trawl gear was collected from the States of Tasmania, Victoria and New South Wales, from CSIRO and from New Zealand. Using these data required the large assumption that factors apart from mesh size and depth – area, agency, vessel, skipper, gear – would have little effect on mesh selectivity. The appropriateness of this assumption was tested for blue grenadier, a species for which there were extensive data.

Unfortunately, early results showed this assumption was not met – the model was unable to fit the observed data sufficiently. This was unfortunate, especially as blue grenadier was one of the species that seemed to have the most consistent data sets, and we decided to abandon this approach for trawl-caught fish.

4.8.3 Absolute selectivity – Trawl-caught fish

4.8.3.1 Recent covered cod-end studies

During the period of this study, trawl net mesh selectivity data were collected from covered cod-end trials as part of FRDC Project 98/204 *Maximising yield and reducing discards in the South East Trawl Fishery through gear development and evaluation* (Ian Knuckey, MAFRI, PI). These data were used to estimate absolute mesh selectivity. Because the underlying population length frequency is ‘known’ in covered cod-end trials, model fitting is much simplified.

The covered cod-end experiments were conducted on recognised trawl grounds in the eastern sector (Bermagui) and western sector (Portland) of the South East Trawl Fishery. Two commercial vessels were chartered for the duration of the trials, the 'Shelley H' in Bermagui and 'Zeehaan' in Portland. Both vessels are 'typical' trawl vessels for their respective ports. Both vessels use the minimum specified mesh size of 90 mm inside knot length, constructed of 4 mm double braid mesh.

The cover comprised two sections. A large mesh skirt was placed at the leading edge of the cover to assist water flow. The skirt was constructed of 10 meshes of 105 mm mesh length, 3 mm diameter polyethylene braid. The main body of the cover was of a four panel construction. Each panel consisted of 100 meshes by 100 meshes of 45 mm mesh, 60 ply polyethylene twine. The covered cod-end method has been noted as possibly affecting selectivity due to a phenomenon known as "masking" in which the cover meshes block the cod-end meshes, effectively inhibiting species from escaping through the cod-end. To alleviate this problem, two hoops were constructed and placed in two areas of the cover. The hoops were constructed of 14mm diameter irrigation pipe. The forward hoop had a diameter of 1.6 m and the aft hoop a diameter of 2.2 m and kept the cover well away from the codend.

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

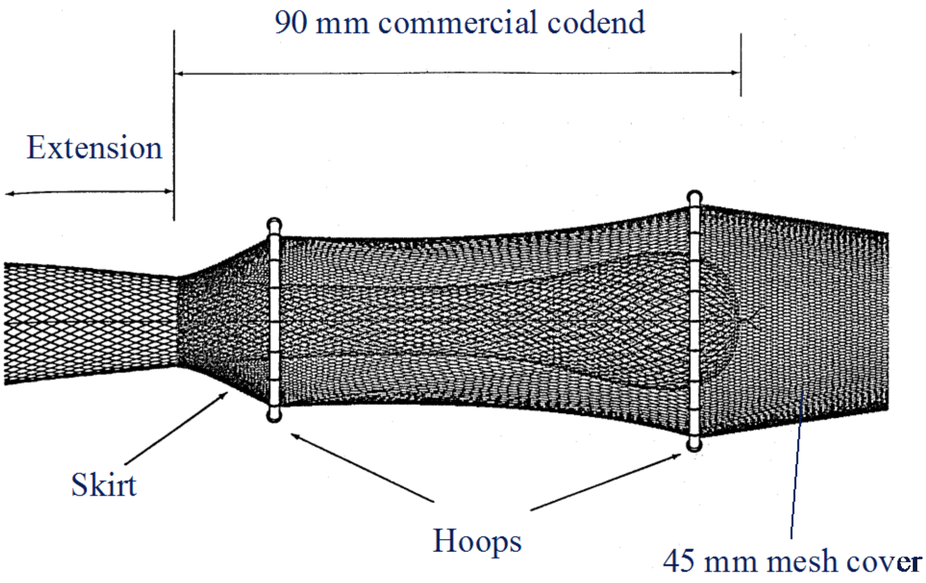


Fig. 4.8.3.1 Diagram showing the small mesh cover placed around the standard 90mm codend used in the South East Trawl Fishery. Hoops supported the cover to ensure there was no masking of the codend. (Figure modified from Wileman et al. 1996).

In normal commercial operations, tows are usually of 3 to 4 hours duration. For the covered-cod-end experiments, tow duration was reduced to between sixty and ninety minutes due to the potentially large quantities of small fish retained in the cover. Over a period of 8 months, 51 separate shots were conducted (28 off Bermagui and 23 off Portland) over 19 days. Once a shot was completed, the trawl was hauled to the vessel and both cod-end and cover were brought on board and sorted separately. The weights and numbers of each species caught in both the cover and cod-end were recorded.

Collected data are described in Table 4.8.3.1.

Table 4.8.3.1 Species for which selectivity data were collected during covered cod end studies by Knuckey at al. (FRDC Project 98/204)

Species	Common name	Mesh size (mm)	Location
Rexea solandri	Gemfish	90	Bermagui
Rexea solandri	Gemfish	90	Portland
Macruronus novaezelandiae	Grenadier	90	Portland
Neoplatycephalus conatus	Deep water flathead	90	Portland
Helicolenus sp	Ocean Perch (offshore form)	90	Portland
Genypterus blacodes	Ling	90	Bermagui
Helicolenus sp	Ocean Perch (inshore form)	90	Bermagui
Helicolenus sp	Ocean Perch (offshore form)	90	Bermagui
Neoplatycephalus richardsoni	Tiger flathead	90	Bermagui
Centroberyx affinis	Redfish	90	Bermagui

Logistic selectivity curves were fitted to the data and the lengths of 25, 50 and 75% selection estimated for each species for the different cod-end mesh sizes tested.

4.8.3.2 Earlier covered cod-end studies

In addition to these data, previously published estimates of trawl and Danish seine mesh selectivity trials in the SEF were available (Table 4.8.3.2). Estimates were available either as the size of 50% selection or as the selection factor (size of 50% selection/mesh size). These data were compiled and whenever possible reanalyzed to estimate two parameters for each species - the selection factor and the part selection factor (mesh size/size of 25% selection). These two parameters define the midpoint and slope of the selectivity curve. Unless noted otherwise, only results from covered cod-end data were used in subsequent analyses.

Table 4.8.3.2 Published data on mesh selection results (expressed as the size of 50% retention) for SEF fish.

	Trawl cod-end mesh size (mm)						
	25	82	84	91	92.8	110	Experimental design
N. richardsoni			L50=33	L50=35			Covered cod-end
N. richardsoni	L50=16						Cumulative percent frequency
R. solandri					901	344	Covered cod-end (preliminary)
C. affinis		L50=19.5					Covered cod-end
S. flindersi	L50=9.75						
	Danish seine cod-end mesh size (mm)						
	42	70	73	82	92.8	110	
N. richardsoni			L50=27.5	L50=33			Covered cod-end
N. richardsoni	L50=27.5	L50=29.3				L50=38	Cumulative percent frequency
S. flindersi	L50=16.5	L50=21.5				L50>>	Cumulative percent frequency

[a] Rowling (NSW Fisheries) pers. comm.
[b] Wankowski 1986
[c] Wankowski 1987

Several of the SEF fish species occur in New Zealand waters. Results from mesh selectivity studies of interest to this study are barracouta, elephant fish, blue grenadier, jack mackerel, red cod, red gurnard, snapper, jackass morwong and silver trevally (Table 4.8.3.3).

Table 4.8.3.3 Selection factors (50% escapement length/mesh size) from New Zealand mesh selectivity studies (Data from Massey and Hore 1987).

Species		Cassie 1955	Mundy 1968	James 1970	Clarke 1972	Fisher 1978	Patchell 1979	JAMARC 1981	Hore unpubl	Massey unpubl	M.&Hore 1987	Range
Thyrsites atun	Barracouta				4.06						5.04	4.06 - 5.04
Peltorhamphus novaezelandiae	Common sole			2.47								2.47 - 2.47
Callorhynchus milli	Elephant fish				2.32							2.32 - 2.32
Macruronus novaezelandiae	Blue grenadier					5.70	6.50					5.70 - 6.50
T. declivis and T. novaezelandiae	Jack Mackerel				2.94			3.50				2.94 - 3.50
	Leatherjackets									1.98		1.98 - 1.98
Pelotretis flavilatus	Lemon sole			2.22	2.30							2.22 - 2.30
Pseudophycis bachus	Red cod				3.16					3.58	3.54	3.16 - 3.58
Chelidonichthys kumu	Red gurnard	2.40			2.26				2.42	2.37	2.13	2.13 - 2.42
Rhombosolea plebeia	Sand flounder		1.57	1.77						1.93		1.57 - 1.93
Argentina elongata	Silverside					4.21						4.21 - 4.21
Chrysophrys auratus [a]	Snapper	2.35			2.43				2.32			2.32 - 2.43
Micromesistius australis	S blue whiting					4.85						4.85 - 4.85
Cheilodactylus macropterus [b]	Tarakihi	2.50							2.45	2.54	2.26	2.26 - 2.54
Carynx georgianus [c]	Trevally				2.69							2.69 - 2.69
Technique		Cover	Alternate	Cover	Cover	Cover	Cover	Alternate	Cover	Cover	Cover	
Mesh sizes used			3			4		2			2	
Comments					Biased ?							

[a] *Chrysophryus auratus*	Renamed	*Pagrus auratus*	SEF name	Snapper
[b] *Cheilodactylus macropterus*	Renamed	*Nemadactylus macropterus*	SEF name	Jackass Morwong
[c] *Carynx georgianus*	Renamed	*Pseudocarynx dentex*	SEF name	Silver trevally

Extension to species for which data are not available

The difference between selection factor for fish of contrasting body shape is quite clear - longer-bodied forms (barracouta, blue grenadier) have selection factors greater than 4, while the selection factors for deeper-bodied forms (jackass morwong, trevally) are less than 2.5 (Table 4.8.3.3). This suggests that there may be a relationship between selection factor and the increase in girth with length.

The exponents relating maximum head girth and maximum body girth of each fish species to length (Section 4.2) were plotted against selection and partial selection factors determined from recent covered cod end studies and the literature, and the relationship between selection factor and body shape determined. Additional data on the length girth relationship for fish not covered in Section 4.2 came from FRDC Project 96/275 (Bax et al. 1999) and other CSIRO collections.

The selection and partial selection factors for species where there are no data on mesh selectivity were estimated from this relationship.

4.9 Biological Interactions

A key assumption of MSYPR is that biological interactions through competition or predation are negligible. Extensive work on fish diets of the Southeast continental shelf have shown that although many of the larger and more abundant (usually commercial) fish species ate high proportions of fish, they ate mainly non-commercial species (Bulman et al. 2001). A variety of non-commercial bottom fish ate fish, but they also ate few commercial species. Marine mammals and birds ate a lot of fish, but mainly smaller surface and mid-water species. There were no indications that predation on commercial fish species controlled their numbers; it is more likely that fish numbers are controlled by the availability of suitable prey. This may be symptomatic of a fishery where top-order predators have been reduced by a century of harvesting.

It is very difficult to determine the presence or absence of competition between different species (Bax 1998), as not only must it be demonstrated that they share a common food source or prey, but it must also be demonstrated that availability of the particular prey source impacts the predators’ behaviour and/or diet.

We have assumed for the purposes of this study that any competitive interactions between the fish species are minimal in comparison to the technical interactions due to fishing.

4.10 Single species yield per recruit for all species

Yield per recruit analyses are undertaken on individual species to determine the optimum yield from a cohort given a range of fishing gear selectivities (or age at first capture) and a range of fishing mortalities. Maximum yield per recruit is then a tradeoff between the increase in weight associated with growth and the decrease in fraction surviving (non-fishing) mortality. A number of age-based yield per recruit models have been developed (eg. Thompson and Bell 1934; Ricker 1945; and Beverton and Holt 1957), all of which require information on the growth and mortality of the species concerned as a function of its age. A major advantage of single-species per recruit models is that they do not depend on information about the actual levels of recruitment in a fishery, although this is one of the main sources of variability in the total yield from a fishery.

The data collected above will be used to determine the yield per recruit curves for each species and the eggs per recruit curves where possible. Economic yield per recruit curves will be determined or estimated for all species where there is a price differential per kg with size.

4.11 Multi-species yield per recruit models

Single species yield per recruit models are readily extended to include more than one species and/or more than one fishery (Murawski 1984, Sainsbury 1984, Pikitch 1987, Marchal and Horwood 1996).

Standard fishery approaches are used to model the dynamics of each species. Species specific subscripts are omitted from the following formulae, for ease of representation, although parameter values are unique to each species and sex.

For each age t, length at age l_t , is calculated using the von Bertalanffy equation:

$$l_t = L_\infty (1 - \exp(-K(t - t_0)))$$

where: L_∞ is asymptotic length, and

K is the growth coefficient

Weight at age, w_t, is calculated:

$$w_t = a \cdot l_t^b$$

where: a and b are constants.

Following Murawski (1984) and Pikitch (1987) instantaneous fishing mortality rate, F, is assumed directly proportional to fishing effort, f. All fish caught are assumed to die regardless whether they are landed or discarded at sea:

$$F = q \cdot f$$

where: q is the catchability coefficient.

Then the number caught for a particular gear/mesh size combination (yield in numbers) is:

$$C = \sum_t C_t = \sum_t \left\{ N_t \cdot \frac{(F \cdot PR_t)}{(F \cdot PR_t + M)} \times [1 - \exp[-(F \cdot PR_t + M)]] \right\}$$

where:

N_t is the number fish in age class t

PR_t is the fraction of age t fish retained by the gear, and

M is the instantaneous mortality rate (assumed invariant over age)

Number of fish in age class t is determined by the recursive formula, where N_0 is customarily set equal to 1 (per recruit):

$$N_{t+1} = N_t \cdot \left[\exp\left(-\left(M + F \cdot PR_t\right)\right)\right]$$

Yield in weight is given by:

$$WC = \sum_t w_t C_t$$

Gross revenue, *GR*, (yield in dollars) is given by:

$$GR = \sum_t w_t C_t \, p_t$$

where: p_t is the weight (age) specific ex-vessel price per unit weight.

Egg production, *EP*, is given by:

$$EP = \sum_t w_t C_t e_t$$

where: e_t is the weight(age) specific fecundity (zero of males).

For a multi-species fishery that consists of several geographically or seasonally distinct fisheries, fishing mortality may be different for each species. Total fishing mortality on a species/stock i is thus defined as:

$$F_{i\bullet} = \sum_{j=1}^{m} q_{ij} f_j$$

Catchability coefficients are not only species specific but may also vary between fisheries (Murawski 1984). In the case of the SEF fishery, where the size composition of species can change between sub-fisheries that are at different depths, partial recruitments may also vary by sub-fishery.

The results from multi-species yield per recruit models may be difficult to interpret because the relative selectivity for different species depends on both the vulnerability of the species to the type of gear and its average recruitment strength relative to the other species. Relative recruitment strength and relative vulnerability are confounded unless there are additional data to estimate parameters. This can result in multi-species yield per recruit analyses having little power to differentiate alternative harvesting scenarios with any confidence (Sainsbury 1984). In this study we used independent datasets to estimate vulnerability and relative recruitment strength.

5 RESULTS/DISCUSSION

5.1 Biological data collection

5.1.1 Morphometry

Over 2,500 length and girth measurements were collected for 14 quota species (2 by sex), and 8 of the most common discard species as determined by earlier discarding studies off NSW (Liggins 1996). The number of girth measurements per species depended on the availability of a wide size range of specimens, and ranged from 47 to 278 for quota species and from 20 to 92 for non-quota species (Table 5.1.1.1).

The linear relationship between length (l) and girth (G) fitted to the data showed values for the slope of less than 1. In general, longer-bodied forms with round cross section (e.g. gemfish, ling, blue grenadier, whiting) had slopes less than 0.5, indicating that the girth of these fish would change relatively slowly with increases in length. Shorter-bodied, laterally compressed forms (e.g warehou, roughy, redfish, ocean perch, morwong and blue-eye trevalla) had slopes between 0.6 and 0.9, indicating that the girth of these fish would increase more rapidly with length.

The implication of this difference in relationship of girth size to body length is that the longer-bodied forms would have a greater range of body lengths over which they are susceptible to a particular mesh size than shorter-bodied forms.

Table 5.1.1.1 Estimated relationship between weight, girth and length for SEF quota and common discard species (including standard errors SE, or coefficients of variation CV).

	Weight (kg)								Girth 1 (cm)						Girth 2 (cm)					
	n	SE	Mean	CV	Constant a	SE	Exponent b	SE	n	CV	Constant a	SE	Slope b	SE	n	CV	Constant a	SE	Slope b	SE
SEF quota species																				
Blue grenadier (male)	110	0.0585	1.099	22.0	3.46E-06	2.02E-06	3.04	0.133	128	6.19	-0.893	0.400	0.344	0.006	128	9.41	-1.740	0.670	0.391	0.010
Blue grenadier (female)	168	0.1528	1.855	21.1	1.57E-05	7.25E-06	2.70	0.101	190	4.90	-0.599	0.272	0.339	0.003	190	9.97	-2.110	0.622	0.400	0.008
Ling	140	0.1390	2.340	15.9	1.09E-06	2.73E-07	3.39	0.055	212	8.70	-6.595	0.557	0.478	0.008	212	10.07	-9.007	0.702	0.548	0.010
Orange roughy	145	0.0318	1.280	13.9	6.52E-05	1.65E-05	2.80	0.067	164	4.38	2.658	0.289	0.883	0.008	164	5.21	1.758	0.342	0.908	0.010
Redfish	120	0.0008	0.352	8.1	6.09E-05	8.75E-06	2.76	0.043	119	3.67	1.884	0.189	0.822	0.008	119	3.76	1.700	0.196	0.839	0.009
Mirror dory									70	6.17	8.606	2.401	0.672	0.056	70	5.37	4.124	2.319	0.874	0.054
John dory																				
Ocean perch	130	0.0013	0.207	17.3	7.96E-06	1.63E-06	3.26	0.061	129	7.03	-0.624	0.350	0.730	0.016	129	4.89	0.229	0.241	0.683	0.011
Tiger flathead	85	0.0023	0.589	8.2	2.49E-06	5.88E-07	3.31	0.062	84	4.60	-3.419	0.711	0.543	0.017	84	5.83	-5.891	0.924	0.614	0.022
Eastern school whiting	164	0.0001	0.051	10.4	1.32E-05	2.74E-06	2.93	0.072	38	4.23	-0.188	0.685	0.476	0.037	38	3.82	1.381	0.642	0.407	0.035
Silver trevally																				
Jackass morwong	85	0.0058	0.578	13.2	4.29E-05	1.23E-05	2.78	0.080	84	5.30	1.984	0.701	0.696	0.023	84	5.91	0.372	0.840	0.809	0.028
Gemfish (male)	35	0.0018	0.209	20.4	2.00E-06	9.90E-07	3.31	0.133	84	5.94	-1.351	0.582	0.420	0.017	84	6.39	-1.821	0.693	0.475	0.021
Gemfish (female)	35	0.0018	0.209	20.4	2.00E-06	9.90E-07	3.31	0.133	84	5.94	-1.351	0.582	0.420	0.017	84	6.39	-1.821	0.693	0.475	0.021
Blue eye trevalla	30	0.1020	3.663	8.7	1.57E-05	9.28E-06	3.06	0.145	29	3.54	-2.130	2.691	0.754	0.047	29	6.02	0.024	4.746	0.743	0.084
Blue warehou	170	0.0216	1.336	11.0	8.04E-06	1.69E-06	3.25	0.055	171	5.81	-1.833	0.603	0.716	0.015	171	6.67	-4.220	0.751	0.834	0.019
Spotted warehou	47	0.0130	1.923	5.9	1.53E-05	7.90E-06	3.05	0.134	120	5.87	1.869	0.863	0.590	0.022	120	5.75	5.370	0.940	0.574	0.023

Table 5.1.1.1 Estimated relationship between weight, girth and length for SEF quota and common discard species, continued.

	Weight (kg)								Girth 1 (cm)						Girth 2 (cm)					
	n	SE	mean	CV	Constant a	SE	Exponent b	SE	n	CV	Constant a	SE	Slope b	SE	n	CV	Constant a	SE	Slope b	SE
Non-quota species																				
King dory	28	0.0018	0.459	9.3	8.20E-06	3.44E-06	3.29	0.123	27	3.32	4.358	1.291	0.942	0.047	27	3.47	1.962	1.550	1.194	0.057
Barracouta	92	0.0127	0.960	11.7	1.97E-05	5.07E-06	2.63	0.061	91	4.57	2.814	0.481	0.249	0.008	91	6.57	4.439	0.759	0.251	0.013
Tooth whiptail	72	0.0003	0.127	13.5	9.22E-07	2.38E-07	3.29	0.067	71	5.22	0.987	0.288	0.297	0.008	71	6.43	-1.500	0.335	0.351	0.009
Cucumber fish	83	0.0002	0.108	12.6	1.31E-05	3.84E-06	2.95	0.093	83	5.31	0.875	0.447	0.427	0.021	83	5.35	-0.162	0.476	0.505	0.023
Grooved gurnard	20	0.0001	0.056	5.9	9.07E-06	6.53E-06	3.14	0.257	19	3.00	0.371	1.257	0.617	0.078	19	4.96	-3.190	1.870	0.772	0.116
Round snouted gurnard	29	0.0001	0.099	7.6	9.40E-06	1.97E-06	3.12	0.067	28	4.52	-0.206	0.481	0.633	0.025	28	5.57	0.792	0.554	0.539	0.029
Stinkfish	21	0.0001	0.073	7.3	2.61E-04	1.56E-04	1.99	0.210	20	5.75	2.985	1.572	0.426	0.093	20	7.40	5.830	1.786	0.185	0.106
Jack mackerel	58	0.0020	0.222	20.2	4.15E-05	2.54E-05	2.63	0.176	54	8.81	0.600	0.291	0.438	0.011	54	10.19	0.884	0.372	0.475	0.015
Supplemental species																				
School shark															173		-24.094	4.344	0.546	.0.030
Gummy shark[1]									103		-1.761	0.577	0.344	0.007	103		-2.347	0.719	0.327	0.009
Squalus megalops[2]									12		-33.055	10.197	0.426	0.025	12		-28.099	6.453	0.284	0.016
Psuedophycis bacchus[2]									5		-8.943	8.947	0.627	0.021	5		-10.258	13.932	0.656	0.03
Chelidonichthys kumu[2]									9		-85.73	12.834	0.810	0.036	9		-66.751	10.105	.725	0.028
Pagrus auratus[2]									8		14.654	9.659	0.743	0.025	8		21.286	9.245	0.747	0.024

[1] Girth estimated from abdomen height and head width or abdomen width

[2] Girths estimated from head and body depths and widths. Small samples sizes covered range of smallest to largest fish caught

5.1.2 Growth

Growth data from existing data collections, supplemented by special collections were collated for 13 of the 15 fish quota species (Table 5.1.2.1). Much of the ageing data for the quota species was derived from collections at the Central Ageing Facility at MAFRI. Ageing of non-quota species was derived from CSIRO project 94/040. von Bertalanffy parameters were estimated. Examination of residuals from the fitted curves, indicate that the available data for some species (e.g. blue eye trevalla) may have been truncated at smaller lengths. This will have biased the von Bertalanffy parameters.

Table 5.1.2.1 Estimated von Bertalanffy growth parameters and coefficient of variations for SEF quota species.

	von Bertalanffy growth parameters										
	n	s	x	CV	Linf	SE	K	SE	Tzero	SE	Source
SEF quota species											
Blue grenadier (male)	2806	40.746	8.10	78.8	85.24	0.350	0.31	0.010	-0.67	0.117	This study
Blue grenadier (female)	2185	58.847	9.28	82.7	104.05	0.697	0.17	0.006	-1.77	0.162	This study
Ling (male)	409	52.424	5.38	134.6	97.70	3.573	0.17	0.020	-1.60	0.305	This study
Ling (female)	470	60.791	4.69	166.2	123.16	6.260	0.12	0.014	-1.63	0.253	This study
Orange roughy	502	2.294	28.35	5.3	39.05	1.890	0.06	0.001	-3.18	0.129	This study
Redfish	2532	8.7405	7.84	37.7	25.04	0.140	0.30	0.009	-0.15	0.074	This study
Mirror dory	156	10.956	7.07	46.8	65.25	5.316	0.16	0.041	-0.38	0.718	This study
John dory	166	2.3251	3.51	43.4	66.96	2.817	0.10	0.007	-1.48	0.096	This study
Reef ocean perch	159				34.7		0.16		-0.78		Knuckey & Curtain 2001
Ocean perch (offshore)	784				42.87		0.07		-5.96		Knuckey & Curtain 2001
Tiger flathead (male)	1865	20.367	4.73	95.4	59.54	3.670	0.12	0.018	-2.46	0.411	This study
Tiger flathead (female)	2572	18.692	5.45	79.3	74.51	2.920	0.09	0.008	-2.14	0.219	This study
Eastern school whiting					23.90		0.46		-0.50		Hobday and Wankowski 1986
Silver trevally	1292				63.16		0.051		-6.47		Rowling and Raines 2000
Jackass morwong (male)	377	4.6018	7.60	28.2	35.18	0.204	0.41	0.014	-0.20	0.051	This study
Jackass morwong (female)	520	7.2054	7.49	35.8	36.39	0.247	0.34	0.013	-0.45	0.072	This study
Gemfish (Male)	894	17.144	65.83	6.3	90.06	1.262	0.25	0.012	-0.44	0.088	This study
Gemfish (Female)	1766	20.776	80.56	5.7	111.19	1.430	0.16	0.007	-1.02	0.123	This study
Blue eye trevalla (male)					89.9		0.08		-5.86		Baelde 1995
Blue eye trevalla (female)					96		0.08		-5.25		Baelde 1995
Blue warehou (male)	676	12.4	3.22	109.4	55.44	2.602	0.27	0.038	-0.75	0.220	This study
Blue warehou (female)	898	12.142	3.22	108.2	55.14	1.745	0.28	0.030	-0.69	0.183	This study
Spotted warehou	881	9.7225	2.96	105.3	51.25	0.465	0.46	0.022	-0.65	0.082	This study

5.1.3 Natural mortality

Based on their life history parameters, four estimation techniques were used to derive natural mortality estimates for the quota species (Table 5.1.3.1). In addition, mortality estimates derived from specific studies and stock assessments are included here.

The different techniques yielded considerably different estimates of natural mortality for the various species. Without data to validate these estimates in most instances, it was difficult to determine which method was more appropriate. In general, Hoenig's (1983) 5% estimator (assuming that the oldest recorded fish was the 95 percentile) provided lower and thus more conservative estimates of natural mortality and were used in the yield per recruit analyses for this study, unless a separate natural mortality estimate was available from a recent stock assessment. Separate estimates were available for orange roughy (0.059; Wayte and Bax 2001); redfish (0.1 Thompson 2001a); blue warehou (0.50; Punt 2000a) and spotted warehou (0.25; Thompson 2001b). In all cases, these estimates were above those of Hoenig's 5% estimator.

Table 5.1.3.1 Life history parameters and natural mortality estimates for SEF commercial species

	LIFE HISTORY PARAMETER										
	Tmax	Linf	Tmat	Lmat	GSI	K	Temp	M This study	M Hoenig	M Hoenig	M Pauly	M Gunderson
SEF quota species									1%	5%		
Blue grenadier (male)	21	85	5	73		0.31	6		0.22	0.14	0.30	
Blue grenadier (female)	25	104	5	73		0.17	6		0.18	0.12	0.20	
Ling (male)	26	97	4			0.17	8		0.18	0.12	0.23	
Ling (female)	28	123	4	65		0.12	8		0.16	0.11	0.17	
Orange roughy	170	39	25	32		0.06	3	0.06	0.03	0.02	0.09	
Redfish	44	25	5	19		0.30	10	0.10	0.10	0.07	0.52	
Mirror dory	12	65	5			0.16	12		0.38	0.25	0.30	
John dory	12	66	4			0.10	10		0.38	0.25	0.19	
Reef ocean perch	17	35		30		0.16	12		0.27	0.18	0.35	
Ocean perch (offshore)	62	43		30		0.07	10		0.07	0.05	0.18	
Tiger flathead (male)	14	60	4	25	9%	0.12	10		0.33	0.21	0.22	0.05
Tiger flathead (female)	17	77	4	30	18%	0.09	10		0.27	0.18	0.18	0.47
Eastern school whiting	8	26	2	15		0.46	10	1.20	0.58	0.37	0.69	
Silver trevally	24	63	5	20	10%	0.05	10		0.19	0.12	0.13	
Jackass morwong (male)	31	46	3	22	8%	0.41	12		0.15	0.10	0.59	0.00
Jackass morwong (female)	38	52	3	22	10%	0.34	12		0.12	0.08	0.51	0.09
Gemfish (male)	12	94	4	60		0.25	10		0.38	0.25	0.32	
Gemfish (female)	17	110	5	65		0.16	10		0.27	0.18	0.24	
Blue eye trevalla (male)	39	90	8	62		0.08	10		0.12	0.08	0.16	
Blue eye trevalla (female)	42	96	11	71	14%	0.08	10		0.11	0.07	0.15	
Blue warehou	8	58	4	35	15%	0.25	9	0.50	0.58	0.37	0.36	0.33
Spotted warehou	14	63	4	40		0.46	12	0.25	0.33	0.21	0.59	

5.1.4 Size and market value

Average 1996 market value of different size categories of fish were obtained from the Melbourne and Sydney fish markets and fishermen's cooperatives (Table 5.1.4.1). The size categories are not absolute but are adjusted dependent on the size range of fish available on the market at any time (Table 5.1.4.2).

Table 5.1.4.1 Market value of different size categories of SEF commercial species

	Market value $/kg			
	Small	Medium	Large	Xlarge
Blue Grenadier	$1.80	$2.55	$2.80	
Ling	$3.26	$4.15	$4.60	$4.69
Orange roughy	$1.84	$3.20	$3.84	
Redfish	$1.04	$1.35	$2.19	$2.70
Mirror dory	$1.27	$1.69	$2.97	$3.23
John dory	Not used			
Ocean perch	$1.69	$2.93	$4.68	$5.21
Tiger flathead	$1.40	$1.90	$2.69	$3.30
School whiting	$1.12	$1.58	$2.06	$3.07
Silver trevally	$1.67	$2.36	$1.92	$1.99
Jackass morwong	$2.00	$2.31	$2.94	$3.06
Gemfish	$2.40	$4.13	$5.17	$4.94
Blue eye trevalla	$5.91	$6.54	$5.84	$6.08
Blue warehou	$1.43	$2.34	$3.26	$2.77
Spotted warehou	$1.57	$1.51	$1.60	$1.58

Table 5.1.4.2 Size categories of SEF commercial species

	Market size $/kg				
	Xsmall	Small	Medium	Large	Xlarge
Blue grenadier		< 50	50 - 55	> 55	
Ling	< 40	40 - 50	50 - 68	68 - 90	> 90
Orange roughy		27 - 30	30 - 40	> 40	
Redfish	< 23	23 - 25	25 - 29	29 - 35	> 35
Mirror dory		< 37	37 - 42	42 - 47	> 47
John dory		< 24	24 - 31	31 - 40	> 40
Ocean perch		< 23	23 - 30	30 - 36	> 36
Tiger flathead		<33[a]	33 - 38	38 - 45	> 45
School whiting		27-31	31-35	35-40	>40
Silver trevally	25	25 - 30	30 - 36	36 - 40	> 40
Jackass morwong		28 - 34	34 - 40	40 - 45	> 45
Gemfish		< 50	50 - 60	> 60	
Blue eye trevalla		< 50	50 - 70	> 70	
Blue warehou		< 40	40 - 45	45 - 55	>55
Spotted warehou		< 40	40 – 45	45 - 55	>55

[a] Melbourne market

5.1.5 Discussion

Biological data are fundamental to our understanding of SEF fishery resources and the advice provided to managers, be it through limited examination of the data or through sophisticated assessment models. Commercial trawling off southeast Australia started in the early 20th Century on the shelf (Klaer 2001), and expanded to the upper continental slope in the in 1968 (Graham et al. 2001). Further expansion to the deepwater fisheries began in the early 1980s with the development of the orange roughy fishery (Bax et al. in press).

While the collection of some biological data was expected for this project, especially non-standard fisheries data including girth/length relationships, market sizes and price, and non-commercial species, it is surprising that basic biological data were missing or inadequate for many of the quota species, some of which have been fished for almost a century. The biological data collected as part of this study have gone a long way towards remedying this long-term deficit, as is shown by their uptake by the single species stock assessment groups. Eleven of the 16 quota species have had their biological data completed or updated as a result of this project (Table 5.1.2.1). Where earlier estimates were available, they were deemed less reliable than those collected in this study and were replaced.

However, the standard of biological data available for the South East Fishery remains inadequate (Tilzey and Rowling 2001). Only one of the techniques for estimating natural mortality (Hoenig’s 1983 method based on maximum age) could be used for the majority of species in this study. Age estimates for many of the species remain unverified and some of the estimates provided in this report are derived from small sample sizes. Regional and seasonal differences in biological parameters have not been examined, although there are distinct trends over area at multiple scales for most quota species (eg. Bax and Williams 2000). There was a lack of small fish for some of the biological relationships, and those species which were sampled only from the commercial fisheries were likely biased by the selection of faster growing members of the younger age classes.

The sophistication of assessment and management advice provided to fishery managers increases each year as the scientific community develops improved techniques and models to synthesize and digest the available information. While this is admirable, it is ultimately flawed without a sound basis for the underlying data used to run these models. Increased effort needs to be spent in ensuring that the biological data underlying stock assessments in the SEF are unbiased and representative of the fishery being managed.

5.2 Abundance estimates

Relative abundance (number of 1 year-olds) was estimated from single species yield per recruit analyses fitted to the values of fishing mortality and catch (including discards) contained in assessment reports (Table 5.2.1). A range of estimates – different assessment models or assessment years – was used where possible to provide an idea of the range of possible values.

5.1.1 Discussion

Single species yield per recruit has a distinct advantage over multi-species yield per recruit – no estimates of abundance (or abundance relative to other species) are required to develop relative recruitment multipliers. Single species yield per recruit analyses can therefore be completed for all species where biological and selectivity data exist or can be reliably estimated. Multi-species yield per recruit will be restricted to those species for which relative abundance is available and reliable.

Relative recruitment multipliers can be derived from fishery-dependent data (ie. stock assessments) or fishery-independent data (eg. research surveys), although it may be only rarely possible to correct catch per tow data for availability and vulnerability of individual species to the sampling gear (Murawski 1984). And even then, interannual variation in catchability can be high (Francis et al 2001). There have been no studies of the relative availability of species to the trawl in SEF and in this analysis we were restricted to those species where relative recruitment multipliers could be derived from fishery-dependent data – stock assessments. Stock assessments have the advantage that they tend to explicitly model the data from several years, and therefore, theoretically, should not be unduly influenced by single years of unusual catchability.

Assessments were available for only six species in the areas selected for multi-species yield per recruit. This is perhaps not surprising given the paucity of basic biological data for many of the species. However, even these assessments are quite speculative and there is little confidence that they accurately portray abundance or exploitation rates for spotted warehou, blue warehou or school whiting. Ultimately, school whiting could not be included in the multi-species yield per recruit because the relative recruitment multiplier was not credible. However, as it is primarily caught by the Danish seine fleet, using a smaller mesh size than the trawl fleet, this may not have been a disadvantage. No estimates were available for John Dory or silver trevally.

