Title: Developing a support tool for management decisions in coastal multi-species scalefish fisheries

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Contents

1. NON-TECHNICAL SUMMARY

2008/010 Developing a support tool for management decisions in coastal multi-species scalefish fisheries

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OBJECTIVES:

Characterise the fleet dynamics including fishing strategies, key drivers for fishing activities and fishers' responses to management changes in multi-species coastal scalefish fisheries through a synthesis of logbook data and industry survey.

Characterise the fishery and stock dynamics in the spatially-structured ISIS-Fish model for multi-gear and multi-species fisheries.

Evaluate the suitability of ISIS-Fish as a support tool for management decisions in coastal multi-species scalefish fisheries in Australia.

NON-TECHNICAL SUMMARY:

OUTCOMES ACHIEVE TO DATE

This study provided statistical tools that can be used to analyse the fishing fleet structure and fleet dynamics of a multi-species and multi-gear fishery. Based on these analyses, it is now possible to identify linkages between different components of a fishery and quantify potential effort shifts should regulatory or environmental conditions change. The ability to account for expected displaced fishing effort is a critical first step in transforming the common single-species management approaches in multi-species fisheries to a more integrated approach.

Using these methods, this study has provided an overview of the Tasmanian fishing fleet structure over the last 15 years and clearly highlighted the importance of intermediate and generalist fishers in the Tasmanian scalefish fishery. The study also quantified the importance of underlying drivers for some of the fishers' decisions that will help to estimate the level of potential effort shifts within the Tasmanian scalefish fishery.

The management decision support tool in the form of the ISIS-Fish model application that was developed in this study combines fleet and population dynamics by simulating both components simultaneously. This tool can not only predict the future catch for each fishing fleets represented in the model, but importantly also the development of the stock biomass over time. This tool is therefore a powerful addition to the approaches available to management and can provide valuable information to the consideration of a management decision.

This project has also raised awareness in Tasmanian fisheries managers and fishing industry, and scientists from other States of the methods available and potential approaches to identifying and assessing the effects of effort shifts within multi-species and multi-gear fisheries.

Single-species fisheries management approaches tend to perform poorly in mixed-species fisheries where a fish species is captured by a number of gear types or several species can be caught simultaneously in a haul. Since fish species and fish stocks are not exploited independently and fishing practices can be easily modified, it is important to understand the structure and dynamics of the fishing fleet in order to assess past management decisions and predict the impact of future decisions on the fishery and the exploited fish stocks.

Complex fleet structure and dynamics are prevalent in many small-scale and coastal scalefish fisheries around Australia. In Tasmania, the fishing activity of scalefish fishers is characterised by (1) the use of small vessels; (2) labour intensive fishing methods with a relatively low level of capital investment, technical equipment and specialisation; (3) the dominance of traditional fishing gears such as gillnets, traps, lines and seine, that are often used in combination; (4) short and decentralised fishing trips in inshore and coastal waters; and (5) great spatial and temporal variability in fishing activity, fishing gear used and target species.

A low level of specialisation and technological equipment allows fishers to rapidly adapt and change their operations in response to changes in spatial and temporal species availability and market opportunities. However, the assessment and management of the Tasmanian scalefish fishery have traditionally disregarded this flexibility and focused on single fish species and individual fishing methods instead.

A more holistic approach to multi-species and multi-gear fisheries assessment and management was needed that can identify and quantify the effects of effort shifts between different components of a fishery on fleet and fish populations as a response to changes in management arrangements and resource availability. This project applied a step-wise approach to develop methods for fleet structure and fleet dynamics analyses and evaluated a decision support tool that may be useful for the management of multi-species scalefish fisheries.

Firstly, the fishing fleet structure and fishing tactics applied within the fishery were identified using a sequence of multivariate analyses of commercial catch and effort logbook data (example R code is available in the report). The analyses identified gear-specific target species, 35 fishing tactics (characterised by target species, fishing gear, location and month), and 20 vessel groups based on common fishing tactics. The vessel groups were then categorised according to varying degrees of specialisation and a deepwater component. The results clearly highlighted that intermediate and generalist fishers are a major feature of the Tasmanian scalefish fishery. Based on these analyses, it is now possible to identify strongly inter-linked components of the fishery and potential effort shifts should regulatory, environmental or market conditions change.

Secondly, an industry survey was combined with random utility models (RUMs) of logbook and economic data to identify and quantify the key drivers for the choice of fishing tactics made by fishers in a subset of the fishery (example R code for the RUMs is available in the report). These analyses indicated that fishers targeting banded morwong, wrasse, calamari and garfish readily adapt their fishing activity and follow species availability, but that the seasonal patterns are consistent over the years. Following fish availability, fishers aim to maximise their revenue from the total catch and account for the numbers of days fished. With a high level of explanatory power, such analyses of fishers' behaviour provide a valuable tool to predict the extent of possible effort shifts.

Thirdly, the ISIS-Fish model framework (Integration of Spatial Information and Simulation for Fisheries, www.isis-fish.org) was evaluated for its suitability as a support tool for management decisions in coastal multi-species scalefish fisheries in Australia. ISIS-Fish is a spatially and seasonally-explicit simulation tool for fish and fleet dynamics, which allows to evaluate the impact of a variety of management strategies on multi-species and multi-gear fisheries. The model was applied to four key fish species and a subset of the scalefish fishing fleet in the South-East and East of Tasmania.

The ISIS-Fish model framework is a powerful simulation tool for predicting the effects of effort displacement on fishery and fish population dynamics. The results of this study indicated that the model can be parameterised to this effect even in data-limited situations inherent to small-scale fisheries in Australia. The model simulations indicated that the single-species management decisions had relatively small but nevertheless measurable effects on landings and biomass of the target species as well as on other species in the fisheries. While single-species management actions affected predominantly the target species, they also affected the landings and biomass of non-target species just as strongly as some management actions intended for the non-target species alone.

Nevertheless, the Tasmanian model application has also highlighted the limits of this model approach when the complexity of fleets and fish populations represented in the model is high and the level of information available is low. Due to the many assumptions required for the parameterisation of stock biomass, stock productivity and the fishery, the predicted effects of fishing on the biomass of all four species were highly uncertain. The ISIS-Fish model framework appears to be suitable for simpler applications or in situations with abundant fishery and species data, including some fisheries in other Australian States. In addition, the ease of the model to include different fishing fleets or fishing sectors, including e.g. the recreational sector, and the potential to evaluate the individual impacts of these fleets on the fish stocks, means that the model could also be used to investigate issues on resource allocation between sectors and the effects of management changes on recreational fishing activities.

The ISIS-Fish model framework has a number of advantages and disadvantages that need to be considered when choosing an appropriate model approach. Advantages include the open source code and the free availability of the model framework, a good support network, and the high flexibility to represent many processes important to multi-gear and multi-species fisheries including economic aspects. Disadvantages include the high model complexity that requires a substantial time commitment to develop an ISIS-Fish model application and adapt it to the specific situation, relatively slow model runs, Java as the model coding language (a disadvantage for those unfamiliar with this language), and the frequent use of French in model documentations and support.

Based on the results from this project, the following steps are recommended when considering a management change in a multi-species fishery:

(1) Evaluate if strongly-interlinked components of the fishery (or whole fisheries) are affected by the management change and if there could be potential effort shifts, e.g. with an analysis of fleet structure.

(2) If there is an identified potential for effort shifts, quantify the likely effects of the management change on fishing effort and fleet dynamics, e.g. with an analysis of fishers' behaviour.

(3) If an appropriate multi-species (and multi-gear) model such as an ISIS-Fish model application is available or could be developed, evaluate and quantify the effects of the management change on fishery and fish population dynamics through simulations.

For the Tasmanian scalefish fishery, the analyses and results from this study will provide a valuable tool in informing future management decisions and providing direction for the fishery in the upcoming review of the scalefish fishery management plan.

KEYWORDS: Multi-species fisheries, multi-gear fisheries, scalefish, fleet structure, fleet dynamics, fishery management, population modelling, ISIS-Fish model

2. ACKNOWLEDGEMENTS

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3. BACKGROUND

Single-species fisheries management approaches tend to perform poorly in mixed-species fisheries where a fish species is captured by a number of gear types or several species can be caught simultaneously in a haul. Since fish species and fish stocks are not exploited independently and fishing practices can be easily modified, it is important to understand the structure and dynamics of the fishing fleet in order to assess past and predict the impact of future fishing and management decisions on exploited fish stocks (ICES 2003).

Complex fleet structure and dynamics are prevalent in small-scale fisheries. Small-scale fisheries are often characterised by (1) the use of small vessels; (2) labour intensive fishing methods with a relatively low level of capital investment, technical equipment and specialisation; (3) the dominance of traditional fishing gears such as gillnets, traps, lines and seine, that are often used in combination; (4) short and decentralised fishing trips in inshore and coastal waters; and (5) great spatial and temporal variability in fishing activity, fishing gear used and target species (e.g. Berkes et al. 2001). Small-scale fisheries tend to be of great social significance for coastal communities due to the high number of people being directly or indirectly involved in the fishery. However, with small overall fishery production and revenue, these fisheries receive comparatively little attention by science and management (Mahon 1997). Many small-scale fisheries are open access or are managed by limiting fishing effort that can be applied with particular gear types or directed towards a fish species, disregarding potentially strong interactions between different fishing practices (e.g. Salas et al. 2007).

Many of the typical characteristics of small-scale fisheries apply to the coastal scalefish fishery around Tasmania, Australia. Tasmanian fishers use a number of gear types such as nets, hooks and pots to harvest a diverse range of fish, shark and cephalopod species. Fishing vessels are deployed from many ports and launching sites, are typically small (3-20 m length) and owner-operated with less than three crew members. Catches and economic returns by individual fishers are often low. In 2008, the total catches of the fishery were around 1 500 tonnes and valued at $AU 5.22 million (ABARE 2009). Between 1995/96 and 2008/09, 56% of all fishers reported on average less than 1 tonne per year landed, while only 18% of all active fishers caught on average more than 5 tonnes per year during the period. For full-time fishers, these low catches were reflected in an annual average profit from the fishery of just AU$ 37 000 (Bradshaw 2005). Around 60% of the participants in Bradshaw's survey were full-time fishers, but two thirds of these were also active in other fisheries. The remaining 40% were part-time fishers and some of these had full-time employment outside commercial fisheries.

A low level of specialisation and technological equipment allows fishers to rapidly adapt and change their operations in response to changes in spatial and temporal species availability and market opportunities. However, the assessment and management of the Tasmanian scalefish fishery have traditionally disregarded this flexibility and focused on single fish species and individual fishing methods instead (Ziegler and Lyle 2010). Fisheries management has mainly responded to concerns about stock status with input controls, such as restrictions on fishing gear and licence numbers, and spatial and temporal closures to limit catches of a particular species, e.g. banded morwong, wrasse and calamari. While such management measures may alleviate the fishing pressure on the targeted fish stocks, the effects of these measures on other fish stocks remain unclear yet could be significant. Because the overall access to the fisheries is rarely reduced, some fishers would often simply switch their activity to target other fish species or other areas. While fisheries managers may have anecdotal information about potential effort shifts, such effort shifts caused by management interventions are rarely quantifiable.

A more holistic approach to multi-species and multi-gear fisheries assessment and management is needed to assess and quantify fleet and species interactions brought about by effort shifts between different components of the whole fishery as a response to changes in management arrangements and resource availability. In this project, a step-wise approach was followed to develop and evaluate a decision support tool for fisheries management that may be useful in coastal multi-species scalefish fisheries.

Firstly, we analysed the fishing fleet structure and fishing tactics applied within the fishery to identify linkages within the fishery (Tzanatos et al. 2006, Katsanevakis et al. 2010, Castro et al. 2011, Davie and Lordan 2011). Step-wise multivariate analyses of commercial logbook data were used to identify target species, fishing tactics and vessel groups. The terms 'fishing tactic' (Laloë and Samba 1991, Pelletier and Ferraris 2000), 'metier' (Biseau and Gondeaux 1988, Laurec et al. 1991, Marchal 2008), or 'fishery' (Murawski et al. 1983, Lewy and Vinther 1994, Ulrich and Adersen 2004) describe the fishing intention in respect to species targeted, fishing area, and fishing gear. Similarly, the terms 'vessel groups' (Ulrich and Adersen 2004) or 'fleets' (Laurec et al. 1991, Lewy and Vinther 1994, Marchal 2008) are used to describe vessels sharing similar characteristics in respect to technical features and fishing tactics.

Secondly, we aimed to identify and quantify the main factors that drive fishers' behaviour and their decision making to be able to estimate future changes in the effort allocation between alternative fishing activities when biological, economic or regulatory conditions change. To achieve this goal, we conducted a small industry survey to identify candidate variables of behavioural drivers and conducted an analysis of the selected variables with random utility models (RUMs).

Thirdly, we characterized the fishery and stock dynamics in the ISIS-Fish model framework and evaluated its suitability as a support tool for management decisions in coastal multi-species scalefish fisheries in Australia. ISIS-Fish (Integration of Spatial Information and Simulation for Fisheries, www.isis-fish.org) is a spatially and seasonally-explicit simulation tool of fisheries dynamics, which aims to evaluate the impact of a variety of management strategies on multi-species and multi-gear fisheries (Mahévas and Pelletier 2004, Pelletier and Mahévas 2005, Pelletier et al. 2009). This is achieved by concurrently simulating the dynamics of both resource and exploitation, and subsequent fishing mortality for each fish population including that brought about by effort shifts between different components of the fishery as a response to changes in management arrangements.

While the ISIS-Fish model has been developed mainly with the aim to evaluate the performance of marine protected areas, it can be used to assess a range of management measures. The model has been applied to the multi-species fishery of Norway lobster and hake in the Bay of Biscay (Drouineau et al. 2006), the flatfish fishery in the English Channel (Marchal et al. 2011), the anchovy fishery in the Bay of Biscay (Lehuta et al. 2010) and the cod fishery in the Baltic sea (Kraus et al. 2009). It has also been tested on the small coastal multi-fleet fishery for white sea bream in the Mediterranean Sea (Capoulade 2005, Hussein et al. 2011a, 2011b), the small-scale fishery for red spiny lobster in Corsica (Rocklin 2010), and the multi-species artisanal and recreational fisheries of the New Caledonian lagoon (Preuss 2012).

As a generic framework, it is applicable to fisheries that can be described through their population dynamics, fleet dynamics and management measures. ISIS-Fish is an open source model written in Java and can be adjusted to suit specific situations by changing parameter values and if needed, the source code. Because of its nature, parameterising the populations of each species and characterising the different fishing fleets and strategies for each region and time step in the ISIS-Fish model is complex and data-intensive. Using ISIS-Fish is a cost-effective way to develop a support tool for fisheries management decisions in coastal multi-species fisheries around Australia, since it involves the adaptation of an existing model rather than building new models.

4. NEED

The Tasmanian fishing industry and management identified the need for a better understanding of structure and strategies of the scalefish fishery. The required information ranges from the number of fishers targeting the various species, to the degree of operational specialisation or generalisation, and the seasonal and spatial fishing strategies including key drivers for fishing decisions.

Amalgamating these multi-species and multi-gear fishery dynamics into a holistic fishery approach in stock assessment and management, rather than the commonly-used single-species approaches, was needed. Such an approach is crucial to estimate cross-species impacts brought about by effort shifts between different components of the whole fishery as a response to changes in management measures and/or resource availability.

This project addressed three key research and development priorities for wild fisheries outlined in the Tasmanian Fisheries and Aquaculture Research Strategic Plan (2005-2008):

- Management options/assessment by seeking to optimise management measures for the scalefish fisheries;
- Resource assessment & monitoring by providing information on the current and projected structure of scalefish resources;
- Impacts of fishing by supporting the evaluation of the effects of alternative management and fishing scenarios on fished populations.

This project also addressed the FRDC R&D “Natural resource sustainability” priority to ‘Measure and mitigate the interactions of fishing and non-fishing activities on the aquatic environment and fish stocks’ and ‘Developing spatially explicit management models for fish stocks’. Considering the spatial overlap and interactions of scalefish species and their fisheries, the project supported the FRDC's strategic vision to move towards assessment and management of Australia’s fisheries at the ecosystem rather than single-species level.

5. OBJECTIVES

1. Characterise the fleet structure and fleet dynamics including fishing strategies, key drivers for fishing activities and fishers' responses to management changes in multi-species coastal scalefish fisheries through a synthesis of logbook data and industry survey.
2. Characterise the fishery and stock dynamics in the spatially-structured ISIS-Fish model for multi-gear and multi-species fisheries.
3. Evaluate the suitability of ISIS-Fish as a support tool for management decisions in coastal multi-species scalefish fisheries in Australia.