Table 5.2.1 Mortality and catch estimates used to estimate recruitment values used in the per recruit analyses.

Species	Year	Mortality Estimates M	F	Z	Total catch (t)[a]	Discards (t)[a]	Other data and comments	Sources for M,F,Z and other data
Spotted warehou	1996-1999	0.25			2955	297	~10*10^6 1yr olds 1990-97	Thomson 2001b
	1986-1989			1.2	1270			Smith 1989
Blue warehou	1996-1999			1.7-2.3	1248	60		Smith&Wayte 2000
	1996-1999	0.5		0.6			1996-1998 age 4-7+	Punt 2000a
Tiger flathead	1996-1999	0.2	1.0		2918	224		Smith&Wayte 2000 (M from this study)
	1984-1986			1.1	1904			Montgomery 1985;
	1984-1986			0.7	1904			Wankowski et al 1986
Jackass morwong	1996-1999	0.09	0.09		986	30		Smith&Wayte 2000
School whiting	1996-1999	0.37			1981	6		This study
	1985-1986			1.3	2214			Wankowski et al. 1986; Hobday and Wankowski 1986
	1992-1994			1.26 - 2.27	2322			Smith&Wayte 2000
	1996-1998		0.62-0.91				1996-1998 age 4-6+	Punt 2000b
Redfish	1996-1999	0.1	0.14		1575	1114		Thomson 2001a

[a] Landings and discard data from SEF Fisheries Assessment Report 2000 (Smith and Wayte 2001).

5.3 Size composition and availability

Size compositions by depth were determined from recent trawl surveys off New South Wales and eastern Victoria by NSW Fisheries (Graham et al. 1995, 1996) and CSIRO (Bax and Williams 2000). All length frequency data for the relevant species from surveys between 1993 and 1994 (NSW Fisheries) and 1993 and 1996 (CSIRO) were included in the analysis. All data were averaged for each latitude and depth cell and weighted by the estimated number of fish in the catch.

These data were compared with the total size composition of commercial catches and discards monitored by the ISMP between 1996 and 1999 aggregated on the same latitude and depth cells.

Blue warehou was described as having a “bigger-deeper” pattern denoting a distribution where fish size increases with depth (Bax and Williams 2000). Blue warehou caught on scientific surveys increased from an average 20 cm at less than 50 m depth to 47 cm at greater than 150 m depth (Table 5.3.1; Figure 5.3.1a). Average lengths were larger in the south. Fish in commercial catches (ISMP data) were significantly larger than those in survey catches (Kolmogorov-Smirnov test), indicating selection against smaller fish in the commercial fishery.

The average size of flathead increased with depth and latitude (Table 5.3.1; Figure 5.3.1b). Average size in the commercial fishery was larger than that in the surveys at the primary fishing depths for this species (100-200 m; Rowling 1994). Shallower than 50 m and deeper than 300 m, average size was smaller in the commercial fishery than the surveys.

Larger jackass morwong were caught at depth and generally with increasing latitude (Table 5.3.1; Figure 5.3.1c). The commercial fishery caught on average larger fish than the survey in the northern sector, but smaller fish than the survey in the southern sector.

Average sizes of redfish increased with depth and with latitude (Table 5.3.1; Figure 5.3.1d). Fish caught by the commercial fishery were larger than those caught on the surveys in the northern sector. There was a tendency for the commercial fishery to catch larger fish than the survey in the southern sector but the difference was not as distinct.

Average sizes of school whiting increased with depth but decreased with latitude (Table 5.3.1; Figure 5.3.1e). Fish caught in the commercial fishery were generally larger than those caught on surveys, except at 50-150 m in the southern sector. Commercial catches for this species are typically taken at less than 50 m depth (Smith 1994).

Spotted warehou increased in size with depth; there was no consistent trend with latitude (Table 5.3.1; Figure 5.3.1.f). The commercial fishery consistently caught larger fish on average than the survey.

5.3.1 Discussion

The trend for an increasing size of fish with increasing depth has been well described in the SEF (eg. Chen et al 1997; Bax and Williams 2000) so it is no surprise that it should be evident in data from both research surveys and commercial fisheries. There was also a tendency to increased size with increased latitude. Again this has been observed before, but mostly when comparing Tasmanian to mainland catches. There are two hypotheses that could explain these observations:

- larger fish move deeper and/or further south (age or size specific movement), and
- fish that grow in deeper areas or further south grow to a larger size (either an increased size at age or an increased survival rate leading to more older fish in the population)

It is not possible with the current data to distinguish these two hypotheses. Regardless of which hypothesis is correct, this change in length with depth and latitude (plus change in length with habitat for some species – Bax and Williams 2000), exemplifies the spatio-temporal complexity that characterizes this fishery. Ideally this complexity would be accounted for in the collection of data and assessment of this fishery. Unfortunately that is not possible and the fishery is generally assessed and managed treating populations that range across the different depths and latitudes as single stocks.

The tendency for larger fish to be caught by the commercial fishery than by the research surveys is expected given the larger cod end mesh size of the commercial trawls (90mm) than the research trawls (40 mm). We had originally expected the differences to be more pronounced. Effective mesh selectivity of the commercial fishery is considered in a following section.

Table 5.3.1 Average lengths (cm) of fish caught on surveys (S) and by the commercial fishery (C). Significantly different Kolmogorov-Smirnov test results are given as: ** p<0.01; * p<0.05. Others are not significantly different p>0.10. Sample sizes were based on the smaller of the two samples.

Area[a]	Blue warehou			Flathead			Jackass morwong			Redfish			School whiting			Spotted warehou		
	S	C		S	C		S	C		S	C		S	C		S	C	
NORTH50	20			29	28	**	17			12	13		17	20	**	16		
NORTH150	29	30	**	27	33	**	23	29	**	14	17	**	19	21	**	32		
NORTH300	28	27	**	30	35	**	28	31	*	17	20	**				35	40	**
NORTH600				39	37	*				22	22	**				38	43	**
SOUTH50	22			34	33	**	7			12	12	**	16	18	**	15	23	**
SOUTH150	34	42	**	36	37		29	23	**	20	21		19	18	**	30	37	**
SOUTH300	42	47	*	42	38		35	32	**	21	24	*				34	40	**
SOUTH600		47			38			34			27						45	

[a] See table 5.4.3.2 for area definitions.

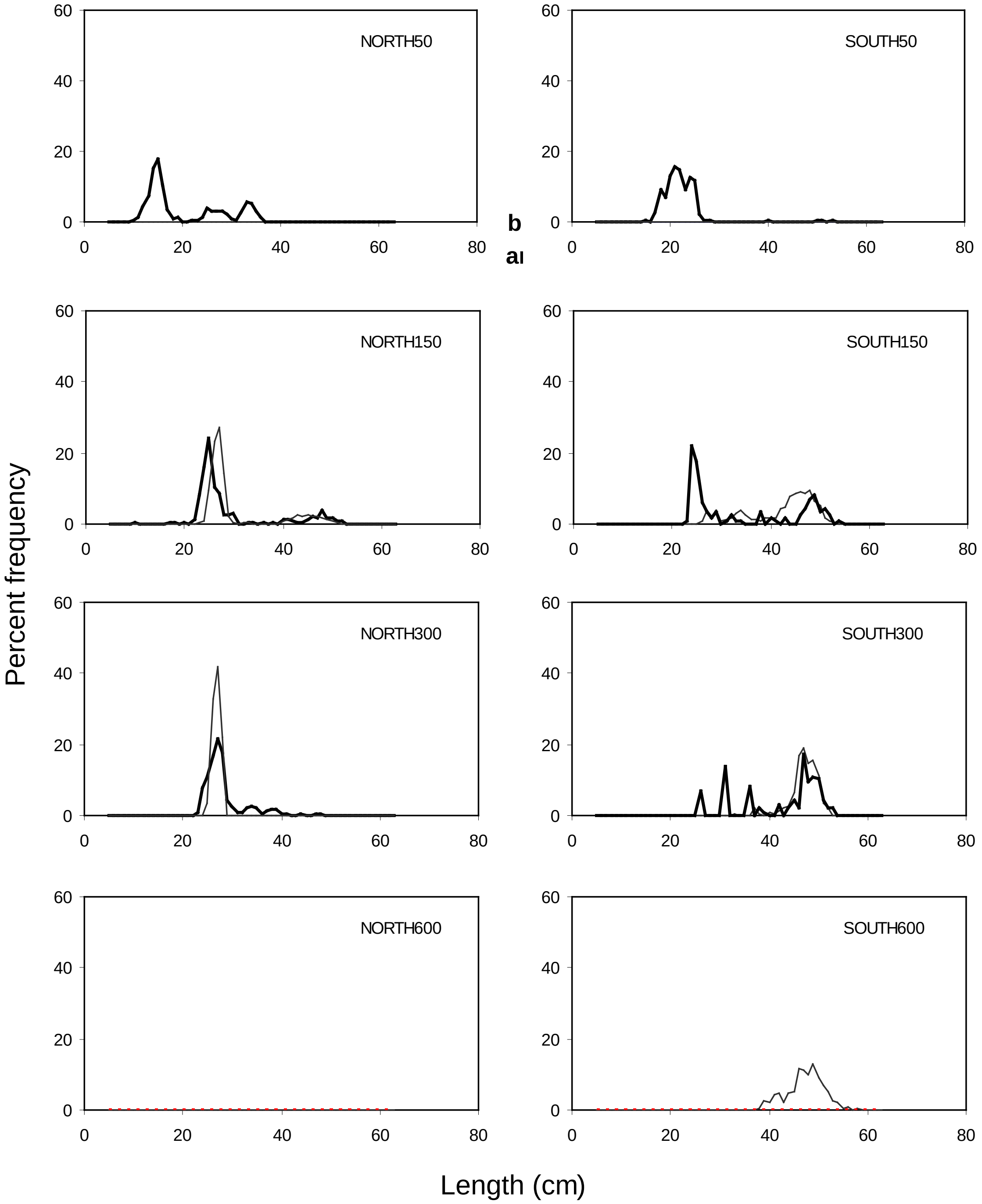


Fig. 5.3.1.a. Percent length frequencies of blue warehou caught in survey (bold) and commercial catches (normal) by depth and latitude.

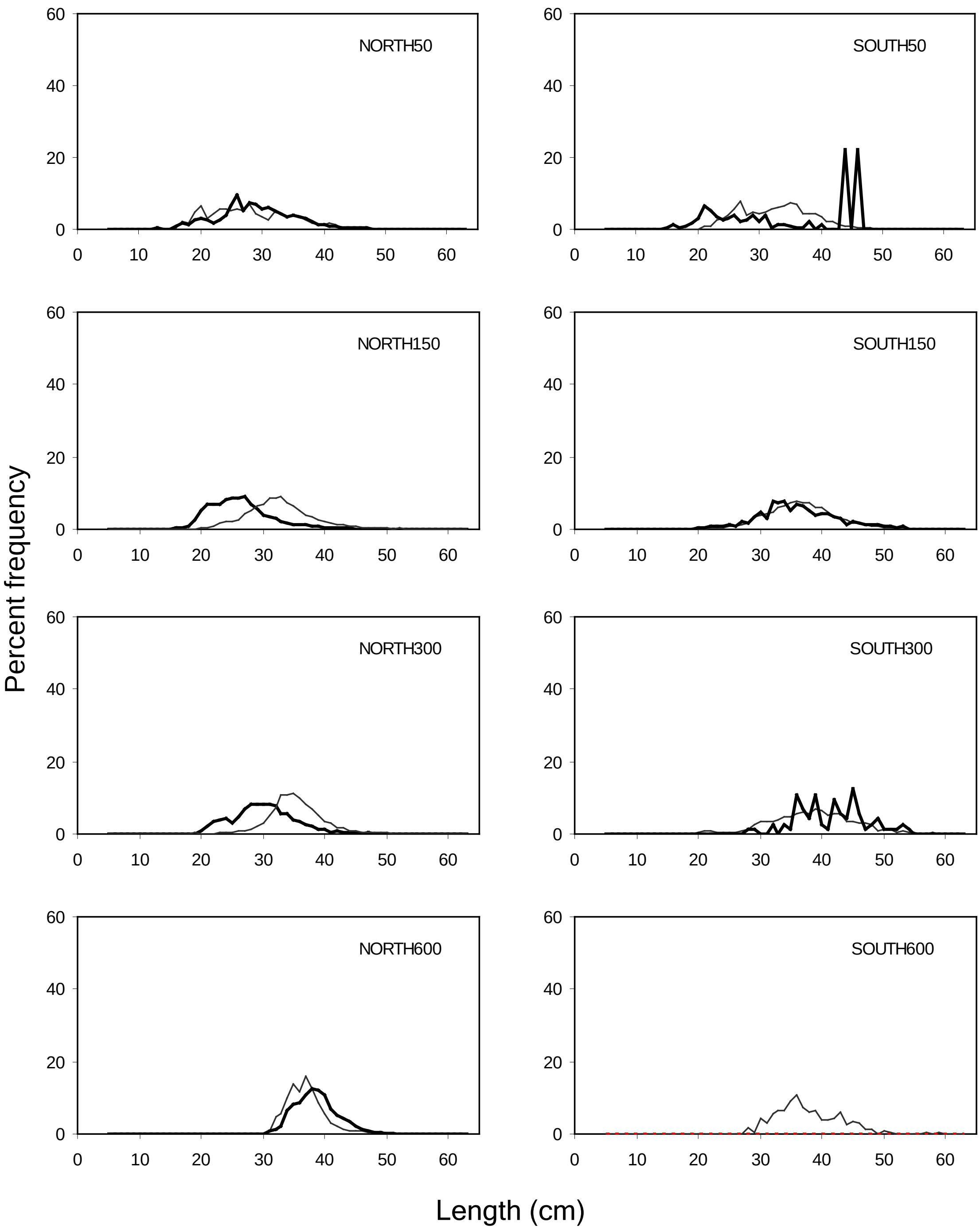


Fig. 5.3.1.b. **Percent length frequencies of tiger flathead caught in survey (bold) and commercial (normal) catches by depth and latitude.**

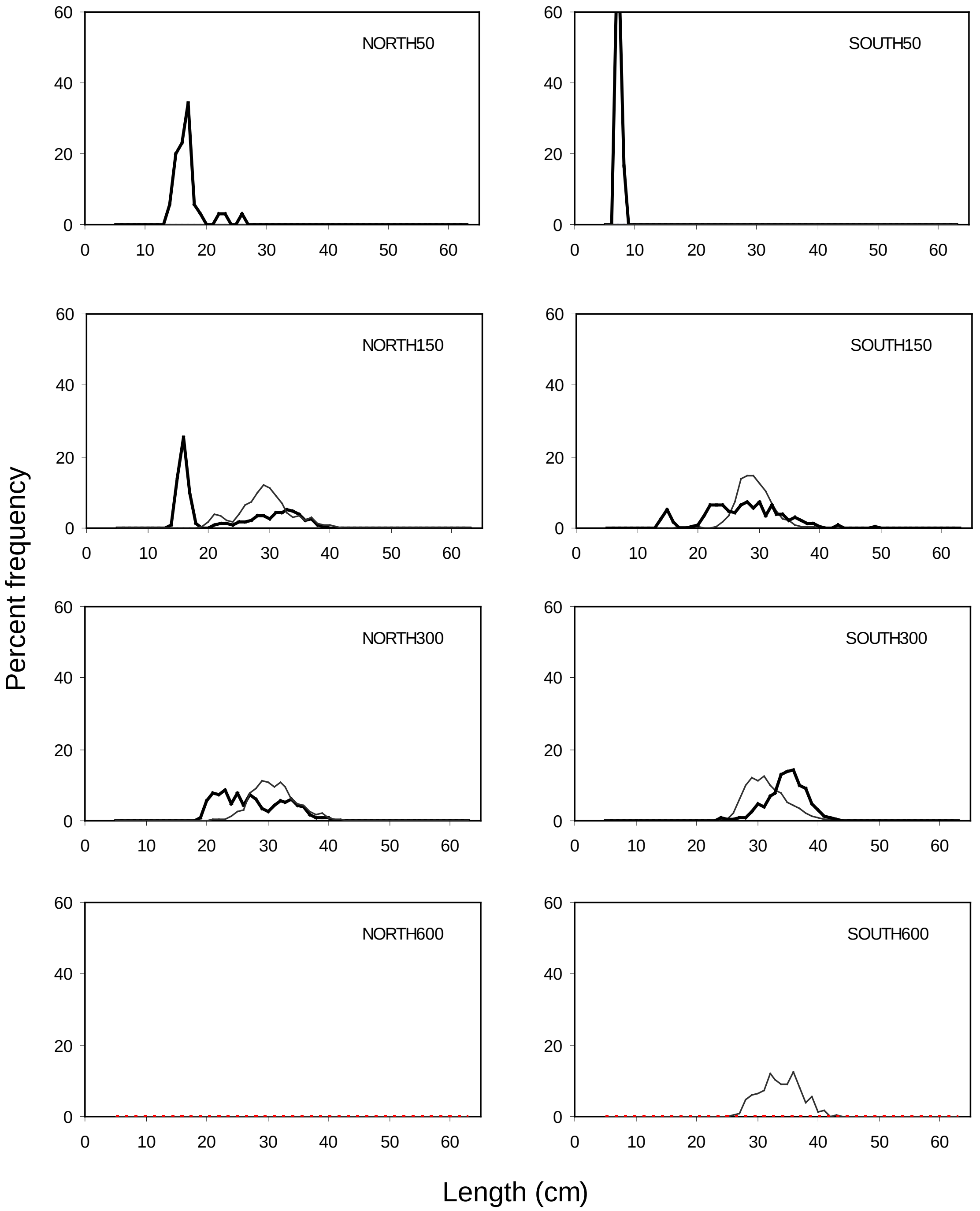


Fig. 5.3.1.c. Percent length frequencies of jackass morwong caught in survey (bold) and commercial (regular) catches by depth and latitude.

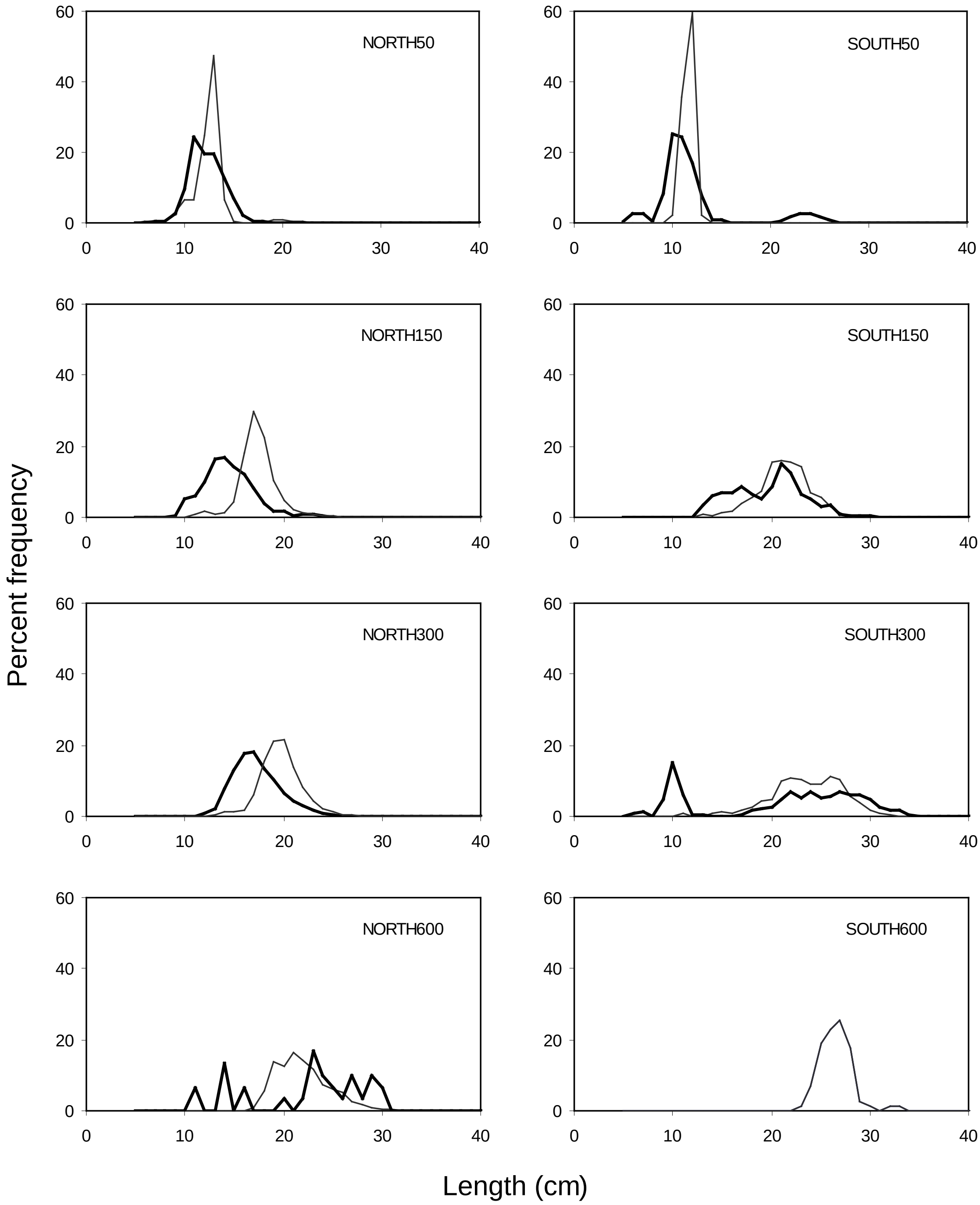


Fig. 5.3.1.d. **Percent length frequencies of redfish caught in survey (bold) and commercial (regular) catches by depth and latitude.**

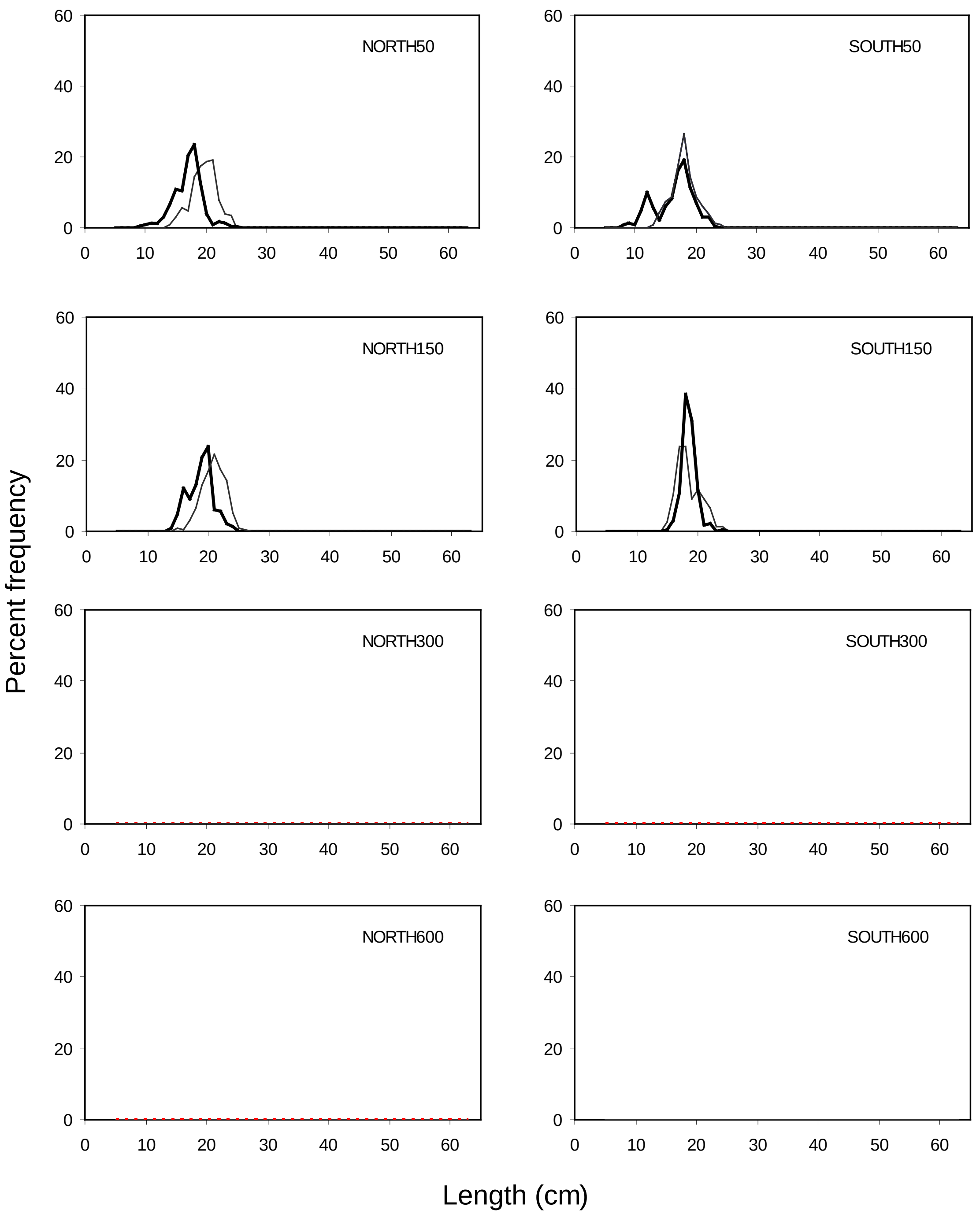


Fig. 5.3.1.e. Percent length frequencies of school whiting caught in survey (bold) and commercial (regular) catches by depth and latitude.

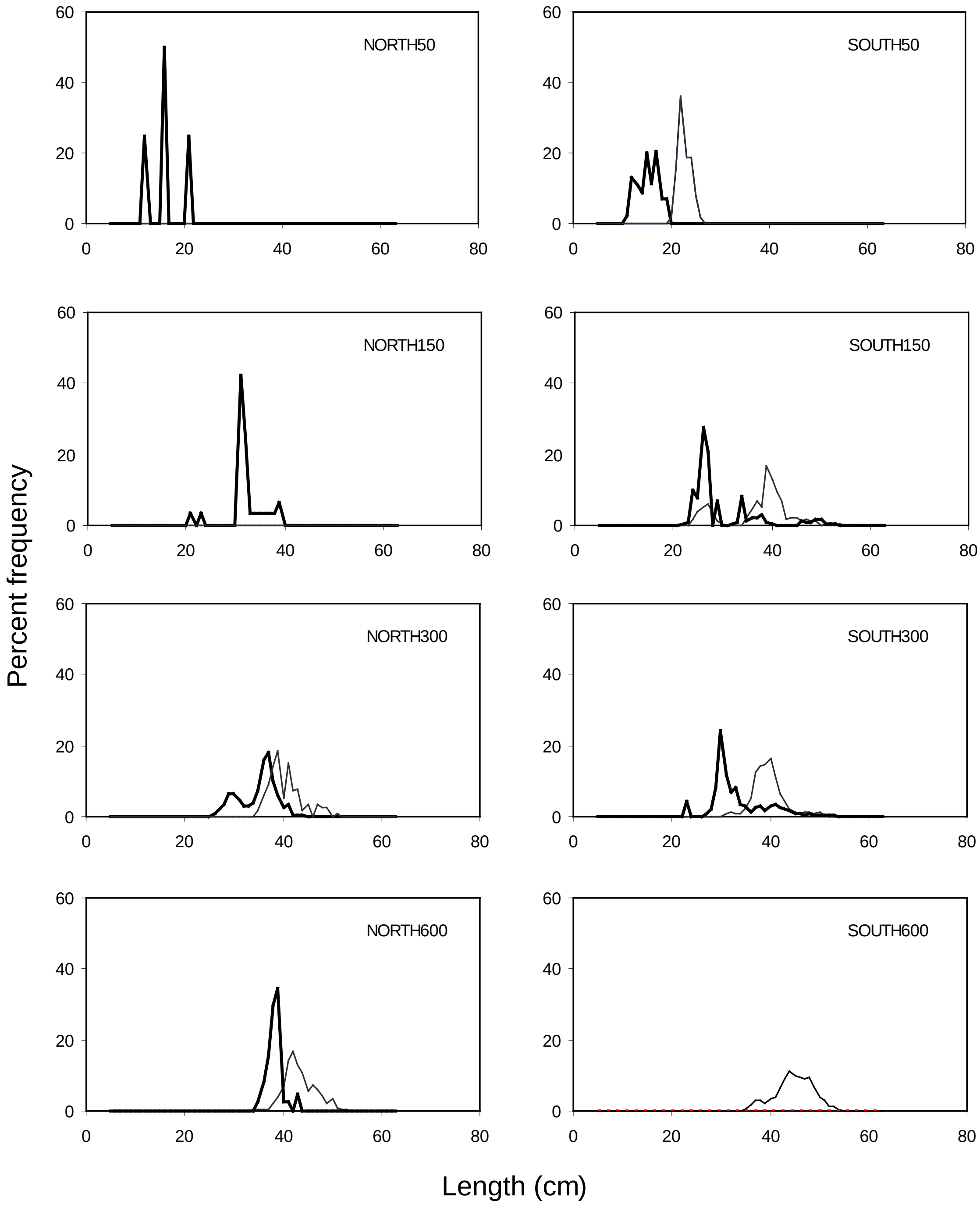


Fig. 5.3.1.f. **Percent length frequencies of spotted warehou caught in survey (bold) and commercial (regular) catches by depth and latitude.**

5.4 Discards in commercial fishery

Discards from the trawl fishery were determined from ISMP records summarized over the period 1996-1999. Discard rates for the various non-trawl methods as determined in a 2000 observer study are relatively low (Knuckey et al 2001b), and are not considered further.

Discards of blue warehou by weight averaged 5% from 1996-1999 over all depths (Table 5.4.1). Discards were higher in shallower water at 6% at <50 m in the northern sector and 6% at 50-150 m in the southern sector. Discarded fish were generally smaller than retained fish (Figure 5.4.1a).

Flathead discards averaged 14%, ranging from 26% in the northern sector from 50-150m to 5-12% for depths greater than 150m. Discarded fish were smaller than retained at all depths (Figure 5.4.1b).

Discards of jackass morwong averaged 4% over all depths, with discarding higher in inshore waters – 5% from <150m in the northern sector; 6% from 50-150m depth and 32% from <50m in the southern sector, the latter figure coming from only 6 samples. Discarded fish were smaller than retained fish (Figure 5.4.1c).

Redfish discards averaged 14% with maximum discards from shallower waters – 32% from 50-150 m in the northern sector and 83% from <50 m in the southern sector. Discards from waters deeper than 150m ranged from 0 to 8%. Smaller fish were discarded especially in inshore waters (Figure 5.4.1d).

Discarded school whiting formed on average 4% of the total catch. Largest percentage discards were in the northern sector (17-29%) compared with 1% in the southern sector (Table 5.4.1). Discarded fish were smaller than retained (Figure 5.4.1e). It is important to note that discard figures for the northern sectors were predominantly obtained from the otter trawl fleet whereas the discard figures for the southern sectors were derived almost entirely from the Danish seine fleet that operates out of Lakes Entrance. The Danish seine fleet uses a smaller codend mesh size (45mm) when targeting whiting.

Spotted warehou were discarded at an overall rate of 8%. Highest discards (10-19%) were in water depths <150m. Based on these data, smaller fish were discarded (Figure 5.4.1f), however according to BWAG spotted warehou are discarded when they cannot be marketed and discarding therefore may not always be a function of fish length (Thomson 2001b).

5.4.1 Discussion

The importance of the discards in the SEF has been well described (eg. Knuckey and Liggins 1999; Bycatch Action Plan 2001). Spatial and temporal variation in the level of discards of particular species make it difficult to make broad generalizations, and while the data presented here are informative, readers are directed to more comprehensive analyses for this issue.

Discarding generally occurs for one of three reasons (Liggins and Knuckey 1999; Bycatch Action Plan 2001):

- catch which is of no commercial value, or where the return on the catch would not be adequate to cover fishing and marketing costs;

- fluctuating market forces can encourage discarding of smaller specimens or less-valued species, so that an operator can maximize the use of the limited storage space available on board; or

- limited quota can encourage an operator to discard less valuable fish (typically smaller specimens) so that the maximum value can be achieved from the quota, or in instances where it is uneconomic or infeasible to arrange to lease quota if an operator's individual quota is exceeded.

Discarding in the areas and years summarized here ranged from: 0-6 percent for blue warehou; 3-26 percent for flathead; 0-32 percent for jackass morwong; 1-83 percent for redfish; 0-29 percent for school whiting; and 0-19 percent for spotted warehou. Discarding was typically of smaller fish (blue warehou may have been an exception), and discarding rates were typically higher inshore. This suggests that an increased mesh size would reduce discarding and further, that avoiding the inshore areas of the continental shelf would further reduce the capture and subsequent discarding of smaller fish. However, these suggestions need to be balanced by the potential for an increased level of effort to take a commercially viable catch with larger mesh, and the particular dynamics of some species, that might make inshore waters particularly productive for fishing at some times of the year. These two options are worked through in subsequent sections.

Table 5.4.1 Percent (by weight) of fish discarded by trawlers fishing off southeastern Australia by species, area and year (number of observations). Data from South East Fishery Integrated Scientific Monitoring Program.

Species	Area[a]	1997		1998		1999		2000		All years	
Blue warehou	North50	6	(75)							6	(75)
	North150			2	(10)	0	(17)	1	(28)	1	(55)
	North300			0	(8)	0	(6)	0	(4)	0	(18)
	North600			0	(3)	0	(2)	0	(1)	0	(6)
	South50			100	(2)	0	(1)	100	(2)	3	(5)
	South150	1	(48)	4	(35)	28	(26)	1	(11)	6	(120)
	South300	7	(24)	0	(28)	0	(10)	0	(2)	2	(64)
	South600	0	(2)	0	(4)	0	(1)	0	(2)	0	(9)
	Total	6	(149)	4	(90)	10	(63)	1	(50)	5	(352)
Flathead	North50	5	(230)	69	(6)	19	(16)	31	(18)	7	(270)
	North150			37	(65)	32	(154)	20	(198)	26	(417)
	North300			16	(42)	13	(84)	9	(77)	12	(203)
	North600			0	(9)	3	(16)	1	(14)	3	(39)
	South50			7	(10)	4	(11)	48	(16)	18	(37)
	South150	1	(116)	6	(68)	8	(76)	3	(59)	4	(319)
	South300	0	(45)	9	(46)	0	(25)	0	(10)	5	(126)
	South600	100	(2)	9	(3)	4	(5)	0	(9)	8	(19)
	Total	3	(393)	16	(249)	19	(387)	16	(401)	14	(1430)
Jackass morwong	North50	5	(180)	0	(1)	0	(2)			5	(183)
	North150			0	(42)	0	(59)	9	(95)	5	(196)
	North300			0	(30)	1	(48)	1	(41)	1	(119)
	North600			0	(7)	0	(8)	0	(9)	0	(24)
	South50			50	(1)	11	(5)			32	(6)
	South150	11	(90)	2	(40)	2	(57)	3	(36)	6	(223)
	South300	2	(49)	4	(46)	0	(29)	2	(10)	2	(134)
	South600	7	(12)	0	(17)	0	(24)	0	(11)	1	(64)
	Total	6	(331)	2	(184)	1	(232)	5	(202)	4	(949)
Redfish	North50	6	(172)	97	(2)	89	(4)	50	(2)	10	(180)
	North150			59	(55)	5	(112)	9	(154)	32	(321)
	North300			3	(42)	0	(74)	8	(73)	3	(189)
	North600			0	(18)	0	(32)	0	(23)	0	(73)
	South50			78	(2)	31	(5)	100	(10)	83	(17)
	South150	0	(26)	21	(22)	2	(13)	3	(14)	7	(75)
	South300	15	(21)	12	(25)	0	(10)	0	(7)	6	(63)
	South600	0	(2)	17	(9)	0	(2)	0	(1)	8	(14)
	Total	6	(221)	32	(175)	3	(252)	8	(284)	14	(932)
School whiting	North50	35	(20)	30	(5)	14	(10)	0	(14)	29	(49)
	North150			39	(9)	11	(26)	19	(29)	17	(64)
	North300			0	(1)					0	(1)
	North600										
	South50			0	(9)	1	(16)	0	(12)	1	(37)
	South150							0	(1)	0	(1)
	South300										
	South600										
	Total	35	(20)	12	(24)	1	(52)	5	(56)	4	(152)

Note: Year columns span 1997, 1998, 1999, 2000, All years.