6. METHODS

6.1 Characterisation of fleet structure

6.1.1 Data

The commercial Tasmanian scalefish fishery is defined through the requirements that participants hold Tasmanian fishing licences and report their fishing activity in Tasmanian logbooks. These reporting requirements have changed over the years and with them which fishers and vessels have been part of the Tasmanian scalefish fishery. Prior to 1998, the Tasmanian logbooks included dually endorsed Tasmanian and Commonwealth fishers with a significant amount of fishing activity in offshore waters of Australia's economic exclusion zone (EEZ) targeting pelagic and deepwater species. Since then, most of the fishing activity of these vessels has been stepwise reclassified and these vessels are now part of the Commonwealth Southern and Eastern Scalefish and Shark Fisheries (SESSF) and the Southern Squid Jig Fisheries (SSJF). Nowadays, Tasmanian fishing licences generally restrict fishing to waters within 3 nautical miles of the coast. These changes have resulted in the sharp decline of total Tasmanian catches from around 3000 to 1500 tonnes from 1999/00 - 2001/02, while catches before and after this decline have remained relatively stable (Figure 6.1a). In contrast, the number of Tasmanian scalefish vessels and fishers (skippers only) has continuously declined from around 400 to 200 from 1995/96 - 2008/09 (Figure 6.1b). Similar numbers of vessel and fishers, particularly in recent years, indicate that most fishers use only one vessel during the course of a fishing year.

Tasmanian commercial logbook entries from July 1995 - June 2009 were used for the analyses, following the Tasmanian fishing year from 1st July - 30th of June of the subsequent year. Logbook data provided daily summaries of fishing operations, including vessel mark, fisher identification mark, fishing gear, location based on 30 x 30 nautical mile fishing blocks, minimum and maximum fishing depth, fishing effort, and catch weights of individual species.

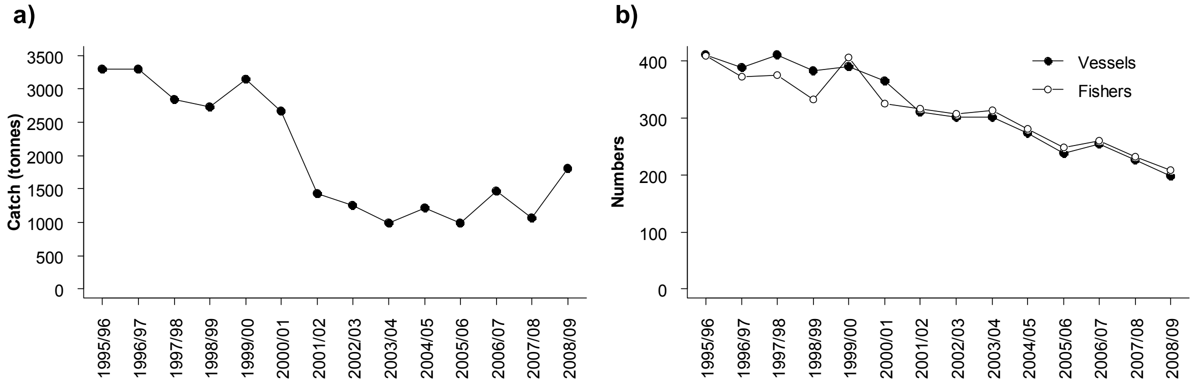


Figure 6.1: (a) Total catch (tonnes) and (b) number of vessels and fishers (skippers only) in the Tasmanian scalefish fishery. The Tasmanian scalefish fishing year lasts from 1st July to 30th of June of the subsequent year.

The logbook entries did not specify whether the daily fishing records would represent a whole trip or part of a multi-day trip. To reduce the noise in daily data and the potential for mis-classification of records for which the target species was not caught on a particular day, daily fishing records were pooled monthly, summarising fishing effort and catch weights for all fish species caught while retaining unique information by vessel, fisher, fishing gear, spatial fishing block, month and year (i.e. catches by a fisher using the same fishing gear in two separate fishing blocks during a particular month resulted in two logbook records). This procedure assumed that a fisher did not change target species for a particular gear during a month and in a spatial fishing block. Erroneous records and records without catch information were excluded from all analyses. These procedures resulted in 55 242 monthly records.

Due to the large number of individual fish species (over 80), larger functional species groups were set up, with a total of 36 species or species groups defined for the analysis. The most common species or species groups were anchovy (Engraulidae), Australian salmon (*Arripis spp*.), banded morwong (*Cheilodactylus spectabilis*) and other morwong (*Nemodactylus spp*.), barracouta (*Thyrsites atun*) and pike (*Dinolestes lewini* and *Sphyraena novaehollandiae*), bastard trumpeter (*Latridopsis forsteri*) and striped trumpeter (*Latris lineata*), blue warehou (*Seriolella brama*), blue-eye trevalla (*Hyperoglyphe antarctica*), flathead (Platycephalidae), southern garfish (*Hyporhamphus melanochir*), jack mackerel (*Trachurus declivis*), mullet (Mugilidae), octopus (*Octopus spp*.), southern calamari (*Sepioteuthis australis*) and Gould's squid (*Nototodarus gouldi*), whiting (Sillaginidae), and wrasse (*Notolabrus spp*.).

The reported 24 gear types were reduced to 17 gear types by pooling similar gear types, e.g. dip and push net, and bottom and shark line.

6.1.2 Methods

The general sequence of analyses followed that of Pelletier and Ferraris (2000) and ICES (2003) and was applied to each fishing gear. Firstly, catch profiles or target species were defined based on catch composition data. Secondly, fishing tactics were described based on the relationship between catch profiles and effort variables such as fishing location and month. Lastly, vessels groups with similar fishing tactics were identified. The analyses were therefore a combination of output-based methods (categorisation of fishing tactics by clustering catch profiles) and input-based methods (relating these clusters to fishing trip characteristics; Marchal 2008). All analyses were conducted with the statistical package R (R Development Core Team, 2011).

6.1.2.1 Identification of target species

The analysis for target species was approximated from catch profiles and conducted separately for each gear type. Catch weights per species for individual monthly records were transformed into catch profiles with relative species composition (i.e. the catch per species was divided by the total catch of that record). The matrix was not normalised, since fishing tactics were expected to depend primarily on the target species rather than the bycatch species. A principal component analysis (PCA) on the Euclidian distances allowed for a visual examination of the data, however all factorial dimensions were retained for the subsequent hierarchical cluster analysis (HAC). Clusters were identified based on the minimum variance criterion by Ward (1963). Initially, the appropriate number of clusters was chosen where there was only little additional increase in the percentage of variance explained with a higher level of clustering. However, this point was not always clearly identifiable and in some cases the final number of clusters was adjusted after visual examination of the structure within cluster groups. Clusters with the same dominant target species were pooled.

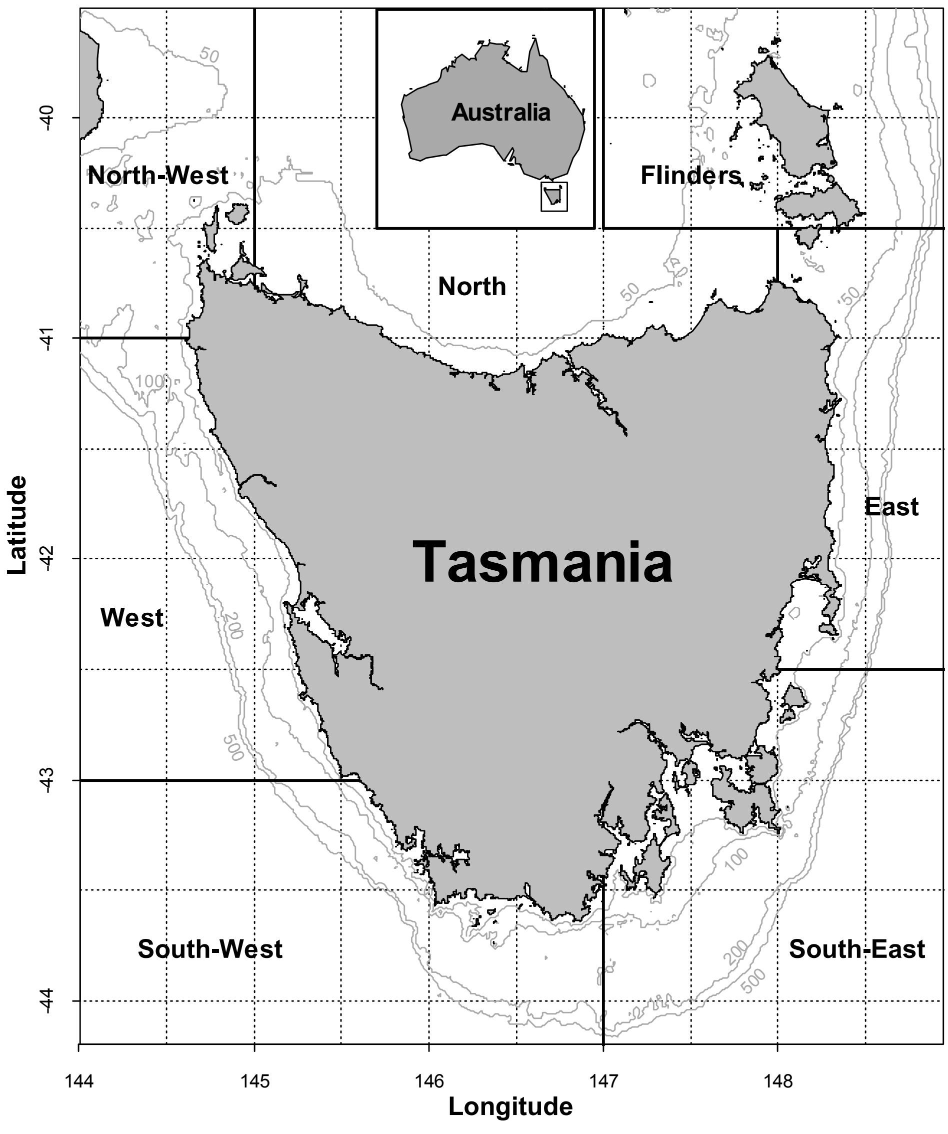


Figure 6.2: Map of Tasmania with fishery regions, spatial reporting blocks (marked by dotted lines) and depth contour lines (depth in meters). Top insert: Map of Australia with Tasmania depicted in the box.

6.1.2.2 Identification of fishing tactics

Fishing tactics by gear type were identified by the similarity of records with regards to target species and the effort variables fishing location and month. While the spatial resolution of the monthly records was by spatial fishing block, the analysis was conducted on a regional level by dividing the Tasmanian waters into seven regions (South-East, East, Flinders, North, North-West, West and South-West; Figure 6.2). A multiple correspondence analysis (MCA) based on an eigenvalue decomposition of the Burt matrix (Nenadić and Greenacre 2007) was conducted for a data matrix consisting of monthly records as individuals and fishing region, month and target species as categorical variables. This resulted in 19 effort-related categories (7 regions and 12 months) and a number of gear-specific species categories. To reduce marginal effects in the data, only a subset of factorial axes up to a substantial elbow point of the eigenvalues was retained. The subsequent HAC was conducted in a similar way as that for the identification of target species.

6.1.2.3 Identification of vessel groups

Fishing vessels with similar fishing activities were identified as vessel groups. Consistency in fishing activity was believed to be related not only to fishing vessel but also to the fisher. Since most fishing vessels in the fishery ranging from aluminium dinghies of less than 6 m to larger vessels up to 30 m tended to have a low level of specialisation, completely different fishing tactics can be practiced on the same vessel depending on the fisher. Therefore, a combination of vessel and fisher ('vessel-fisher') was used in this analysis to identify vessel groups (1675 vessel-fishers in total). All vessels-fishers were retained for the analysis given the aim to describe the total fishing fleet rather than just dominant components.

Using similar methodology as for the identification of target species, fishing vessels with similar fishing tactics were clustered into vessels groups through a PCA for visual examination and a subsequent HCA on fishing vessels as individuals and the percentage of records for each fishing tactics as variables. Vessel groups were then characterized by the main fishing tactics and catch composition, polyvalence in fishing activities based on the Shannon index (1948), main fishing regions and vessel length. Information on vessel length was available for 74% of all vessels.

6.2 Characterisation of fishers' behaviour

6.2.1 Data

The commercial logbook returns for the period from 2000 - 2008 combined with the results from the characterisation of fleet structure were used for the characterisation of fishers' behaviour.

The characterisation of the fleet structure (see Results) indicated close linkages between fishing tactics targeting banded morwong ('BMW'), wrasse, calamari and garfish in the South-East and East of Tasmania. The analyses of fishers' behaviour focused on this area and the vessel groups that targeted these species with their main fishing tactics. These vessel groups, which are named after their main fishing tactics (with a suffix 'VG_') practiced a number of fishing tactics that used mainly graball nets (GN), fish traps (FP), hand line (HL), squid jigs (SJ) and dip nets (DN). Five specific fishing tactics were retained (GN_BMW, FP_Wrasse, HL_Wrasse, SJ_Calamari and DN_Garfish), whereas all other fishing tactics practiced by the selected vessel groups that had been identified in the fleet structure analysis, were pooled into one fishing tactic called 'FT_Other' (Table 6.1).

Information on fishing block was retained in the data records, but the choice of fishing block was assumed to be random or not determined by the factors investigated in this study. This assumption may not always be true but can certainly be correct in some instances where the prevailing weather and wind direction would strongly influence the exact fishing location.

In order to examine the behaviour of core fishers, only fishers were retained in the study if they had been active in the selected fishing areas in all years from 2000 - 2008. This restricted data set to 4901 records by 34 fishers (and 74 vessel-fisher combinations).

Table 6.1: Total catch (tonnes) and value of catch per vessel group, and percentage contributed by each fishing tactics. Main fishing tactics for each vessel group is marked in grey. GN is graball nets, FP is fish traps, HL is hand lines, SJ is squid jigs, DN is dip nets, and BMW is banded morwong.

Vessel group	**Total**	**Fishing tactics (%)**					
(VG)		**GN_BMW**	**FP_Wrasse**	**HL_Wrasse**	**SJ_Calamari**	**DN_Garfish**	**FT_Other**
Catch (t)							
VG_GN_BMW	2347	62	3	5	4	0	26
VG_FP_Wrasse	136	2	39	1	1	0	56
VG_HL_Wrasse	25	0	0	41	25	10	23
VG_SJ_Calamari	211	5	2	10	50	2	32
VG_DN_Garfish	180	1	0	5	39	44	12
Value (Au$ '000)							
VG_GN_BMW	1740	81	3	5	2	0	9
VG_FP_Wrasse	551	6	50	2	1	0	40
VG_HL_Wrasse	131	0	0	49	27	8	16
VG_SJ_Calamari	1065	10	2	16	55	2	15
VG_DN_Garfish	908	1	0	7	41	42	9

6.2.2 Methods

To understand the mechanisms and factors that contribute to the choice of fishing tactics, discrete choice random utility models were used (Holland and Sutinen 1999, Wilen et al. 2002, Vermard et al. 2008, Marchal et al. 2009). These models assume that individuals choose the fishing tactic with the highest expected utility (or benefit) from a number of discrete alternatives. The utility function is usually specified as a linear function of observed variables that are assumed to impact the relative utilities of alternative choices. The estimated parameters of the utility function can then be used to predict the relative probabilities of future choices between alternatives by individuals.

A multinomial logit model was used for the analysis with a number of alternative-specific variables (i.e. observations differ between the alternative choices, e.g. fishing tactics) and individual-specific dependent variables (i.e. observations differ between individuals). To determine the types of independent variables that were likely to influence fishers in their choice of fishing tactics, a small number of semi-structured interviews were conducted with fishers. Thirteen fishers were interviewed who were key operators with a long and consistent catch history in the fishing area using graball nets, traps, handlines, squid jigs and dip nets to target banded morwong, wrasse, calamari, and garfish. The questions focused on the types and frequency of past and present fishing activities, the main fishing tactics and factors that determine their choices, and the anticipated impacts of management changes on their fishing operation (for a summary of the survey results and the questionnaire, see Appendix Chapter 17).

The results from the interviews indicated highly variable levels of fishing activity and annual incomes. The average annual income was low and many fishers had either other occupations to supplement their income from fishing, or other contributors to their household income. Fishing patterns were strongly influenced by tradition and established seasonal fishing patterns, and fishers altered their behaviour only to some degree when fish prices increased or decreased in order to achieve higher revenues or profit.

Based on the interviews, a number of variables were explored in the models (Table 6.2). They included proxies for economic aspects, tradition, the level of engagement in the fishery (part-time or full-time fishing activity), fishers' age and vessel length.

Two alternative-specific variables were defined as a proxy for inertia and seasonal fishing patterns or tradition. The percentage of fishing effort in days fished that the fisher spent in each fishing tactics during the previous month (%EffortMonth) was used as a proxy for the short-term persistence or inertia of following the same fishing tactics in subsequent months. As a proxy for the seasonal persistence of following the same fishing tactics at the same time of the year, the percentage of effort in each fishing tactics in the same month of the previous year was used (%EffortYear).

All other variables included in the analyses were individual-specific variables. The total number of fishing days in the previous month (FDaysMonth) and number of fishing days during the previous 12 months (FDaysYear) for each fisher were indicative of the level part-time or full-time fishing activity in the short or long term. The actual number of fishing days during the previous 12 months varied strongly between fisher from 1 to 241 days in the data set, highlighting the wide spectrum of fishing activity levels. Both variables could also be considered as a proxy for the perceived overall stock sizes of the fished species and fish availability to the fishing gear during the last one or twelve months. For example, if a fisher fished many days with the fishing tactic GN_BMW in the previous month and chose to continue to fish the same fishing tactic in the present month, then this could indicate that he considered the stock size of banded morwong to be large at the time.