[a] See table 5.4.3.2 for area definitions

Table 5.4.1 continued

Species	Area	Year									
		1997		1998		1999		2000		All years	
Spotted warehou	North50	17	(136)					100	(1)	17	(137)
	North150			10	(4)	12	(5)	70	(4)	19	(13)
	North300			0	(9)	0	(6)	0	(10)	0	(25)
	North600			0	(24)	0	(14)	0	(22)	0	(60)
	South50					0	(1)			0	(1)
	South150	6	(52)	11	(22)	45	(14)	85	(9)	10	(97)
	South300	18	(38)	6	(28)	0	(16)	1	(10)	7	(92)
	South600	1	(20)	0	(33)	0	(38)	0	(22)	0	(113)
	Total	16	(246)	5	(120)	0	(94)	1	(78)	8	(538)

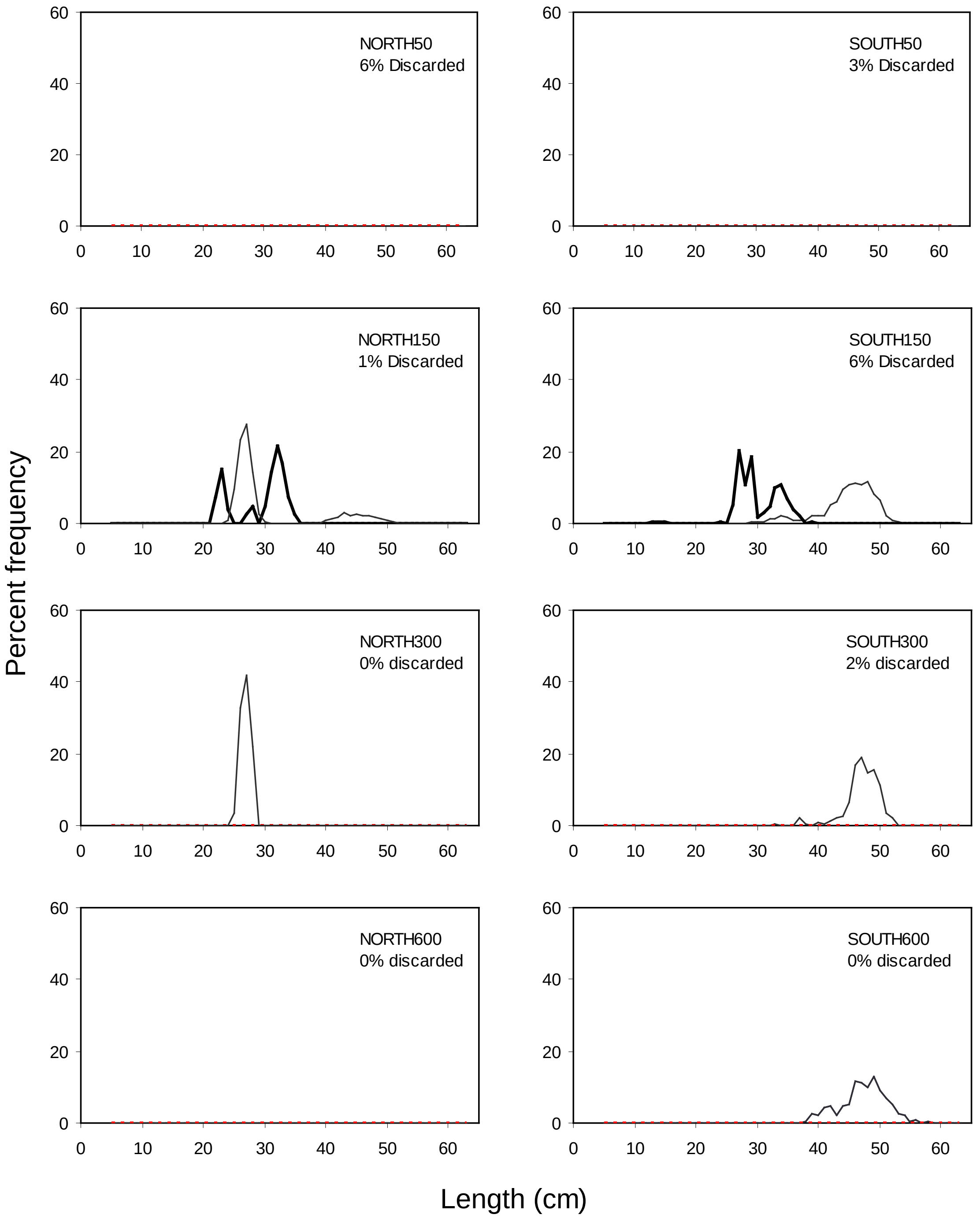


Figure 5.4.1a Length frequency of retained (regular) and discarded blue warehou (bold) as recorded from 1996 to 1999 by the SEF Integrated Scientific Monitoring Program.

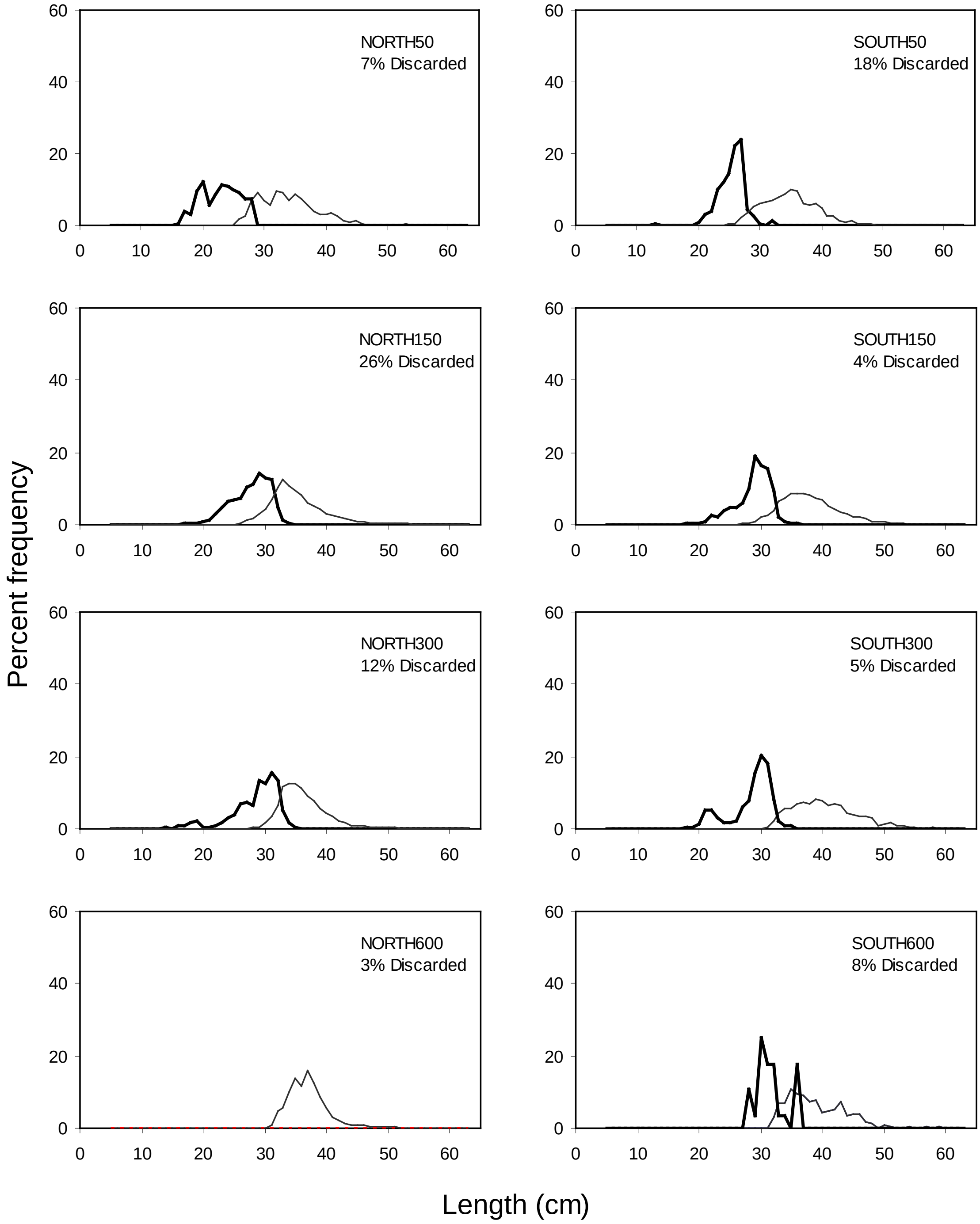


Figure 5.4.1b Length frequency of retained (regular) and discarded flathead (bold) as recorded from 1996 to 1999 by the SEF Integrated Scientific Monitoring Program.

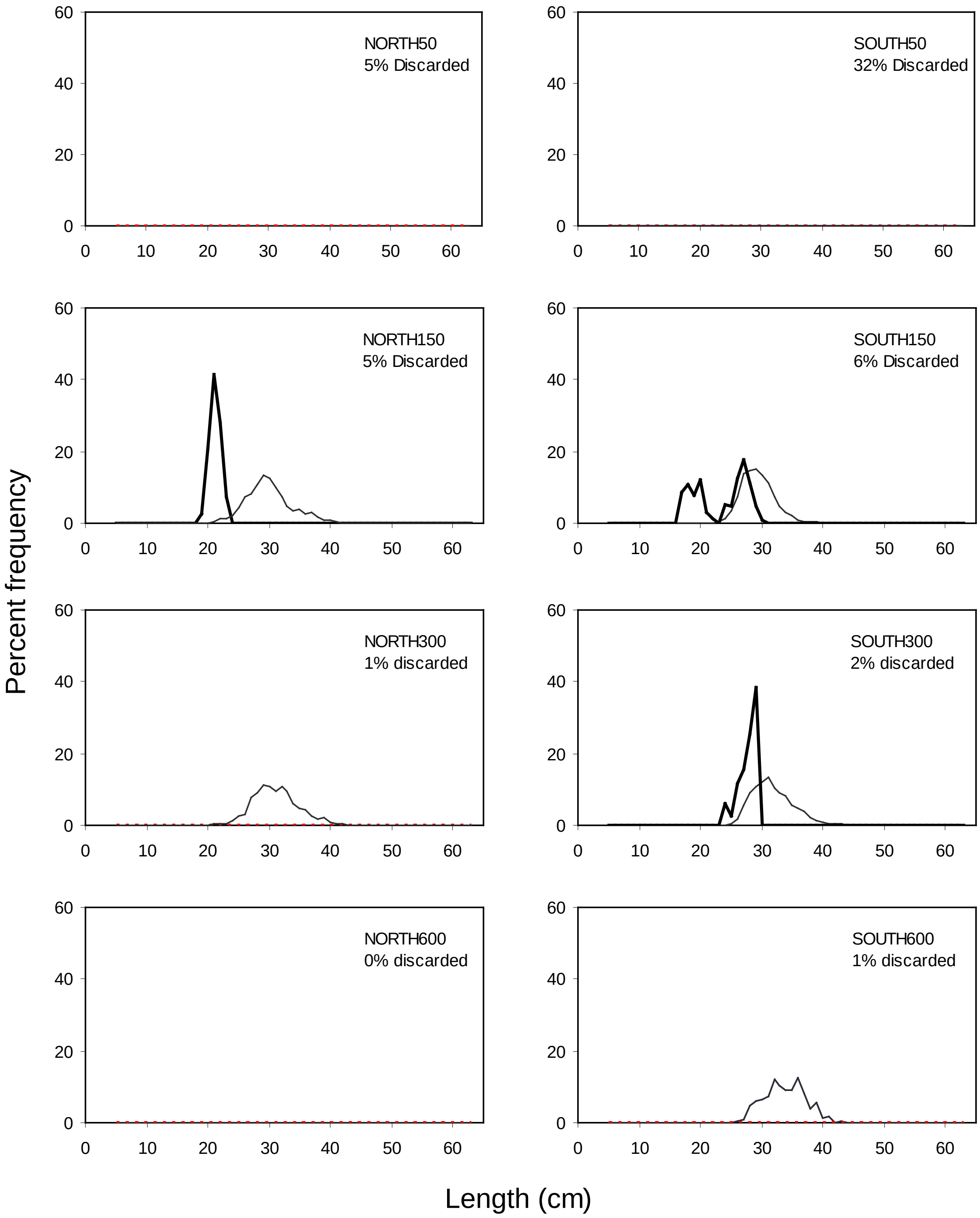


Figure 5.4.1c Length frequency of retained (regular) and discarded (bold) jackass morwong as recorded from 1996 to 1999 by the SEF Integrated Scientific Monitoring Program.

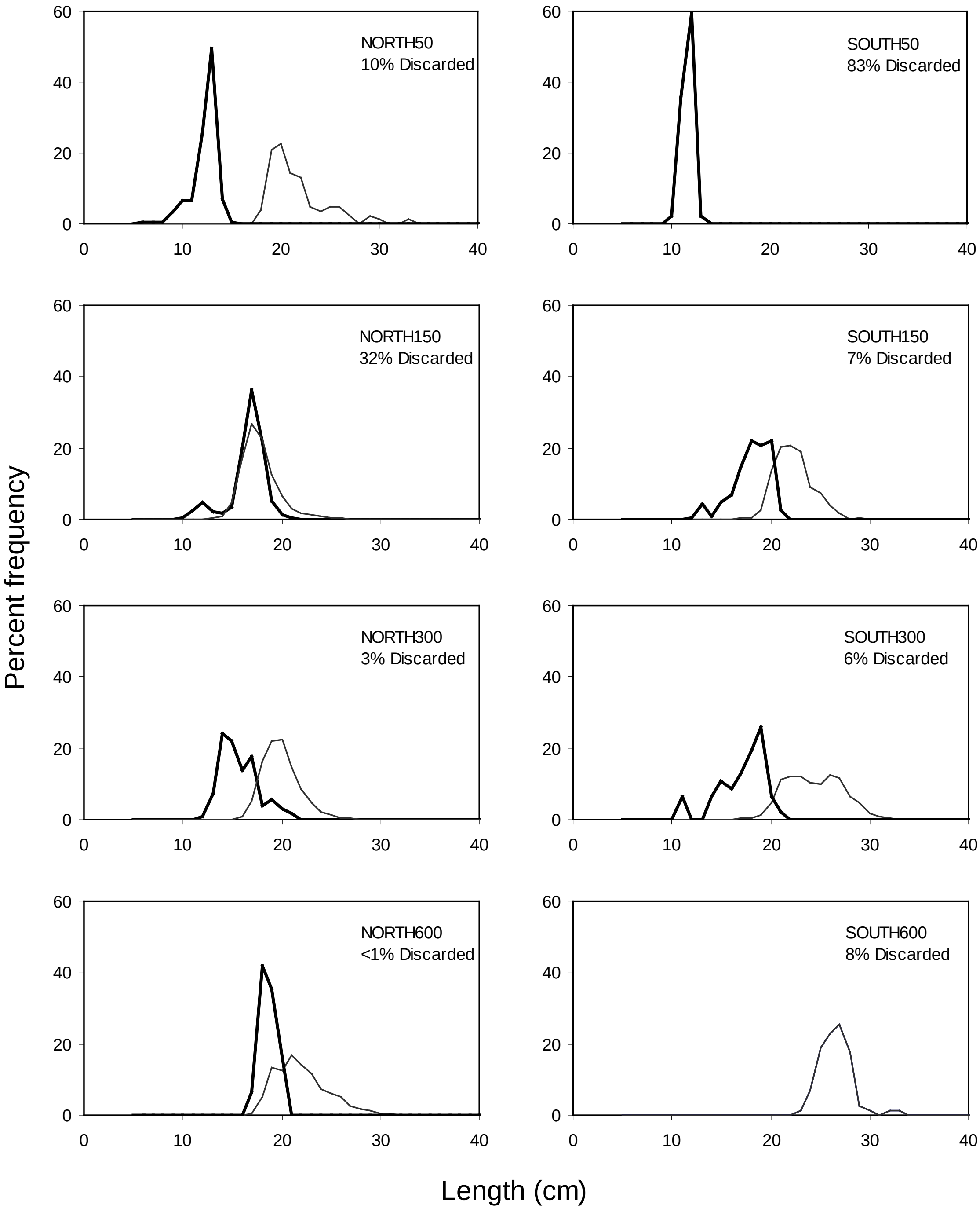


Figure 5.4.1d Length frequency of retained (regular) and discarded (bold) redfish as recorded from 1996 to 1999 by the SEF Integrated Scientific Monitoring Program.

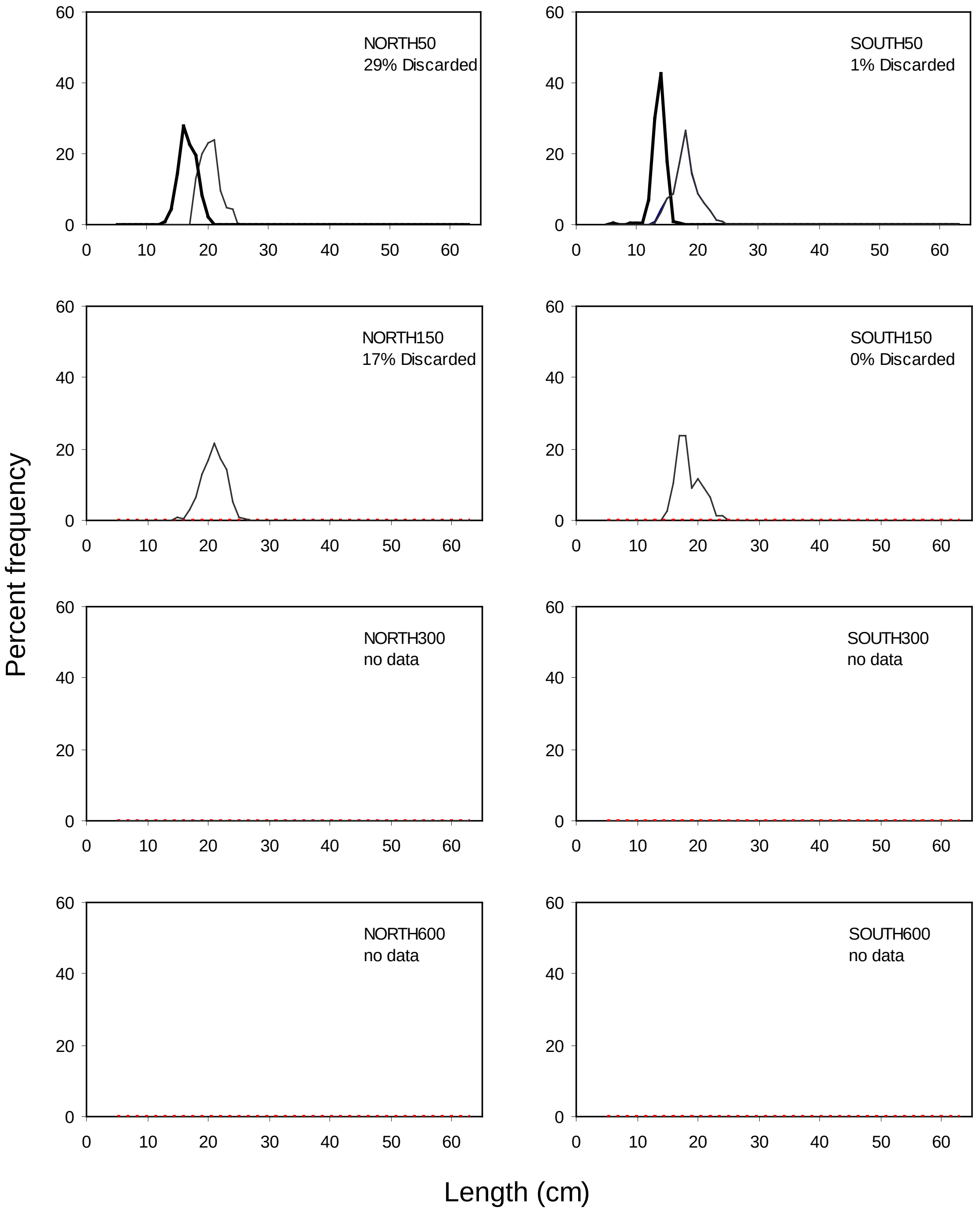


Figure 5.4.1e Length frequency of retained (regular) and discarded (bold) school whiting as recorded from 1996 to 1999 by the SEF Integrated Scientific Monitoring Program.

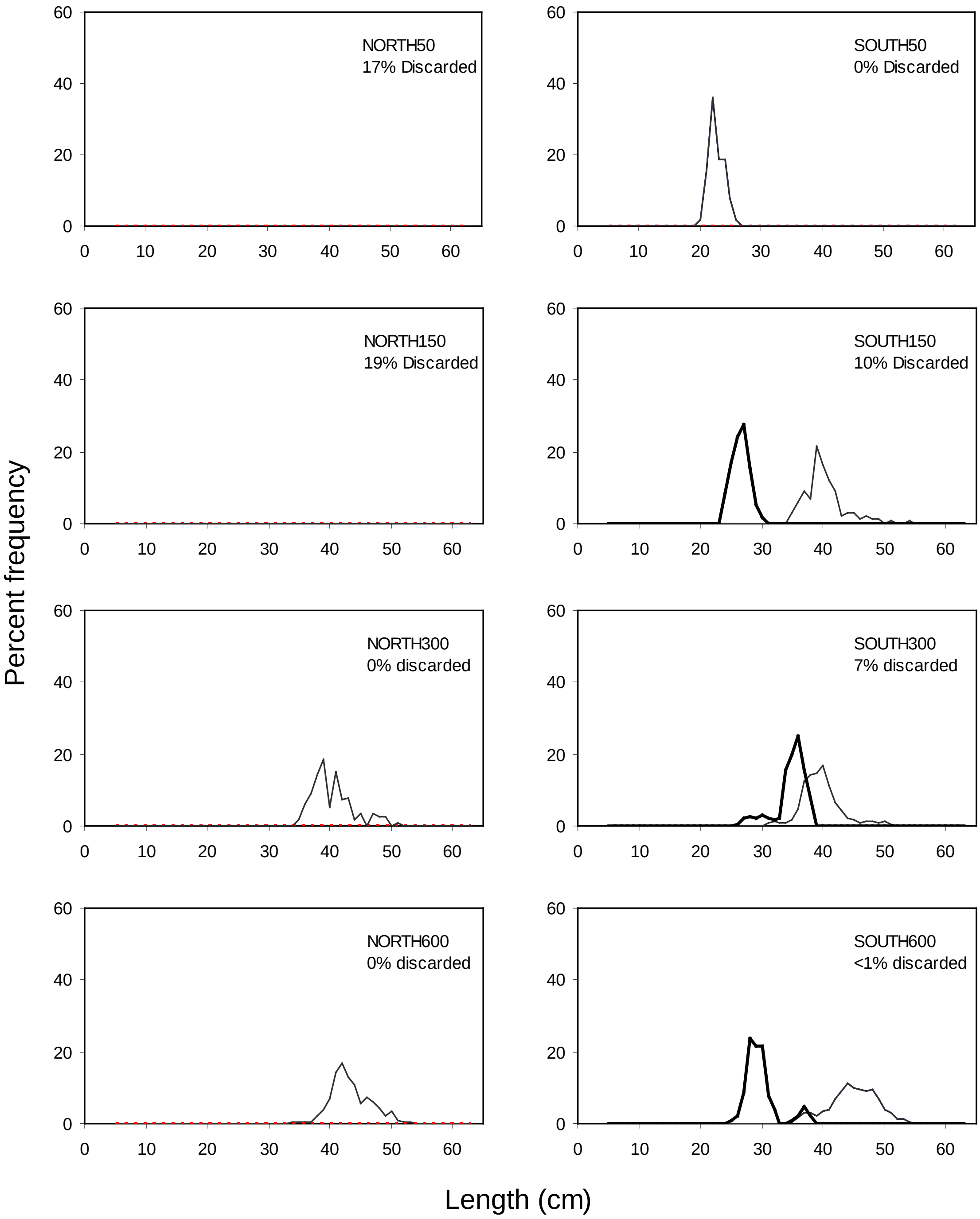


Figure 5.4.1f Length frequency of retained (regular) and discarded (bold) spotted warehou as recorded from 1996 to 1999 by the SEF Integrated Scientific Monitoring Program.

5.5 Gear selectivity

5.5.1 Gillnet-caught fish (from Cui et al. 2001)

Twenty species were caught with the 6-panel gillnet in 1996 (Table 5.5.1).

Table 5.5.1 Length frequency data available from six-panel gillnet studies (Data from Bax and Williams 2000)

Species	Gillnet Mesh Size (in)					
	2	3	4	5	6	7
Asymbolus sp D	141	89	0	0	5	0
Caesioperca lepidoptera	252	106	3	0	14	0
Centroberyx affinis	31	124	38	19	9	4
Cephaloscyllium laticeps	30	90	26	66	178	161
Emmelichthys nitidus nitidus	375	4	0	0	0	0
Genypterus blacodes	4	39	26	29	8	0
Helicolenus percoides	75	160	12	0	5	0
Heterodontus portusjacksoni	5	4	1	17	18	19
Nemadactylus douglasi	2	34	7	14	12	6
Mustelus antarcticus	1	21	47	74	33	26
Nemadactylus macropterus	7	290	204	46	3	0
Neoplatycephalus richardsoni	61	122	36	3	5	1
Parika scaber	0	37	0	0	0	0
Pseuodocarynx dentex	0	2	2	8	12	0
Scomber australicus	10	232	9	2	0	0
Seriolella brama	8	15	119	204	52	3
Seriolella punctata	0	4	35	0	0	0
Squalus megalops	309	2020	734	148	16	3
Thyrsites atun	36	196	20	0	1	0
Trachurus declivis	324	1596	269	27	14	5

There were sufficient data from 5 species for further analysis. Analysis was based on habitat and depth to determine the effects of these variables on population size structure and selectivity (Table 5.5.2).

Analyses showed that caution needed to be taken in using these data because: 1) although the selectivity curves at each depth achieve their maxima at virtually the same size, those for the deepest zone are notably broader for tiger flathead and jackass morwong, and 2) for dogfish and blue warehou there was a significant (though fairly small) decline in θ_1 with increasing mesh size indicating that the assumption that the length of maximum retention was linearly related to mesh size did not hold. These provisos need to be considered in the future use of mean levels of the selectivity parameters.

Table 5.5.2. Catches during the experiment by depth zone and habitat type and the widths assumed for the size-classes when fitting the model used to estimate selectivity. The column 'number of size-classes' lists the number of size-classes when the data are pooled across depth zones and habitat types. The data for the habitat type – depth zone combinations indicated by asterisks are not used in the analyses due to small sample size (<20 individuals).

Species name	Catch by depth zone and habitat zone								Total catches used	Size-class width (mm)	Number of size-classes
	Rough				Smooth						
	A	B	C	D	A	B	C	D			
Shots conducted	3	3	0	13	0	4	4	9			
Mustelus antarcticus (Gummy shark)	5*	20	-	5*	-	39	190	4*	249	100	12
Seriolella brama (Blue warehou)	0*	40	-	222	-	16*	172	50	484	30	9
Neoplatycephalus richardsoni (Tiger flathead)	0*	0*	-	42	-	60	9*	132	234	50	9
Nemadactylus macropterus (Jackass morwong)	0*	0*	-	428	-	1*	75	69	572	30	8
Non-quota species											
Squalus megalops (Spiny dogfish)	0*	77	-	977	-	128	310	1223	2715	20	21

Results from the Cui et al. (2001) study were combined with those from other sources to determine if there was a consistent relationship between fish morphometry (slope of the girth to length) and selection factors (size at 50 or 100% retention, or the size range from 25-75% retention as a function of mesh size) (Table 5.5.3). Selection factors were derived from the parameters of the fitted curve for Cui et al. (2001), and Kirkwood and Walker (1986) and read off the graph for Cottier et al. (1993).

Table 5.5.3 Summary data on selection and changes in body girth with length for gillnet-caught fish.

Species	Habitat depth (m)	Girth to length n	Girth to length slope	Selection factors SF100	Selection factors SF50	Selection range Factor (SRF)	Data or Est.	parameters a	parameters b	Source
Blue warehou	Soft 80	171	0.834	5.35	3.10	4.51	D	72.34	5.01	
	Soft 120			4.96	2.43	5.07	D	16.08	20.90	
	Rough 40			5.38	3.21	4.32	D	121.71	2.99	
	Rough 120			5.13	2.79	4.67	D	36.17	9.60	
	Unknown			3.15	0.00	2.91	D			Cottier et al. (1993)
Tiger flathead	Soft 40	84	0.614	6.25	5.50	1.52	D	86.58	7.34	Cui et al. (2001)
	Soft 12			9.14	4.55	9.18	D	17.87	34.65	
	Rough 120			8.87	4.94	7.85	D	46.04	13.05	
Jackass morwong	Soft 80	84	0.809	4.49	2.63	3.73	D	83.84	3.63	Cui et al. (2001)
	Soft 120			4.51	2.62	3.78	D	76.73	3.99	
	Rough 120			4.56	2.67	3.79	D	84.00	3.68	
	Unknown			2.76	0.00	2.60	D			Cottier et al. (1993)
Jack mackerel	Unknown	83	0.475	3.87	0.00	3.58	D			Cottier et al. (1993)
Gummy shark	Soft 40	103	0.327	6.77	5.39	2.77	D	28.60	24.06	Cui et al. (2001)
	Soft 80			6.78	5.24	3.08	D	22.81	30.19	
	Rough 40			6.22	4.22	4.01	D	10.38	60.88	
	Unknown			7.08	0.00	5.88	D	19.23	38.34	Kirkwood&Walker (1986)
Spiny dogfish	Soft 40	12	0.284	6.98	3.97	6.03	D	57.18	8.27	Cui et al. (2001)
	Soft 80			7.67	5.97	3.40	D	54.75	9.49	
	Soft 120			8.02	4.41	7.24	D	39.22	13.86	
	Rough 40			7.78	5.92	3.72	D	76.42	6.89	
Ling		212	0.548	6.14		4.49	E			

Selection factors were plotted against the slope of the body length/body girth relationship for all species and habitat/depth contrasts (Figure 5.5.1 a, b). There was a consistent relationship between the 100% selection factor and the slope of the body girth to length relationship (r^2 = 0.65) indicating that the selection factor declined for deeper and wider bodied species. Although there is considerable spread in the individual data points, this spread is typically within a species as much as between species, suggesting that the difference is due to methodological error. In all cases selection factors estimated from Cottier et al. (1993) are lower than the values from Cui et al. (2001). These data were omitted and the data replotted (Fig 5.5.2 a, b).

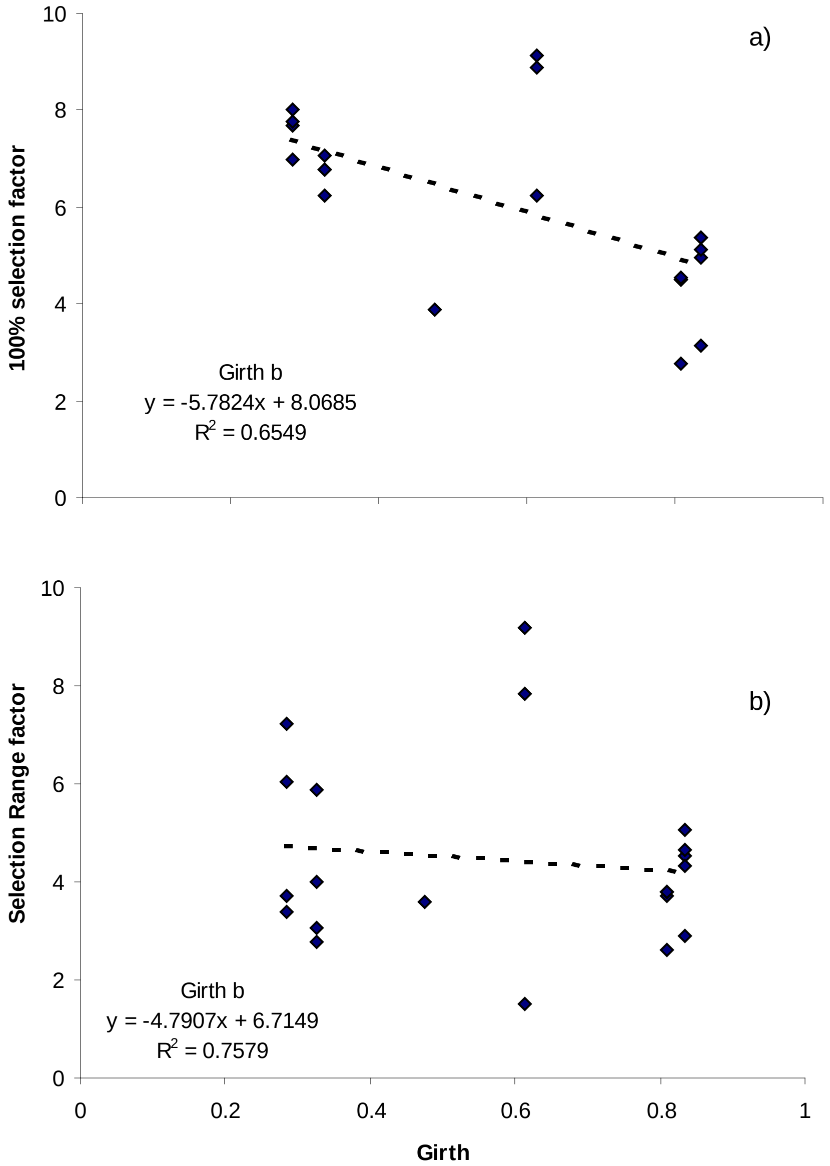


Figure 5.5.1 **Relationship between 100% selection factor, selection range (25-75% selection) factor and body girth for species listed in Table 5.5.3.**

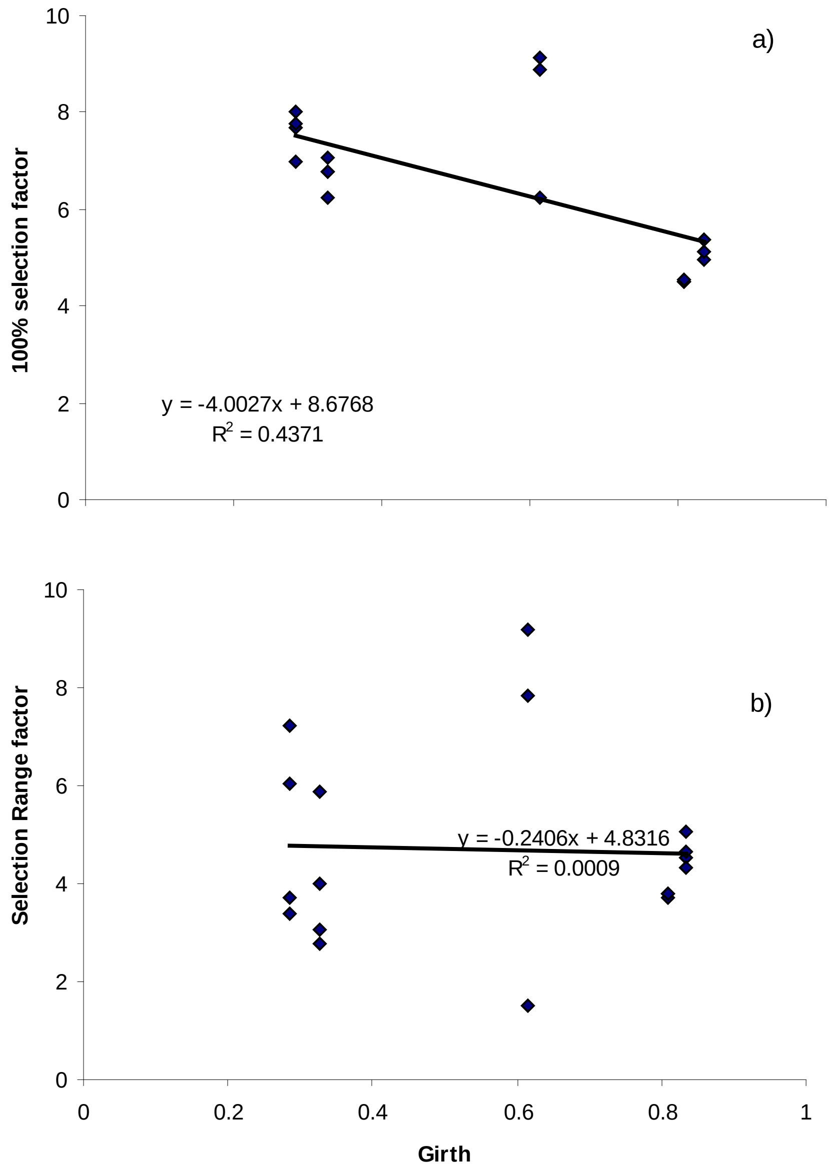


Figure 5.5.2 Relationship between 100% selection factor, selection range (25-75% selection) factor and body girth for species listed in Table 5.5.3, excluding values from Cottier et al (1993).