In the initial model parameterisation, four different proxies for gross revenue and profit were evaluated. The revenue and value per unit effort (VPUE) were calculated for the total catch and target species in the previous month if the same fisher had chosen the same fishing tactic (Revenue_total, Revenue_target, VPUE_total, and VPUE_target). In the case of the fishing tactic ‘FT_Other’, the target species included all species except the target species of the alternative fishing tactics. For revenue, monthly average fish prices from processors’ dockets were multiplied with each species’ catch weight and summed up to calculate the total revenue. This approach assumed that the majority of the catch was sold in Tasmania, or that transport costs would make up the difference in fish price if the catch was sold at a higher price at interstate markets. For VPUE, revenue was divided by days fished per record as a measure of fishing effort. If fishing costs across gear types and fishing tactics were comparable, this would be also a proxy for profit. However, fishing costs can vary substantially between small and large vessels and between fishing trips where travel costs to the fishing location depends on the distances travelled on water and land (the latter applies to small vessels that are moved around on a trailer to one of the many launching sites in the fishing area). To make these economic variables conditional, each was multiplied with a dummy variable indicating if the fisher had actually chosen the same fishing tactic in the previous month (dummy set to 1) or not (dummy set to 0).

Table 6.2: Variables tested in the random utility models.

Dependent variable	Representation
%EffortMonth	% Effort in each fishing tactic in the previous month
%EffortYear	% Effort in each fishing tactic in the same month of the previous year
FDaysMonth	Total fishing days in the previous month
FDaysYear	Total fishing days in the previous 12 months
Revenue_total	Revenue achieved by the fisher from all species caught with the same fishing tactic in the previous month
Revenue_target	Revenue achieved by the fisher from the target species caught with the same fishing tactic in the previous month
VPUE_total	Value per unit effort (days fished) achieved from all species caught by the fisher with the same fishing tactic in the previous month
VPUE_target	Value per unit effort (days fished) achieved by the fisher from the target species caught with the same fishing tactic in the previous month
FisherAge	Age of fisher
VesselLength	Length of fishing vessel

The fishers' interviews indicated that fishers may alter their behaviour with age (FisherAge), with older fisher being more risk adverse and following established fishing traditions more commonly than young fishers. In the models, the influence of the age of fishers as well as the length of their vessel (VesselLength) on the selection of fishing tactics was investigated. Vessel length is related to the type of vessels, and can vary substantially between fisher. Small vessels of around 6 m length tend to be used on short trips up to one day and have a small range of operation. Larger vessels up to and over 20 m length allow for multi-day fishing trips and fishing activity further offshore and along the coast, and can hold more gear.

Model coefficients were estimated relative to the fishing tactic 'FT_Other' (Greene 2008) and based on data from the period 2000 - 2006. The model was evaluated by the correct number of predictions which was calculated as the choice for each record with the maximum utility. Subsequently, the predictive power of the model was evaluated with data from the period 2007 - 2008, again by comparing the observed choices with the choices based on the highest utility as estimated using the model parameters.

6.3 Characterisation of the fishery and stock dynamics in ISIS-Fish

6.3.1 ISIS-Fish model structure

ISIS-Fish is a spatially-explicit deterministic simulation model with a monthly time step (Mahévas and Pelletier 2004, Pelletier and Mahévas 2005). It is composed of three interacting sub-models that are spatially explicit: a species population dynamics sub-model, which depicts growth, natural mortality, reproduction, recruitment and movements; a fleet dynamics sub-model, which calculates fishing effort; and a management sub-model, which describes management measures.

The model is based on a grid with a spatial resolution relating to the dynamics of the represented fish stock and fishery, and the availability of data. Zones (i.e. sets of contiguous grid cells) are defined for each fish population, fishing activity and management measure. The fisheries take place in regions that comprise one or several zones. Seasons (i.e. sets of successive months) are also defined independently for each population, fishing activity and management measure. Fish population abundance and fishing variables such as effort and catch are assumed to be distributed homogeneously within each zone and season.

The population sub-model can be age-, length- or stage-structured. Population zones and seasons are defined according to the timing and spatial structure of biological processes such as migrations or reproduction. Species catchability, i.e. the probability that a fish present in the specific zone during a season is caught by a unit of standardised effort, can also be season-, age or length class- and/or zone-dependent. At each time step, the model computes the abundance of each population per class and zone. With the model being deterministic, parameter uncertainty can only be included by performing sensitivity analysis.

Exploitation is modelled through fishing effort which is a function of the number and characteristics of the vessels in the fishery, and the fishing activities they practice (Table 6.3). Vessels are classified into vessel types according to their technical characteristics (such as length and engine power). All vessels from a given vessel type share similar fuel costs and have the same maximum trip duration (which is related to fuel autonomy). Vessel groups (VG) are groups of vessel from the same vessel type that originate from a given port. Each vessel group has a specific technical efficiency.

Fishing activity is described through fishing tactics (also called metiers) and strategies. A fishing tactic describes fishing activity at the scale of the fishing trip. It is defined by a gear (characterised by a standardisation factor and a selectivity model for each species), a set of target species (with corresponding target factors), a season and a zone. A fishing strategy describes a specific combination of fishing tactics at the scale of the year and is characterised by the monthly allocation of fishing effort between fishing tactics. Fishers' behaviour is specified indirectly at the strategy level by modifying the effort allocation between fishing tactics to mimic changes in fishers' fishing pattern. The same fishing strategy can be practiced by several vessel groups. At each time step, the exploitation model computes the standardised fishing effort of each vessel group. Combining the exploitation sub-model with the population sub-model, fishing mortality for each population is calculated for each age or length class and zone at each time step.

Table 6.3: Principal parameters of the exploitation sub-model, adapted from Mahévas and Pelletier (2004) and Pelletier et al. (2009).

Model entities and definitions	Parameters
Gear Fishing gear, e.g. squid jig	Value Selectivity Standardisation factors
Fishing tactics (FT) Fishing activity at the scale of the fishing operation, defined by a fishing gear, target species, a fishing zone and a season	Gear used Season Zone Target species and corresponding target factors
Vessel groups (VG) Groups of vessels with the same vessel type (i.e. with similar technical characteristics such as length or engine power) and home port	Number of vessels Number of trips per month Duration of fishing trips Technical efficiency
Strategies (S) Fishing activity of vessel groups at the scale of the year, characterised by a list of fishing tactics practiced and the monthly allocation of fishing effort between these fishing tactics	Proportion of a vessel group that practises the strategy Fishing tactics practised Proportion of fishing effort allocated to each fishing tactic during a given month by vessels from a given vessel group

The management sub-model describes the management scenarios and their impact on the fishing activities. A management measure can affect various parameters such as target species, zone, gear or period. Once implemented, management scenarios constrain exploitation which leads vessels to adapt their fishing effort in response to the constraints. The response of the vessel group to a change in management arrangements is specified at each time step as a change in the monthly allocation of fishing effort between fishing tactics of the fishing strategies affected by the management scenario.

6.3.2 Tasmanian ISIS-Fish model

The model implementation in this study focused on the main fishing area of the Tasmania scalefish fishery in the South-East and East of Tasmania, between statistical fishing blocks 4H3 and 7G3 (Figure 6.3). Tasmanian commercial logbook entries from 1998 - 2008 were used for catch and effort data. Logbook data provided daily summaries of fishing operations, including vessel mark, fisher identification mark, fishing gear, location based on 30x30 nautical mile fishing blocks, minimum and maximum fishing depth, fishing effort, and catch weights of individual species. To match the size of fishing blocks reported in the logbooks, the basic spatial unit in the model was a 30 x 30 nautical mile block (Figure 6.3).

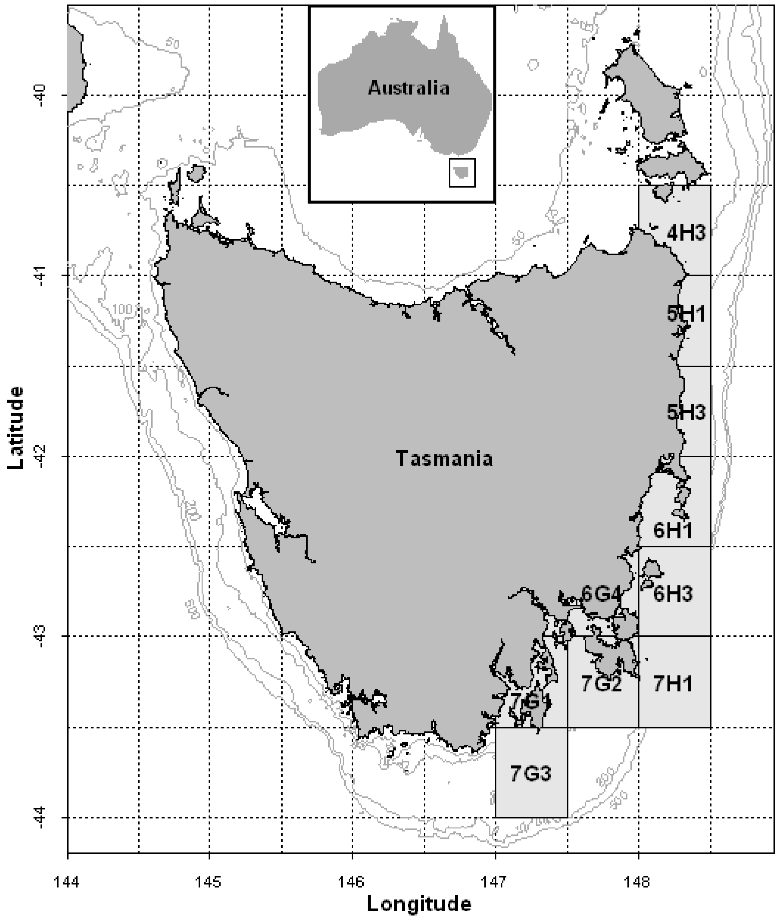


Figure 6.3: Map of Tasmania with scalefish fishing blocks (grey) in the South-East and East that are represented in the ISIS-Fish model.

Of the over 80 different species that are caught in the fishery, four main species were selected. While their yearly contribution to the total scalefish catch did not exceed 30% during the study period, these species were selected because they (i) contributed substantially to the total fishery catch, (ii) were targeted by a number of fishing tactics and vessel groups, and (iii) were of particular interest to management. Banded morwong and wrasses (combining blue-throated wrasse *Notolabrus tetricus* and purple wrasse *N. fucicola*) inhabit rocky reefs in shallow waters. Both species are targeted as live fish, banded morwong by graball nets, wrasses mainly by fish traps and hand line. The two wrasse species have rarely been differentiated in fishing logbooks and were therefore treated as a single species despite differences in their life-history characteristics. Southern calamari and southern garfish are highly mobile species and are mainly caught by squid jig (calamari) and dip nets or purse seine (garfish). Most of the catch is sold to local processors for local and interstate markets.

The sub-models for the species population dynamics, fleet dynamics, and management are summarised below. A more detailed description can be found in Chapter 18.

6.3.2.1 Population sub-model

A population sub-model was developed for each of the four species or species groups reflecting the different life-history characteristics. A summary of each species' characteristics used in the model is presented in Table 6.4. Age-based population models with 15 and 8 age classes were used to represent wrasse and garfish, respectively. For banded morwong, a two-sex length-based population model structured in 15 length classes per sex was developed due to differential growth between males and females. The choice of a length-based model over an age-based model was the result of restrictions in ISIS-Fish, which currently allows sex separation only in a length-based model. However, the length-based model essentially behaved like an age-based model, where each length class represented only one age class. Finally, the annual life cycle of calamari with rapid and extreme variable growth and seasonal recruitment was simplified by one adult length class. For each species, a single and closed population that was homogeneously distributed over the whole area was assumed, even though species such as banded morwong and wrasse tend to move over short distances only (Murphy and Lyle 1999) and the dynamic-pool assumption for these species is likely to be violated in reality.

The ISIS-Fish model simulated a historical period from 1998 - 2008 and a projection period over 20 years from 2009 - 2028. To obtain the initial numbers-at-age in 1998 and subsequent number of recruits from 1998 - 2008, an integrated statistical catch-at-age stock assessment model that had been originally developed for banded morwong (Ziegler and Lyle 2010), was used for banded morwong, wrasse and garfish. The models were fitted to catch rates from 1996-2008 and age composition data from the east coast that were collected during research trips.

For banded morwong, age data were available for 1996 - 1997 and in most years since 2001. For wrasse, age data were only available for the period from 1999 - 2002 and for garfish in 1996 and from 2008 - 2009. Due to the lack of consistent age data for wrasse and garfish, catch rates were weighted strongly in the model fits. Biological parameters for growth, natural mortality, selectivity were similar to the ones described below for the ISIS-Fish model. No information was available on calamari recruitment or adult stock size. For the historic recruitment of calamari, recruitment was estimated from annual catches assuming that calamari catches equated to 50% of the population biomass.

6.3.2.2 Exploitation sub-model

Fishing mortality was quantified through fishing effort. Fishing effort is a function of the number and characteristics of vessels in the fishery and the fishing activity they practice (Table 6.3), i.e. the fishing tactics at the scale of the fishing operation and the fishing strategies at the scale of the year (Pelletier et al. 2009). In the model, both fish abundance and fishing effort are uniformly distributed over their respective population and fishing tactics zones, so that the contribution of fishing effort to fishing mortality is directly tied to the intersection between population zone and fishing tactic zone (Mahévas and Pelletier 2004). Fishing mortality also depends on additional parameters including catchability, gear selectivity, a gear standardisation factor and a fishing tactic target factor (Mahévas and Pelletier 2004, Pelletier et al. 2009).

Table 6.4: Species life-history and population characteristics as represented in the ISIS-Fish model, with the type of population model, parameters of the length-at-age and length-weight relationship, natural mortality M, annual recruitment with mean μ and standard deviation σ of the lognormal distribution, and estimated catchability coefficients.

<table>
<tr><th>Species</th><th>Population model</th><th>Length-at-age</th><th>Length-weight</th><th>Natural mortality M</th><th>Annual recruitment</th><th>Catchability q</th></tr>
<tr><td>Banded morwong</td><td>Two-sex length-based model (15 classes each)</td><td>Schnute-Richards growth function
L in mm, t in years<table><tr><th>Parameter</th><th>Females</th><th>Males</th></tr><tr><td>$L\infty$</td><td>442</td><td>516</td></tr><tr><td>α</td><td>51.4</td><td>0.1</td></tr><tr><td>a</td><td>18.8</td><td>2.3</td></tr><tr><td>b</td><td>3.3^{e-7}</td><td>$3.3e^{-3}$</td></tr><tr><td>c</td><td>0.05</td><td>0.33</td></tr></table></td><td>W in g, L in mm<table><tr><th>Parameter</th><th>Females</th><th>Males</th></tr><tr><td>a</td><td>$3.563e^{-5}$</td><td>$3.729e^{-5}$</td></tr><tr><td>b</td><td>2.875</td><td>2.852</td></tr></table></td><td>0.07</td><td>μ = 11.08
σ = 0.47</td><td>$9.25e^{-5}$</td></tr>
<tr><td>Wrasse</td><td>Age-based model (15 classes</td><td>Von Bertalanffy growth function
L in cm, t in years
L_∞ = 44.7
K = 0.085
t_0 = 3.23</td><td>W in g, L in cm
a = 0.0161
b = 3.0407</td><td>0.02</td><td>μ = 13.09
σ = 0.36</td><td>$2.44e^{-4}$</td></tr>
<tr><td>Calamari</td><td>Length-based model with 1 classes</td><td>L = 300 mm</td><td>W in g, L in mm
a = 0.0008
b = 2.427</td><td>0.80</td><td>μ = 11.99
σ = 0.29</td><td>$q_1 = 7.00e^{-5}$
$q_2 = 2.50e^{-4}$
$q_3 = 7.00e^{-4}$
$q_4 = 24.50e^{-4}$</td></tr>
<tr><td>Garfish</td><td>Age-based with 8 classes</td><td>Von Bertalanffy growth function
L in cm, t in years
L_∞ = 34.3
K = 0.54
t_0 = -0.23</td><td>W in g, L in cm
a = 0.0011
b = 3.4403</td><td>0.60</td><td>μ = 14.09
σ = 0.43</td><td>$5.31e^{-5}$</td></tr>
</table>

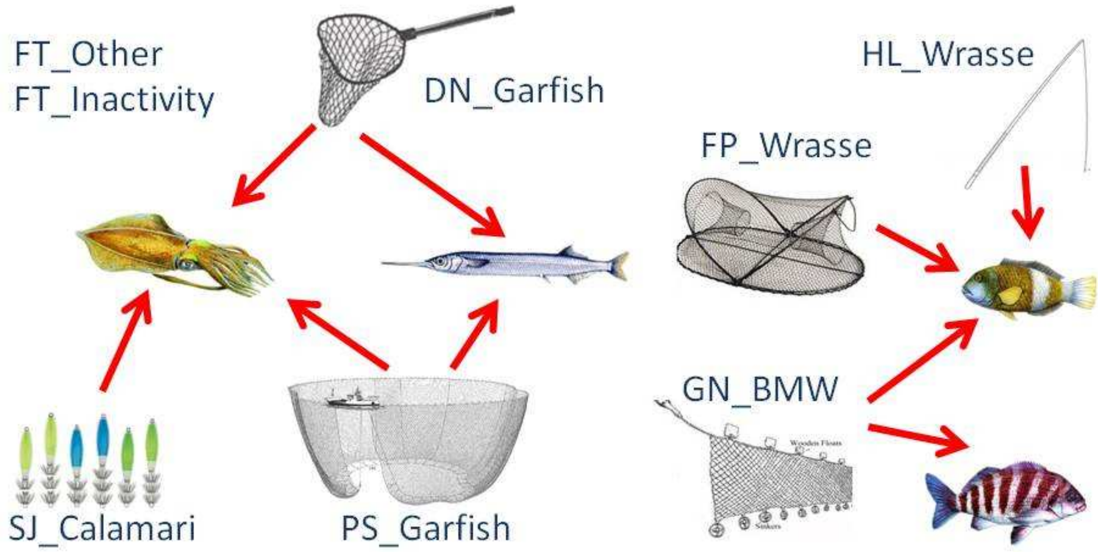


Figure 6.4: Target species and fishing tactics defined for the Tasmanian ISIS-Fish model application.