In contrast, with the Cottier et al. (1993) data removed, the relationship between the body length to girth relationship and selection range disappeared.

Estimated selectivity curves for gummy shark and flathead are provided in Figure 5.5.3 for 4, 6 and 9 inch mesh. Both sets of curves show considerable variability depending on the depth and habitat type. Variability is primarily in the length of maximum selectivity for gummy shark, while for flathead, the variability is primarily in the spread around this maximum selectivity as would be expected from the large spread in selection range factor for this species (girth 0.614 in Fig. 5.5.2).

Selectivity parameters from rough ground at 80-240 m were used in the yield per recruit analyses as this corresponds best with the principal fishing areas by gillnetters in the SEF.

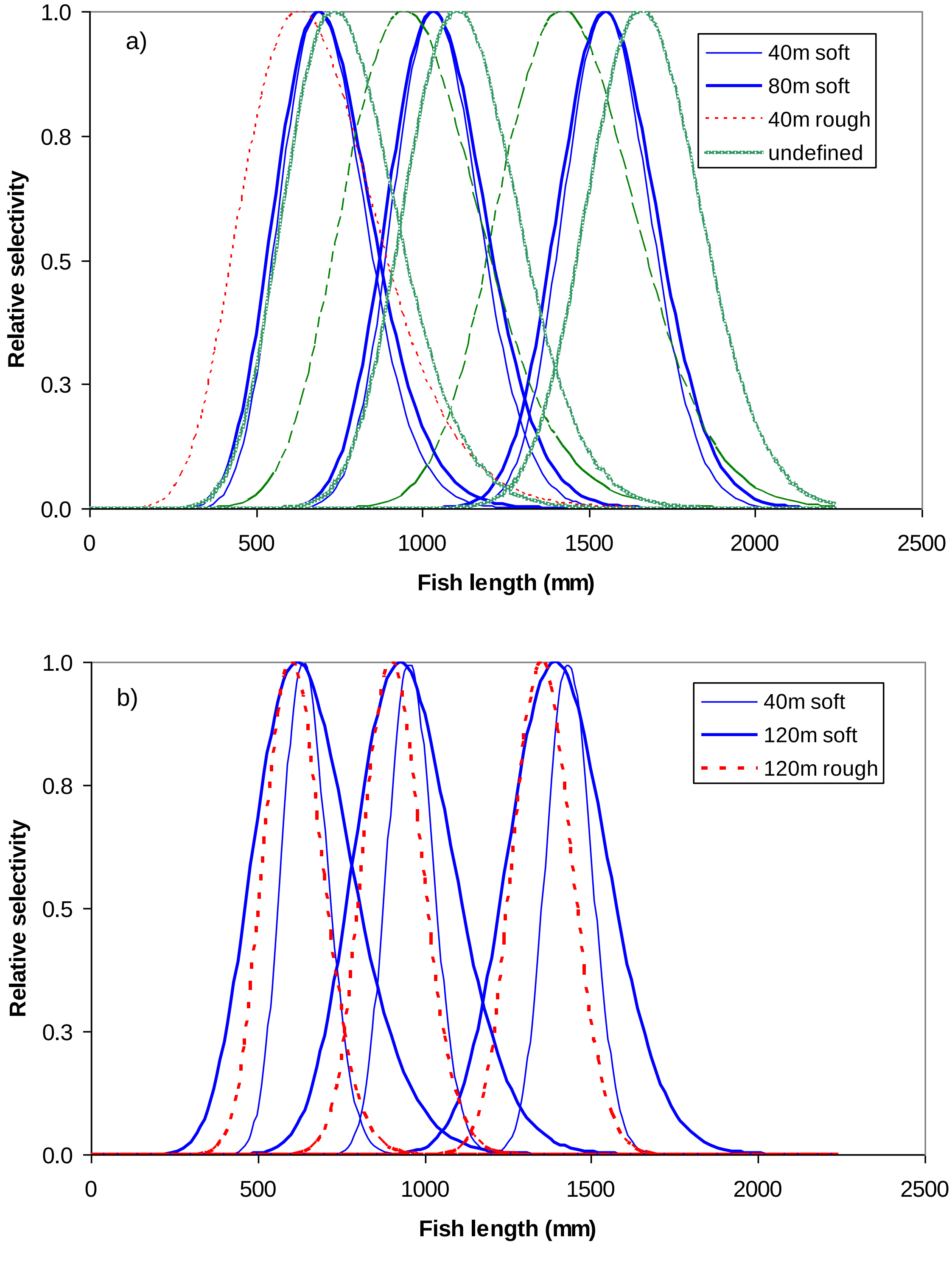


Figure 5.5.3 **Selection curves for a) gummy shark and b) flathead for different mesh sizes – 4, 6 and 9 inch. (9 inch for gummy shark only).**

5.5.2 Trawl-caught fish

Data from covered cod end trials were available from FRDC Project 98/204 (Ian Knuckey PI), and earlier published and unpublished data. Data were reported as size at 50 or 75% selection (L50 or L75), as the selection factor (L50/Mesh size) or these values were read off graphed data (Table 5.5.2.1). Selection range was estimated as the difference between the length of 25 and 75% selectivity (or twice the difference between 50 and 75% selectivity). Linear relationships between body girth and length were derived in Section 6.1. Data are from covered cod end studies except for Wankowski (1986) and JAMARC (1981) that were alternate haul studies.

Table 5.5.2.1 Summary data on selection and changes in body girth with length.

Species	Mesh size (mm)	Slope of body Girth to length	Selection Factors 50%	Selection Factors 25%	Selection range (cm)	Source
Blue grenadier	90	0.40	4.71	4.20	95	Knuckey (unpub data)
		0.40	5.70			Fisher (1978)
		0.40	6.50			Patchell (1979)
Ling	90	0.55	4.78	4.43	62	Knuckey (unpub data)
Redfish	90	0.84	1.46	1.31	26	Knuckey (unpub data)
	82	0.84	2.38	2.23	24	Rowling (unpub data)
Ocean perch inner shelf	90	0.68	1.76	1.47	52	Knuckey (unpub data)
Ocean perch outer shelf	90	0.68	2.08	1.82	45	Knuckey (unpub data)
	90	0.68	2.24	2.02	40	Knuckey (unpub data)
Tiger flathead	90	0.61	2.57	2.18	70	Knuckey (unpub data)
	84	0.61	3.93	3.69	40	Rowling (unpub data)
	91	0.61	3.85	3.44	74	Rowling (unpub data)
Eastern school whiting	25	0.41	3.92			Wankowski (1986)
	42	0.41	3.93			Wankowski (1986)
	70	0.41	3.07			Wankowski (1986)
Jackass morwong		0.81	2.50			Cassie (1955)
		0.81	2.45			Hore (unpub data)
		0.81	2.54			Massey (unpub data)
		0.81	2.26			Massey & Hore (1987)
Gemfish	90	0.48	3.17	2.64	95	Knuckey (unpub data)
	90	0.48	3.88	3.34	96	Knuckey (unpub data)
Barracouta		0.25	5.04			Massey&Hore (1987)
Jack mackerel		0.48	3.22			JAMARC (1981)
Red gurnard		0.73	2.42			Hore (unpub data)
		0.73	2.37			Massey (unpub data)
		0.73	2.13			Massey&Hore (1987)
Snapper		0.75	2.35			Cassie (1955)
		0.75	2.32			Hore (unpub data)
Red cod		0.66	3.58			Massey (unpub data)
		0.66	3.54			Massey&Hore (1987)

There was a consistent relationship between the body girth to length relationship and the 50% and 25% selection factors (Figures 5.5.2.1 a and b), a linear regression explaining 65 and 51% of the variability respectively. Much of the variation occurs within a species rather than between species. For example in Figure 5.5.2.1.a, the vertical spread of 5 data points consist of blue grenadier (3 points) and Eastern school whiting (3 points, one invisible). This indicates considerable variability in selection factor between trials (especially for slender fish).

The linear relationships for 25 and 50% selection can be used to determine the parameters of a logistic selection curve for any given fish shape and mesh size. However, because of small sample sizes, the linear relationships were different when all data were used (solid line in Fig 5.5.2.1.a) compared to when only those data available for both 25 and 50% selection were used (dashed line).

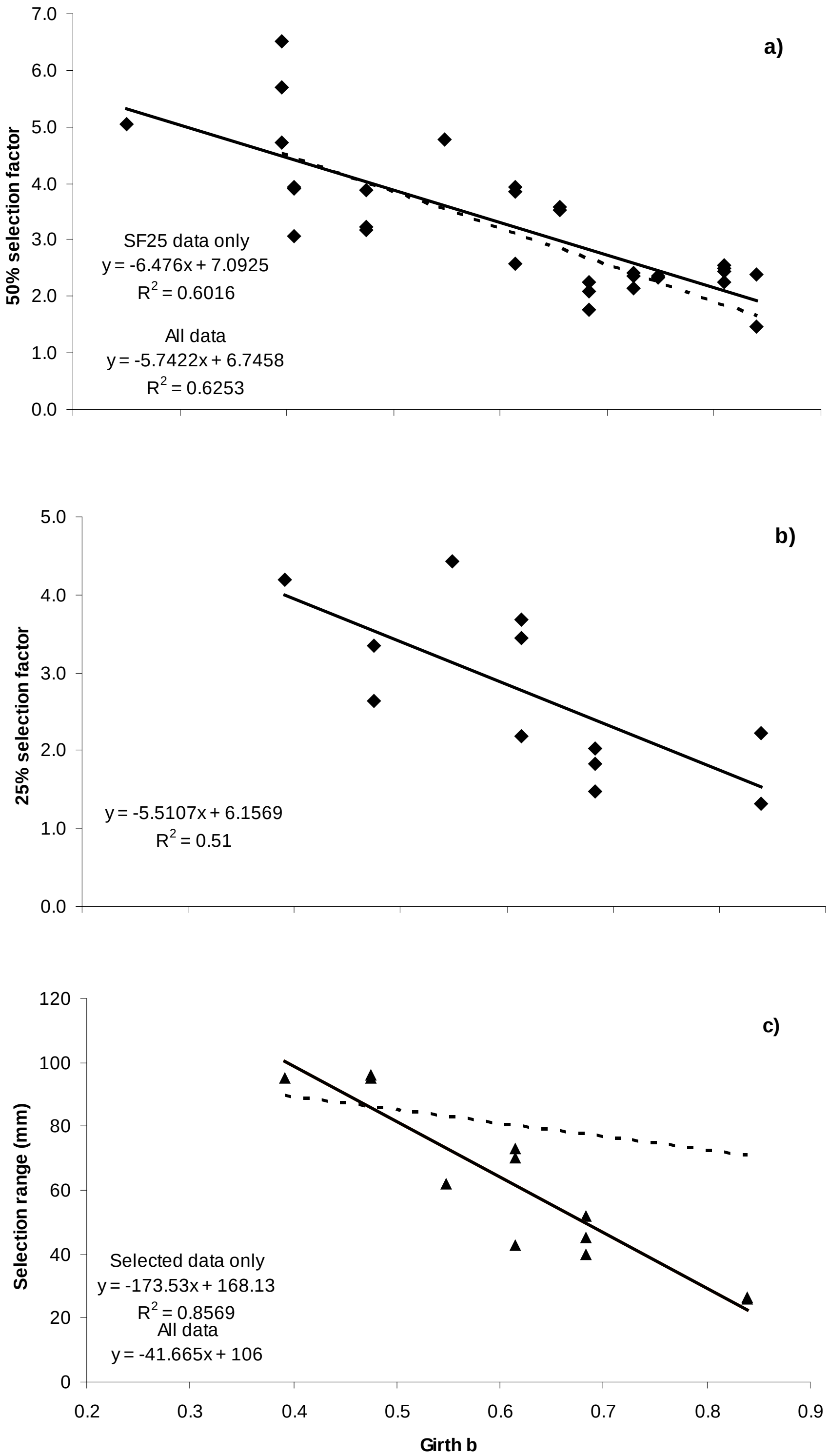


Figure 5.5.2.1 The distribution of a) 50% selection factor, b) 25% selection factor, and c) the selection range factor with the slope of the length body girth relationship. Solid lines are the fitted linear relationship. The dashed line in a) is the selection range estimated from only those species with data for 25 and 50% selectivity; the dashed line in c) is the selection range factor estimated using all available data.

The slight difference in slopes for fits to the partial and complete data causes considerable variation in estimating the liner relationship between the length girth relationship and the selection range factor (Fig 5.5.2.1 c). Therefore, in the following estimates, the selection range factor was estimated only from data for which 25 and 50% selection factor data were available; the 50% selection factor was estimated from the entire dataset (Table 5.5.2.2).

Table 5.5.2.2 Selection factors, selection range and parameters of the logistic selection curve for SEF species, estimated from the data (D) or from the relationships derived from the data for other species (E)

	Girth to length		Selection factors		Selection range	Data or	Logistic parameters[1]	
	n	slope	SF50	SF25	Factor (SRF)	estimated	S1	S2
Blue grenadier	318	0.396	5.637	4.200	1.056	D	11.7340	0.0231
Ling	212	0.548	4.778	4.433	0.689	D	15.2388	0.0354
Orange roughy[2]	164	0.908	1.532		0.117	E	28.6690	0.2079
Redfish	119	0.839	1.917	1.771	0.291	D	14.4837	0.0840
Mirror dory[2]	70	0.874	1.727		0.183	E	20.7416	0.1334
John dory								
Ocean perch	129	0.683	2.026	1.770	0.507	D	8.7729	0.0481
Tiger flathead	84	0.614	3.447	3.103	0.689	D	10.9921	0.0354
Eastern school whiting	38	0.407	3.640		1.083	D50	7.3824	0.0225
Silver trevally								
Jackass morwong	84	0.809	2.438		0.308	D50	17.3726	0.0792
Gemfish (male)	84	0.475	3.522	2.994	1.061	D	7.2934	0.0230
Blue eye trevalla	29	0.743	2.479		0.436	E	12.5080	0.0561
Blue warehou	171	0.834	1.957		0.260	E	16.5315	0.0939
Spotted warehou	120	0.574	3.450		0.761	E	9.9555	0.0321
King dory	27	1.194	Not estimated as girth/length relationship outside range					
Barracouta	91	0.251	5.040		1.384	D50	8.0006	0.0176
Tooth whiptail	71	0.351	4.730		1.191	E	8.7242	0.0205
Cucumber fish	83	0.505	3.846		0.894	E	9.4480	0.0273
Grooved gurnard	19	0.772	2.313		0.380	E	13.3864	0.0643
Round snouted gurnard	28	0.539	3.651		0.829	E	9.6777	0.0295
Stinkfish[2]	20	0.185	5.683		1.511	E	8.2624	0.0162
Jack mackerel	54	0.475	3.220		0.952	D50	7.4297	0.0256
School shark	173	0.546	3.611		0.815	E	9.7296	0.0299
Gummy shark	103	0.327	4.868		1.238	E	8.6426	0.0197
Dogfish	12	0.284	5.115		1.321	E	8.5109	0.0185
Red cod	5	0.656	3.560		0.603	D50	12.9659	0.0405
Red gurnard	9	0.725	2.307		0.470	D50	10.7779	0.0519
Snapper	8	0.747	2.335		0.428	D50	11.9920	0.0571

[1] 90 mm mesh: S1=S2*L50
S2=2*LN(3)/SR

[2] Girth to slope relationship outside of range for which data are available

5.5.3 Discussion

Selectivity is a basic requirement for most stock assessments. It is also difficult to estimate, is variable (gear, operator, season, area, year) and is often aliased with other parameters (eg. natural mortality). Previous studies on multi-species yield per recruit (Murawski 1984, Pikitch 1987) have used absolute mesh selectivities derived from published covered cod-end experiments, or from a published linear relationship between size at (knife-edge) recruitment and mesh size (Sainsbury 1984).

Estimating mesh selectivity has been a major part of this study. As originally proposed, mesh selectivity was to have been estimated by assuming that selectivity was directly proportional to girth. Length to girth relationships for the different species estimated in section 5.2 were then to be used to determine selectivity by length; selectivities by age were then to be estimated via the age-length keys. This method was revised early on in the project and it was decided to determine relative selectivity from comparing the length frequency of catches from trawl and gillnet surveys using different sized mesh in cod ends while controlling for depth.

Gillnet data were analysed first as we had a very controlled dataset derived from fishing two six-multipanel gillnets as part of an earlier ecosystem research study (Bax and Williams 2000). Data were available for seven quota species and one non-quota species, but only 5 of these datasets proved sufficient to parameterize the new model developed to estimate selectivity. The dataset also allowed us to determine variability in selectivity as a function of depth and habitat type for the five species. Selectivity for gummy shark and flathead varied considerably with depth and habitat, where the variability was either in the length of maximum selectivity (gummy shark) or the spread of around this maximum selectivity (flathead). Additionally, the assumption that the length of maximum retention was linearly related to mesh size did not strictly hold for dogfish and blue warehou. Based on the estimated relationship of selectivity parameters to the length/girth relationships, gillnet selectivity was estimated for ling.

The variability in selectivity parameters determined from a very controlled dataset, indicates the difficulty in extrapolating outside the depth and habitat type from where the data were collected, let alone to other species. The model used to estimate gillnet selectivity was tested on length frequency data collected from States of Tasmania, Victoria and New South Wales, from CSIRO and from New Zealand. However, the model could not fit the data – the variability in selectivity parameters between the different areas, depths, vessels, gear and operators was too great to estimate a general relationship. Variability in selectivity parameters between depths and habitat types might be expected to larger for the trawl than the gillnet, because the spread of the doors and angle of bridles can vary considerably between different depth and habitats, potentially having an effect on mesh shape. However, while a second method was adopted to estimate absolute selectivity, this inability to fit data to estimate relative selectivity indicates the great simplifications that are being made in stock assessments (and in this study) where selectivity is considered invariant to everything apart from mesh size.

Trawl selectivity parameters from existing Australian and New Zealand covered codend (and tow alternate haul) studies were added to data from the concurrent FRDC Project 98/204 to provide selectivity data for 14 species (30 estimates). The differences in selection factors for slim-bodied fish (eg barracouta and blue grenadier) and deep-bodied fish (eg jackass morwong, trevally) were marked, indicating a relationship between selectivity and body shape as expected. Linear regressions explained 65 and 51 percent of the variability in the 50 and 25 percent selection factors, with much of the variation occurring within species, emphasizing (again) the variability in selectivity on factors other than mesh size. The linear relationships were used to estimate selection factors for 13 further species for which biological data had been collected as part of this study, however two of those species (orange roughy and mirror dory) had a girth/length relationship outside the range for which data were available, so should be treated with (more) caution.

Estimating selection parameters is fraught with difficulty and is probably best achieved as part of an integrated analysis of data, where available. However integrated analyses are available for only a few of the SEF species and the relationship between morphometry and selection parameters provides an alternative approach for those species where no integrated analysis exists, or data are insufficient to fit both natural mortality and selectivity within the analysis.

5.6 Single species yield per recruit

5.6.1 Yield per recruit as a function of trawl mesh size

There were data available to fit single species yield per recruit as a function of six trawl mesh sizes for 12 of the SEF quota species. Yield was estimated separately for males and females, although mostly the results are identical or very similar, as key biological data, especially natural mortality, do not distinguish between the sexes. Maximum yield per recruit for each mesh size is expressed in units of biomass, landed value and, in the case of blue warehou, percent of maximum egg production (Table 5.6.1). Yield curves for biomass yield per recruit for females are given in Figure 5.6.1. The fishing mortality in these graphs extends from zero to approximately double the current estimated fishing mortality.

Yield per recruit for most species increased at mesh sizes larger than currently used (90mm), especially at higher fishing mortality (Table 5.6.1 and Fig. 5.6.1)., It was especially clear that at current fishing mortality (about half way along the mortality axis) substantially increased yields would result from increased mesh size for ling, gemfish, Eastern school whiting, jackass morwong, ocean perch (deep), blue warehou, tiger flathead and spotted warehou. At current fishing mortality, a slight increase in mesh size would provide improved yield per recruit for blue grenadier, redfish and ocean perch (reef). Yield per recruit was relatively insensitive to increased mesh size for blue eye trevalla at current fishing mortality. Yield per recruit decreased with increasing mesh size at lower fishing mortality only for Eastern school whiting, redfish, spotted warehou and ocean perch (reef). Eastern school whiting yield per recruit peaked at intermediate mesh sizes (note different scale of mesh sizes used).

Ranking the species down from those where mesh sizes larger than the current 90 mm mesh resulted in the greatest increase in yield per recruit and plotting the biological parameters, illustrates the parameters that the yield per recruit computations are most sensitive to with respect to mesh size (Fig. 5.6.2). It is difficult to determine distinct trends in the parameters with respect to this overall property, indicating that a variety, or combination, of population characteristics can lead to similar responses to changed mesh sizes.

At the current mesh size, yield per recruit for most species peaked at fishing mortality levels lower than current levels. Reduced yield per recruit at higher fishing mortality was especially severe for gemfish, ling and Eastern school whiting; moderate for blue warehou, blue eye trevalla, spotted warehou, jackass morwong, tiger flathead and blue grenadier (Fig 5.6.1). The decrease in yield with increased fishing mortality observed for most species was mitigated by larger mesh sizes for all species except blue eye trevalla, which was relatively invariant to mesh size changes over the range considered. For some species – Eastern school whiting, spotted warehou – there was an increased yield at increased fishing mortalities at larger mesh sizes.

Overall, yield per recruit for most species was maximized at the largest mesh size tested – well above the current maximum mesh size (Table 5.6.1). The notable exceptions were male and female school whiting and redfish, where yields were maximized at mesh sizes only slightly larger than those used currently. Yield per recruit of male tiger flathead, blue grenadier, and yield in biomass for male and female spotted warehou and ocean perch (reef) were maximized at mesh sizes less than the maximum tested in this study.

Table 5.6.1 Maximum single species yield per recruit for 6 mesh sizes estimated in units of biomass, landing values and (for blue warehou only) egg production. Bolded values show mesh size where yield per recruit was maximized (based on original results, not rounded values). Note that percentage of maximum eggs is estimated for each mesh size, assuming that fishing mortality is at the level that would maximize yield per recruit.

			Maximum YPR by mesh size (mm)					
Species	Sex	Units	90	103	115	128	140	153
Blue warehou	M	kg	0.145	0.155	0.165	0.174	0.182	**0.189**
		$	0.209	0.222	0.236	0.249	0.261	**0.270**
	F	kg	0.149	0.158	0.168	0.178	0.186	**0.193**
		$	0.213	0.227	0.241	0.254	0.266	**0.276**
	% max eggs		0.157	**0.180**	0.144	0.153	0.143	0.152
Jackass Morwong	M	kg	0.311	0.330	0.349	0.362	0.367	**0.367**
		$	0.677	0.727	0.777	0.817	0.835	**0.837**
	F	kg	0.344	0.365	0.386	0.403	0.412	**0.414**
		$	0.773	0.824	0.876	0.920	0.943	**0.948**
Tiger flathead	M	kg	0.118	0.122	0.124	**0.125**	0.124	0.123
		$	0.340	0.366	0.381	**0.386**	0.386	0.383
	F	kg	0.173	0.184	0.192	0.197	0.199	**0.200**
		$	0.540	0.584	0.620	0.642	0.652	**0.654**
Blue grenadier	M	kg	0.403	0.425	0.439	**0.440**	0.416	0.366
		$	1.090	1.169	1.215	**1.226**	1.161	1.023
	F	kg	0.506	0.532	0.551	0.561	**0.561**	0.540
		$	1.369	1.465	1.527	1.559	**1.563**	1.510
Ling	M	kg	0.816	0.875	0.932	0.989	1.041	**1.082**
		$	3.615	3.883	4.160	4.449	4.723	**4.937**
	F	kg	1.135	1.206	1.276	1.356	1.431	**1.508**
		$	5.128	5.489	5.836	6.216	6.604	**6.981**
Redfish	M	kg	0.135	0.142	**0.146**	0.138	0.113	0.072
		$	0.140	0.148	**0.152**	0.144	0.118	0.076
	F	kg	0.135	0.142	**0.146**	0.138	0.113	0.072
		$	0.140	0.148	**0.152**	0.144	0.118	0.076
Gemfish	M	kg	0.435	0.459	0.482	0.503	0.522	**0.538**
		$	2.130	2.254	2.370	2.480	2.574	**2.655**
	F	kg	0.757	0.787	0.818	0.859	0.895	**0.925**
		$	3.707	3.867	4.022	4.229	4.413	**4.566**

Table 5.6.1 continued.

Species	Sex	Units	Maximum YPR by mesh size (mm) 90	103	115	128	140	153
Blue eye trevalla	M	kg	1.769	1.770	1.774	1.788	1.821	**1.871**
		$	10.872	10.876	10.899	10.989	11.202	**11.525**
	F	kg	2.064	2.065	2.071	2.092	2.139	**2.207**
		$	12.686	12.692	12.730	12.865	13.163	**13.597**
Spotted warehou	M	kg	0.536	0.566	0.587	0.597	**0.601**	0.599
		$	1.226	1.332	1.435	1.510	1.552	**1.562**
	F	kg	0.536	0.566	0.587	0.597	**0.601**	0.599
		$	1.226	1.332	1.435	1.510	1.552	**1.562**
Ocean perch (reef)	M	kg	0.067	0.070	0.072	0.074	**0.074**	0.074
		$	0.177	0.191	0.203	0.212	0.217	**0.219**
	F	kg	0.067	0.070	0.072	0.074	**0.074**	0.074
		$	0.177	0.191	0.203	0.212	0.217	**0.219**
Ocean perch (deep)	M	kg	0.213	0.228	0.245	0.260	0.273	**0.283**
		$	0.774	0.849	0.935	1.026	1.111	**1.181**
	F	kg	0.213	0.228	0.245	0.260	0.273	**0.283**
		$	0.774	0.849	0.935	1.026	1.111	**1.181**
	Mesh size		25	42	70	90	103	115
School Whiting	M	kg	0.029	0.034	**0.037**	0.035	0.032	0.028
		$	0.040	0.048	**0.052**	0.049	0.045	0.039
	F	kg	0.033	0.040	**0.043**	0.041	0.039	0.034
		$	0.046	0.055	**0.060**	0.058	0.054	0.048

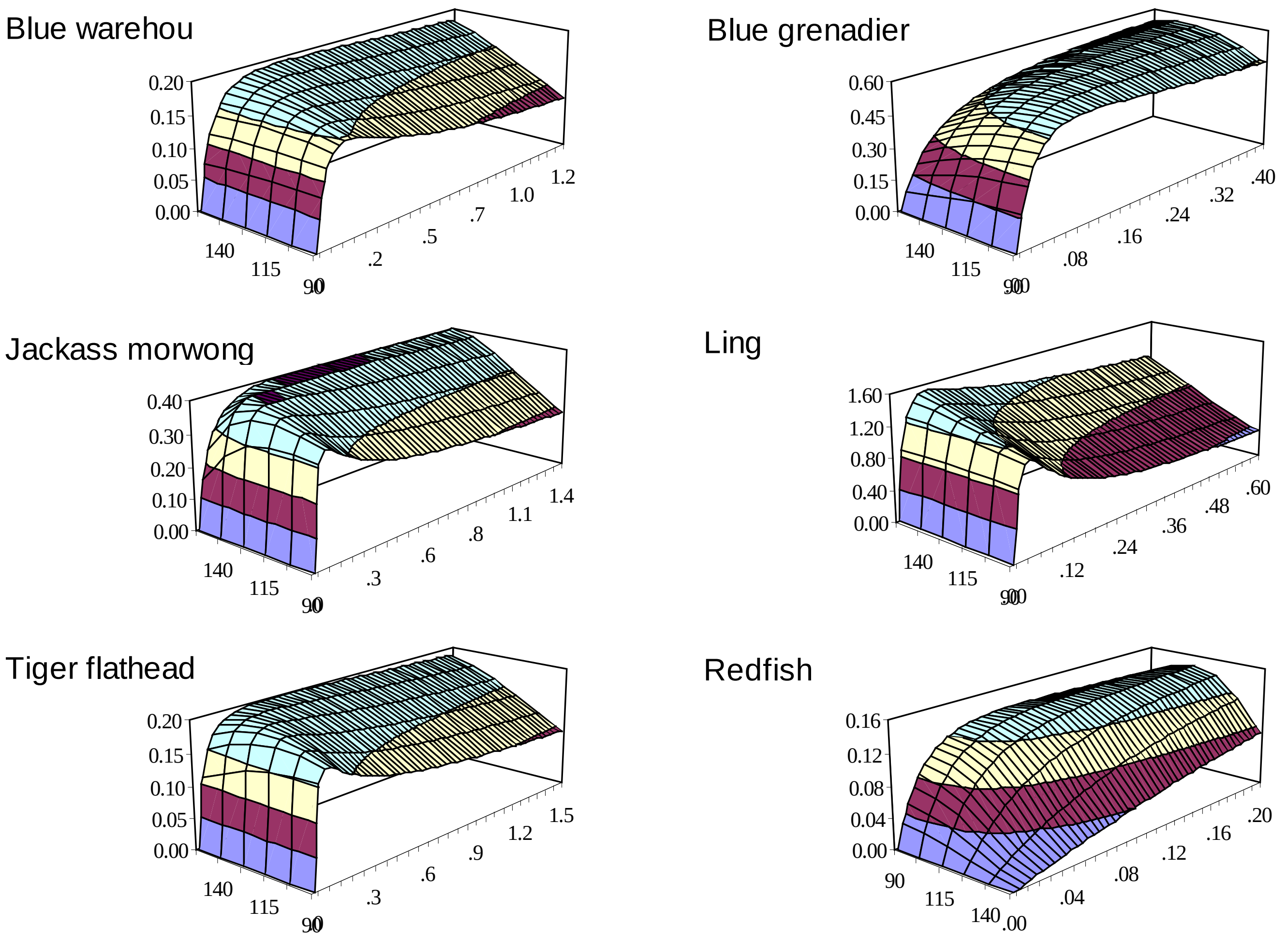


Figure 5.6.1 **Female yield per recruit (kg – y axis)) for 12 quota species as a function of fishing mortality (x axis) and trawl mesh size (90, 102.5, 115, 127.5, 140, 152.5 mm – z axis). Note that mesh sizes are different for Eastern school whiting. Fishing mortality extends from 0 to double current estimated fishing mortality for each species.**

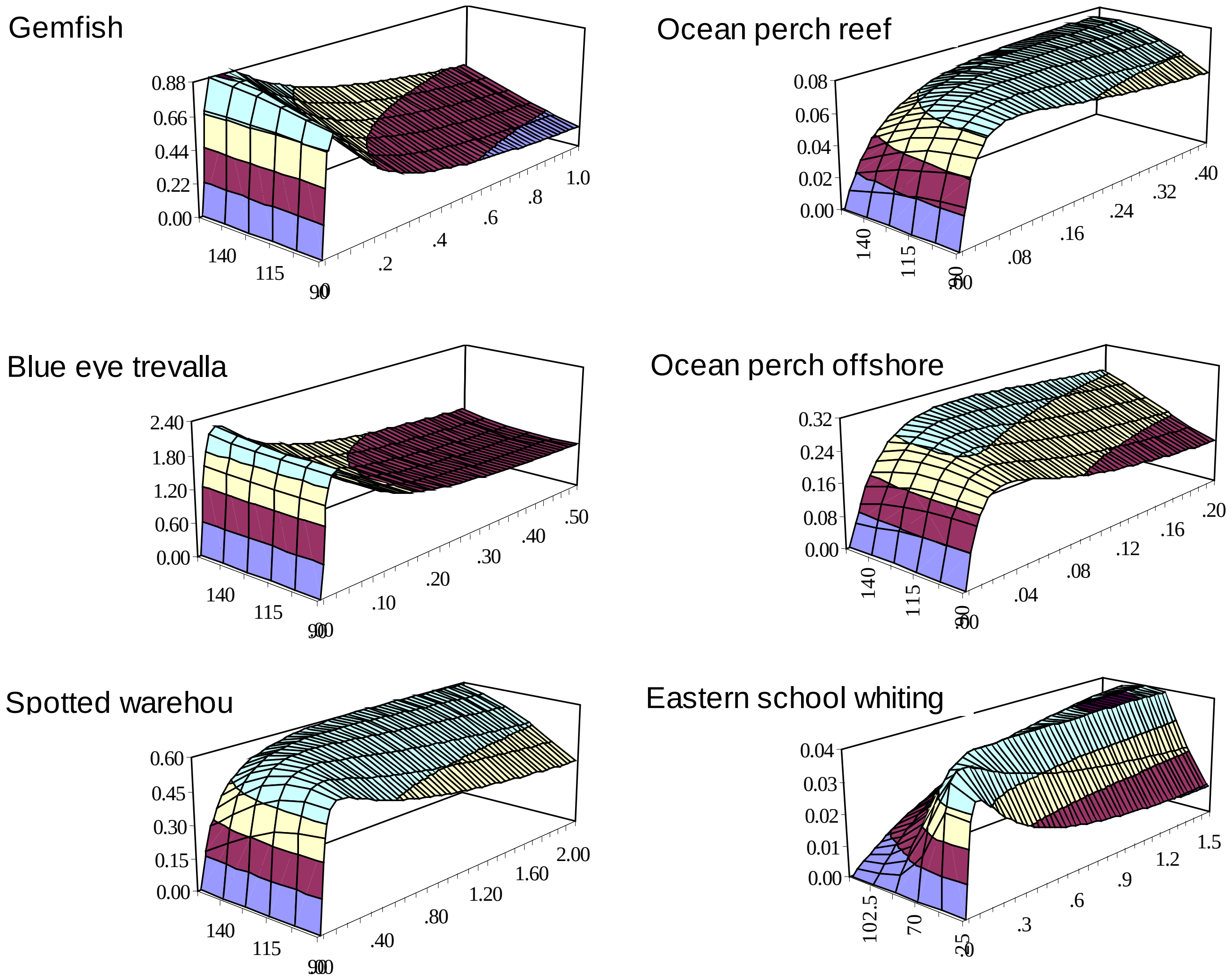


Figure 5.6.1 **continued**

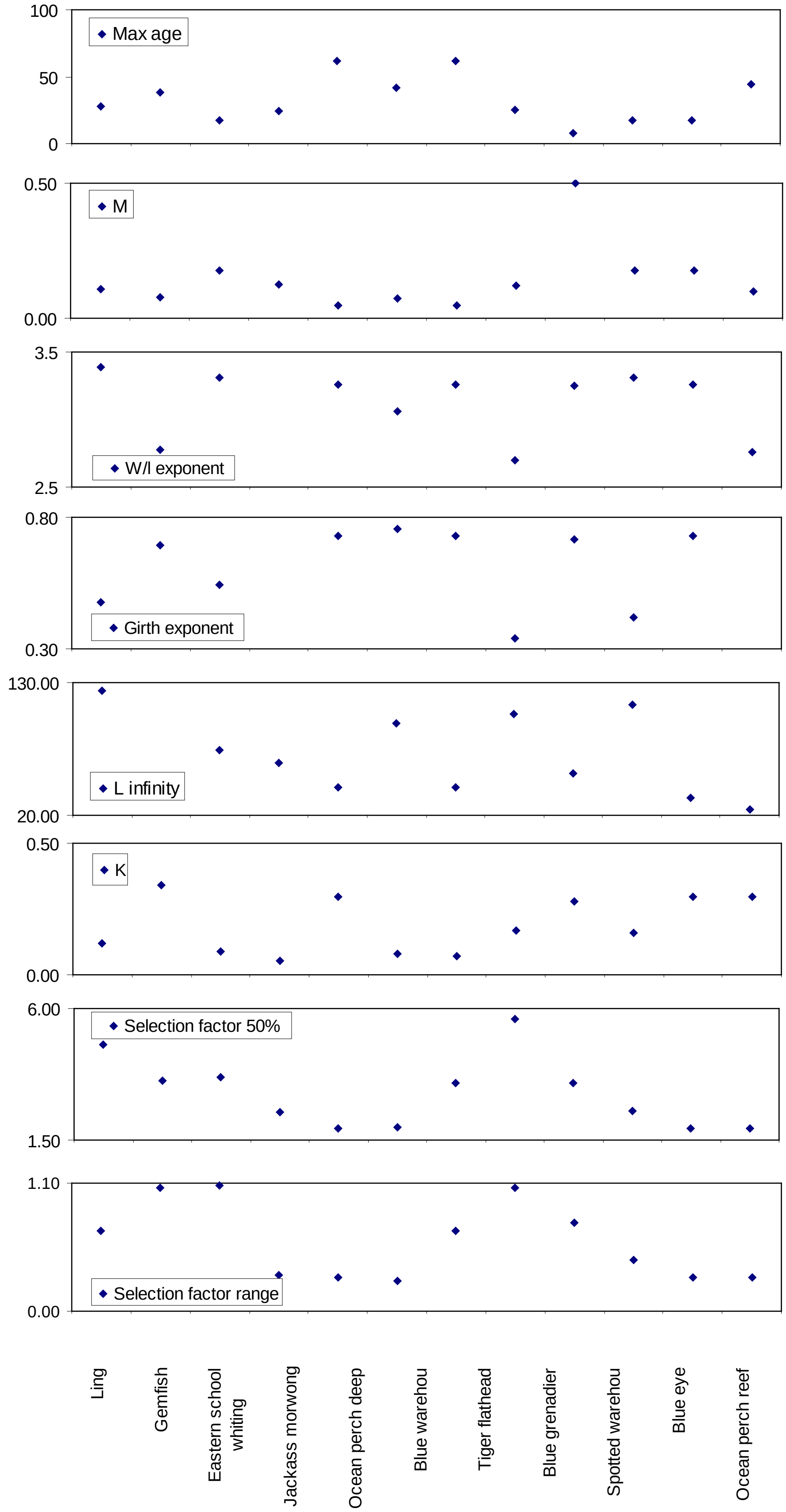


Fig. 5.6.2 **Biological factors for the 12 quota species arranged with species showing highest increases in yield per recruit with increased mesh size at current fishing mortalities to the left.**

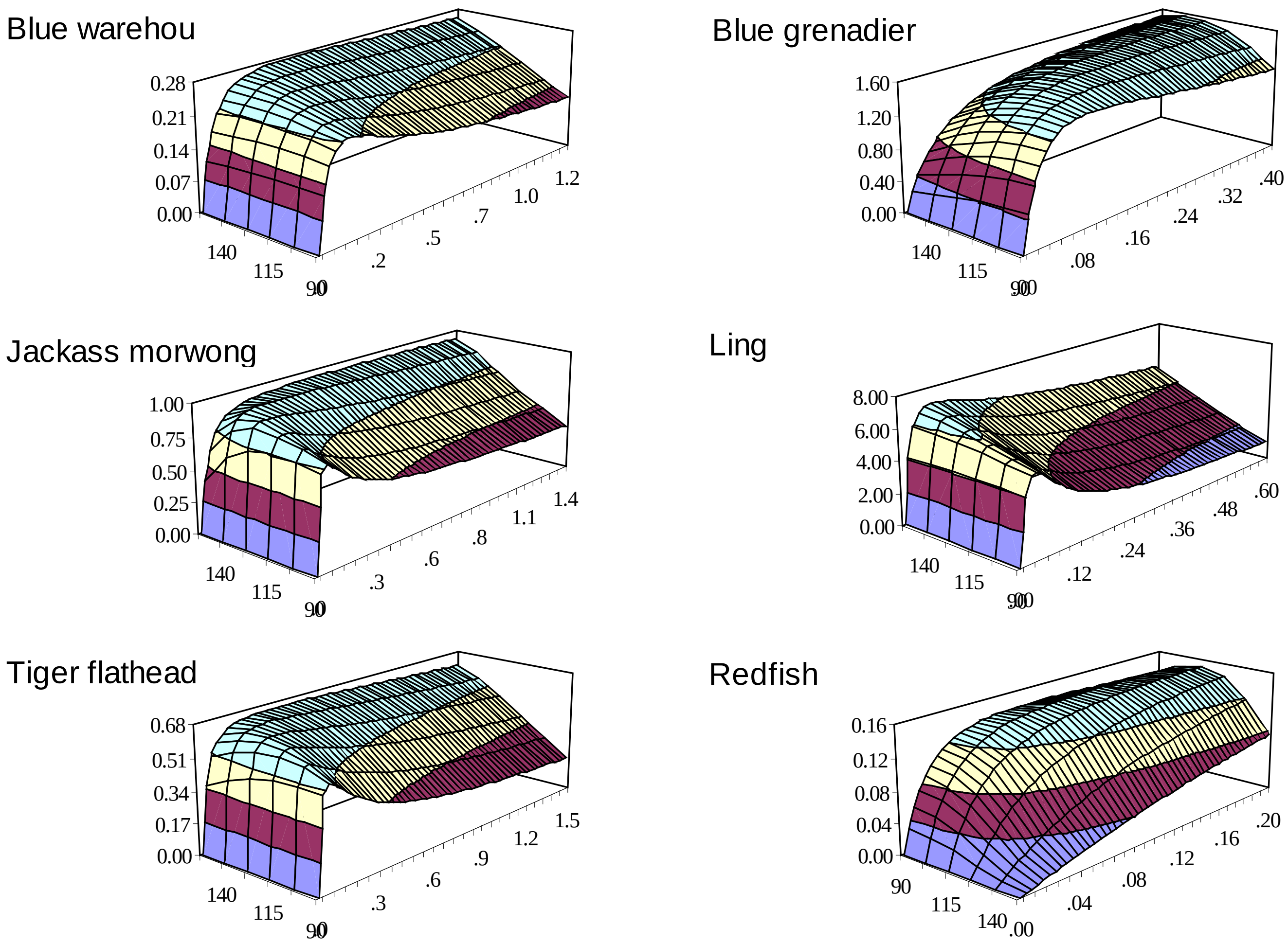


Figure 5.6.3 **Female yield per recruit ($ - y axis) for 12 quota species as a function of fishing mortality (x axis) and trawl mesh size (90, 102.5, 115, 127.5, 140, 152.5 mm – z axis). Note that mesh sizes are different for Eastern school whiting.**

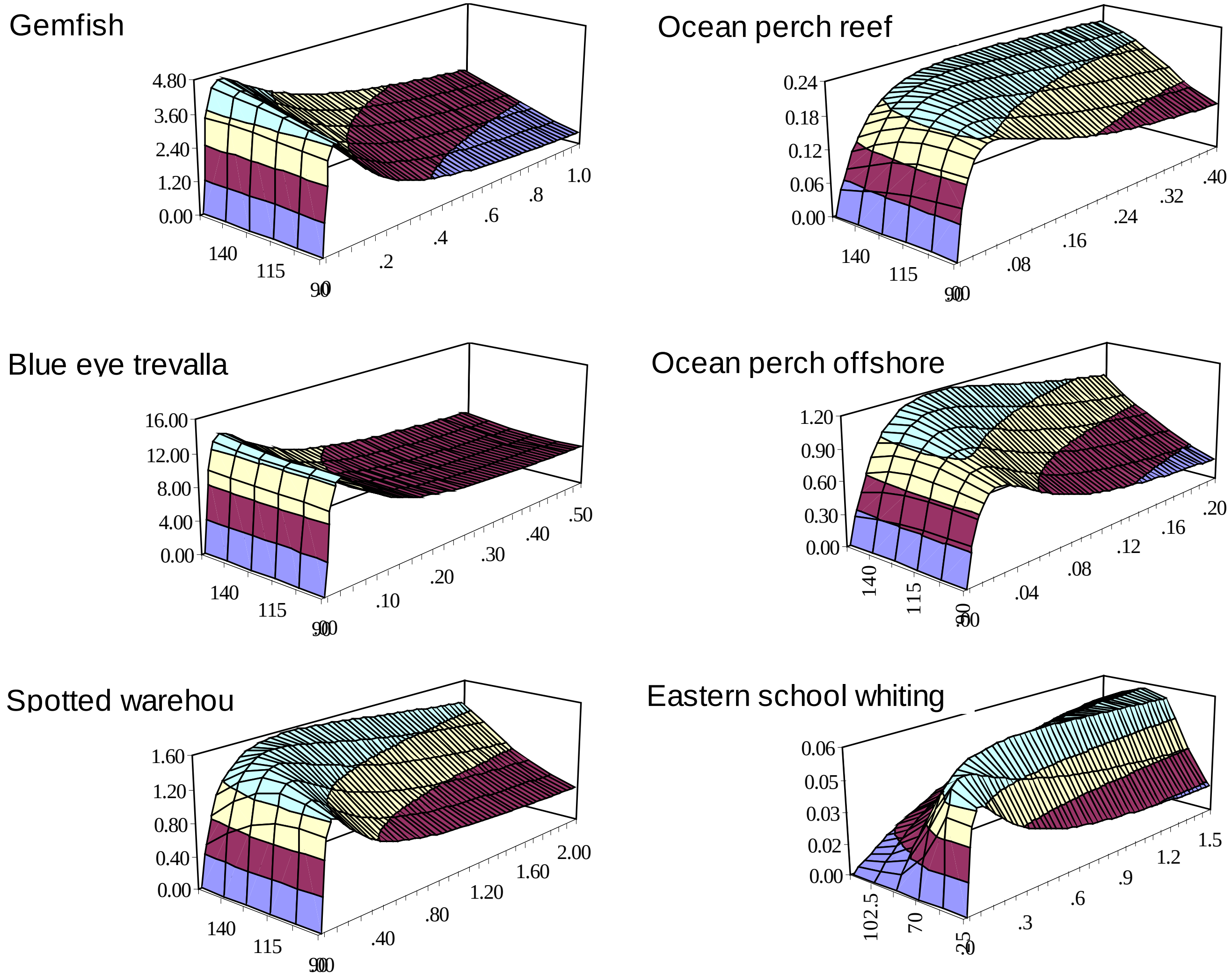


Figure 5.6.3 **continued.**

Although yields were typically higher for larger mesh sizes, the fishing mortality required to produce maximum yield per recruit was also higher (Table 5.6.2), indicating that the yield per recruit in dollar terms might decrease with larger mesh sizes, once operating costs were included.

Typically the fishing effort required to maximize monetary yield per recruit was comparable to that required to maximize yield per recruit in biomass terms. Effort required to maximize monetary yield per recruit was fractionally lower for: jackass morwong, tiger flathead and blue grenadier; and markedly lower for spotted warehou and ocean perch (reef) (Table 5.6.2)

Egg per recruit for blue warehou, the only species for which data are available was maximized at lowest effort and largest mesh sizes as would be expected (Figure 5.6.4). An interesting result is that the percent of maximum egg per recruit was obtained at a smaller mesh size (103mm) IF fishing was occurring at the level that would lead to maximum biomass yield per recruit (Table 5.6.1).

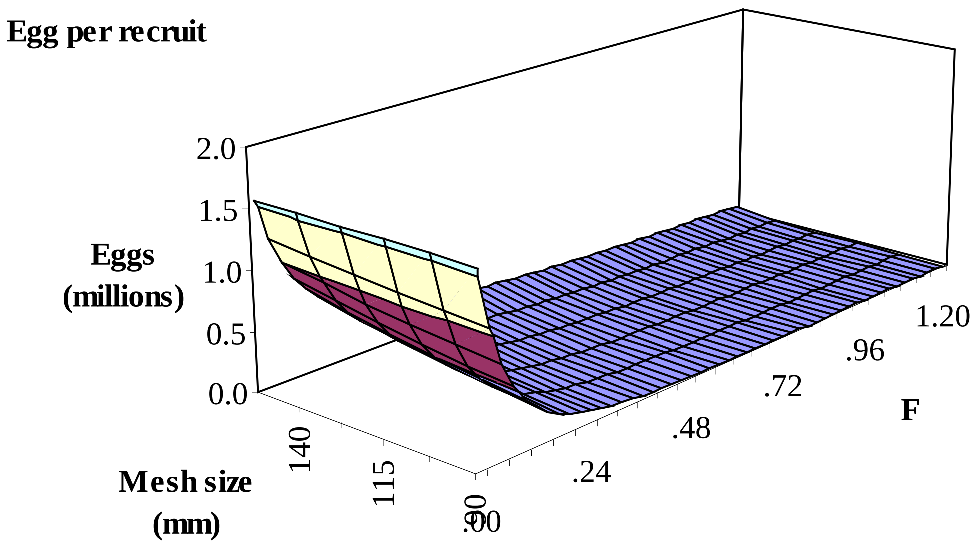


Figure 5.6.4 Fecundity for blue warehou as a function of fishing mortality and trawl mesh size for fishing mortality from zero to approximately double the current level.

Table 5.6.2 Fishing mortality that produces maximum single species yield per recruit in biomass and landing value for 6 mesh sizes.

			Fishing mortality producing Maximum YPR					
Species	Sex	Units	90	103	115	128	140	153
Blue warehou	M	kg	0.14	0.14	0.19	0.24	0.29	0.38
		$	0.12	0.14	0.19	0.22	0.29	0.38
	F	kg	0.14	0.14	0.19	0.22	0.29	0.38
		$	0.12	0.14	0.19	0.22	0.29	0.38
Jackass Morwong	M	kg	0.08	0.08	0.14	0.25	0.56	1.40
		$	0.06	0.08	0.11	0.20	0.48	1.37
	F	kg	0.06	0.08	0.11	0.17	0.31	0.87
		$	0.06	0.06	0.08	0.11	0.25	0.73
Tiger flathead	M	kg	0.12	0.18	0.33	0.63	1.20	1.50
		$	0.09	0.12	0.21	0.39	0.75	1.38
	F	kg	0.06	0.09	0.12	0.18	0.27	0.42
		$	0.06	0.09	0.12	0.15	0.24	0.39
Blue grenadier	M	kg	0.14	0.21	0.33	0.40	0.40	0.40
		$	0.13	0.19	0.30	0.40	0.40	0.40
	F	kg	0.11	0.14	0.21	0.33	0.40	0.40
		$	0.10	0.14	0.19	0.31	0.40	0.40
Ling	M	kg	0.05	0.05	0.06	0.07	0.08	0.12
		$	0.04	0.05	0.05	0.06	0.08	0.12
	F	kg	0.04	0.04	0.04	0.05	0.05	0.06
		$	0.04	0.04	0.04	0.05	0.05	0.06
Redfish	M	kg	0.09	0.13	0.20	0.20	0.20	0.20
		$	0.09	0.13	0.20	0.20	0.20	0.20
	F	kg	0.09	0.13	0.20	0.20	0.20	0.20
		$	0.09	0.13	0.20	0.20	0.20	0.20
Gemfish	M	kg	0.06	0.08	0.08	0.10	0.12	0.14
		$	0.06	0.08	0.08	0.10	0.12	0.14
	F	kg	0.04	0.04	0.06	0.06	0.06	0.06
		$	0.04	0.04	0.06	0.06	0.06	0.06

Table 5.6.2 continued

Species	Sex	Units	Fishing mortality producing Maximum YPR 90	103	115	128	140	153
Blue eye trevalla	M	kg	0.03	0.03	0.03	0.03	0.03	0.03
		$	0.03	0.03	0.03	0.03	0.03	0.03
	F	kg	0.03	0.03	0.03	0.03	0.03	0.03
		$	0.03	0.03	0.03	0.03	0.03	0.03
Spotted warehou	M	kg	0.16	0.20	0.28	0.44	0.76	1.28
		$	0.08	0.12	0.16	0.20	0.36	0.60
	F	kg	0.16	0.20	0.28	0.44	0.76	1.28
		$	0.08	0.12	0.16	0.20	0.36	0.60
Ocean perch (reef)	M	kg	0.08	0.10	0.14	0.21	0.31	0.40
		$	0.05	0.06	0.07	0.10	0.14	0.19
	F	kg	0.08	0.10	0.14	0.21	0.31	0.40
		$	0.05	0.06	0.07	0.10	0.14	0.19
Ocean perch (deep)	M	kg	0.03	0.03	0.04	0.05	0.06	0.08
		$	0.02	0.02	0.03	0.04	0.04	0.06
	F	kg	0.03	0.03	0.04	0.05	0.06	0.08
		$	0.02	0.02	0.03	0.04	0.04	0.06
	Mesh size		25	42	70	90	103	115
School Whiting	M	kg	0.09	0.15	0.75	1.50	1.50	1.50
		$	0.09	0.15	0.75	1.50	1.50	1.50
	F	kg	0.06	0.12	0.60	1.50	1.50	1.50
		$	0.06	0.12	0.60	1.50	1.50	1.50

5.6.2 Yield per recruit (trawl and gillnet) for jackass morwong and blue warehou

Yield per recruit for various trawl and gillnet mesh sizes is given in Figures 5.6.5 for blue warehou and Figure 5.6.6 for jackass morwong. Trawl yield per recruit surfaces show a gradually increasing yield as mesh size increases beyond that used in the fishery today, and a gradually decreasing yield with increasing effort, especially at smaller mesh sizes. In contrast, gillnet yield per recruit surfaces show a marked maximum in yield per recruit at, or below the mesh sizes in current use. Gillnet yield per recruit surfaces show a monotonic increase in yield with increasing effort, compared to the trawl yield per recruit surfaces where yields are maximized at intermediate effort levels, especially at smaller mesh sizes similar to those used in the fishery today.

Maximum yield per recruit for gillnets and trawls are given in Table 5.6.3 – the final column gives the ratio of gillnet maximum yield per recruit to trawl maximum yield per recruit, over the sizes assessed. Maximum biomass and monetary yield per recruit of blue warehou are slightly lower for the gillnet than the trawl. Maximum biomass and monetary yield per recruit of jackass morwong are equivalent for gillnet and trawl. Effort at maximum yield per recruit for the trawl leads to blue warehou egg production at 15% of the egg production for an unfished stock; for the gillnet it is 27-48% depending on whether 4 or 5-inch mesh size is used.

Differences in yield per recruit between gillnet and trawl have implications for transfer of quota between the trawl and non-trawl sectors. A tonne of blue warehou or jackass morwong caught with a trawl is unlikely to be equivalent to a tonne caught with the gillnet and unmonitored transfer between sectors could lead to increased fishing pressure on the stock, despite TACs remaining unchanged.

Table 5.6.3 Maximum yield per recruit for a range of mesh sizes of trawl and gillnet and the ratio of maximum yields for gillnet versus trawl for jackass morwong and blue warehou. Maximum yield per recruit for each gear type is bolded. % eggs is the percent of the eggs produced compared to that produced by the unfished population.

		Maximum YPR by mesh size												
		Trawl (mm)						Gillnet (in)						Gillnet/
Sex	Units	90	103	115	128	140	153	4	5	6	7	8	9	trawl
								Blue warehou						
M	kg	0.15	0.16	0.16	0.17	0.18	**0.19**	**0.17**	0.16	0.10	0.03	0.00	0.00	0.88
	$	0.21	0.22	0.24	0.25	0.26	**0.27**	**0.24**	0.24	0.15	0.05	0.00	0.00	0.88
F	kg	0.15	0.16	0.17	0.18	0.19	**0.19**	**0.17**	0.17	0.11	0.03	0.00	0.00	0.88
	$	0.21	0.23	0.24	0.25	0.27	**0.28**	**0.24**	0.24	0.16	0.05	0.00	0.00	0.88
	% eggs	0.16	0.18	0.14	0.15	0.14	0.15	0.27	0.48	0.75	0.95	1.00	1.00	5.54
								Jackass morwong						
M	kg	0.31	0.33	0.35	0.36	0.37	**0.37**	0.34	**0.38**	0.01	0.00	0.00	0.00	1.02
	$	0.68	0.73	0.78	0.82	0.83	**0.84**	0.75	**0.87**	0.03	0.00	0.00	0.00	1.03
F	kg	0.34	0.36	0.39	0.40	0.41	**0.41**	0.37	**0.42**	0.07	0.00	0.00	0.00	1.02
	$	0.77	0.82	0.88	0.92	0.94	**0.95**	0.82	**0.98**	0.18	0.00	0.00	0.00	1.03

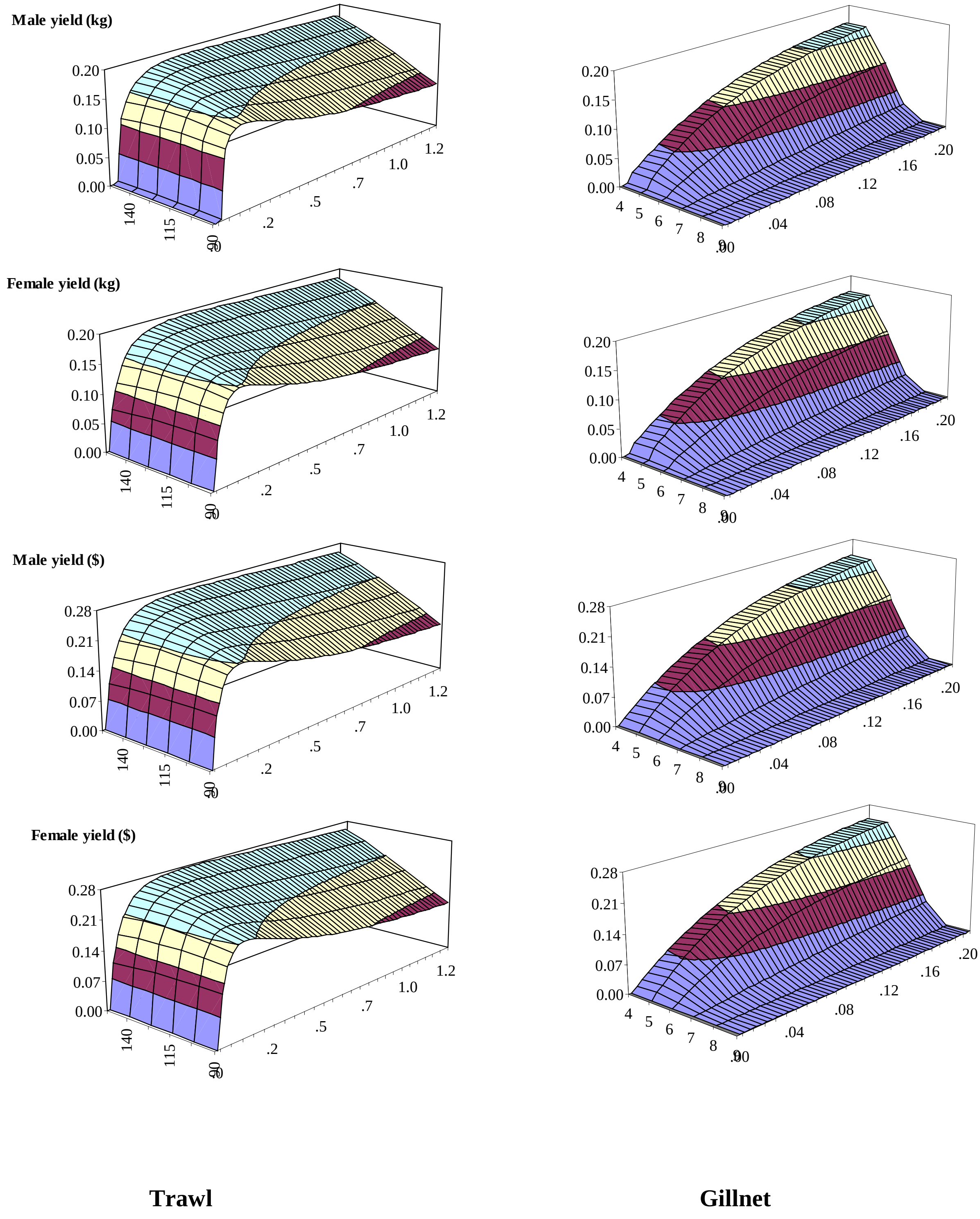


Figure 5.6.5. **Yield per recruit ($ - y axis) for blue warehou as a function of fishing mortality (x axis) and mesh size (trawl 90, 102.5, 115, 127.5, 140, 152.5 mm; gillnet 4, 5, 6, 7 8, 9 inches – z axis).**

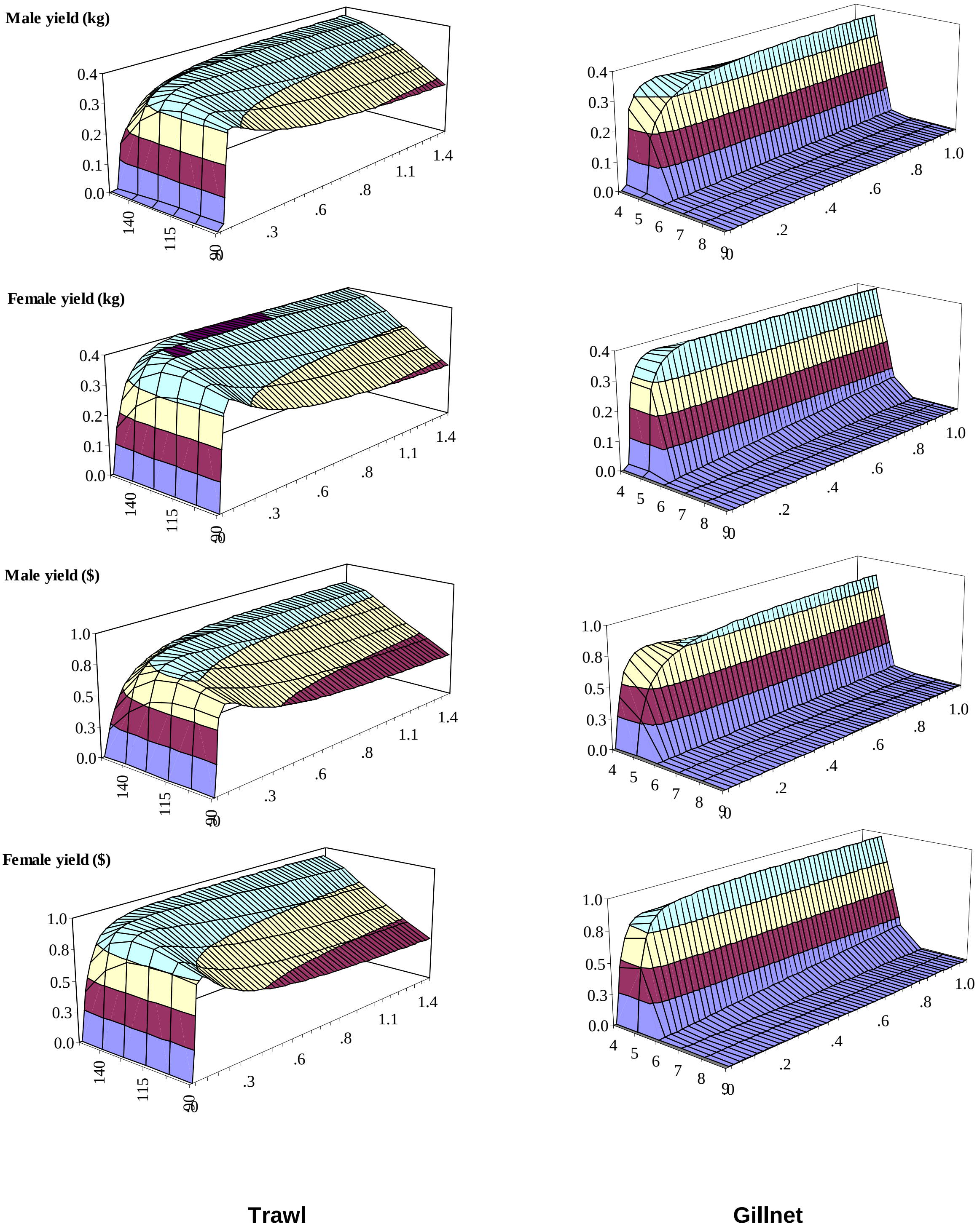


Figure 5.6.6. Yield per recruit ($ - y axis) for jackass morwong as a function of fishing mortality (x axis) and mesh size (trawl 90, 102.5, 115, 127.5, 140, 152.5 mm; gillnet 4, 5, 6, 7 8, 9 inches – z axis).

Maximum yield per recruit for blue warehou caught with the gillnet, trawl and the combined gears is given for range of trawl mesh sizes and for 3 levels of gillnet fishing effort (Table 5.6.4). The gillnet mesh size was fixed at 6-inch mesh, the size currently used in the fishery. Fishing mortalities that produce maximum yields are provided in Table 5.6.5.

Maximum yield per recruit for the gillnet is constant for all trawl mesh sizes (Table 5.6.4), because it occurs in the absence of any trawl fishing mortality (Table 5.6.5), that would otherwise remove smaller warehou, before they grow to a sufficient size to be recruited to the gillnet fishery.

Maximum yield per recruit for the trawl increases with mesh size in a similar manner, and at a similar level to when there is no gillnet fishery (compare Tables 5.6.3 and 5.6.4). Maximum yield per recruit remains almost constant as gillnet fishing mortality increases (Tables 5.6.4), indicating little effect of the gillnet fishery on yield per recruit from the trawl fishery. However, the fishing mortality needed to take the maximum yield per recruit increases as gillnet fishing mortality increases, especially at larger mesh sizes (Table 5.6.5).

Maximum yield per recruit in biomass from the combined gear types is slightly higher than that obtained by either gear alone especially at the lowest trawl mesh sizes (ie. those in use in the fishery today). Trawl fishing mortality that maximizes the combined yield per recruit in biomass is less than that maximising trawl yield per recruit alone, especially at higher gillnet fishing mortalities and smaller mesh sizes (Table 5.6.5). Maximum yield per recruit in dollar terms for the combined gears occurs at very reduced trawl fishing mortalities for all except the lowest gillnet fishing mortalities (Table 5.6.5).

These results indicate that yield per recruit for blue warehou would be not be increased for a combined gillnet and trawl fishery, over what could be achieved with a trawl fishery alone. Yield per recruit (in biomass and monetary terms) would be lower for a gillnet fishery alone. Given that there is gillnet fishing mortality, then maximum yields are obtained at reduced trawl fishing mortality, compared to the trawl fishery operating alone.

These are single species scenarios. Maximum yield per recruit for a multi-species fishery are described in a later section.

Table 5.6.4 Maximum yield per recruit for blue warehou (both sexes) over a range of trawl mesh sizes at various fishing mortality levels for the current 6- inch gillnet mesh size. Maximum yield per recruit for each mesh size is bolded.

Gillnet		Maximum YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.10	Gillnet	0.21	0.21	0.21	0.21	0.21	0.21
	Trawl	0.28	0.30	0.33	0.35	0.36	**0.38**
	Combined	0.30	0.32	0.34	0.35	0.37	**0.38**
0.25	Gillnet	0.25	0.25	0.25	0.25	0.25	0.25
	Trawl	0.28	0.30	0.32	0.35	0.36	**0.38**
	Combined	0.31	0.32	0.34	0.36	0.37	**0.38**
0.50	Gillnet	0.27	0.27	0.27	0.27	0.27	0.27
	Trawl	0.28	0.30	0.32	0.34	0.36	**0.38**
	Combined	0.31	0.33	0.34	0.36	0.37	**0.38**
		Maximum YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.10	Gillnet	0.31	0.31	0.31	0.31	0.31	0.31
	Trawl	0.41	0.44	0.47	0.50	0.52	**0.54**
	Combined	0.44	0.46	0.48	0.51	0.53	**0.55**
0.25	Gillnet	0.36	0.36	0.36	0.36	0.36	0.36
	Trawl	0.40	0.43	0.46	0.49	0.52	**0.54**
	Combined	0.44	0.46	0.49	0.51	0.53	**0.55**
0.50	Gillnet	0.39	0.39	0.39	0.39	0.39	0.39
	Trawl	0.40	0.43	0.46	0.49	0.52	**0.54**
	Combined	0.45	0.47	0.49	0.51	0.53	**0.55**

Table 5.6.5 **Trawl fishing mortality maximizing yield per recruit of blue warehou (both sexes) for gillnet, trawl and the combined gears for a range of trawl mesh sizes at various fishing mortality levels for the current 6- inch gillnet mesh size.**

Gillnet F	Fishery	F maximisng YPR (kg) by mesh size (mm)					
		90	103	115	128	140	153
0.10	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.14	0.16	0.19	0.23	0.29	0.36
	Combined	0.10	0.12	0.15	0.19	0.24	0.31
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.16	0.18	0.21	0.26	0.32	0.40
	Combined	0.08	0.10	0.13	0.16	0.21	0.29
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.17	0.19	0.23	0.28	0.34	0.44
	Combined	0.04	0.06	0.09	0.13	0.19	0.26
		F maximising YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.10	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.11	0.12	0.13	0.15	0.17	0.19
	Combined	0.04	0.04	0.05	0.06	0.07	0.09
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.12	0.14	0.16	0.18	0.20	0.23
	Combined	0.00	0.00	0.00	0.00	0.00	0.01
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.14	0.16	0.18	0.21	0.25	0.29
	Combined	0.00	0.00	0.00	0.00	0.00	0.00

The 6-inch mesh size currently used in the gillnet fishery is estimated to have a relatively low selectivity for jackass morwong, and yield per recruit estimates for the trawl fishery were relatively invariant to gillnet fishing effort. To explore the dynamics of mixed gillnet and trawl fishery further, the gillnet mesh size was set at 5-inch. This is the mesh size that maximizes yield per recruit for jackass morwong and is close to the mesh size at maximum yield per recruit for the blue warehou (Table 5.6.3).