The fleet dynamics sub-model included only those fishing tactics identified by the fleet structure analysis with substantial and consistent contributions to catches of the four species of interest, i.e. that contributed to at least 10% of the annual species catch for 8 of 11 years from 1998-2008. These fishing tactics were practiced with the gear types graball net (GN), fish trap (FP), hand line (HL), squid jig (SJ), dip net (DN), and purse seine (PS). Six fishing tactics, named after the target species, were retained in the model: GN_BMW (where 'BMW' is banded morwong), FP_Wrasse, HL_Wrasse, SJ_Calamari, DN_Garfish and PS_Garfish (Figure 6.4). The remaining fishing tactics practiced in the model area, including e.g. GN_Mixed that used graball nets to target a range of species (see Chapter 7.1), were grouped into one additional fishing tactic called FT_Other. An additional dummy fishing tactic (FT_Inactivity) was also created to reflect periods where vessels were not active in the fishery.

Following the same selection rules as for the fishing tactics, six vessel groups were retained (named after their dominant fishing tactics with a suffix 'VG'): VG_GN_BMW, VG_FP_Wrasse, VG_HL_Wrasse, VG_SJ_Calamari, VG_DN_Garfish, and VG_GN_Mixed. The average number of active fishing vessels during the most recent years from 2003-2008 was used for all years, although the number of active vessels in a given vessel group fluctuated from year to year (see Chapter 18). Based on logbook data, two vessel types were defined for the model: small vessels less than 6 m in length that are only capable of 1-day trips, and large vessels more than 6 m in length that are capable of performing 5-day trips. The proportion of vessel types within each vessel group varied to some degree from year to year, but there was a consistent dominance of a particular vessel type within a vessel group over time. For example, the vessel groups VG_GN_BMW, VG_SJ_Calamari and VG_DN_Garfish were always dominated by small vessels, while VG_FP_Wrasse and VG_HL_Wrasse were dominated by large vessels. In order to obtain a fixed proportion of each vessel type, the proportion of small and large vessels in the most recent years from 2003 - 2008 was averaged. Vessel types that constituted over 80% of a given vessel group were considered as the sole vessel type for that vessel group.

The spatial distribution of fishing effort by fishing tactics differed between vessel groups and appeared to be linked to whether the fishing tactic was the main or a secondary fishing tactic for a vessel group. Accordingly, two fishing zones were defined for each fishing tactics, with a “main fishing zone” for the vessel groups using the fishing tactic preferentially and a “secondary fishing zone” for all other vessel groups using the fishing tactics as a side activity. The effort per fishing blocks was averaged from 1998 - 2008 for each fishing tactic. Only fishing blocks which contributed 10% or more to the total effort for the fishing tactic were included in the fishing zone.

Fishing strategies describe the fishing activity of vessel groups at the scale of the year and are characterised by a list of fishing tactics practiced and the monthly allocation of fishing effort between these fishing tactics (Mahévas and Pelletier 2004). Yearly fishing strategies for the selected vessel groups were estimated from the logbooks returns from 1998 - 2008. While fishing occurred every month of the year, vessel groups were only active for parts of the month (on average 20-40% depending on the vessel group). Fishing strategies in the earlier years of the study period also differed from those in the late 2000s. This was mainly caused by the presence and opportunistic targeting of blue warehou by many vessel groups in the early 2000s, which increased the contribution of the fishing tactic FT_Other in the strategies. Since the model did not represent blue warehou, only the period from 2003 - 2008 was used to estimate an average fishing strategy for each vessel group. All vessel groups with the exception of vessel groups VG_FP_Wrasse and VG_HL_Wrasse had one fishing strategy. Two fishing strategies were represented in VG_FP_Wrasse and VG_HL_Wrasse, since the home ports of about one third of vessels was located outside the main fishing area and these vessels with ‘outside’ port allocated their fishing effort between the fishing tactics differently from vessels with ‘inside’ ports. This resulted in a total of eight fishing strategies (named with a suffix ‘S’): S_GN_BMW, S_FP_Wrasse, S_FP_Wrasse_out, S_HL_Wrasse, S_HL_Wrasse_out, S_SJ_Calamari, S_DN_Garfish, and S_GN_Mixed.

Estimates of gear selectivity, gear standardisation factors, fishing tactic target factors and technical efficiency of vessel groups were based on other studies or the results of a generalised linear model. Catchability was first calibrated using the monthly landing of vessel groups from 1998 - 2005, as well as the estimated biomass from the stock assessment models for these species (1998 - 2002 for wrasse). Catchability values were then validated for the period from 2006 - 2008 for all four species by simulating monthly landings and biomass estimates for banded morwong and garfish and comparing the results with observed data.

6.3.2.3 Simulations of various management scenarios

The management arrangements for the historical period from 1998 - 2008 were stable for most of the four fish species and used in the model as specified in Table 6.5. The fishing for garfish was only limited by a minimum size limit of 250 mm. Minimum size limits were also in place for wrasse (300 mm), together with a species-specific licence to land live fish. For banded morwong, minimum and maximum size limits were set to 360 mm and 460 mm in 1998 and have remained at that level until 2008. In addition, a closed season from March to April had been introduced in 1995 to protect fish during the peak spawning period. Similarly to wrasse, a species-specific licence was required to fish for live banded morwong. At the end of the study period in late 2008, a quota management system with a Total Allowable Catch (TAC) was introduced in the entire South-East and East and parts of Tasmania’s North. The initial TAC was set to 40.3 t per fishing year, starting in March each year.

Table 6.5: Species-specific management arrangements during the historical period of the model from 1998-2008. 'BMW' is banded morwong.

Species	Management arrangements	Represented in Scenario 1 (Base Case) for projections
BMW	Minimum (360 mm) and maximum (460 mm) size limits	Yes
	Temporal closure during spawning season (Mar-Apr)	Yes
	Species-specific licence for live banded morwong	No
Wrasse	Minimum size limit of 300 mm	Yes
	Species-specific licence for live wrasse	No
Calamari	Variable temporal closure of spawning grounds: 1999-2002: Twice two weeks between Oct - Nov 2003-2004: Sep - Nov 2005-2006: Mid Sep - Mid Dec 2007-2008: Oct - Mid Dec	1-month closure in Oct
Garfish	Minimum size limit of 250 mm	Yes

For calamari, the targeted fishery has been managed through closures of the main spawning grounds to protect spawning activity when calamari are particularly vulnerable to fishing. The timing of these closures has varied over the years, but typically lasted 1-3 months between September and December (Table 6.5). By 2008, an extended spawning ground closure was in place from October to mid December. The model followed the overall length and timing of historical spawning closures for the period from 1998 - 2008. Spatially, the actual size of the spawning ground closures was very small (about half of a fishing block), but about two thirds of the fishing effort of the only fishing tactic targeting calamari (SJ_Calamari) was concentrated on the spawning grounds. Since the ISIS-Fish model assumes homogenous fishing effort within a fishing zone, the spawning ground closures were approximated by closing an area of the metier that was proportional to the fishing effort on the spawning grounds, i.e. two of the three fishing blocks in which the fishing tactic SJ_Calamari was active.

A number of scenarios were tested with changes in management and fishing strategies in the study area over the projection period from 2009 - 2028 (Table 6.6). In each scenario, two species-specific outputs variables were analysed, namely monthly landings in weight (tonnes) summed over all fishing strategies, and yearly biomass per species in weight (tonnes). Scenario 1 represented the Base Case with management arrangements as described in Table 6.5, and historical average fishing strategies from 1998 - 2008 were used in the projections.

In all other scenarios, management arrangements were altered for at least one species and potentially affected other species through effort displacement between fishing tactics (Table 6.6). Seasonal closures were simulated by modifying the fishing strategies. During the closure period, the proportion of effort allocated to fishing tactics primarily targeting a fish species to which the closure applied were set to zero. The effort was then redistributed during this period to other fishing tactics in the strategy. This equates to assuming that fishers do not become inactive but rather target other species during the closure. Effort redistribution followed one of two general patterns, i.e. the effort was proportionally redistributed to all other fishing tactics that were active at the time in the strategy, or only to one or two fishing tactics selected as indicated by the industry survey (see Chapter 17).

Table 6.6: Management scenario tested. Only differences from the Base Case scenario (Scenario 1) are presented in the table. 'BMW' is banded morwong, 'FT' is fishing tactics, 'equal' is equal redistribution of fishing effort, 'prop' is proportional redistribution of fishing effort.

Scenario	Affected Species	Management rule	Effort displacement
1 Base Case	-	-	None
2	BMW	Decrease max size limit to 430 mm	None
3	BMW	25% effort reduction for GN_BMW	Equal to HL_Wrasse and FT_Other
4	BMW	25% effort reduction for GN_BMW	Prop to HL_Wrasse and FP_Wrasse
5	Wrasse	2-month closure (Oct-Nov)	Prop to all other active FT
6	Wrasse	2-month closure (Oct-Nov)	All to GN_BMW
7	Calamari	1-month spawning ground closure (Oct)	Prop to all other active FT
8	Calamari	1-month spawning ground closure (Oct)	All to DN_Garfish
9	Calamari	2-month spawning ground closure (Oct-Nov)	Prop to all other active FT
10	Garfish	1-month closure (Dec)	Prop to all other active FT
11	Garfish	1-month closure (Dec)	All to SJ_Calamari
12	Garfish	2-month closure (Dec-Jan)	Prop to all other active FT
13	Garfish	6-month closure (Dec-May)	Prop to all other active FT
14	Calamari AND Garfish	1-month of spawning ground closure (Oct) 1-month closure (Dec)	Prop to all other active FT during both closures

Spatial closures were simulated similarly to seasonal closure, with the difference that only effort from the closed area was redistributed towards other fishing tactics. Most scenarios were chosen to reflect potential future changes in management, while others were chosen to test the effects of drastic management changes in the fishery.

In Scenario 2, the maximum size limit of banded morwong was reduced from 460 mm to 430 mm without any redistribution of fishing effort. This scenario did not affect species other than banded morwong and was conducted to verify the model dynamics with increased protection of large fish. Scenarios 3 and 4 simulated a monthly 25% reduction of effort in the main fishing tactic targeting banded morwong (GN_BMW) for the vessel group VG_GN_BMW, which approximated an immediate reduction of the catch (or the TAC which was introduced in late 2008) from around 40 to 30 tonnes. In Scenario 3, effort was redistributed equally towards the second and third most important tactics practised by the vessel group VG_GN_BMW, namely HL_Wrasse and FT_Other, while in scenario 4 effort was redistributed towards fishing tactics targeting wrasse only (HL_Wrasse and FP_Wrasse) in proportion to their original contribution to the strategy.

Scenarios 5 and 6 simulated seasonal closures of the wrasse fishery for two months during spawning. Effort was redistributed during this period either to all other active fishing tactics that did not target wrasse (Scenario 5) or exclusively towards the fishing tactic GN_BMW since banded morwong was commonly targeted by wrasse fishers (Scenario 6).

Two scenarios tested the effects of a 1-month closure of the calamari spawning grounds in October with different redistribution of effort. In Scenario 7, effort in the spawning ground area was redistributed from the fishing tactic SJ_Calamari towards all other active fishing tactics in proportion to their original contribution to the strategy, while in Scenario 8 effort was redistributed exclusively towards the fishing tactic DN_Garfish, since many fishers targeted calamari and garfish together or switched frequently between the species. Scenario 9 tested an increase in the time of the closure to two months, which had been implemented in some of the past years. The redistribution of effort was identical to Scenario 7.

Scenario 10 and 11 represent a 1-month garfish closure in December, similar to the actual closure for the east coast of Tasmania in place since 2010. Effort was redistributed from the fishing tactic DN_Garfish towards all other active fishing tactics in that month for Scenario 10, and towards SJ_Calamari only in Scenario 11, as calamari is the second most targeted species by the vessel group VG_DN_Garfish. Scenarios 12 and 13 represented 2-month and 6-month closures, respectively. In both cases, effort was redistributed towards all other active fishing tactics, proportionally to their original contribution to the strategy.

Scenario 14 was the only scenario to test two management actions simultaneously, a 1-month calamari spawning ground closure in October and a 1-month garfish closure in December. However, the closures did not overlap in time, thus there was no cumulative effect in any one month. For both closures, the effort was redistributed to all other active fishing tactics, proportionally to their original contribution to the strategy.

For each scenario, 200 simulations were run with stochastic recruitment for each year of the projection. Annual recruitment was randomly selected from the log-normal distributions described in Table 6.4. For each scenario *n* and each species, the mean cumulative landings from 2009-2028 and the average biomass in the final simulation year 2028 were compared to those of the Base Case (Scenario 1). Results were expressed as the relative difference between the mean of the scenario and the Base Case Scenario. The relative Standard Error of Difference (SED) in percent was used as measure of error for each species by:

$$\% \, SED = \frac{\sqrt{\left(SE_n{}^2 + SE_{Base\ Case}{}^2\right)}}{mean_{Base\ Case}} * 100$$

where *SE* is the standard error, *n* is the scenario number and $mean_{Base\ Case}$ is the mean cumulative landings or mean final biomass for the Base Case Scenario.

7. RESULTS

7.1 Characterisation of the fleet structure

7.1.1 Target species

The HAC led to the identification of 1-16 clusters of target species per gear type, describing 51-86% of the variances. A highly characteristic species or species group was found for most clusters and these clusters were named after these species (Table 7.1). Clusters with a heterogeneous species composition were sub-classified, but when this second step did not result in a dominant species, clusters were named 'mixed species'.

Table 7.1: Target species per gear type in the Tasmanian scalefish fishery as identified by PCA and HCA. Target species are ordered by total catch weights. Some target species derived from more than one cluster.

Gear code	Gear type	No of records	No of clusters	Variance described	Target species
AJ	Automated jig	184	1		Gould's squid
BL	Bottom line	2220	6	81.1%	Shark, deepwater species, striped trumpeter, flathead
BS	Beach seine	2311	12	78.1%	Australian salmon, garfish, jack mackerel, mullet, anchovy, mixed species
DL	Drop line	2355	5	71.3%	Blue-eye trevalla, striped trumpeter, shark, barracouta, mixed species
DN	Dip net	1811	5	84.9%	Garfish, calamari, mixed species
DS	Danish seine	629	4	58.4%	Flathead, whiting
FP	Fish trap	4592	1		Wrasse
GN	Graball net	14072	16	55.7%	Blue warehou, banded morwong, bastard trumpeter, Australian salmon, shark, miscellaneous reef fish, striped trumpeter, flounder, barracouta, flathead, wrasse, octopus, trevally, jack mackerel, mullet, mixed species
HC	Hand collection	373	1		Octopus
HL	Hand line	8399	14	73.7%	Wrasse, striped trumpeter, flathead, barracouta, shark, Australian salmon, mixed species
MN	Small mesh net	1154	11	51.1%	Blue warehou, mullet, Australian salmon, flathead, pike, barracouta
OP	Octopus pot	609	1		Octopus
PS	Purse seine	533	6	65.1%	Jack mackerel, garfish, calamari, anchovy, Australian salmon, mullet
SJ	Squid jig	3727	2	84.6%	Calamari , Gould's squid
SN	Shark net	7679	1		Shark
SP	Spear	1923	6	78.1%	Calamari, flounder, octopus
TR	Troll	2671	7	86.2%	Barracouta, Australian salmon, tuna, pike, mixed species

No clustering was conducted where a gear type was used to target only a single species or species group, as in the case of automated jig targeting Gould's squid, hand collection and octopus pots targeting octopus, shark nets targeting shark, and wrasse traps targeting wrasse. A number of records for wrasse traps reported catches of a range of reef fish species without wrasse, but based on anecdotal evidence these records were assumed to be the result of failing to catch legal-sized wrasse in heavily fished locations rather than targeting other reef species.