Maximum yield per recruit for the jackass morwong with the gillnet and trawl and the combined gears is given in Tables 5.6.6. Maximum yield per recruit in terms of weight and landed value are highest at the 140-mm mesh size for the trawl fishery when operating alone. Maximum yield per recruit and landed value are higher at the 153-mm mesh size for the combined fishery. Maximum biomass and monetary yield per recruit are higher for gillnet than for the trawl except at the largest trawl mesh sizes and lowest gillnet fishing mortalities. The maximum yield per recruit from the combined gears is greater than that from either gear alone at these combinations of lower gillnet fishing mortalities and larger trawl mesh sizes.

Trawl fishing mortality leading to the maximum yield per recruit is zero for the gillnet fishery (no fish are taken out before they recruit to the gillnet fishery)(Table 5.6.7). Trawl fishing mortality required to take the maximum yield per recruit for the trawl fishery increases with mesh size and increases as gillnet fishing mortality increases especially for the larger trawl mesh sizes – ie. there is competition between the two gear types. In contrast, trawl fishing mortality required to take the maximum yield per recruit for the combined fisheries declines as gillnet fishing mortality increases, reaching zero for the smaller mesh sizes in current use in the fishery and for higher levels of gillnet fishing effort, especially when yield is expressed in landed value rather than biomass.

In general, trawl fishing mortality required to take the maximum yield per recruit is much less than that maximising trawl yields alone, and reaches zero as gillnet fishing mortality increases. The trawl and gillnet fisheries are competing for the same fish, and when the trawl fishery wins the competition by catching the fish at smaller sizes, overall yield to the combined fisheries is diminished. As with morwong, blue warehou maximum yields for the combined fisheries would be obtained by minimising trawl fishing mortality. However, this is for a single species scenario, and this may change when more than one species is included in the analysis.

Table 5.6.6 Maximum yield per recruit for jackass morwong (both sexes) over a range of trawl mesh sizes at various fishing mortality levels for a 5- inch gillnet mesh size (current mesh size is 6-inch). Maximum yield per recruit for each gillnet fishing mortality is bolded.

Gillnet		Maximum YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.10	Gillnet	0.65	0.65	0.65	0.65	0.65	0.65
	Trawl	0.59	0.64	0.69	0.72	**0.73**	0.71
	Combined	0.69	0.72	0.75	0.77	0.78	**0.78**
0.25	Gillnet	0.75	0.75	0.75	0.75	0.75	0.75
	Trawl	0.56	0.62	0.67	0.70	**0.71**	0.64
	Combined	0.75	0.75	0.76	0.78	0.78	**0.78**
0.50	Gillnet	0.79	0.79	0.79	0.79	0.79	0.79
	Trawl	0.54	0.60	0.65	**0.68**	**0.68**	0.55
	Combined	0.79	0.79	0.79	0.79	0.79	0.79
		Maximum YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.10	Gillnet	1.55	1.55	1.55	1.55	1.55	1.55
	Trawl	1.27	1.38	1.51	1.60	**1.64**	1.62
	Combined	1.57	1.63	1.69	1.75	1.78	**1.79**
0.25	Gillnet	1.75	1.75	1.75	1.75	1.75	1.75
	Trawl	1.19	1.31	1.43	1.53	**1.56**	1.45
	Combined	1.75	1.75	1.75	1.77	1.79	**1.80**
0.50	Gillnet	1.82	1.82	1.82	1.82	1.82	1.82
	Trawl	1.13	1.26	1.38	1.46	**1.49**	1.25
	Combined	1.82	1.82	1.82	1.82	1.82	1.82

Table 5.6.7 Trawl fishing mortality maximizing yield per recruit of jackass morwong (both sexes) for gillnet, trawl and the combined gears for a range of trawl mesh sizes at various fishing mortality levels for the 5- inch gillnet mesh size (current gillnet mesh size is 6-inch).

Gillnet		F maximisng YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.10	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.12	0.15	0.21	0.39	0.99	1.50
	Combined	0.03	0.06	0.09	0.15	0.36	1.02
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.12	0.18	0.27	0.54	1.50	1.50
	Combined	0.00	0.00	0.03	0.09	0.27	0.75
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.15	0.21	0.36	0.75	1.50	1.50
	Combined	0.00	0.00	0.00	0.00	0.09	0.30
		F maximising YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.10	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.09	0.12	0.18	0.33	0.81	1.50
	Combined	0.03	0.03	0.06	0.12	0.30	0.84
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.12	0.15	0.24	0.45	1.20	1.50
	Combined	0.00	0.00	0.00	0.06	0.21	0.57
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.15	0.18	0.30	0.60	1.50	1.50
	Combined	0.00	0.00	0.00	0.00	0.03	0.12

There were sufficient data from a previous study (Knuckey and Sivakumaran 1999) to estimate eggs per recruit for blue warehou. Egg per recruit declined consistently with increased effort at all trawl mesh sizes reflecting the reduced biomass of mature fish. Larger gillnet mesh sizes had little impact on egg per recruit, as yield to the fishery was very low and the biomass of mature fish remained high (Fig. 5.6.7).

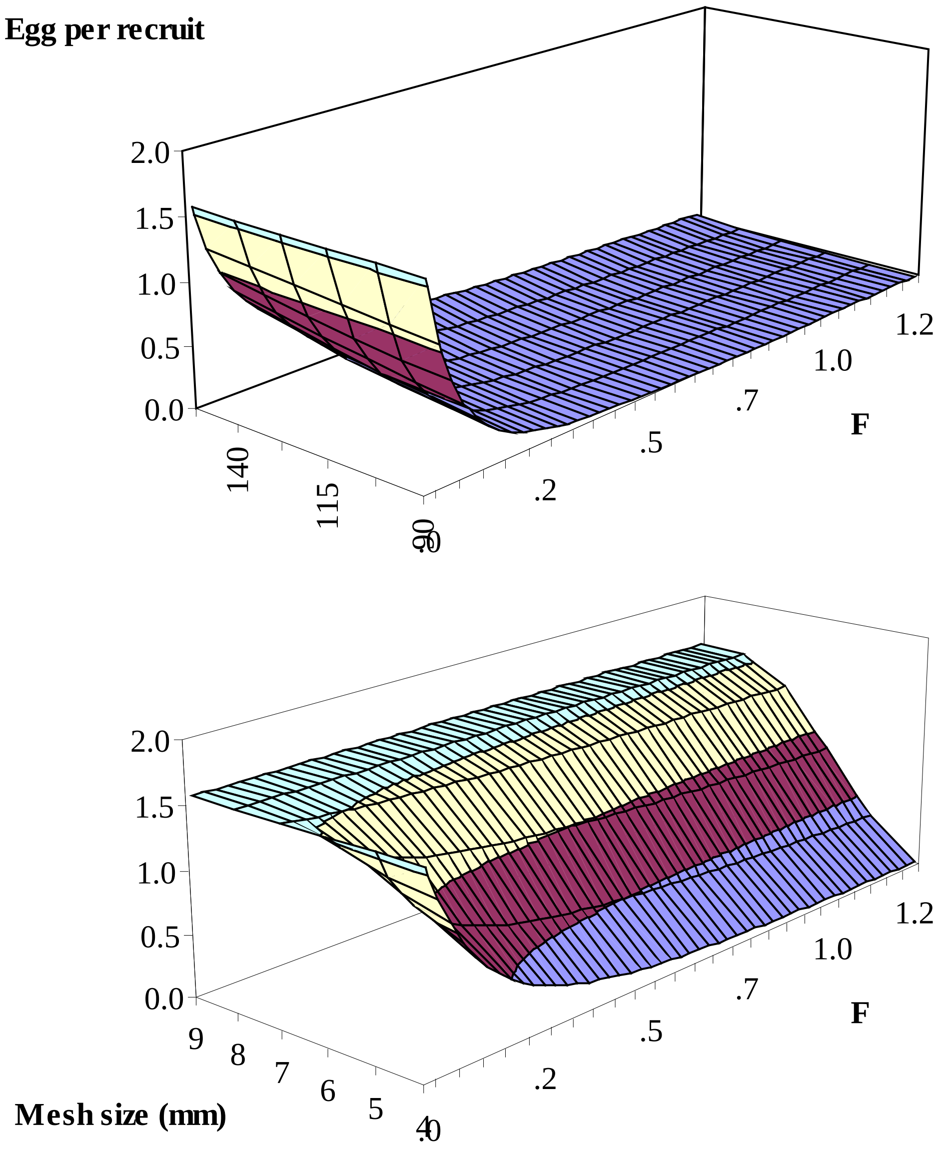


Figure 5.6.7. Egg per recruit isopleths (millions) for blue warehou caught with the trawl (above) and gillnet (below). Note different effort levels.

5.6.3 Yield per recruit as a function of trawl mesh size and depth for redfish

There is a consistent within species increase in size with depth for the majority of SEF quota species – larger fish are found offshore (Bax and Williams 2000). This provides an opportunity to alter the selectivity of fishing operations by choosing (or avoiding) particular water depths. Redfish is one species for which there is a strong trend for increasing size with depth and Chen et al. (1997) parameterized the size dependency of offshore movement as a logistic model (Fig 5.6.8).

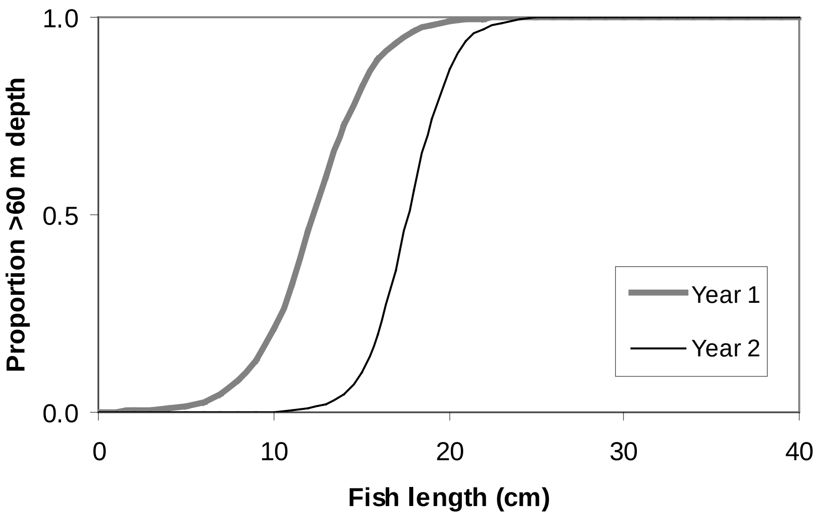


Figure 5.6.8. Proportion of redfish found offshore (>60 m depth) off the New South Wales coast over two years (parameter estimates from Chen et al. 1997)

The single species yield per recruit model used for redfish above (Section 5.6.1) was subdivided into inshore and offshore regions and the availability of redfish to the trawl fishery modeled using the logistic equation of Chen et al. (1977) for year 2. Using the logistic equation from year 1 produced greater contrast than that shown below. The results for biomass and monetary yield per recruit were very similar so only biomass recruits are presented.

Maximum yield per recruit for male fish and the effort required to produce it was relatively constant for male redfish regardless of the depth fished (Table 5.6.7), although yield per recruit was maximized at intermediate mesh sizes as shown previously. The fishing mortality required to catch maximum yield per recruit was slightly higher for male redfish when fishing only one of the depth zones.

Differences were more pronounced for female redfish, with yield per recruit being much lower in inshore waters and the effort required to achieve that yield being higher. Based on these observations, fishing for redfish inshore of 60-m depth will lead to decreased yields of female redfish.

Table 5.6.7 Maximum biomass yield per recruit and the fishing effort producing that maximum yield for trawl-caught redfish caught inshore only (<60m depth), offshore only (>60m depth) and all depths.

		Maximum YPR by mesh size (mm)					
Depth	Sex	90	103	115	128	140	153
Inshore	Male	0.13	0.14	0.15	0.14	0.10	0.06
	Female	0.05	0.03	0.01	0.01	0.00	0.00
Offshore	Male	0.14	0.15	0.15	0.14	0.11	0.07
	Female	0.14	0.15	0.15	0.14	0.11	0.07
All	Male	0.13	0.14	0.15	0.14	0.11	0.07
	Female	0.13	0.14	0.15	0.14	0.11	0.07
		Fishing effort producing Maximum YPR					
	Sex	90	103	115	128	140	153
Inshore	Male	0.10	0.14	0.20	0.20	0.20	0.20
	Female	0.20	0.20	0.20	0.20	0.20	0.20
Offshore	Male	0.12	0.16	0.20	0.20	0.20	0.20
	Female	0.12	0.16	0.20	0.20	0.20	0.20
All	Male	0.09	0.13	0.20	0.20	0.20	0.20
	Female	0.09	0.13	0.20	0.20	0.20	0.20

5.6.4 Discussion

Single species yield per recruits were estimated for the 12 species for which data were available. Six trawl mesh sizes were used, the smallest of which was the one in use by the fishery today (90 mm). Yield for all species would be increased by increasing the mesh size. In most instances yield increased as mesh size increased up to the maximum tested in this project (153 mm). Exceptions were tiger flathead (128 mm), blue grenadier (128 – 140 mm), redfish (115 mm), spotted warehou (140 mm biomass only), and school whiting (70 mm Danish seine), for which maximum yields were obtained at the mesh sizes indicated.

Single species yield per recruit is only one output variable for a fishery, and it is important to note in this instance that the fishing mortality producing maximum yield per recruit also increased with mesh size. While it is a simplification to suggest that fishing mortality is directly proportional to fishing effort (although a simplification commonly used in stock assessments), the increases in fishing effort to achieve the necessary fishing mortality at larger mesh sizes can be expected to be high and are unlikely to be economically viable.

Most major species in the SEF are considered fully exploited or in some cases over-exploited (Caton 2002) and are unlikely to be able to support higher levels of fishing effort. Higher fishing effort would probably have negative impacts on fishers' economic returns in a fishery for which there is already little profit margin for most operators. Bottom time would be increased (increasing impacts on non-target biota and the seafloor), and fossil fuel consumption would increase.

An interesting result was that eggs per recruit for blue warehou (the only species for which fecundity data were available) were maximized at a lower mesh size than the optimum, assuming that fishing mortality was only at the level necessary to maximize yield per recruit. This reinforces the conclusion that more factors need to be taken into account than just managing to maximize yield per recruit.

However, the SEF today does not operate to maximize yield per recruit. Fishing mortalities (where known) seem to be considerably higher than those required to maximize yields for the current 90 mm mesh size. For example, estimated fishing mortalities for tiger flathead, spotted warehou and school whiting are already at levels that would reach (or even exceed) maximum yield per recruit at the optimum mesh sizes. Other species (blue warehou, jackass morwong and redfish) would require a fishing mortality higher than currently imposed to maximize yield per recruit at the optimal mesh size, although yield per recruits could be maximized at intermediate mesh sizes.

Mesh size and fishing mortality can be considered complementary approaches to managing a fishery. Improvements in yield could be achieved for many species at the current mesh size if fishing mortality was significantly reduced, and the shape of the yield curve is such that yield per recruit drops off with increased mortality above that required to achieve maximum yield. As mesh size increases, the decline in yield per recruit for fishing mortalities in excess of that required to take the maximum yield per recruit has a smaller effect, providing a level of insurance for fisheries where effort cannot be regulated sufficiently.

Another management approach to maximizing yields is to change the gear mix. During 2001 a global TAC for all quota species was introduced in the SEF enabling transfer of quota between trawl and non-trawl sectors. Here we considered whether a gillnet, trawl or a combined fishery would provide the maximum yield per recruit from blue warehou and jackass morwong – the main trawl species that have been targeted by gillnets. Yield per recruit for blue warehou and jackass morwong were lower with the gillnet than the trawl, but if smaller gillnet mesh sizes than currently used in the gillnet fishery were fished, then yields would be about 10 percent higher than yields from the trawl fishery with 90 mm mesh. With current mesh sizes, the gillnet fishery has little effect on yields from the trawl fishery, although trawl fishing effort needs to increase to take these same yields. Yields from a combined gillnet and trawl fishery could be greater than from the trawl fishery alone, however trawl fishing mortalities would need to be reduced to achieve this. Blue warehou caught by both gears are mature (Knuckey and Sivakumaran 1999), but those caught by the gill net sector are generally larger and older than those caught by the trawl sector in other areas of the fishery (Smith 1999). This primarily reflects differing selectivities of the current trawl codend mesh (90 mm) compared to the gill nets (150 mm). Based on eggs per recruit, Knuckey and Sivakumaran (1999) found that capture by trawl alone would potentially reduce the reproductive capacity of the blue warehou stock to a greater degree, than if the quota was caught by gill nets alone. Similarly, the present study found that egg per recruit for blue warehou was higher at maximum yield per recruit for the gillnet than the trawl fishery. It is important to note that in recent years, catches from the gill net fishery have been poor (Smith and Wayte 2001) and under the global TAC, most quota has been leased from the non-trawl sector to the trawl sector (AFMA, unpublished data).

Lastly, using redfish as an example, we considered whether there were gains to be made in yield per recruit by changing the depth of fishing, in particular moving effort offshore and away from juvenile fish. Yields of female redfish would be increased 3-fold by fishing only in water depths greater than 60 m, as compared to fishing water depths less than 60 m, however there was little improvement in yields compared to fishing all depths (ie. no management of fishing effort by depth). Fishing mortality would have to increase to maximize yield per recruit if restricted to waters deeper than 60 m depth.

5.7 Multi-species yield per recruit

5.7.1 Yield per recruit as a function of trawl mesh size

Multi-species yield per recruit analyses were run for two similar scenarios, differing only by the presence or absence of redfish:

- trawl-caught shelf species off southern New South Wales – spotted warehou, tiger flathead, jackass morwong, redfish and blue warehou;

- trawl-caught shelf species off eastern Victoria – spotted warehou, tiger flathead, jackass morwong, and blue warehou

School whiting were not included in the yield per recruit analyses because they are primarily caught by Danish seines (which use different mesh sizes), and because the recruitment multipliers estimated from available assessment data (Table 5.2.1) were not credible.

Yield per recruit in terms of biomass and landed values were maximized at trawl mesh sizes of at least 128 mm, with or without redfish (Table 5.7.1). Yield per recruit was approximately 10 percent higher in biomass and 15 percent higher in value at the larger mesh sizes compared to that currently used in the fishery. The fishing mortality required to take this yield at a mesh size of 128 mm was almost 3 times higher than that required with the current mesh size. The results were relatively insensitive to the presence or absence of redfish (Table 5.7.1). Maximum monetary yield per recruit was obtained at a fishing mortality 20-30 percent lower than the fishing mortality required to maximize biomass yield per recruit. If mesh size were increased from the current 90 mm to 103 mm, then maximum yield per recruit would be increased by approximately 5 percent, and the fishing mortality required to reach this yield would be increased by 20-30 percent.

The proportion of unfished biomass that was left when fishing mortality equaled that necessary to take the maximum yield per recruit increased from 24-28 percent to 30-32 percent when mesh size increased from 90 m to 128 mm (Table 5.7.1).

Yield per recruit isopleths are given for each mesh size in Figure 5.7.1. The feature evident in these graphs that is not evident in the tables is the shape of the yield per recruit isopleths. Isopleths are peaked for smaller mesh sizes, especially for yield per recruit in landed value. As the mesh size increases, yield per recruit curves become asymptotic. This indicates that the potential for overfishing (in terms of yield per recruit) is greater for smaller than for larger mesh sizes. Using larger mesh sizes would be risk averse strategy on this metric. However, larger mesh sizes require higher fishing mortality and presumably (it is not explicitly modeled in these analyses) higher fishing effort. Higher fishing effort could have its own environmental impacts resulting from increased bottom contact time, especially if increased effort leads to opening up new grounds or expanding current fishing grounds.

Table 5.7.1 Maximum yield per recruit, effort maximizing yield per recruit and proportion of unfished biomass at effort maximizing yield per recruit for various trawl mesh sizes for all species in MSYPR and for all species without redfish.

		Mesh size (mm)					
Units	Species	90	103	115	128	140	153
		Maximum YPR					
Weight (kg)	All	0.95	1.01	1.05	1.07	1.07	1.07
	no redfish	0.84	0.89	0.93	0.95	0.96	0.96
Value ($)	All	1.83	1.97	2.07	2.13	2.15	2.15
	no redfish	1.72	1.85	1.95	2.01	2.03	2.04
		Fishing effort maximising YPR					
Weight (kg)	All	0.12	0.16	0.22	0.34	0.62	1.00
	no redfish	0.12	0.16	0.22	0.32	0.56	0.98
Value ($)	All	0.10	0.12	0.18	0.28	0.50	0.90
	no redfish	0.10	0.12	0.18	0.28	0.46	0.84
		Proportion of unfished biomass at effort maximising YPR					
Weight (kg)	All	0.24	0.26	0.28	0.30	0.31	0.34
	no redfish	0.25	0.26	0.28	0.30	0.31	0.31
Value ($)	All	0.28	0.30	0.31	0.33	0.34	0.35
	no redfish	0.28	0.31	0.31	0.32	0.33	0.33

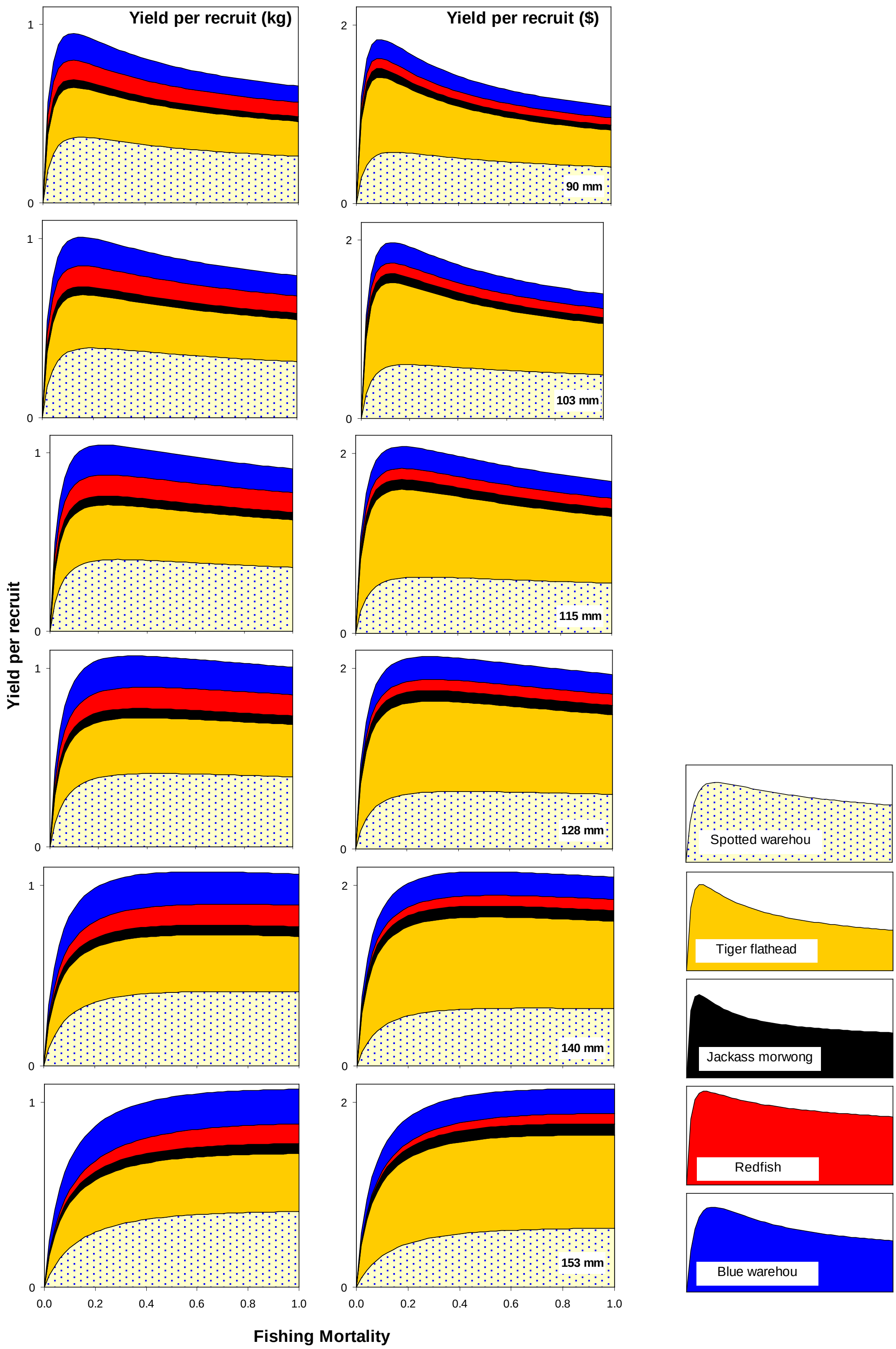


Figure 5.7.1. Individual and combined yield per recruit isopleths for five species (y-axis) over a range of fishing mortalities (x-axis). Separate graphs for species (lower right) show shape of yield per recruit curve for 90 mm mesh.

5.7.2 Yield per recruit as a function of trawl and gillnet mesh size

Yield per recruit estimates were made for three scenarios:

- trawl mesh sizes from 90 to 153 mm, the current 6 inch gillnet mesh, standardized fishing mortalities for all trawl-caught species, plus 3 levels of gillnet fishing mortality;
- trawl mesh sizes from 90 to 153 mm, a reduced 5 inch gillnet mesh, standardized fishing mortalities for all trawl-caught species, plus 3 levels of gillnet fishing mortality;
- trawl mesh sizes from 90 to 153 mm, a reduced 5 inch gillnet mesh, fishing mortalities set at multiples of those currently estimated for all trawl-caught species, plus 3 levels of gillnet fishing mortality.

A 5-inch gillnet mesh size was tested because selectivity of 6-inch gillnet mesh is quite low for blue warehou and lower again for jackass morwong. Fishing with the current 6-inch gillnet mesh size had little impact on trawl yield per recruit computations with standardized fishing effort.

Fishing mortality is typically the same for all species in a multi-species yield per recruit, partly as a way to keep the possible number of combinations of fishing effort at a manageable number. An alternative approach is to assume that fishing mortalities keep their current relativity – currently estimated fishing mortalities for all species are all adjusted up or down by a set multiple. In this manner, the effects of uniformly increasing or decreasing current fishing mortalities can be examined. Results for a 5 inch mesh gillnet fishery are shown. Results for a 6 inch gillnet fishery were similar, but not as pronounced.

5.7.2.1 Standardised trawl fishing mortality and 6 inch gillnet mesh

Biomass yield per recruit for the current combined fisheries – 6-inch mesh gillnet and trawl – is greater than that for the gillnet fishery alone, but only marginally (about 1 percent) larger than that taken with by the trawl fishery alone (Table 5.7.2). Monetary yield per recruit is again only slightly higher than the trawl fishery alone (about 2 percent). Maximum yield per recruit continues to increase gradually with mesh size (Figure 5.7.2).

The fishing mortality required to take the maximum yield per recruit increases substantially with mesh size (Table 5.7.3). It is slightly lower for the combined fisheries than for the trawl fishery alone, especially at higher levels of gillnet fishing mortality and lower trawl mesh sizes.

Yield per recruit slopes continue to be domed at lower trawl mesh sizes, but asymptotic at larger mesh sizes (Fig 5.7.2).

Table 5.7.2 **Maximum yield per recruit for the five species over a range of trawl mesh sizes at various fishing mortality levels for the current 6- inch gillnet mesh size.**

Gillnet		Maximum YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.95	1.01	1.05	1.07	1.07	1.07
	Combined	0.95	1.01	1.05	1.07	1.07	1.07
0.25	Gillnet	0.12	0.12	0.12	0.12	0.12	0.12
	Trawl	0.94	1.00	1.04	1.07	1.07	1.07
	Combined	0.95	1.01	1.05	1.07	1.07	1.07
0.50	Gillnet	0.14	0.14	0.14	0.14	0.14	0.14
	Trawl	0.94	1.00	1.04	1.07	1.07	1.07
	Combined	0.96	1.01	1.05	1.07	1.07	1.07
		Maximum YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	1.83	1.97	2.07	2.13	2.15	2.15
	Combined	1.83	1.97	2.07	2.13	2.15	2.15
0.25	Gillnet	0.17	0.17	0.17	0.17	0.17	0.17
	Trawl	1.82	1.96	2.07	2.13	2.15	2.15
	Combined	1.85	1.98	2.08	2.13	2.15	2.15
0.50	Gillnet	0.21	0.21	0.21	0.21	0.21	0.21
	Trawl	1.81	1.96	2.06	2.13	2.15	2.15
	Combined	1.85	1.98	2.08	2.13	2.15	2.15

Table 5.7.3 **Trawl fishing mortality maximising yield per recruit of 5 species for gillnet (only 2 of the 5 species caught), trawl and the combined gears for a range of trawl mesh sizes and 3 fishing mortality levels for the current 6-inch gillnet mesh.**

Gillnet		F maximisng YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.12	0.16	0.22	0.34	0.62	1.00
	Combined	0.12	0.16	0.22	0.34	0.62	1.00
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.12	0.16	0.22	0.36	0.62	1.00
	Combined	0.12	0.14	0.22	0.34	0.62	1.00
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.12	0.16	0.24	0.36	0.62	1.00
	Combined	0.10	0.14	0.22	0.34	0.62	1.00
		F maximising YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.10	0.12	0.18	0.28	0.50	0.90
	Combined	0.10	0.12	0.18	0.28	0.50	0.90
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.10	0.14	0.18	0.30	0.50	0.90
	Combined	0.08	0.12	0.18	0.28	0.50	0.90
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.10	0.14	0.20	0.30	0.50	0.90
	Combined	0.08	0.12	0.18	0.28	0.50	0.90

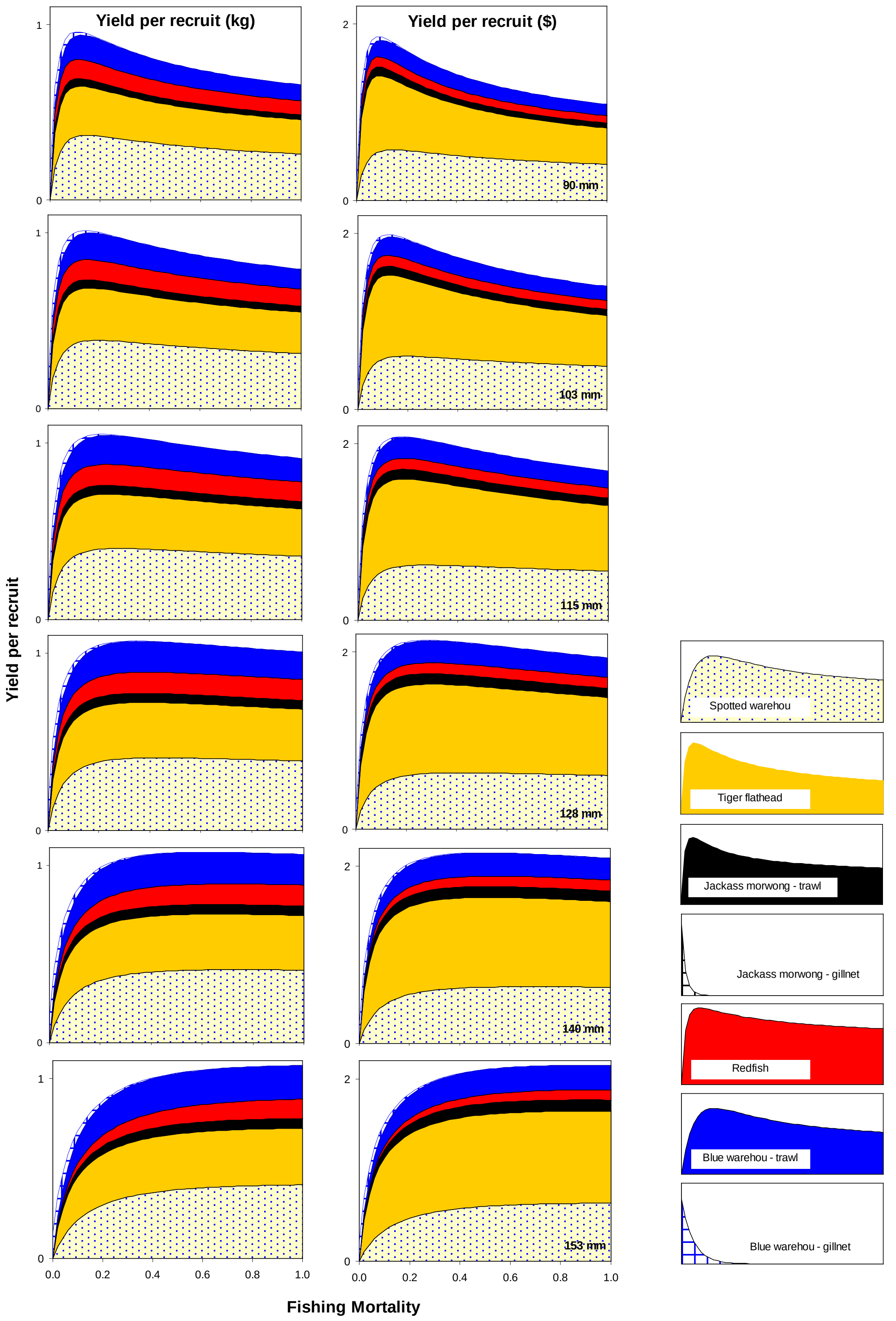


Figure 5.7.2. **Individual and combined yield per recruit isopleths for five species with trawl and 6-inch gillnet (F gillnet =0.5). Separate graphs for species (lower right) show shape of yield per recruit curve for 90 mm mesh.**

5.7.2.2 Standardised trawl fishing mortality and a reduced 5 inch gillnet mesh

Yield per recruit for the combined trawl and 5-inch mesh gillnet fishery were approximately 5 percent higher than that for the trawl fishery alone for higher gillnet fishing mortalities and current trawl mesh sizes (Table 5.7.4). The increased yield from the combined fishery disappeared at higher trawl-mesh sizes.

Trawl fishing mortalities required to reach maximum yield per recruit were about 20 percent lower for the combined fishery than the trawl fishery alone. This effect remained for all mesh sizes (Table 5.7.5).

The yield per recruit with the gillnet dropped much more rapidly with increased fishing effort than the yield per recruit for the trawl (Fig. 5.7.3). This is due to the removal of the larger fish susceptible to the gillnet at higher levels of fishing mortality in the trawl fishery.

Table 5.7.4 **Maximum yield per recruit for the five species over a range of trawl mesh sizes at various fishing mortality levels for a reduced 5- inch gillnet mesh size.**

Gillnet F	Fishery	Maximum YPR (kg) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.95	1.01	1.05	1.07	1.07	1.07
	Combined	0.95	1.01	1.05	1.07	1.07	1.07
0.25	Gillnet	0.23	0.23	0.23	0.23	0.23	0.23
	Trawl	0.92	0.98	1.03	1.05	1.06	1.05
	Combined	0.97	1.02	1.05	1.07	1.07	1.07
0.50	Gillnet	0.25	0.25	0.25	0.25	0.25	0.25
	Trawl	0.91	0.97	1.02	1.05	1.06	1.04
	Combined	0.97	1.02	1.05	1.07	1.07	1.07
		Maximum YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	1.83	1.97	2.07	2.13	2.15	2.15
	Combined	1.83	1.97	2.07	2.13	2.15	2.15
0.25	Gillnet	0.38	0.38	0.38	0.38	0.38	0.38
	Trawl	1.77	1.92	2.03	2.10	2.12	2.11
	Combined	1.87	1.99	2.08	2.13	2.15	2.15
0.50	Gillnet	0.41	0.41	0.41	0.41	0.41	0.41
	Trawl	1.75	1.90	2.01	2.08	2.10	2.09
	Combined	1.88	2.00	2.09	2.13	2.15	2.15

Table 5.7.5 Trawl fishing mortality maximizing yield per recruit of 5 species for gillnet (only 2 of the 5 species caught), trawl and the combined gears for a range of trawl mesh sizes and 3 fishing mortality levels for a reduced 5-inch gillnet mesh.

Gillnet		F maximisng YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.12	0.16	0.22	0.34	0.62	1.00
	Combined	0.12	0.16	0.22	0.34	0.62	1.00
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.14	0.18	0.26	0.42	0.72	1.00
	Combined	0.10	0.14	0.20	0.34	0.60	1.00
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.14	0.20	0.28	0.44	0.76	1.00
	Combined	0.10	0.14	0.20	0.34	0.60	1.00
		F maximising YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.10	0.12	0.18	0.28	0.50	0.90
	Combined	0.10	0.12	0.18	0.28	0.50	0.90
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.10	0.14	0.22	0.34	0.58	1.00
	Combined	0.08	0.12	0.18	0.28	0.48	0.90
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.10	0.14	0.22	0.36	0.62	1.00
	Combined	0.08	0.12	0.16	0.28	0.48	0.88

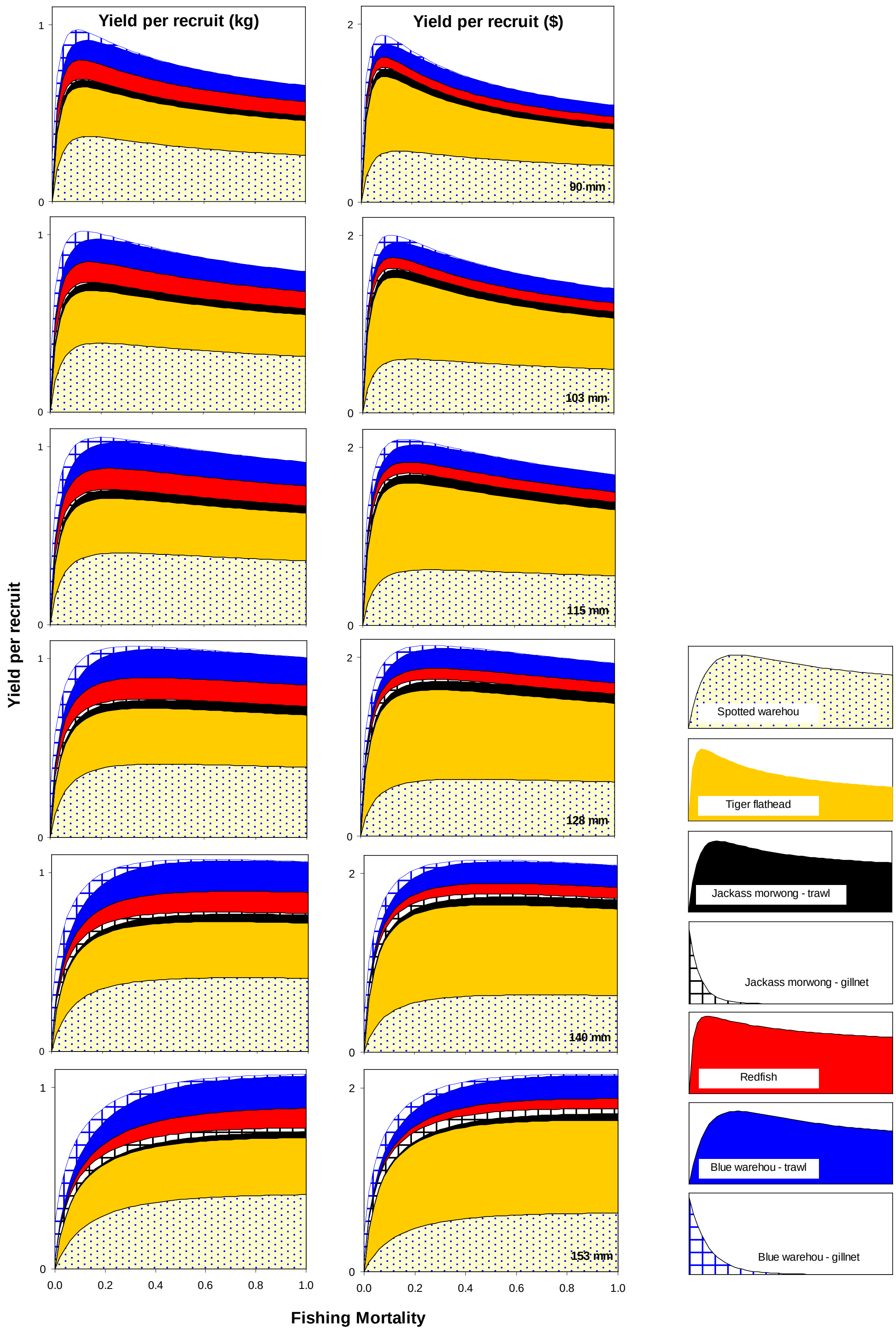


Figure 5.7.3. Individual and combined yield per recruit isopleths for five species with trawl and 5-inch mesh gillnet (F gillnet =0.5). Separate graphs for species (lower right) show shape of yield per recruit curve for 90 mm mesh.

5.7.2.3 *Multipliers of current trawl fishing mortality and a reduced 5 inch gillnet mesh*

Maximum yield per recruit for the combined fishery is 6–9 percent greater than that of the trawl fishery alone for the current 90 mm trawl mesh size and gillnet fishing mortalities of 0.25 and 0.50 (Table 5.7.6). The increased catch from the combined fishery declines as the trawl mesh size increases.

The fishing effort required to reach maximum yield at current mesh sizes is from 12-20 percent of current effort, depending on the whether biomass or monetary value is to be maximized, and the level of gillnet fishing effort (Table 5.7.7). Only at the largest mesh sizes (>140 mm) would an increase in fishing effort be required to maximize yield per recruit. Maximizing monetary yield per recruit requires a greater reduction in current fishing effort than maximizing biomass yield per recruit.

The smaller the mesh size, the more rapidly that yield per recruit drops as a result of fishing mortality exceeding the optimum level (Fig. 5.7.4).

Table 5.7.6 Maximum yield per recruit for the five species over a range of trawl mesh sizes and multipliers of current fishing mortality over three fishing mortality levels for a 5- inch gillnet mesh size.

Gillnet F	Fishery	Maximum YPR (kg) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.92	0.98	1.02	1.04	1.04	1.03
	Combined	0.92	0.98	1.02	1.04	1.04	1.03
0.25	Gillnet	0.23	0.23	0.23	0.23	0.23	0.23
	Trawl	0.89	0.96	1.00	1.02	1.03	1.01
	Combined	0.94	0.99	1.03	1.04	1.04	1.03
0.50	Gillnet	0.25	0.25	0.25	0.25	0.25	0.25
	Trawl	0.88	0.94	0.99	1.02	1.02	1.00
	Combined	0.95	1.00	1.03	1.04	1.04	1.03
		Maximum YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	1.81	1.94	2.05	2.10	2.11	2.10
	Combined	1.81	1.94	2.05	2.10	2.11	2.10
0.25	Gillnet	0.38	0.38	0.38	0.38	0.38	0.38
	Trawl	1.74	1.89	2.00	2.06	2.07	2.06
	Combined	1.85	1.98	2.06	2.10	2.11	2.10
0.50	Gillnet	0.41	0.41	0.41	0.41	0.41	0.41
	Trawl	1.71	1.86	1.98	2.04	2.05	2.03
	Combined	1.86	1.98	2.06	2.10	2.11	2.10

Table 5.7.7 Multipliers of trawl fishing mortality maximizing yield per recruit of 5 species for gillnet (only 2 of the 5 species caught), trawl and the combined gears for a range of trawl mesh sizes and 3 fishing mortality levels for a reduced 5-inch gillnet mesh.

Gillnet		Multiplier of current F maximisng YPR (kg) by mesh size (mm)					
F	Fishery	90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.20	0.24	0.36	0.52	0.96	1.72
	Combined	0.20	0.24	0.36	0.52	0.96	1.72
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.20	0.28	0.40	0.64	1.12	2.00
	Combined	0.16	0.20	0.32	0.52	0.92	1.72
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.24	0.32	0.44	0.72	1.24	2.00
	Combined	0.16	0.20	0.32	0.52	0.92	1.72
		Multiplier of current F maximising YPR ($) by mesh size (mm)					
		90	103	115	128	140	153
0.00	Gillnet	N/A	N/A	N/A	N/A	N/A	N/A
	Trawl	0.12	0.20	0.28	0.40	0.68	1.24
	Combined	0.12	0.20	0.28	0.40	0.68	1.24
0.25	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.16	0.20	0.32	0.48	0.84	1.48
	Combined	0.12	0.16	0.24	0.40	0.68	1.20
0.50	Gillnet	0.00	0.00	0.00	0.00	0.00	0.00
	Trawl	0.16	0.20	0.32	0.52	0.92	1.60
	Combined	0.12	0.16	0.24	0.40	0.68	1.20

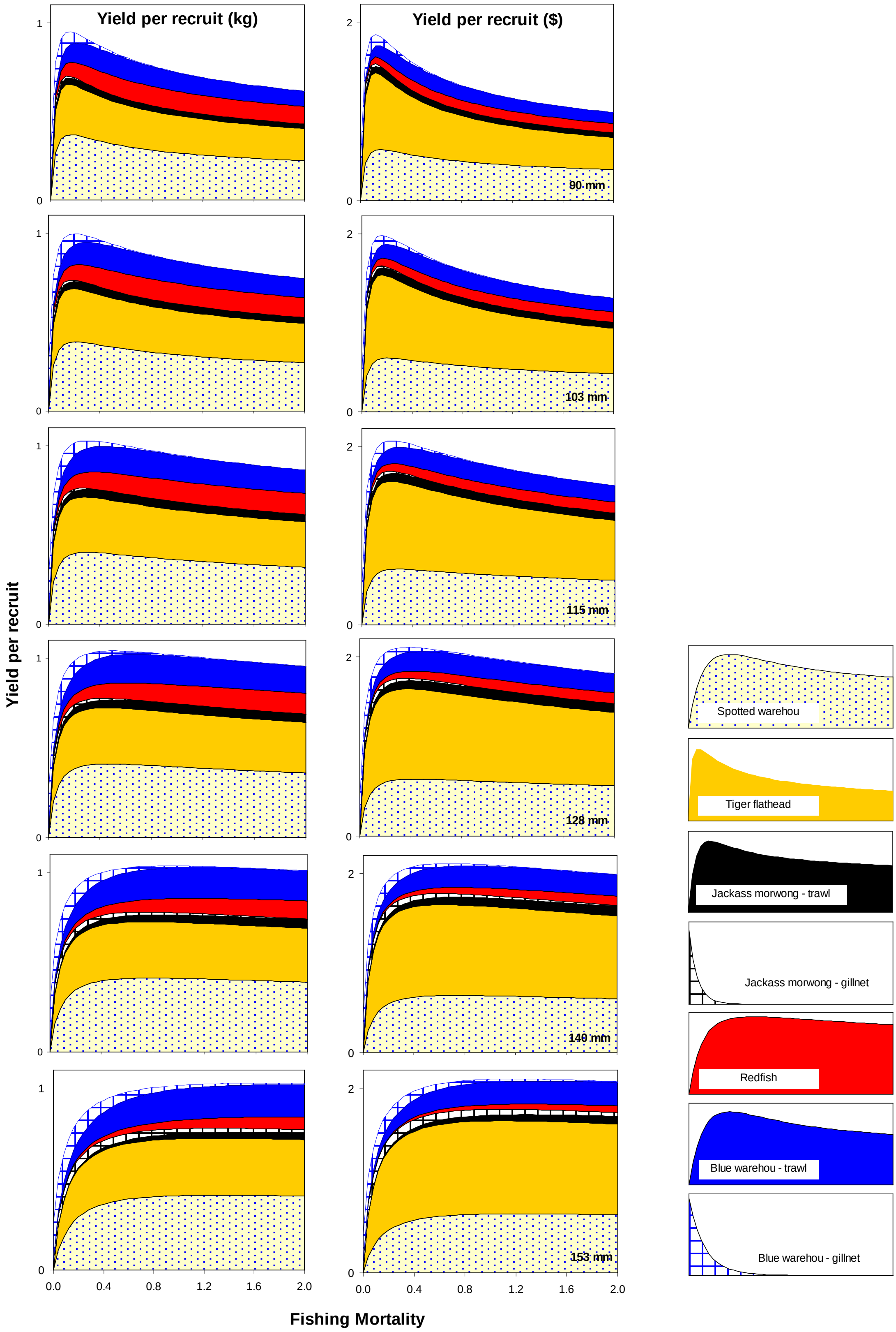


Figure 5.7.4. Yield per recruit isopleths for five species with trawl and 5-inch mesh gillnet (F gillnet =0.5), where fishing mortality is represented as a multiplier of current fishing mortality. Separate graphs for species (lower right) show shape of yield per recruit curve for 90 mm mesh.

5.7.3 Discussion

Data demands increase commensurately with model sophistication. There were sufficient earlier studies and/or biological data to estimate selectivity for 13 quota species, and 13 non-quota species. Single species yield per recruits could be estimated for 11 of the quota species. Multi-species yield per recruit could be estimated for only 5 species (although this number is reduced in part because of the choice of geographic areas). And the additional data required for the more sophisticated models is typically not well estimated. This is particularly the case in multi-species models. Multi-species yield per recruit, has the advantage over multi-species trophodynamic modeling (through assuming that biological interactions are negligible) of not requiring the estimation of biological interactions – there are n^2 biological interactions, where n represents the number of biological components in the system. However, even the estimation of the n=5 estimates of relative recruitment strength, was stretching the available data to its limit – using the output from stock assessment models over which the stock assessment scientists have considerable misgivings. In fact the sixth species (school whiting) was dropped from the analysis in part because the abundance estimates were not credible.

Given the above caveats, the multi-species yield per recruit analyses again indicated that yields would be maximized by increasing mesh size without limit over the range of mesh sizes examined (90-153 mm). However, the fishing effort required to take this yield increased with increasing mesh size making it impractical for the larger mesh sizes. In practical terms therefore, it is likely that a combination of larger mesh size and reduced fishing mortality is required to achieve optimal yield per recruit in the trawl fishery. For several of the species (tiger flathead, redfish and spotted warehou) fishing mortalities are already considerably above the level required to maximize the yield at higher mesh sizes. Estimated fishing mortalities for blue warehou and jackass morwong are at about the level that would maximize the multi-species yield at current mesh sizes, so fishing mortality on these two species would have to be increased to achieve maximum yield per recruit at the larger mesh sizes.

Interestingly fishing mortality for blue warehou and jackass morwong might be underestimated, as they are also taken by the gillnet fishery. Increased gillnet fishing mortality would seem to provide an option to selectively increase the fishing mortality on these two species. This option was tested in the multi-species and multigear yield per recruit analyses. There was a negligible increase in monetary yield per recruit as fishing effort with the gillnet increased and no increase in the biomass yield per recruit. This is partly because yields of blue warehou and jackass morwong are not optimized with the current 6 inch gillnet mesh. If gillnet mesh size was reduced to 5 inches, a still small but noticeable (~2 percent) increase in combined yields could occur.

A shortcoming of the standard multi-species yield per recruit approach is that the same fishing mortality is applied to all species fished with the same gear. It is assumed that all species are fished to the same degree. No account is taken of local availability or targeting that is or could operate in the fishery.

If we take the current levels of fishing mortality estimated for the trawl fishery as the baseline and compute maximum yield per recruit as multiples of this effort a different pattern emerges. Maximum yield per recruit from the trawl fishery alone is reduced (because fishing mortality on some species is too high), and the addition of a 5-inch mesh gillnet fishery that targets jackass morwong and blue warehou can increase yields by 6–9 percent or more for current trawl mesh sizes. The multiplier of current trawl fishing effort that leads to maximum biomass yield per recruit at current mesh sizes is about 12 to 20 percent of current fishing mortality. An increase of fishing mortality would only be necessary to maximize biomass yield per recruit if mesh sizes increased above 140 mm. If the gillnet mesh size remained at 6 inches, the increase in the yields of the combined fishery is approximately half that obtained from the 5 inch gillnet fishery (results not shown).

There are many aspects of the biology of the fish species, their interaction with the environment, and the behavior of fishers that will affect catches. Discard rates, total catch and ecological indices can be related to temporal (year, month), spatial (geographical and depth), and operational (primary species sought, cod-end mesh size, vessel size, tow duration, total catch, total discards) factors (Murawski 1996). In addition changing year class strengths of fish in a fishery will change many of the operational factors. We have shown here that one way of increasing yield per recruit is to combine a selective gillnet fishery with the current trawl fishery. There will be many other ways in which yields could also be increased. However, given that currently estimated fishing mortalities are 4-5 times higher than that required to take maximum yield per recruit at the current mesh size (6-8 times higher if the objective is maximize monetary yield per recruit), the most obvious gains to be made in the fishery would come from a combination of reduced fishing mortality and/or increased mesh size.

6 BENEFITS

The prime beneficiaries of this research will be the commercial fishing industries of the SEF, primarily the trawl and gillnet operators. Results from this work have already informed management decisions made by the AFMA Board and have been directly used by assessment groups assessing SEF species.

Benefits will most likely be accrued through improved management strategies to increase the biological and economic yield from the different fisheries. The amount of these benefits is difficult to estimate because it will depend on the management options that are available and enforceable. Options, including decreasing the mesh size of the gillnet fishery, increasing the mesh size of the trawl fishery and above all reducing the trawl fishing mortality all have the potential to increase biological and especially economic yield from the fishery. Decreasing fishing mortality would have flow-on effects by reducing the level of fishing effort and the attendant environmental impacts through discarded bycatch, habitat impact and fossil fuel use.

In addition to the potential benefits to improved fishery management, this project also has had, and will continue to have, direct benefits to the stock assessment process. Biological data collected for the project has already been used to improve the stock assessments of SEF fish. In addition, the extrapolation of trawl selection to other species, based on body shape has been directly used in assessments, where data are insufficient to estimate selectivity in the assessment itself. The data, relationships and results from this project are being used to assist implementation of FRDC Project 98/204 *Maximising yield and reducing discards in the South East Trawl Fishery through gear development and evaluation* (Ian Knuckey PI).

The efficient and selective capture of fish is one of the mainstays of ecologically sustainable development. This project provides part of the information from which to design such a strategy, however, it also clear that more sophisticated approaches will be necessary to represent the spatial and temporal diversity of fishing practices, if changes in fishing strategy are to be successful.

7 FURTHER DEVELOPMENT

Single and multi-species yield per recruit analyses are sensitive to growth, natural mortality, relative recruitment strengths and the selectivity of the gear for different species. Previously accepted biological parameters used were updated as part of this study. Updating parameters has led to fundamental changes in the conclusions from this study (which must temper the enthusiasm with which we promote the results). Further investigation of basic biological parameters (especially for smaller sizes of fish not sampled well by the commercial fishery) is needed to provide a reliable basis of knowledge for the increasingly sophisticated assessment modeling used in providing management advice.

Targeted surveys are needed to ensure the reliability of current biological parameters, and to define any seasonal or spatial bias in their estimation. Natural mortality estimates are a crucial component of stock assessment and will be improved as part of that process. Relative recruitment strengths can be estimated under several different assumptions (eg. based on research survey data or on the basis that current TACs are representative of stock size and productivity). The most reliable method, and the one used in the assessment, is to estimate relative recruitment strengths from assessment results. MSYPR using this approach, is currently limited in the SEF by the number of species that have reliable stock assessments. Comparison of the relative recruitment strengths from different (admittedly preliminary) stock assessments showed their inconsistency. In particular the relative recruitment strength of school whiting was much higher (relative to other species) than was reasonable – either the numbers at age are overestimated in the assessment, or selectivity is overestimated. Extension of robust stock assessment methods to the majority of SEF species is required if analytical multi-species approaches are to have general applicability in the SEF.

In contrast, improving mesh selectivity estimates by direct field experiments is relatively straightforward. The recent trawl selectivity estimates from the SEF Bycatch study (FRDC Project 98/204) and the gillnet selectivity estimates from the SEF Ecosystem study (FRDC project 94/040) were essential in estimating selectivity for use in this study. Comparison of these results with results from earlier studies in Australia and New Zealand showed considerable spread in selectivity estimates. Further selectivity studies are needed to resolve these, improve selectivity estimates and determine how they change with fishing conditions – vessel, gear, depth, etc. Data on gillnet, trap and longline selectivity for ling are needed, perhaps through the SENT observer study. Multigear effects might be expected to be especially noticeable for ling, which are caught with trawl, gillnet, traps and autolongline.

There are many difficulties in developing the parameter estimates needed for MSYPR, however even in this first analysis, advances have been made in using information from one species to gain (or infer) information about other species for which data are lacking. The most obvious example of this is extending mesh selectivity estimates from species for which field trials are available to other species based on body morphology. Further development of multi-species assessment techniques is required that:

1. Uses parameter estimates from robust assessments to add information to developing assessments;

2. Uses additional information (eg. relative abundance and changes in relative abundance indices) to constrain assessments so that they are consistent with one another and with multi-species indicators;

3. Includes the dynamics of the fishing fleets in addition to the biological dynamics, so that advice from multi-species assessments has practical impacts; and

4. Includes the impacts of changes in TACs, and input controls (mesh size, quota transfer, spatial management of effort, ground gear, vessel size, etc.) on the dynamics of the individual species, market value, and environmental impacts (eg. bottom time, bycatch, fossil fuel use).

8 PLANNED OUTCOMES

Planned outcomes for this project were:

1. *The maximum age growth, physical dimensions and rage of natural mortality will have been estimated for quota species and other significant commercial species for the SEF fisheries*.

   Biological data (including, age, growth, physical dimensions, life history and market value) were collected for most quota species, 8 non-quota species and limited data were obtained for 6 supplemental species.

2. *The selectivity of the different types of gear used in the SEF will have been estimated based on prior research data and theoretical studies.*

   Gillnet selectivity was estimated for 4 quota species and 1 non-quota species. The dependence of selectivity on depth and habitat was demonstrated and standard approaches to estimating selectivity updated to incorporate a more appropriate error structure.

   It was harder to find suitable data to estimate trawl net selectivity. In a first attempt, >3.9 million individual lengths and associated gear definitions were obtained from the states of Tasmania, Victoria, New South Wales, from CSIRO and New Zealand. Unfortunately there was too much noise in these data (different vessels, depths, geographic areas, nets) and the models developed for estimating selectivity could not be fitted. As an alternative, selectivity data from ongoing selectivity trials (FRDC Project 98/204) were added to selectivity data from three previous studies in the SEF and ten previous studies in New Zealand. A relationship between the exponent of the length/girth relationship and selectivity parameters was developed to extend selectivity estimates to species for which no selectivity data were available. Selection factors for 13 quota species and 13 non-quota species were estimated.

3. *The aggregate harvesting selectivity of defined fisheries in the SEF will have been estimated, where a fishery is area-specific and may be a mix of different types of gears*.

   Availability of fish to the commercial trawl fishery was compared to the underlying length distributions determined from research trawling for six species off eastern Victoria and southern New South Wales. Discards for the same species and areas were described, and the selectivity of the commercial fleet compared to that expected based on research surveys and estimated selectivity of the commercial fleet.

   Single, multi-species and multigear yield per recruit estimates were completed for the inshore fisheries off southern NSW and Victoria. These were the only species for which survey data were available to estimate relative availability of the different species. Single species yield per recruit analyses were completed for 12 quota species.

4. *Alternative mixes of commercial gear and configurations of that gear will be tested to determine whether it is possible to use an alternative capture strategy to improve the biological and economic yield from the fishery.*

Alternative mixes of the trawl (mesh sizes 90, 103, 115, 128, 140 and 153 mm) were tested for maximum biomass and monetary yield per recruit, and the effort required to achieve that yield. Yield per recruit for the gillnet (mesh sizes 4, 5, 6, 7, 8, and 9 inch) was determined for blue warehou and jackass morwong. Yields from alternative mixes of trawl and gillnet effort were explored using a variety of mesh sizes. The proportion of the spawning population remaining under different conditions was also tested. Following a request from AFMA, the effect of fishing different depths on yield per recruit of redfish was evaluated.

5. *A workshop will have been held under the sponsorship of SEFAG to determine the applicability of the generated results and to generate alternative scenarios that might improve yields of improve likelihood of adoption by industry.*

   Results and findings from this project were used in a SEFAG workshop to define FRDC Project 98/204 *Maximising yield and reducing discards in the South East Trawl Fishery through gear development and evaluation* (Ian Knuckey PI). Project 98/204 was established as the best approach to increase the chances of successful adoption of the results of these studies by industry.

6. *The project will be written up and presented at an industry workshop and submitted to a journal.*

   Results from this project have been overtaken by the more specific results of Project 98/204 that has been extensively presented at industry workshops. Results from this project have been adopted by assessment groups and been provided to AFMA to assist with ongoing management of the SEF. One journal article has resulted from this project to date.

9 CONCLUSION

Data: The data needs of single species fisheries assessment models have yet to be met for even the SEF quota species. Multi-species models generally require these data plus the data required to estimate the species interactions (technical or biological). Data were both the main limitation to this project and one of the main products. Over 2,500 length and girth measurements were collected for 14 SEF quota species, plus 8 of the most common bycatch species. These data were to prove essential for extrapolating selectivity curves from species to species. Growth data from existing collections, supplemented by special collections were collated for 13 SEF quota species. These data were essential for yield per recruit computations, and were used to provide an estimate of natural mortality where none was available from assessments. These data are now being used in SEF stock assessments. Size categories and market value 14 SEF quota species were from fish markets and fisherman's cooperatives. These data led to alternative interpretations of yield per recruit results, by looking at landed value instead of landed biomass.

A key data need in yield per recruit curves (and stock assessments) is the shape of selection curve for each species by gear type (*Objective 2: Determine selectivity of the major fisheries in the SEF, taking account of the mix of gear types and areas fished*). These data are generally missing for SEF species. There were sufficient data to estimate gillnet selectivity curves for 5 shelf quota species from multi-panel experimental gillnet sampling – part of the SEF Ecosystem Study (FRDC Project 94/040), analysed by Cui et al. (2001). These results were combined with earlier results using a similar multi-panel gillnet to provide selectivity curves for 7 SEF species. Forty four percent of the variation in selection factor (size at 50% selection/mesh size) was explained by the exponent of the length/girth relationship. There was no relationship between this exponent and the selection range factor (size range from 25-75% selection/mesh size). In both cases, there was considerable spread from different studies for the same species. Cui et al. (2001) found that gillnet selectivity varied by depth and sometimes habitat type. While variable, these results provide a means to estimate selectivity of the gillnet for species not part of these gillnet trials. Selectivity parameters for jackass morwong and blue warehou used in these analyses were taken from experiments on rough ground 80-240 m.

Selectivity data for the trawl were harder to find. Initial attempts to estimate relative selectivity from >3.9 million available (but dispersed) trawl records from the States of Tasmania, Victoria, and New South Wales, CSIRO and New Zealand were unsuccessful – the effects of area, agency, vessel, skipper and gear dominated the data set and selection parameters could not be estimated. Fortunately, FRDC Project 98/204 estimated absolute selectivity of SEF shelf quota species using covered cod-end experiments, and this project was extended to make use of those data. Results from FRDC Project 98/204 were combined with earlier estimates of trawl selection from covered cod-end and alternate haul studies by Victorian and NSW fisheries, and from New Zealand researchers. In order to extrapolate to species not included in these studies, the relationship between the exponent of the length weight relationship and the 50% and 25% selection factors was examined. This relationship explained 65 and 51% of the variability, respectively, with much of the unexplained variability occurring within species (from different studies). Variability of estimates seemed especially high for slender-bodied species. The slope of the length girth relationship explained 85% of the variability in the selection range factor.

Relative abundance estimates needed for multi-species comparisons were obtained from existing assessments. The only area of the fishery where assessments (or preliminary assessments) were available for the major quota species was on the shelf off Eastern Victoria and southern New South Wales. Multi-species yield per recruit analyses were restricted to those six species (subsequently reduced to five species when the relative abundance data for school whiting were considered unbelievable).

Fishery: A feature common to many SEF quota species is an increase in size with depth. Length frequency compositions from recent trawl surveys off New South Wales (NSW Fisheries) and Eastern Victoria (CSIRO) were collated and compared with the size composition of commercial catches and discards from the same areas and depth zones (ISMP records 1996-1999). Fish in commercial catches were larger than those in scientific survey (blue warehou, school whiting and redfish). For tiger flathead and jackass morwong, fish caught by the commercial sector were generally larger than those caught in the scientific survey except for very shallow sites (tiger flathead) or southern sites (jackass morwong). Thus there is general tendency for larger fish to be caught by the commercial sector (90mm cod-end mesh size) than the in scientific surveys (40mm cod-end mesh size). However, this selectivity for larger fish is insufficient to prevent discarding of smaller fish which averaged 5, 14, 4, 14, 4 and 8% of total catch for (blue warehou, tiger flathead, jackass morwong, redfish, school whiting and spotted warehou) respectively. Discarding was generally reduced in deeper waters, reflecting the general trend to increased sizes with depth. These results indicate that discarding of smaller fish from shelf quota species could be concentrating fishing effort in deeper water, bearing in mind that at times specific fisheries develop in shallower waters.

Selection parameters estimated from covered cod-end trials were used to estimate the effective mesh size of the commercial trawl fishery, by estimating those parameters that gave the best fit between the commercial and survey catches (survey catches used 40mm cod-end mesh size and were assumed to provide an unbiased sample of the population). With the possible exception of redfish, there was little indication that the effective mesh size of the commercial fleet was less than the 90mm legal cod-end mesh size. In most cases, estimated effective mesh size was >>90mm.

Single species yield per recruit: There were sufficient data to fit yield per recruit curves to 11 of the SEF quota species (*Objective 1: Determine size (age) at capture for the main commercial species in the SEF that would maximize their biologic and economic yield, especially for the quota species*). Yield per recruit increased at mesh sizes larger than that currently used in the SEF (90mm), especially at higher levels of fishing mortality. Increased yields with increased mesh size were especially clear for ling, gemfish, Eastern school whiting, jackass morwong, ocean perch (deep), blue warehou, tiger flathead, blue grenadier and spotted warehou. Yield per recruit peaked at intermediate mesh sizes for tiger flathead, blue grenadier and redfish. However, the fishing effort required to produce maximum yield per recruit was higher for larger mesh sizes, indicating that the yield per recruit in dollar terms might decrease with larger mesh sizes, once operating costs were included.

Yield per recruit for most species peaked at intermediate effort levels. Reduced yield per recruit at higher fishing effort was especially noticeable for ling, gemfish, Eastern school whiting, jackass morwong and ocean perch (deep). Species such as jackass morwong, tiger flathead, ling, Eastern school whiting, blue and spotted warehou showed decreased yield per recruit at higher effort levels for small mesh sizes but no decrease at larger mesh sizes, indicating that increased mesh sizes would afford these species protection against growth overfishing. Blue eye trevalla showed little change in yield with mesh size. Typically, the effort maximizing yield per recruit in biomass also maximized yield per recruit in landed value. The exceptions were spotted warehou and ocean perch (deep), where lower fishing effort was required at larger mesh sizes to maximize landed value yield per recruit.

Yield per recruit for jackass morwong and blue warehou were compared for gillnet and trawl (*Objective 3: Evaluate success of alternative gear mixes (type and configuration), maximising overall biologic and economic yield for selected fisheries*). Maximum yield per recruit in biomass is higher for the gillnet than the trawl for blue warehou (at the mesh sizes tested) and vice versa for jackass morwong. However, if gillnet mesh sizes were reduced to 5 inch, while trawl mesh sizes remained the same yields could be up to 20 percent higher with the gillnet. Effort at maximum yield per recruit for the trawl leads to egg production at 18% of the egg production for an unfished stock; for the gillnet it is 48 percent for 5 inch mesh and 75 percent for the current 6 inch mesh (with has a low associated yield per recruit.). These differences in yield per recruit indicate that transfer of quota between the sectors will result in changed fishing mortality.

Examining yield per recruit in a combined fishery of trawl (90 mm cod-end mesh) and gillnet (6 inch mesh) indicates that yield per recruit for blue warehou and jackass morwong would be maximized by minimizing trawl fishing mortality, assuming that gillnet fishing mortality was high enough. However, this analysis treats each species in isolation from other species. Multi-species analysis is needed to look at a broader perspective.

Yield per recruit for redfish could be increased very slightly by concentrating all effort deeper than 60 m depth, for the current 90 mm mesh size. However, the fishing mortality required to take this yield increases.

Multi-species yield per recruit: Multi-species yield per recruit in biomass and landed value was maximized at the trawl cod-end mesh sizes of at least 128 mm, being 10 percent higher than that for the current mesh size (90 mm). However, fishing mortality required to take this yield was almost double that for the current mesh size. The proportion of unfished biomass remaining at the point of maximum yield per recruit was about 25 percent higher at a mesh size of 128 mm compared to that at a mesh size of 90 mm. Larger mesh sizes reduced the loss in yield per recruit when fishing mortalities exceeded that needed to take the maximum catch.

Multi-species yield per recruit for the two fisheries – gillnet and trawl – is slightly larger than for either fishery alone, however the increase over maximum yield per recruit for the trawl alone is only slight (1-2 percent). If the gillnet mesh size were decreased to 5 inch, the improvement of yield per recruit from the combined fishery increases to about 5 percent. Maximum yield per recruit continues to increase with increased trawl cod-end mesh size as does the effort required to take that yield. The increases in yield from fishing blue warehou and jackass morwong with the gillnet as opposed to the trawl are dissipated when yields from other shelf quota species are included – reducing trawl fishing mortality to increase gillnet yields no longer provides an overall benefit to the combined fisheries because reduced fishing mortalities lead to decreased yields from other species. Potential increases in yield (and increases in percent unfished biomass) from fishing with the gillnet depend on whether or not the trawl fishery can target their effort to catch other shelf quota species while avoiding jackass morwong and blue warehou.

When multi-species yield per recruit was run for trawl fishing mortalities set at multipliers of current fishing mortality levels (instead of constant for all species), the increased yield from the combined fishery (5 inch gillnet) approached 10 percent, an effect that was lost as the mesh size of the trawl fishery increased. The fishing mortality required to maximize biomass yield per recruit at current trawl mesh sizes was 20 percent of the current effort and only 12 percent if the goal was to maximize monetary yield per recruit. The current level of fishing effort in the fishery was only required to maximize yield per recruit at mesh sizes of 140 mm and greater. If mesh size were chosen to match current fishing mortality yield per recruit would be increased by over 10 percent. Large mesh sizes also provide more protection against fishing mortalities greater than those necessary to take the maximum yield per recruit.