Graball net was the most diverse gear type targeting a wide range of reef species such as banded morwong, blue warehou, bastard and striped trumpeter. Small mesh net, beach seine and hand lines were also gear types with a large range of species caught.

7.1.2 Fishing tactics

For each fishing gear, the fishing activity of a record was described by the combination of target species, fishing region and month. The MCA and HCA led to the identification of 1-16 clusters per fishing gear, describing 47-64% of the variances (Table 7.2). Similar clusters were subsequently pooled, resulting in up to 10 fishing tactics per fishing gear and a total of 35 fishing tactics. These fishing tactics varied widely in their number of records, from 97 records in BS_JackMackerel to 7671 records in SN_Shark. The top 15 fishing tactics represented close to 80% of the records.

Table 7.2: Fishing tactics obtained from MCA and HCA by gear type. Target species (in bold) and main species caught (with % in weight, only species that contribute more than 10% to the overall catch are shown), number of records, regions of high and medium (in brackets) importance, and indication of monthly activity (black: above expected monthly average; grey: intermediate; white: less than half the expected monthly average). Subsequently, a fishing tactic is named after the fishing gear type and the target species, e.g. AJ_GouldSquid.

Gear type	Target species (bold) and main species caught	No of records	Main regions	Months
AJ	**Gould's squid** (100%)	184	SE	
BL	**Sharks** (43%), deepwater species (40%)	2114	All regions (mainly NW, North, Flinders, East)	
BS	**Australian salmon** (83%), garfish (12%)	1887	North, Flinders	
	Garfish (33%), **mullet** (32%), Australian salmon (30%)	327	North, East	
	Jack mackerel (93%)	97	SE	
DL	**Blue-eye trevalla** (74%), striped trumpeter (14%)	2350	East (SW, SE)	
DN	**Garfish** (82%), calamari (15%)	1810	SE (East, North)	
DS	**Flathead** (49%), **whiting** (45%)	629	SE	Flathead Whiting
FP	**Wrasse** (77%), reef fish (19%)	4577	East, SE (SW, NW, North, Flinders)	

Table 7.2: Continued.

Gear type	Target species (bold) and main species caught	No of records	Main regions	Months
GN	**Australian salmon** (63%)	642	Flinders (North)	
	Blue warehou (70%)	2936	SE (East, North)	
	Banded morwong (78%)	2912	East, SE	
	Bastard trumpeter (49%), striped trumpeter (11%)	3267	SW, SE (East, NW, West)	
	Flounder (75%), Atlantic salmon (11%)	715	North (West)	
	Mixed: Blue warehou (16%), flathead (10%)	1354	SE, Flinders, North (East)	
	Morwong (53%), striped trumpeter (20%)	1012	East (SE)	
	Octopus (94%)	147	SE	
	Shark (64%)	568	North, SE (Flinders)	
	Wrasse (56%), reef fish (11%), bastard trumpeter (10%)	482	East, SE (Flinders, NW)	
HC	**Octopus** (99%)	373	SE	
HL	**Barracouta** (64%), **Australian salmon** (25%)	354	NW (Flinders, North, SE)	
	Flathead (74%), shark (12%)	2124	SE, East (Flinders, North)	
	Mixed: Tuna (10%), morwong (10%), striped trumpeter (10%), calamari (10%)	779	SE (East, NW)	
	Striped trumpeter (73%), gurnards (12%)	1574	SE, East (SW, Flinders)	
	Wrasse (95%)	3539	SE, East, North (NW, Flinders)	
MN	**Mixed**: Blue warehou (33%), barracouta (20%), Australian salmon (15%)	1153	North	
OP	**Octopus** (100%)	609	North	
PS	**Calamari** (94%)	114	East (SE)	
	Garfish (73%), mullet (13%)	239	SE (East)	
	Mixed: Jack mackerel (93%)	179	SE (East)	
SJ	**Calamari** (82%), Gould's squid (16%)	3724	SE (East, North)	
SN	**Shark** (97%)	7671	All regions (mainly Flinders, North, NW)	
SP	**Flounder** (62%), calamari (32%)	1923	SE	
TR	**Barracouta** (88%)	1822	SE (East, North)	
	Australian salmon (67%), barracouta (27%)	843	Flinders, NW	

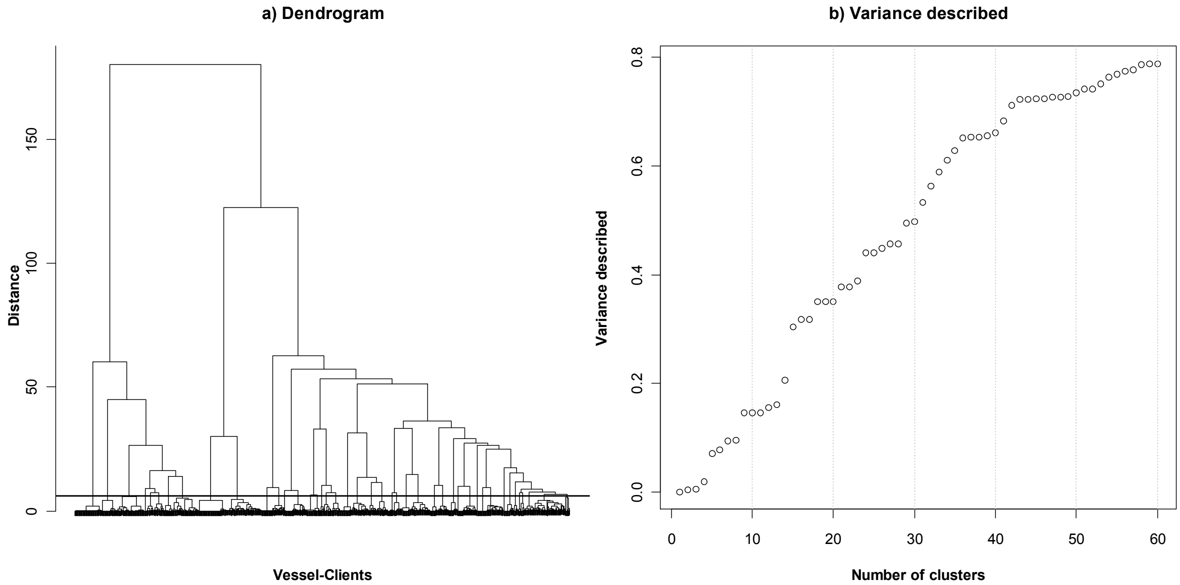


Figure 7.1: Results from the HAC classification of vessels-fishers to vessel groups: (a) dendrogram with the level of partition into 43 clusters (black line), and (b) variance explained with increasing numbers of clusters.

7.1.3 Vessel groups

The HCA classification of vessels groups indicated a possible clustering into 43 clusters, describing 72.2% of the variance (Figure 7.1). Most classifications were unambiguous, but many clusters were highly similar and were subsequently pooled if they showed the same dominating fishing tactic but differing contribution of other tactics. Small vessels groups were retained if few minor fishing tactics were practiced beside the main tactic (e.g. Danish seine, hand collection and octopus pots). In contrast, small groups with frequent other fishing tactics were amalgamated in a group of mixed fishing tactics (VG_Mixed). For example, some fishing activities relating to purse seine occurred only in conjunction with a range of other fishing activities, and thus were considered as part of the VG_Mixed group. Records with a range of mainly graball net tactics were grouped into VG_GN_Mixed. This classification resulted in 20 vessel groups, which were named after the main fishing tactic (with the prefix 'VG' for vessel group).

Vessel groups were characterised based on fishing regions, fishing tactics, and main species caught (Table 7.3). Four categories of vessel groups were identified that accounted for three levels of specialisation in fishing tactics and main species, and a deepwater fleet.

Table 7.3: Characteristics of the identified vessel groups. Vessel groups are named after the dominating fishing tactic (FT). Total numbers of records, total number of vessel-fishers, dominant vessel length, percentage of records of the dominating fishing tactic ('% in main FT'), polyvalence *H* of practiced fishing tactics, regions of high and medium (in brackets) importance, total weight in tonnes caught over all years, main fishing tactics practiced that contributed >10% to the total catch weight, and main fish species caught with >10% of total weight. Vessel groups are named after the main fishing tactic with a prefix 'VG_', where 'AuS' is Australian salmon, 'BMW' is banded morwong, 'Barra' is barracouta, 'STR' is striped trumpeter, and 'BlueEye' is blue-eye trevalla.

Vessel group (VG)	No of records	No of VF	Vessel length	% in main FT	*H*	Main regions	Total weight (t)	Main fishing tactics practiced	Main species caught
(1) Specialists									
VG_SP_Flounder&Calamari	826	16	0-6m	76%	1.09	SE	83	SP_Flounder&Calamari (84%)	Flounder (75%), calamari (13%)
VG_BS_Garfish&AuS	2426	50	0-6m	53%	2.14	Flinders, North	5235	BS_Garfish&AuS (72%), BS_AuS (21%)	Australian salmon (81%)
VG_HL_Wrasse	1903	78	0-20m	59%	1.85	SE (East, North, NW, Flinders)	451	HL_Wrasse (70%)	Wrasse (70%)
VG_AJ_GouldSquid	202	25	10-20m	78%	0.90	SE (East)	1134	AJ_GouldSquid (99%)	Gould's squid (99%)
VG_OP_Octopus	759	12	10-20m	70%	0.82	North (NW)	673	OP_Octopus (93%)	Octopus (93%)
VG_DS_Flathead&Whiting	636	7	10-20m	96%	0.22	SE	1154	DS_Flathead&Whiting (100%)	Flathead (49%), whiting (45%)
(2) Intermediate									
VG_GN_BMW	5384	126	0-6m	47%	1.89	East, SE	1255	GN_BMW (60%), GN_BlueW (11%)	Banded morwong (50%), wrasse (15%)
VG_DN_Garfish	2966	65	0-6m	37%	2.11	SE (East)	1159	PS_JackM (33%), DN_Garfish (22%), SJ_Calamari (19%)	Jack mackerel (39%), calamari (24%), garfish (18%)
VG_MN_MixedNorth	1096	22	0-6m	62%	1.51	North	363	MN_MixedNorth (62%), SJ_Calamari (10%)	Blue warehou (31%), barracouta (22%), Australian salmon (16%), calamari (10%)
VG_SJ_Calamari	4388	102	0-6m	35%	2.43	SE (North)	984	SJ_Calamari (45%), TR_Barra (12%), HL_Wrasse (11%)	Calamari (40%), wrasse (14%), barracouta (11%)
VG_FP_Wrasse	6250	194	10-20m	43%	2.34	East, SE (SW, NW, Flinders)	1019	FP_Wrasse (43%), all GN (22%)	Wrasse (37%), reef fish (12%)
VG_HL_STR	1134	81	10-20m	60%	1.70	SE (East, SW, West)	226	HL_STR (63%), TR_Barra (10%)	Striped trumpeter (54%), barracouta (11%)
VG_TR_Barra&AuS	806	54	10-20m	55%	2.19	North (SE, SW, NW)	214	TR_Barra (62%), TR_Barra&AuS (17%)	Barracouta (62%), Australian salmon (17%)

Table 7.3: Continued.

Vessel group (VG)	No of records	No of VF	Vessel length	% in main FT	H	Main regions	Total weight (t)	Main fishing tactics practiced	Main species caught
(3) Generalists									
VG_GN_Mixed	7330	301	0-20m	59%	2.93	SE (SW, East)	1858	GN_BlueW (27%), GN_BTR (14%), all other GN (17%)	Blue warehou (22%), bastard trumpeter (10%), Australian salmon (10%)
VG_HL_Flathead	2484	75	0-20m	38%	2.47	East, SE, Flinders (SW, NW, North)	269	HL_Flathead (28%), all other HL (20%), GN_BTR (13%)	Flathead (22%), shark (13%), bastard trumpeter (10%), striped trumpeter (10%)
VG_Mixed	2959	88	10-20m		3.26	SE (North)	1492	PS_JackM (48%), all GN (23%)	Jack mackerel (49%)
VG_GN_Flounder	1219	28	0-6m	46%	2.03	North (West)	271	BS_Garfish&AuS (32%), GN_Flounder (24%), GN_BTR (14%)	Flounder (25%), garfish (19%), blue warehou (17%)
(4) Deepwater fleet									
VG_DL_STR&BlueEye	2018	102	10-20m	69%	1.93	East (SW, SE, Flinders)	1444	DL_STR&BlueEyeEast (66%), DL_STR&BlueEyeWest (24%)	Blue-eye trevalla (75%)
VG_BL_Shark	2168	92	10-20m	55%	2.01	NW, East (Flinders, North, West)	1676	BL_Shark (92%)	Deepwater species (43%), Shark (34%)
VG_SN_Shark	8175	157	10-20m	91%	0.54	Flinders (SE, NW, North)	7208	SN_Shark (93%)	Shark (92%)

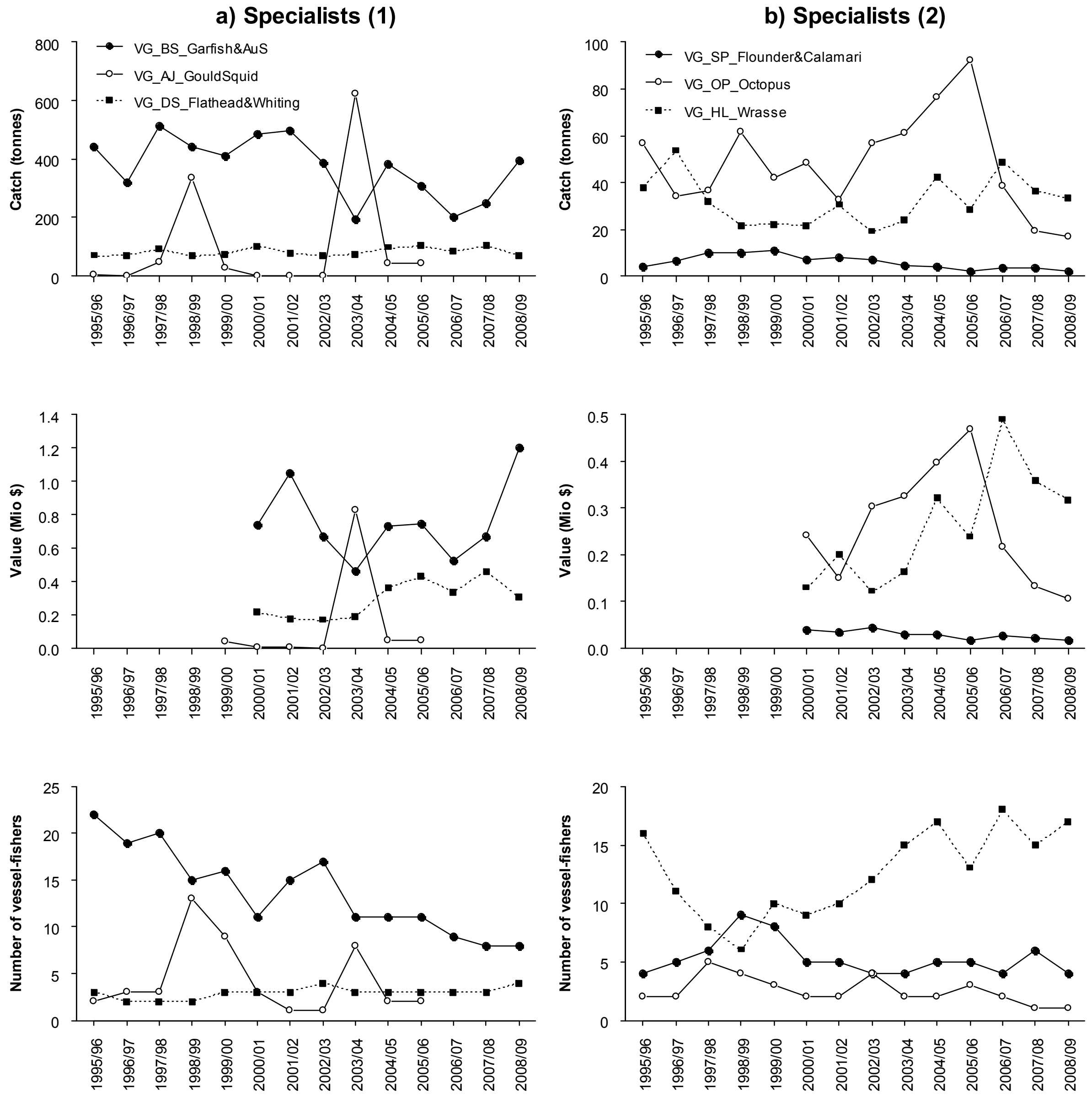


Figure 7.2: Total catch (in tonnes), value (in AU$) and number of active vessels-fishers per fishing year by fishing year for each vessel group of the specialist category. Vessel groups are shown in two separate graphs for clarity. Note that 'vessel-fisher' is a unique combination of vessel and fisher and is used instead of vessel or fisher (see methods).

7.1.3.1 Specialists

Six specialist vessel groups showed a clear dominance (>60%) of one or two particular fishing tactics and species caught. Consequently, polyvalence in fishing tactics tended to be low. Most specialist groups consisted of a low number of vessel-fishers, while the type of operations and total catch weight varied substantially (Figure 7.2a and Figure 7.2b). For example, the overall smallest vessel group VG_DS_Flathead&Whiting consisted of only seven vessel-fishers over the 14-year period and was highly specialised in targeting flathead and whiting with Danish seine in the South-East (94% of total catch). While the low number of vessel-fisher was a result of the requirement for a specialised licence to use Danish seine, the overall catches of 1154 tonnes from 1995/96 - 2008/09 were large compared to that of other vessel groups. Another small vessel group, VG_OP_Octopus, reported intermediate catch levels and consisted of vessels that belonged to a family-operated business in the North which used octopus pots to target octopus (93% of total catch). In contrast, VG_SP_Flounder&Calamari caught overall the lowest fish quantities of all vessel groups (83 tonnes over 14 years) by targeting flounder and calamari with hand-held spear from small dinghies in estuaries and inshore waters.

Gould's squid dominated the total catch (99%) of the vessel group VG_AJ_GouldSquid which followed high squid abundance and market prices around the whole of south-eastern Australia. Two peaks in fishing activity and catches during 1998/99 and 2003/04 in South-East Tasmania reflected the sporadic occurrence of the squid and profitable fish prices, but the vessels were virtually inactive in Tasmanian waters in other years (Figure 7.2a). Gould's squid were e.g. still abundant in 2004/05, but the market price had dropped substantially (J. Lyle, University of Tasmania, pers. comm.).

While most vessels of VG_BS_Garfish&AuS were smaller than 6 m in length and operated mainly close to shore in Flinders and the North, catches of this vessel group were dominated by one large vessel that targeted mainly Australian salmon ('AuS') and caught 71% of the total vessel group catch. Annual fluctuations in the total catch of this vessel group (Figure 7.2a) were largely attributable to the activity of this vessel and market demand of Australian salmon (Ziegler and Lyle 2010). The reminder of the vessel group targeted Australian salmon and garfish more equally and consequently the vessel group had a relatively high polyvalence.

VG_HL_Wrasse was the largest vessel group of this category and targeted mainly wrasse in the South-East using hand line, graball nets and fish traps (70% of total catch). The number of active vessel-fishers in each year decreased rapidly from 1995/96 - 1998/99, but against the trend of most other vessel groups has recovered since to original levels (Figure 7.2b). This increase in interest has coincided with a rapid rise of catch value in recent years, largely thanks to higher beach prices for wrasse.

7.1.3.2 Intermediate

Seven medium-sized vessel groups showed an intermediate level of dominant fishing tactics and species caught. The two largest groups in numbers of vessel-fishers and catch returns were VG_GN_BMW and VG_FP_Wrasse, both operating mainly in the South-East and East (Table 7.3). The vessel group VG_GN_BMW operated from small vessels and caught predominantly banded morwong ('BMW', 50% of total catch). Since 2000/01, catches of this vessel group were the most valuable in this category (Figure 7.3a). Wrasse was an important secondary species, while the contribution of other species such as blue warehou, shark, and squid species to the total catch decreased over the years (Figure 7.5a).

The vessel group VG_FP_Wrasse targeted mainly wrasse with fish traps that resulted in about 40% wrasse of the total catch. In contrast to the specialist group VG_HL_Wrasse, target species other than wrasse and secondary gear types such as graball nets were common for VG_FP_Wrasse, but in both vessel groups the contribution of species other than wrasse has dwindled in recent years (Figure 7.6). Participation and catches of VG_FP_Wrasse have strongly decreased over the last few years (Figure 7.3b), mainly as a result of lower catchability of wrasse in traps due to the prohibition of the preferred bait type in 2006 (Ziegler and Lyle 2010).

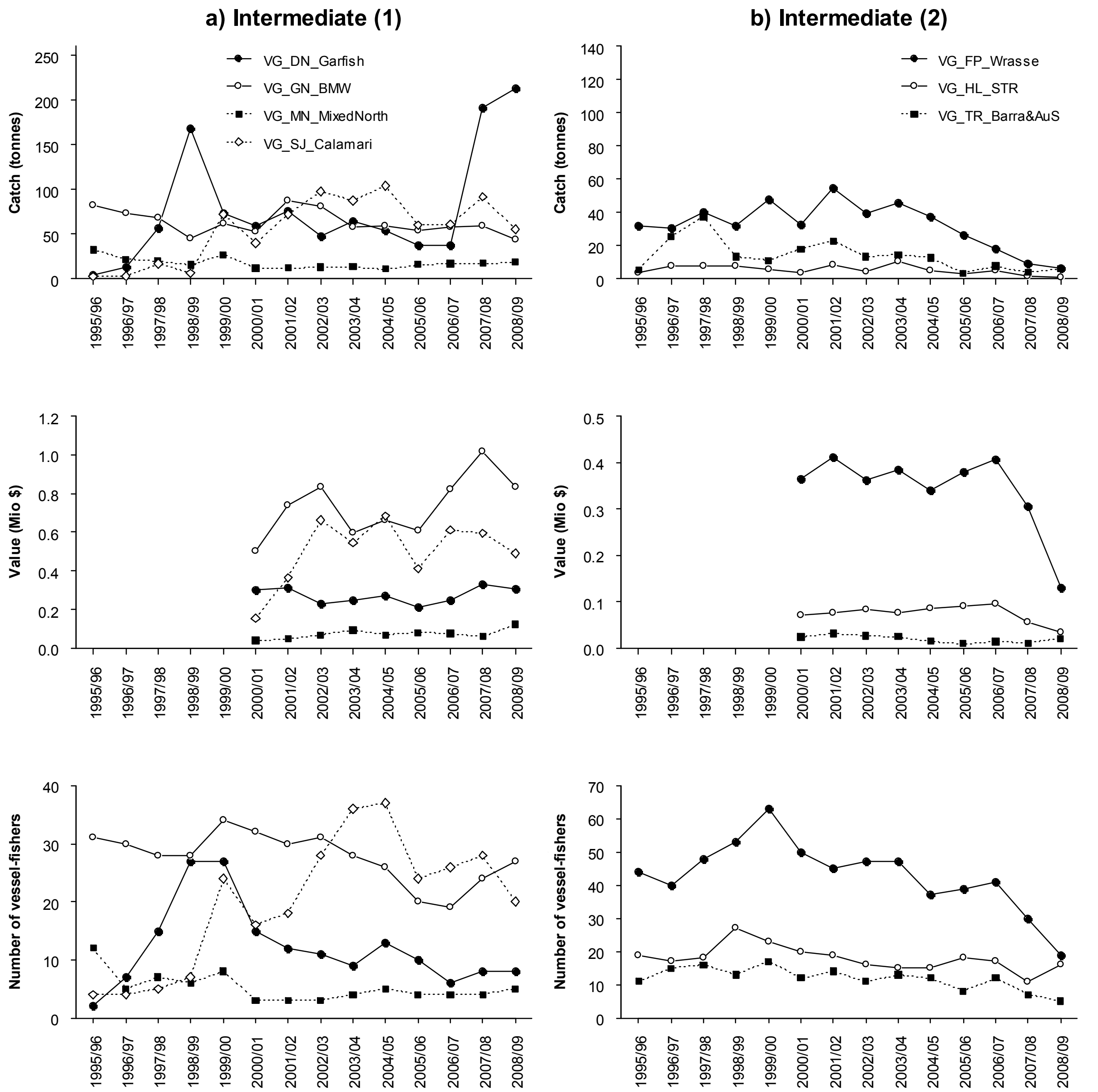


Figure 7.3: Total catch (in tonnes), value (in AU$) and number of active vessels-fishers per fishing year by fishing year for each vessel group of the intermediate category. Vessel groups are shown in two separate graphs for clarity. Note that 'vessel-fisher' is a unique combination of vessel and fisher and is used instead of vessel or fisher (see methods).

Three other vessel groups operated also in the East and South-East. VG_HL_STR targeted mainly striped trumpeter by hand line (54% of total catch). Catches of the vessel group VG_SJ_Calamari mirrored the development of the calamari fishery with rapidly increasing catches after 1998/99 and subsequent stabilisation of catch levels (Figure 7.3a). Fishing of this vessel group was typically conducted from vessels smaller than 6 m length over calamari spawning areas in sheltered waters. Together with garfish, calamari was also commonly captured by the vessel group VG_DN_Garfish, and the two fishing tactics DN_Garfish and SJ_Calamari were often practiced together by the same vessels. Occasional large catches of jack mackerel captured by two larger vessels with purse seine dominated the overall catch returns of VG_DN_Garfish in 1998/99 and 2007/08 - 2008/09, but contributed only little to the overall catch value of the vessel group (Figure 7.3a).

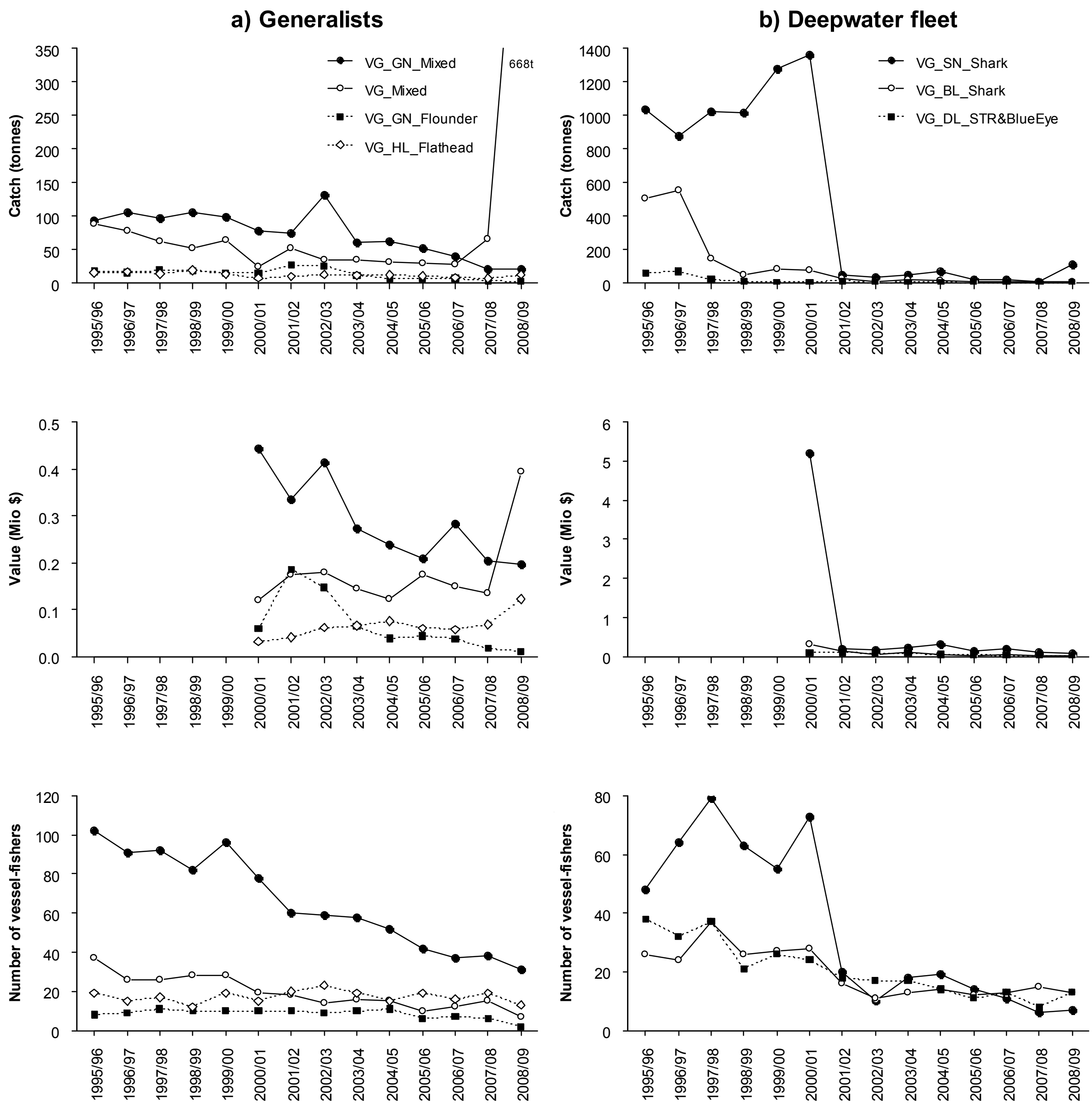


Figure 7.4: Total catch (in tonnes), value (in AU$) and number of active vessels-fishers per fishing year by fishing year for each vessel group of the generalist and deepwater fleet categories. Note that 'vessel-fisher' is a unique combination of vessel and fisher and is used instead of vessel or fisher (see methods).

Only two vessel groups in this category concentrated their fishing activity in the North. The vessel group VG_TR_Barra&AuSalmon caught predominantly barracouta which occurs sporadically in Tasmanian waters (62% of total catch). The relative high polyvalence indicated that fishing vessels pursued a range of other fishing tactics across the years. The vessel group VG_MN_MixedNorth targeted mainly blue warehou, barracouta and Australian salmon, but no species dominated the catch. Both vessel groups reported low catches and numbers of vessel-fishers over the years.

7.1.3.3 Generalists

Four vessel groups were deemed to be generalists. All groups showed a variable catch composition, a number of dominant fishing tactics and high polyvalence. Two groups indicated a dominant gear type, *viz.* hand line for VG_HL_Flathead and graball net for VG_GN_Mixed. The vessel group VG_HL_Flathead practiced a number of hand line tactics along the whole East coast of Tasmania, catching mainly flathead, shark and both species of trumpeters. The vessel group VG_GN_Mixed practiced a whole range of graball net or small mesh net tactics in the South-East and the North. With 301 vessel-fishers, VG_GN_Mixed was the overall largest vessel group, but the number of active vessel-fishers each year had strongly decreased from 102 to 38 from 1995/96 - 2008/09 (Figure 7.4a). Similarly, catch returns decreased over this period, partly because the dominant species of blue warehou had become rarer in Tasmanian waters (Figure 7.5b).

A total of 88 generalist vessel-fishers were part of the vessel group VG_Mixed, and the annual number of participants had strongly declined since 1995/96 from 35 to only 5 in 2008/09 (Figure 7.4a). The group was highly polyvalent and included all fishing tactics, including some minor tactics with low record numbers such as those using purse seine to target anchovy, graball nets to target octopus, and spear to target calamari. The total catch of this group was dominated by one vessel catching large quantities of jack mackerel with purse seine in 2008/09, resulting in a substantial increase in the total catch value in that year. Excluding jack mackerel catches, blue warehou (14%), garfish (12%) and octopus (11%) were the other main species.

The small vessel group VG_GN_Flounder was treated as an independent group because its main characteristics differed substantially from those seen in VG_Mixed. This vessel group operated mainly small dinghies in the North and used a number of beach seine and graball net tactics to catch flounder, garfish and blue warehou.

7.1.3.4 Deepwater fleet

Catches of the three remaining vessel groups were dominated by fish species that now fall under Commonwealth jurisdiction. Therefore, Tasmanian logbook returns revealed the activity of vessel-fishers in these vessel groups only in parts. Until 1998, dually endorsed Tasmanian and Commonwealth fishers of the vessel groups VG_DL_STR&BlueEye and VG_BL_Shark reported large catches of blue-eye trevalla ('BlueEye') and deepwater species (Figure 7.4b). With a switch to reporting catches of these species to Commonwealth logbooks in 1998, total reported catches to Tasmanian logbooks have fallen to low levels since. For VG_DL_STR&BlueEye, the relatively small catches are now dominated by striped trumpeter ('STR') for which the reporting requirement has remained with the Tasmanian logbooks. As a consequence, striped trumpeter appears now to be the targeted species.

In 2001, a new Commonwealth management scheme came into effect for the main shark species (gummy shark *Mustelus antarcticus* and school shark *Galeorhinus galeus*), while only other non-targeted shark species remained under Tasmanian jurisdiction. This change has caused a sharp drop in the participation and catches reported in Tasmanian logbooks by the highly specialised vessel group VG_SN_Shark (Figure 7.4b).