(*Objective 4: Identify fisheries that contain mixes of gear types and species that lead to undesirable selectivity of some species, and that could profit from the development of specified selective techniques*).

Yield per recruit analyses are a great simplification of the complex pattern of biological, spatial, temporal and operational factors that make up a fishery. Any adjustments to fishing patterns or gear would need to take these other factors into account before the outcome of particular management actions could be predicted.

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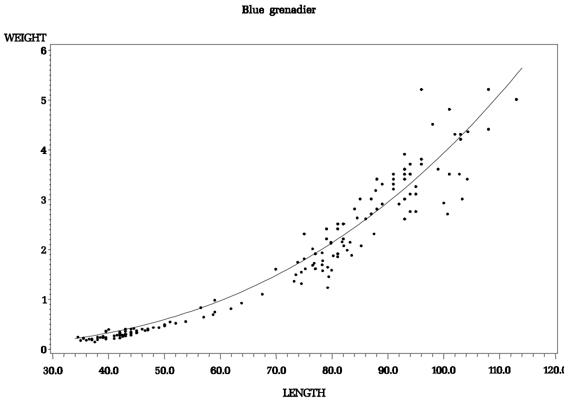
APPENDIX 1: INTELLECTUAL PROPERTY

The intellectual property arising from this work is property of both CSIRO, MAFRI (Victoria) and FRDC.

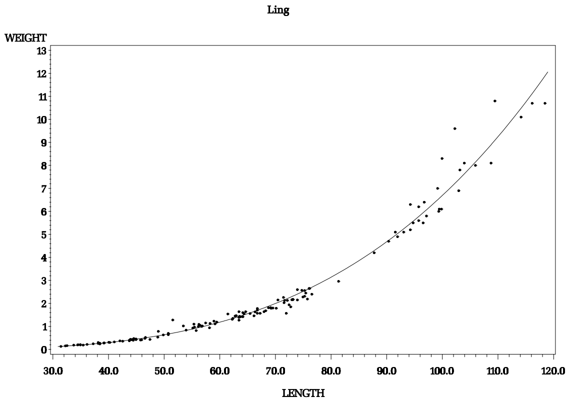
APPENDIX 2: STAFF

Nic Bax	Principal investigator
Ian Knuckey	Co-principal investigator
Peter Cui	Modeller
Kim Woolley	Data analyst
Neil Klaer	Data analyst
Andre Punt	Modeller

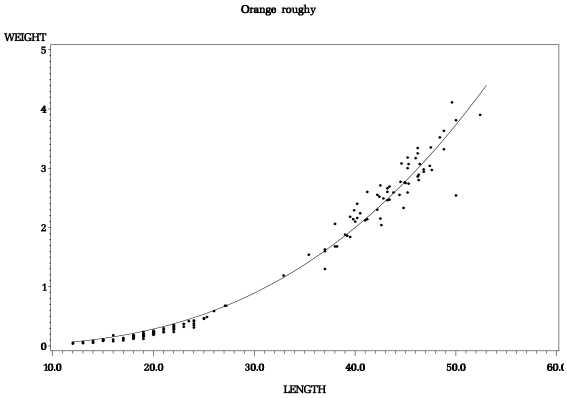
APPENDIX A1: LENGTH–WEIGHT RELATIONSHIPS OF COMMON SEF SPECIES



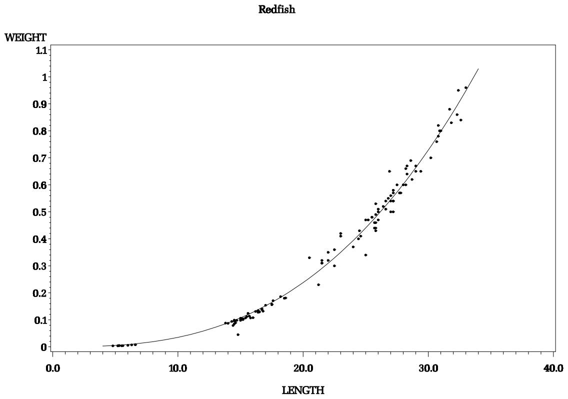
$y = 1.20\text{E-}05\ x^{2.753}$



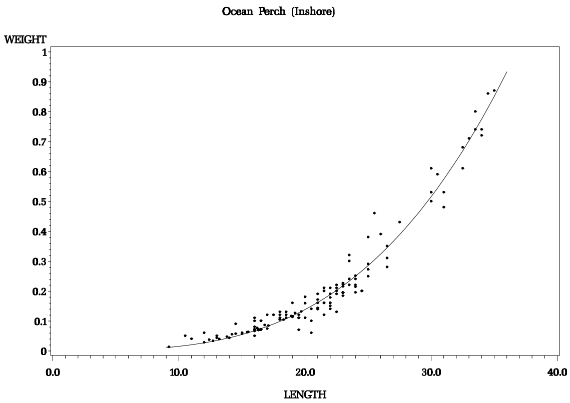
$y = 1.09\text{E-}06\ x^{3.39}$



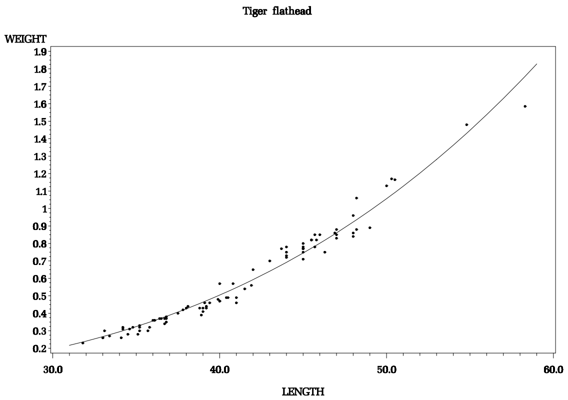
$y = 6.52\text{E-}05\ x^{2.80}$



$y = 6.09\text{E-}05\ x^{2.76}$

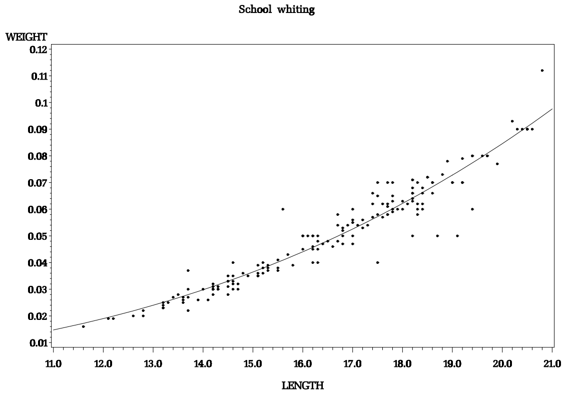


$y = 7.96\text{E-}06\ x^{3.26}$

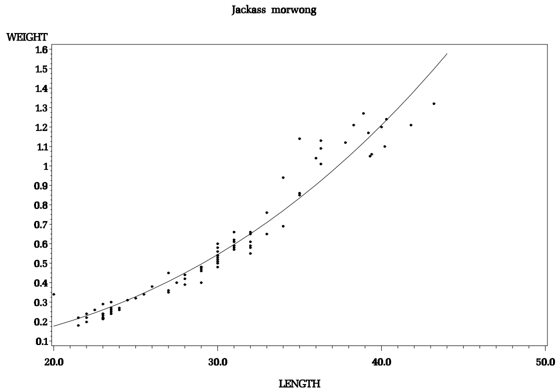


$y = 2.49\text{E-}06\ x^{3.31}$

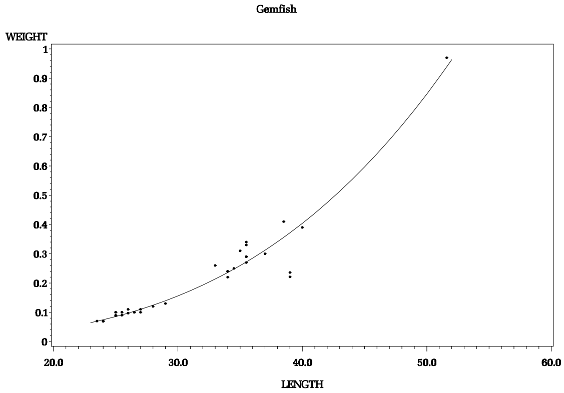
Figure A1 Plots and equations for the length–weight relationships of common SEF species



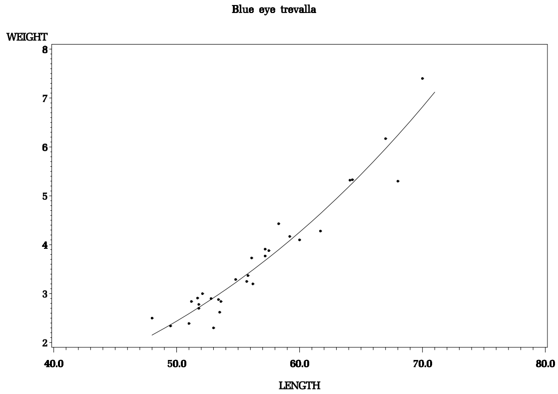
$y = 1.32\text{E-}05\ x^{2.93}$



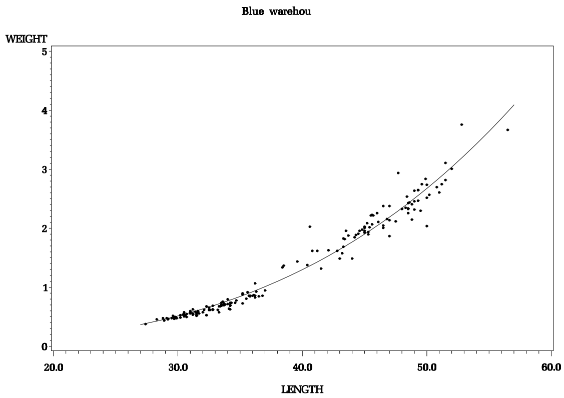
$y = 4.29\text{E-}05\ x^{2.78}$



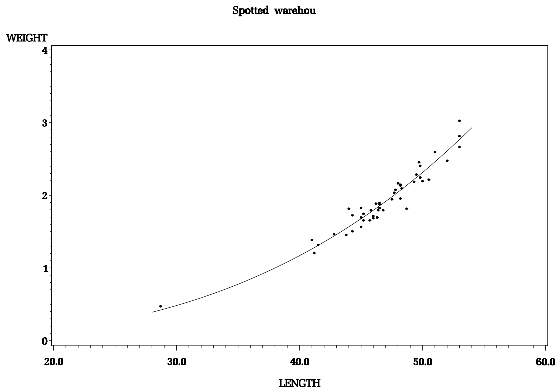
$y = 2.00\text{E-}06\ x^{3.31}$



$y = 1.57\text{E-}05\ x^{3.06}$

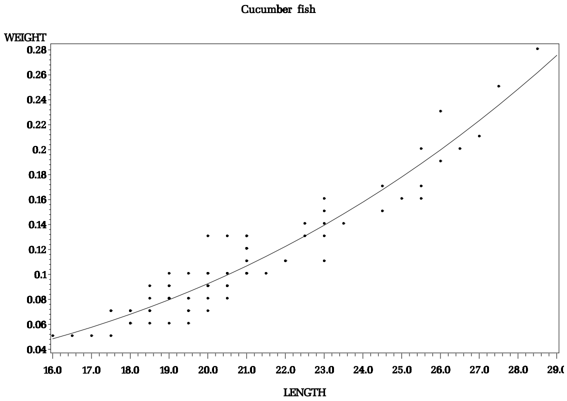


$y = 8.04\text{E-}06\ x^{3.25}$

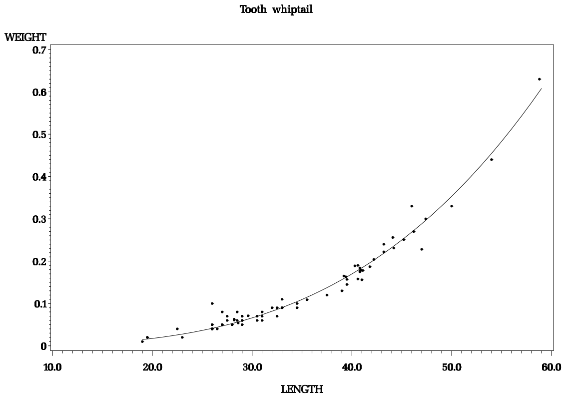


$y = 1.53\text{E-}05\ x^{3.05}$

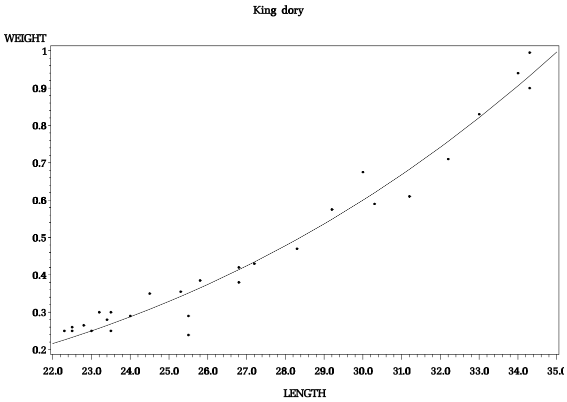
Figure A1 contd… Plots and equations for the length–weight relationships of common SEF species



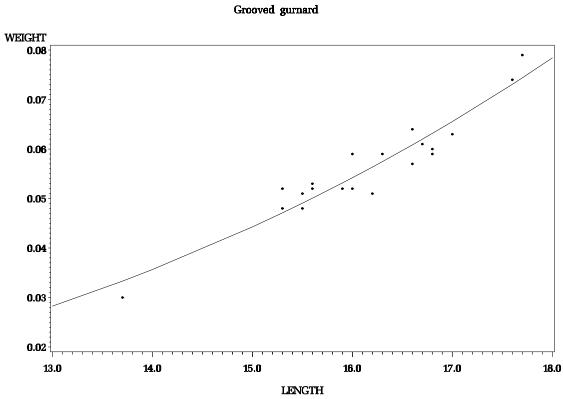
$y = 1.31\text{E-}05\ x^{2.95}$



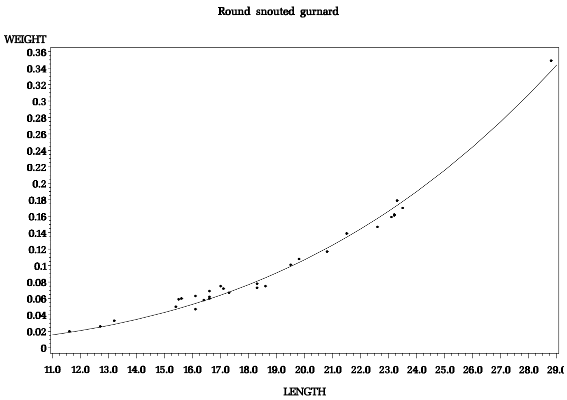
$y = 9.22\text{E-}07\ x^{3.29}$



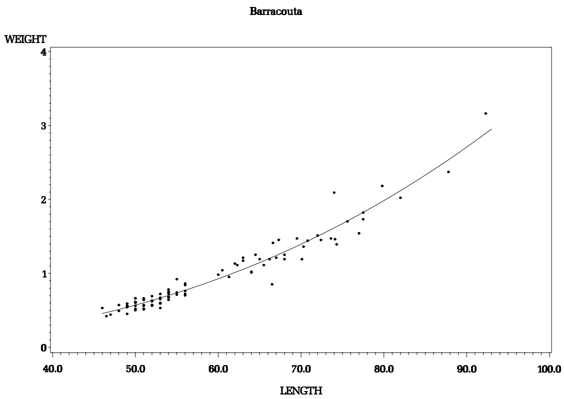
$y = 8.20\text{E-}06\ x^{3.29}$



$y = 9.07\text{E-}06\ x^{3.14}$



$y = 9.40\text{E-}06\ x^{3.12}$

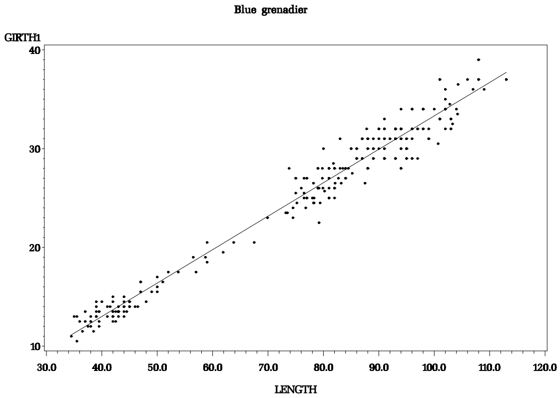


$y = 1.97\text{E-}05\ x^{2.63}$

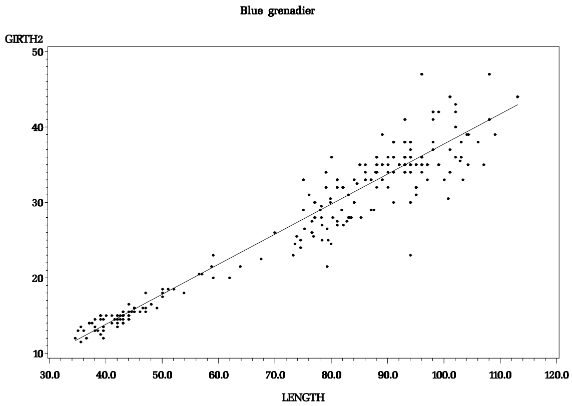
Figure A1 contd… Plots and equations for the length–weight relationships of common SEF species

APPENDIX A2: LENGTH–GIRTH RELATIONSHIPS OF COMMON SEF SPECIES

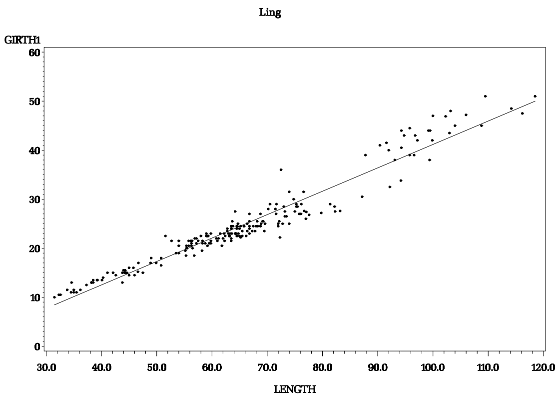
GIRTH 1 GIRTH 2



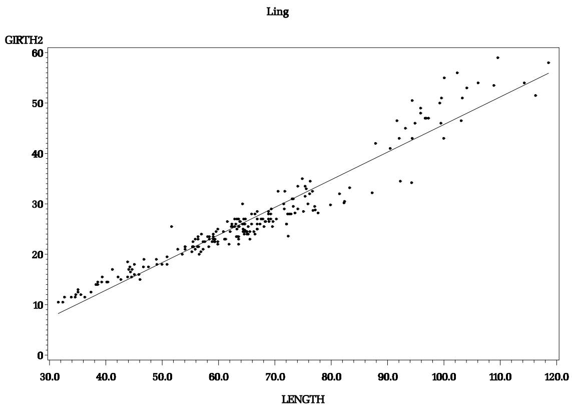
$y = 0.344\,x - 0.893$



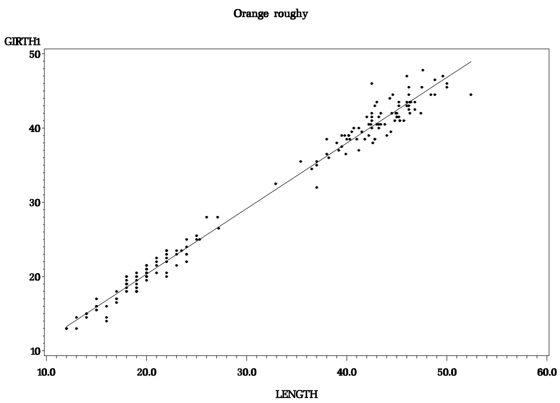
$y = 0.391\,x - 1.740$



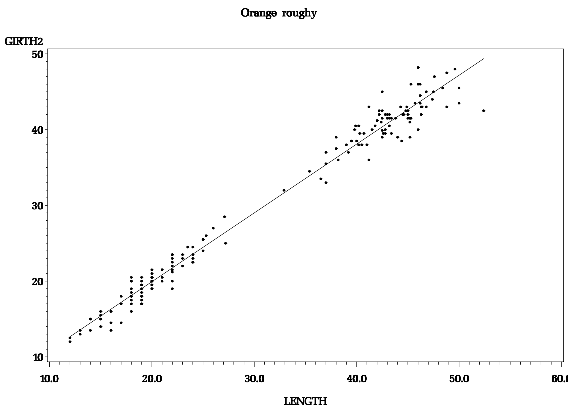
$y = 0.478\,x - 6.595$



$y = 0.548\,x - 9.007$



$y = 0.883\,x + 2.658$

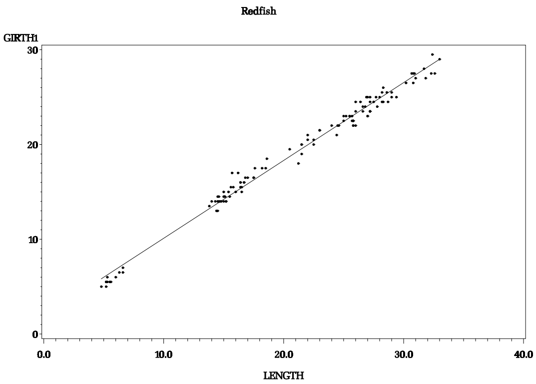


$y = 0.908\,x + 1.758$

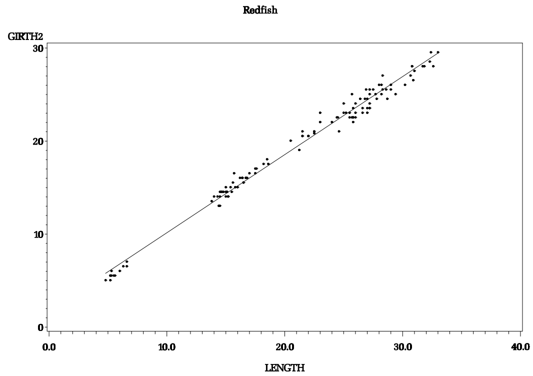
Figure A2 Plots and equations for the length–girth relationships of common SEF species

GIRTH 1

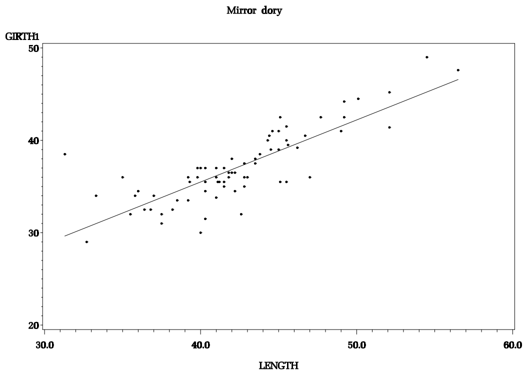
GIRTH 2



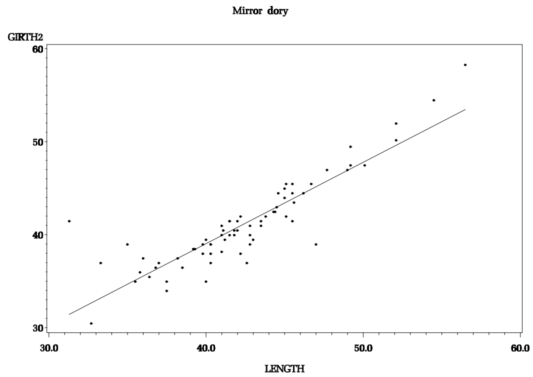
y = 0.822 x + 1.884



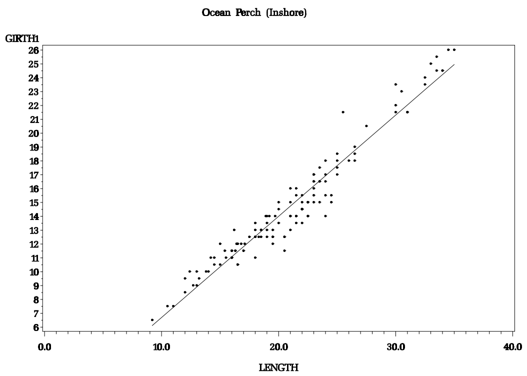
y = 0.839 x + 1.700



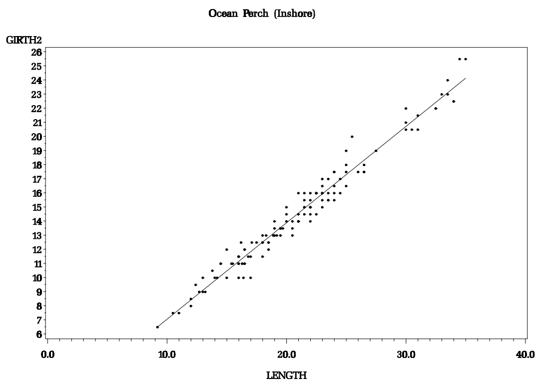
y = 0.672 x + 8.606



y = 0.874 x + 4.124



y = 0.730 x - 0.624

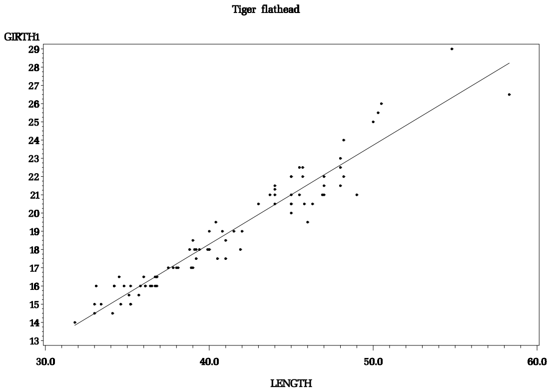


y = 0.683 x + 0.229

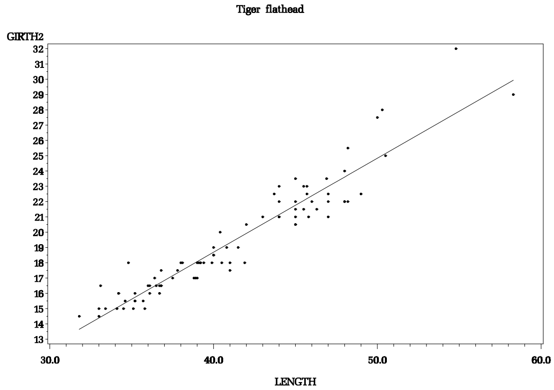
Figure A2 contd… Plots and equations for the length–girth relationships of common SEF species

GIRTH 1

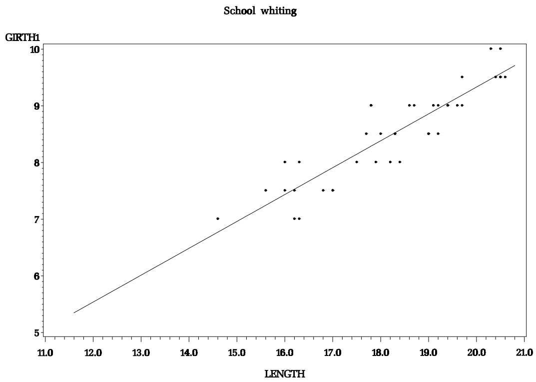
GIRTH 2



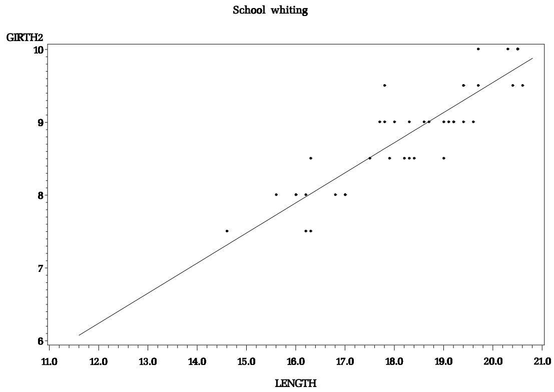
$y = 0.543\,x - 3.419$



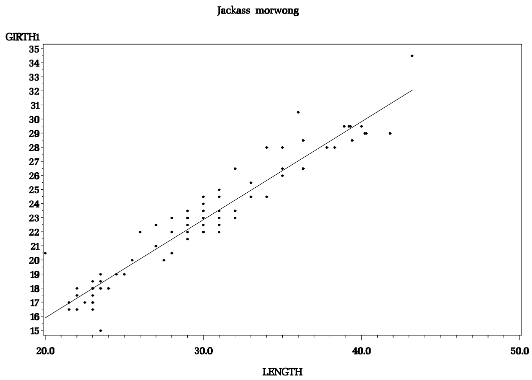
$y = 0.614\,x - 5.891$



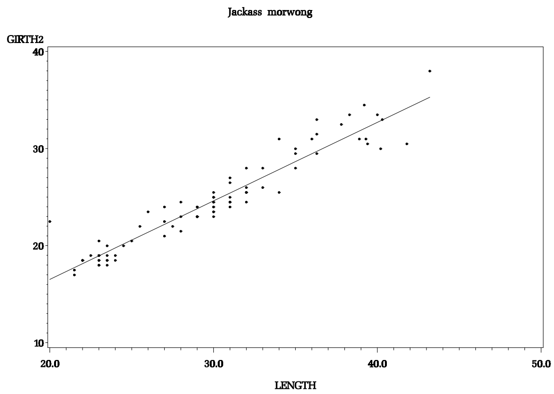
$y = 0.476\,x - 0.188$



$y = 0.407\,x + 1.381$



$y = 0.696\,x + 1.984$

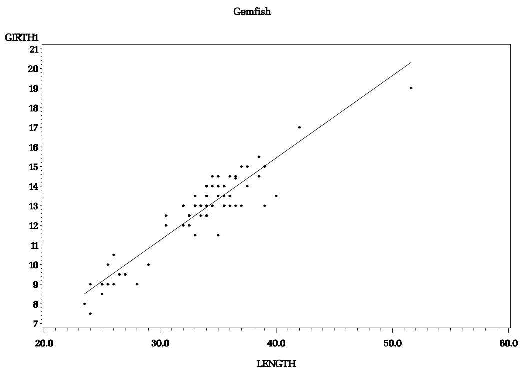


$y = 0.809\,x + 0.372$

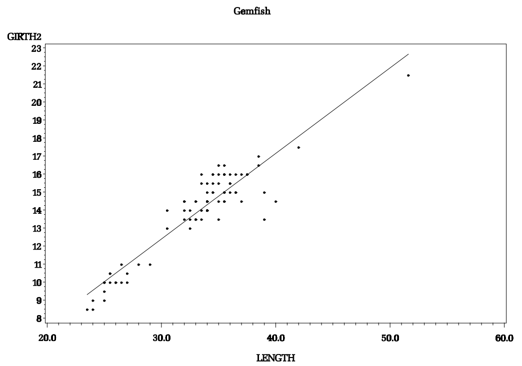
Figure A2 contd… Plots and equations for the length–girth relationships of common SEF species

GIRTH 1

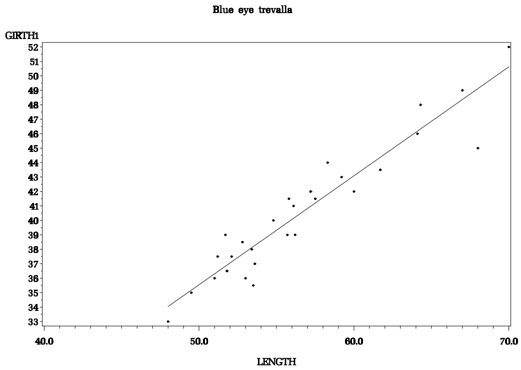
GIRTH 2



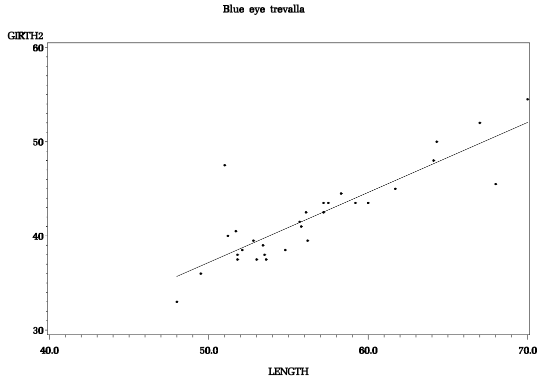
$y = 0.420\,x - 1.351$



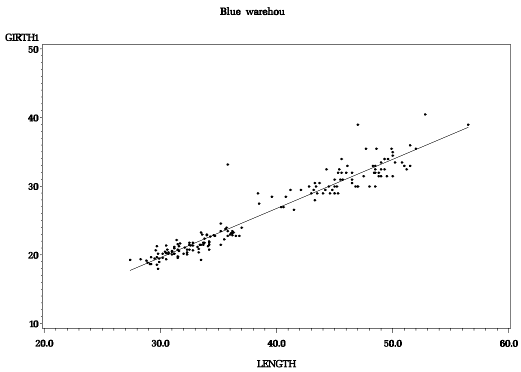
$y = 0.475\,x - 1.821$



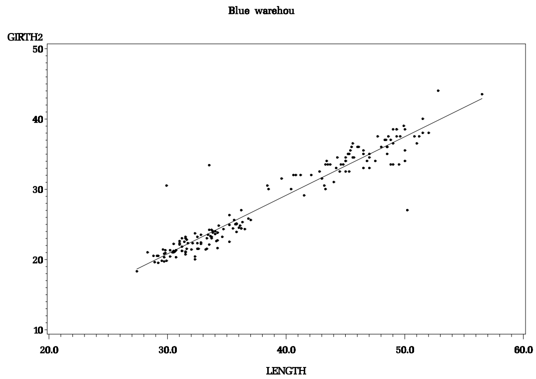
$y = 0.754\,x - 2.130$



$y = 0.743\,x + 0.024$



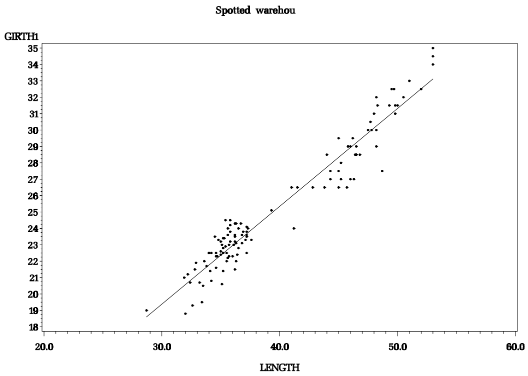
$y = 0.716\,x - 1.833$



$y = 0.834\,x - 4.220$

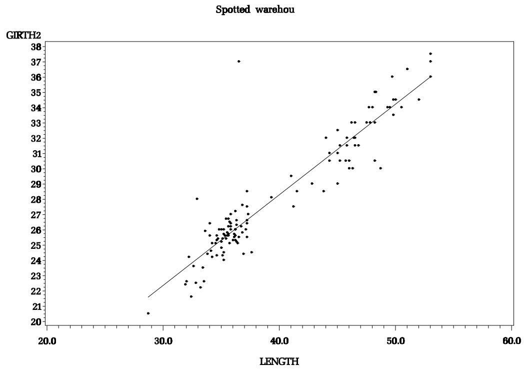
Figure A2 contd… Plots and equations for the length–girth relationships of common SEF species

GIRTH 1



$y = 0.590\,x + 1.869$

GIRTH 2



$y = 0.574\,x + 5.370$

Figure A2 contd… Plots and equations for the length–girth relationships of common SEF species