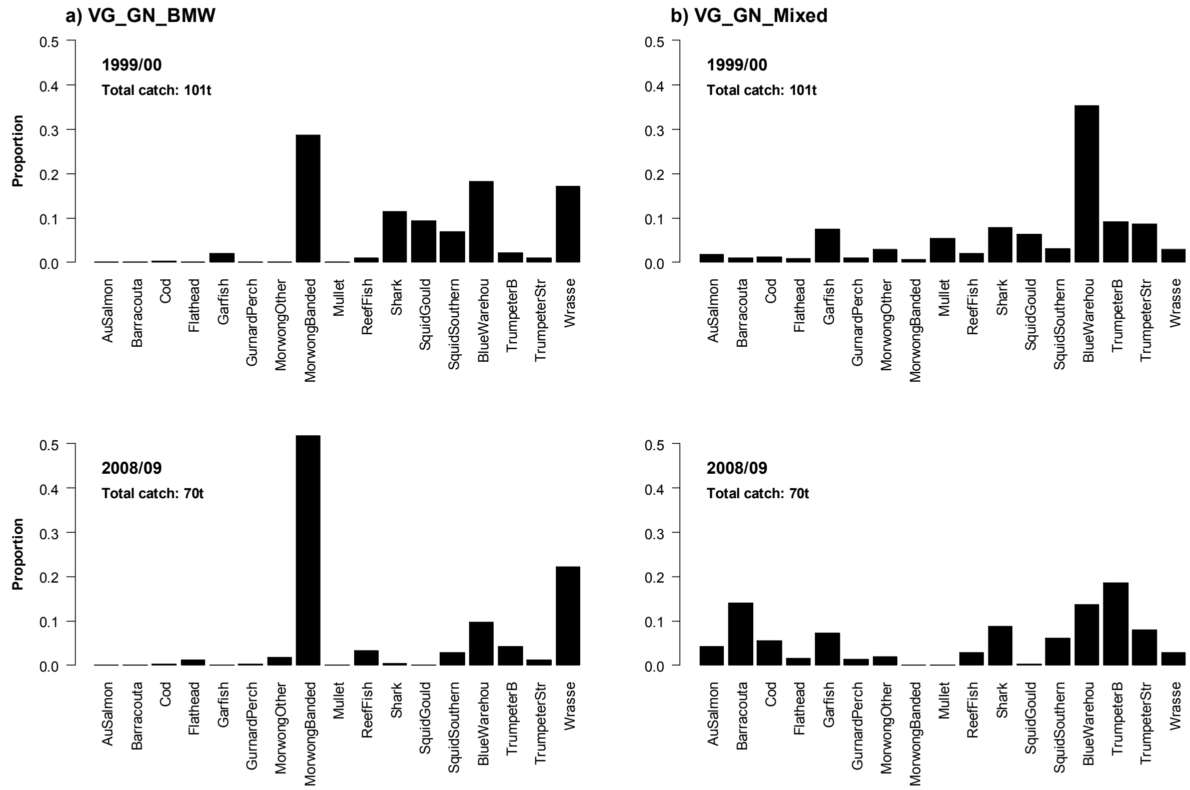


Figure 7.5: Relative catch composition of the vessel groups (a) VG_GN_BMW and (b) VG_GN_Mixed in 1999/00 and 2008/09, where 'BMW' is banded morwong. Species or species groups contributing less than 0.01% to the catch of either vessel group or fishing year are not shown.

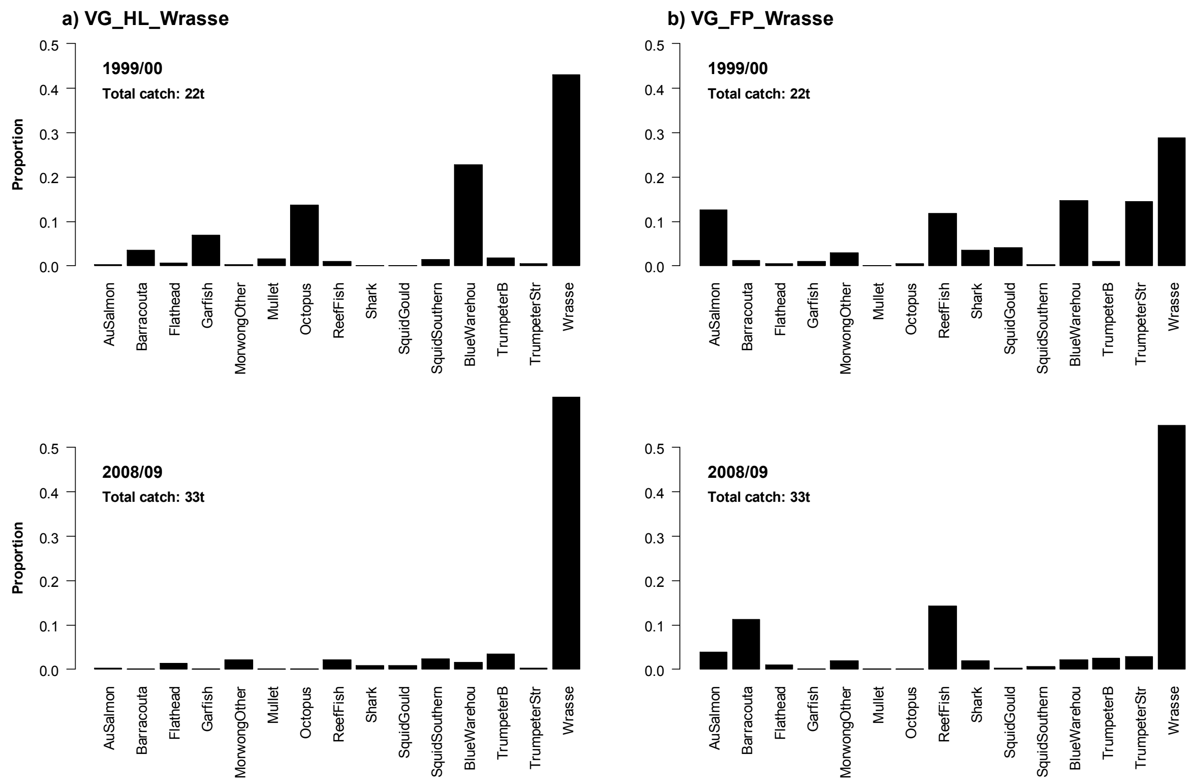


Figure 7.6: Relative catch composition of the vessel groups (a) VG_HL_Wrasse and (b) VG_FP_Wrasse in 1999/00 and 2008/09, where 'BMW' is banded morwong. Species or species groups contributing less than 0.01% to the catch of either vessel group or fishing year are not shown.

7.1.3.5 Fishing activity of vessel groups

A high proportion of vessel-fishers across the four categories of vessel groups reported little fishing activity and a small contribution to the overall catch (Figure 7.7). Over the study period from 1995/96 - 2008/09, almost 20% of all vessel-fishers reported only 1 or 2 logbook records and as many as 50% of all vessel-fishers reported less than 10 records. The proportions of vessel-fishers reporting less than 10 logbook records were variable between vessel groups, but above 30% in all vessel groups except VG_DS_Flathead&Whiting and VG_SN_Shark. This pattern was remarkably similar for individual fishers (rather than vessel-fishers) and was hence an important behavioural characteristic of fishers, and not simply because fishers frequently switched vessels.

Consequently, many vessel-fishers were active in the fishery for only a few months. The actual number of active months was in most cases less than the number of the monthly records, because fishing activity with more than one gear type or in different spatial fishing units within a month resulted in separate records for the analysis. The number of total fishing days of a vessel-fisher within a month was also low and increased only marginally with the number of reported records (2.9 days + 0.002*x* where *x* is the number of reported records, p = 0.02), i.e. fishers participating in the fishery for longer (more months) did not necessarily mean that they were committed to more days fishing during a month. Only in rare cases did vessel-fishers report more than 8 days of activity per month.

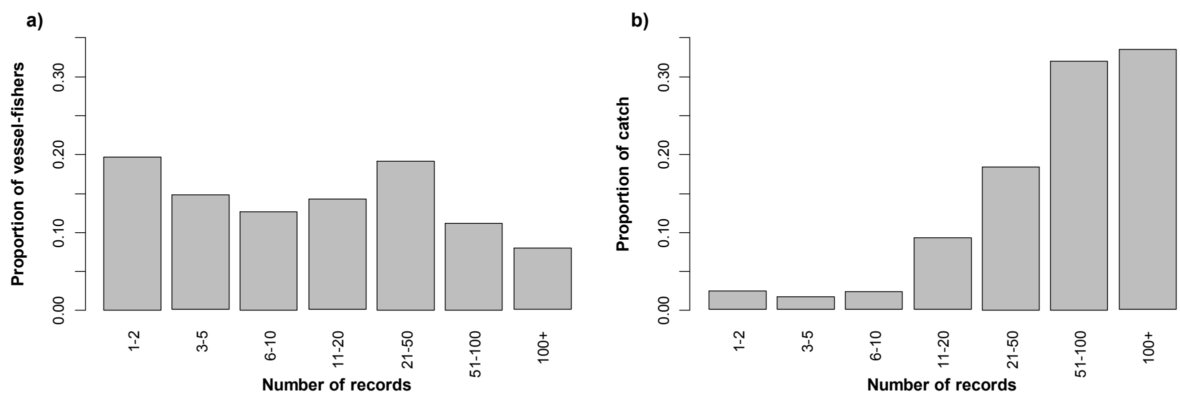


Figure 7.7: Proportion of (a) vessel-fishers and (b) catch returns by total number of records reported by individual vessel-fishers.

7.2 Characterisation of fishers' behaviour

Initially, a full model with all variables was evaluated. Estimates of the variables Revenue_total, Revenue_target, and VPUE_target were non-significant and, guided by the likelihood ratio test and the Akaike's Information Criterion (AIC; Burnham and Anderson 2002), dropped for the final model. All other variables showed some significant coefficient values and dropping individual variables did not improve the likelihood ratio or AIC. Thus, all other variables were retained, even though the model may be over-parameterised.

The final model with the variables %EffortMonth, %EffortYear, FDaysMonth, FDaysYear, VPUE_total, FisherAge and VesselLength was tested against the hypothesis of independence of irrelevant alternatives (IIA) which assumes that the odd ratios are independent of the alternative choices (Hausman and McFadden 1984, Greene 2008). When deleting an alternative choice in the IIA analysis, the statistic *S* did not exceed the critical value or was negative (Table 7.4). This result indicated that the choices were independent or that no important variable was missing in the analysis that could introduce inconsistencies to the variable estimates. This model was therefore accepted.

Many but not all coefficients of the model were statistically significant (Table 7.5). Positive coefficients suggested that the greater the value of the estimate, the higher the influence of the variable on the fishing tactic choice. For negative coefficients, the opposite is the case. Coefficients were positive and highly significant for the effort distribution between fishing tactics in the same month of the previous year (%EffortYear) of all fishing tactics, and for total VPUE when the same fishing tactic had been chosen in the previous month. The coefficients of some fishing tactics were negative for the effort distribution between fishing tactics in the previous month (%EffortMonth), the total number of days fished in the previous 12 months (FDaysYear), fisher age, and vessel lengths.

Table 7.4: Test statistics for the 'Independence of Irrelevant Alternatives' (IIA) property (Hausman and McFadden 1984) for the model with the variables %EffortMonth, %EffortYear, FDaysMonth, FDaysYear, VPUE_total, FisherAge and VesselLength.

Deleted choice	Statistic S	*p*-value
GN_BMW	26.11	0.998
FP_Wrasse	negative	1
HL_Wrasse	negative	1
SJ_Calamari	negative	1
DN_Garfish	negative	1
Degrees of freedom	50	

Table 7.5: Parameter estimates for all variables tested in the model relative to the fishing tactic 'FT_Other'. Given are estimates, standard error in brackets, and significant levels (* for p <0.05, ** for p < 0.01, *** for p < 0.001). The McFadden's pseudo-R^2 was 0.86. 'BMW' is banded morwong. For clarity, significant positive parameter estimates are shown in green, significant negative variable estimates in red.

Variable	**GN_BMW**	**FP_Wrasse**	**HL_Wrasse**	**SJ_Calamari**	**DN_Garfish**
%EffortMonth	-0.080 (0.03) *	-0.083 (0.03) *	-0.184 (0.12)	-0.086 (0.02) ***	-0.099 (0.02) ***
%EffortYear	0.043 (0.00) ***	0.025 (0.00) ***	0.041 (0.01) ***	0.020 (0.00) ***	0.037 (0.01) ***
FDaysMonth	-0.078 (0.04)	-0.022 (0.04)	0.047 (0.04)	-0.014 (0.03)	-0.111 (0.04) **
FDaysYear	0.002 (0.00)	-0.011 (0.00) **	-0.010 (0.00) *	-0.005 (0.00)	0.015 (0.00) **
VPUE_total	0.105 (0.04) *	0.252 (0.13) *	0.240 (0.12) *	0.221 (0.05) ***	0.362 (0.26)
FisherAge	-0.048 (0.02) *	-0.002 (0.02)	0.055 (0.02) **	-0.032 (0.01) *	-0.082 (0.03) **
VesselLength	-0.195 (0.06) **	0.055 (0.04)	-0.208 (0.05) ***	-0.212 (0.04) ***	-0.502 (0.16) **

The McFadden's pseudo-R^2 of 0.86 indicated a high explanatory power of the model. Indeed, the fishing tactic of a high proportion of records was predicted correctly both for the fitted data from 2000 - 2006 (Table 7.6) and the validation data from 2007 - 2008 (Table 7.7). Overall, the fishing tactics of 91% and 90% of records, respectively, were predicted correctly. The fishing tactics GN_BMW had the highest proportion of corrected predictions (93% and 98%), while the fishing tactic HL_Wrasse had the lowest (79% for both periods).

Table 7.6: Predicted versus observed choices of fishing tactics from 2000 - 2006. 'BMW' is banded morwong.

	Observed choices						
Predicted choices	**GN_BMW**	**FP_Wrasse**	**HL_Wrasse**	**SJ_Calamari**	**DN_Garfish**	**Other**	**Total**
GN_BMW	531	6	6	5	0	2	550
FP_Wrasse	3	297	6	9	1	15	331
HL_Wrasse	0	2	183	4	1	6	196
SJ_Calamari	19	12	14	688	6	20	759
DN_Garfish	5	0	0	3	469	4	481
Other	14	55	22	47	26	1040	1204
Sum	**572**	**372**	**231**	**756**	**503**	**1087**	**3521**
% correct predictions	93	80	79	91	93	96	91

Table 7.7: Predicted versus observed choices of fishing tactics from 2007 - 2008. 'BMW' is banded morwong.

	Observed choices						
Predicted choices	**GN_BMW**	**FP_Wrasse**	**HL_Wrasse**	**SJ_Calamari**	**DN_Garfish**	**Other**	**Total**
GN_BMW	207	0	4	1	1	1	214
FP_Wrasse	0	102	5	2	0	6	115
HL_Wrasse	0	0	85	1	0	1	87
SJ_Calamari	0	3	4	190	2	9	208
DN_Garfish	0	0	1	1	72	0	74
Other	4	9	9	18	12	238	290
Sum	**211**	**114**	**108**	**213**	**87**	**255**	**988**
% correct predictions	98	89	79	89	83	93	90

7.3 Characterisation of the fishery and stock dynamics in ISIS-Fish

7.3.1 Model calibration for catchability

The ISIS-Fish model managed to represent the observed landings data and stock biomass as estimated by the external stock assessment model reasonably well. Catch levels simulated by the ISIS-Fish model during the calibration period from 1998 - 2005 (Figure 7.8) and the validation period from 2006 - 2008 (Figure 7.9) matched those estimated by the assessment model. Seasonal patterns of observed landings were well reproduced for banded morwong and calamari, particularly during the calibration period. For garfish and wrasse, the seasonal patterns of observed landings were less consistent over time and could not be captured as well by the ISIS-Fish model, which used averaged monthly fishing strategies over the entire period from 1998 - 2008. ISIS-Fish model estimates of species biomass were within the 90% confidence intervals of biomass estimates from the stock assessment models and thus deemed usable for the simulations (Figure 7.10).

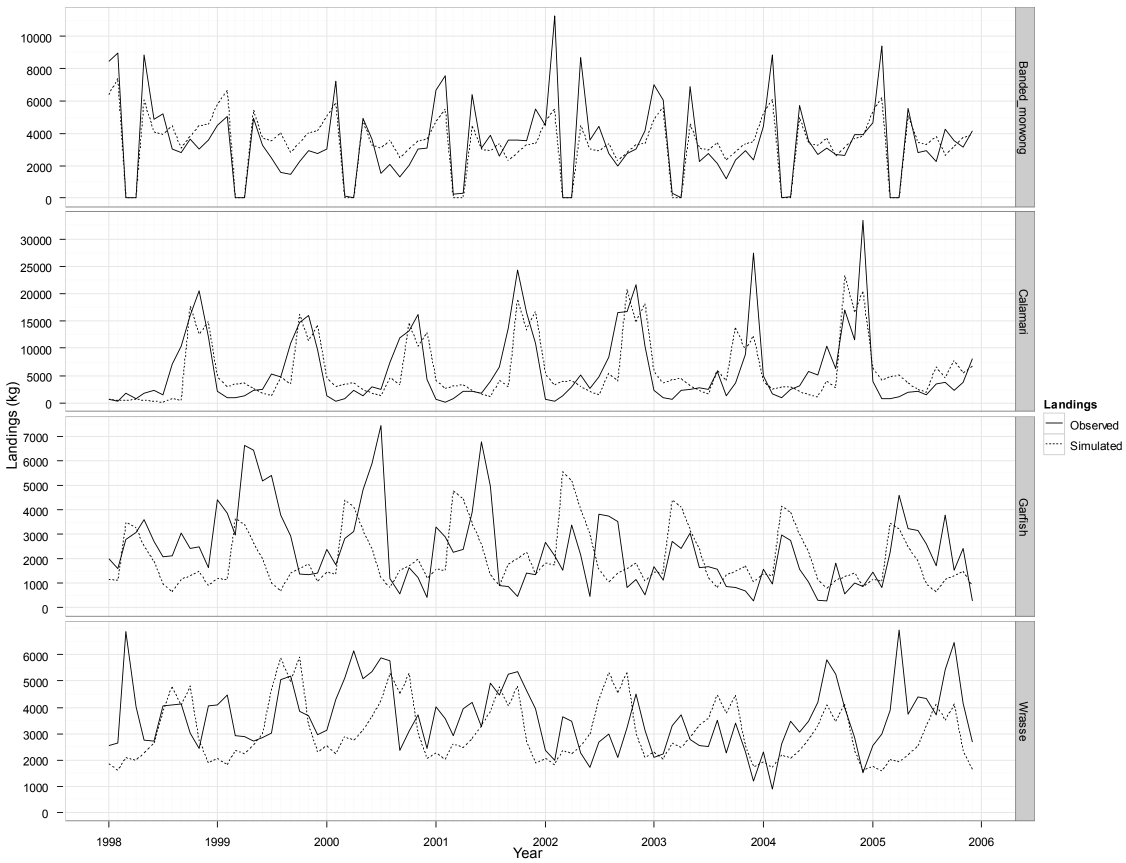


Figure 7.8: Monthly landings (kg) from calibration (1998 - 2005) for banded morwong, calamari, garfish and wrasse. Observed landings (solid lines) and landings simulated by the ISIS-Fish model (dotted lines).

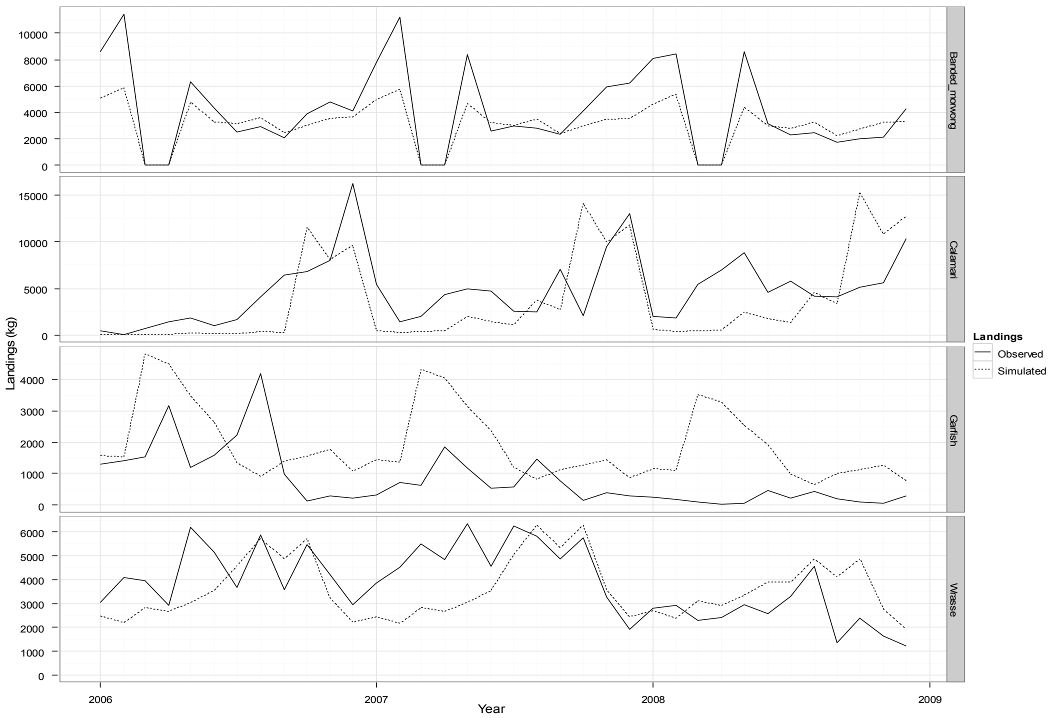


Figure 7.9: Monthly landings (kg) from validation (2006 - 2008) for banded morwong, calamari, garfish and wrasse. Observed landings (solid lines) and landings simulated by the ISIS-Fish model (dotted lines).

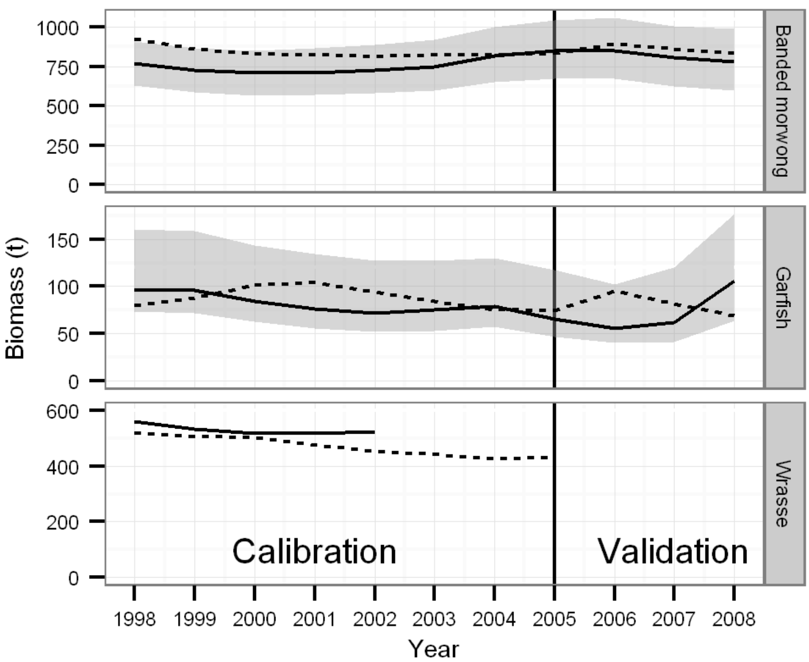


Figure 7.10: Annual stock biomass estimated by the external assessment model from 1998 - 2008 (solid line) with 90% confidence intervals (grey range) and simulated by the ISIS-Fish model (dotted line) from calibration (1998 - 2005) and validation (2006 - 2008) for banded morwong, garfish and wrasse. Confidence intervals were estimated by bootstrapping catch rate residuals. For wrasse external biomass estimates were only available from 1998 - 2002 and no confidence intervals could be estimated since the assessment model relied strongly on catch rate data. No external biomass estimates were available for calamari.

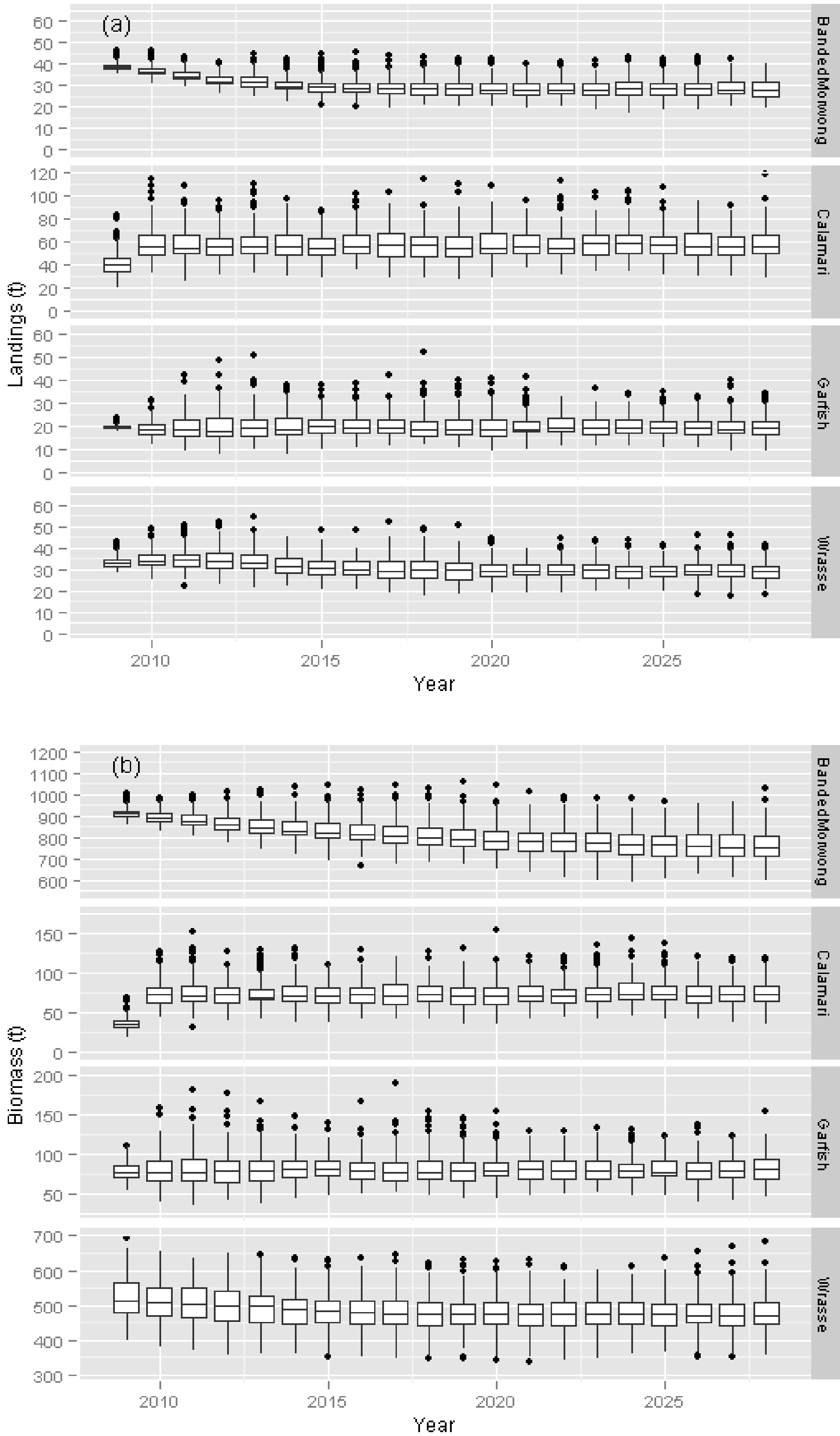


Figure 7.11: Predicted (a) landings and (b) biomass in tonnes for the Base Case (Scenario 1). Biomass is not graphed from zero for clarity. Boxplots represent the 25th, 50th and 75th percentile, the upper and lower limits of the whiskers are based on 1.5 * the inner quartile range.

7.3.2 Model scenarios

In the Base Case (Scenario 1), landings of banded morwong declined for the first 7 years of the projection period before stabilising, while the biomass declined steadily by an average of 150 tonnes over the entire projection period (Figure 7.11). This result agreed with stock projections for this species under annual catches of 40 and 30 tonnes as predicted by Ziegler et al. (2008).

Both calamari and garfish showed stable landings of 55 and 18 tonnes respectively and an average stock biomass of 75 tonnes for both species over the duration of the projection period. Stable landings and biomass were expected for calamari, since the fishery targeted exclusively 1-year old fish and the model applied annual stochastic recruitment without a stock-recruitment function. Wrasse landings increased in the first three years before decreasing and stabilising at around 30 tonnes. Wrasse biomass also declined slightly in the first years before stabilising at around 450 tonnes.

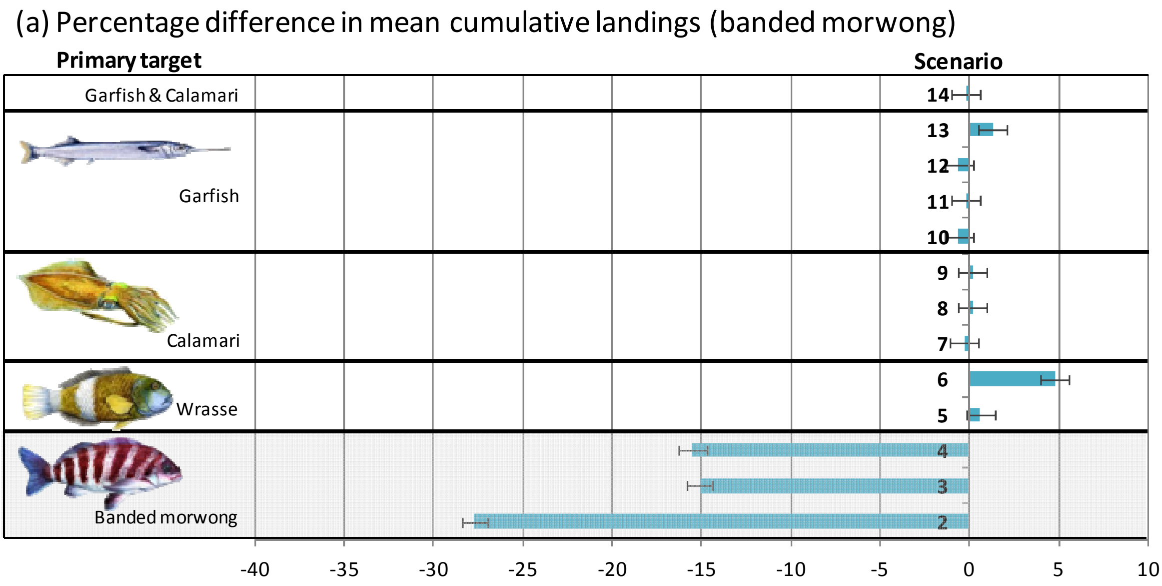
In Scenario 2, the decrease in banded morwong maximum legal size resulted in a decrease in overall landings by 27.9% and an increase of biomass by 15.3% (Figure 7.12). Even though no effort was redistributed to other fishing tactics or targeted other species in this scenario, landings and biomass of calamari, garfish and wrasse varied up to 1.5%, giving an indication of potential levels of variation caused by the stochastic recruitment in the 200 simulations (Figure 7.13 to Figure 7.15).

Cumulative landings of banded morwong were more affected by a change in maximum legal size in Scenario 2 than by the 25% reduction of effort in Scenarios 3 and 4 with a decrease of only around 15% (Figure 7.12). Similarly, final biomass was more affected by Scenario 2 than Scenarios 3 and 4, both with declines of around 9%. Effects on banded morwong from management actions targeting other species were negligible for most scenarios. The 2-month closure of wrasse with displacement of effort specifically to the fishing tactic targeting banded morwong (Scenario 6) was the only management strategy that showed a notable impact, with an increase in landings by 4.8% and a decrease in biomass by 2.9% for the species.

Final biomass and cumulative landings of wrasse were again mostly affected by the management strategies targeting the species itself (i.e. a 2-month closure in Scenarios 5 and 6), with a decrease of 4-5% in cumulative landings and an increase of around 9% in final biomass compared to the Base Case (Figure 7.13). The 2-month calamari closure (Scenario 9) and the effort reduction for banded morwong fishing affected wrasse to a lesser extent. The effort reduction for banded morwong fishing tactics with effort redistribution towards wrasse fishing tactics only (Scenario 4) showed a slightly smaller effect on landings than when effort was redistributed towards one wrasse tactic and FT_Other (Scenario 3). Other scenarios had little impact on wrasse, affecting cumulative landings and biomass by 2% or less.

Calamari was largely unaffected by management actions that targeted other species, even when the displaced effort was allocated to SJ_Calamari in Scenario 11 (Figure 7.14). Cumulative landings changed by less than 1% and biomass up to 2.1%, and were therefore only slightly above background variation. The calamari biomass was only affected by calamari closures over one or two months (Scenarios 7 to 9). While a 1-month closure for both calamari and garfish (Scenario 14) had a similar impact on landings (-7.5% difference) than a 1-month closure for calamari alone (-6.5% difference), it had less impact on the species biomass (1.8% versus 3-4% increase in biomass). Differences in calamari landings between the Base Case and Scenarios 7 and 8 (all representing a 1-month closure) were due to differences in the bycatch rule. The base scenario prohibited the use of squid jig only in the closure area, resulting in some bycatch by other gear types (mainly DN_garfish), while Scenarios 7 and 9 prohibited calamari bycatch from all gear types.

Garfish was the species most affected by management actions on other species (Figure 7.15). Garfish biomass decreased by around 5% with a 25% effort reduction for GN_BMW (Scenario 3), a 2-month closure for wrasse (Scenario 6), and a 1-month closure for calamari where effort was displaced to the fishing tactics DN_Garfish (Scenario 8). The results for the former two scenarios were surprising und somewhat inexplicable, because the effort was not redistributed directly to a fishing tactic targeting predominantly garfish and catch increases were at a much lower level. Direct garfish closures showed variable results. The 1- and 2-month closures caused decreased landings by around 1-2% and 5% respectively, but had negligible effects on the biomass (Scenarios 10 to 12). Only the 6-month closure in Scenario 13 resulted in a substantial 39.6% decrease in cumulative landings and 36.4% increase in final biomass compared to the Base Case scenario. This high impact compared to the shorter 1- or 2-month closures in December and January was related to the fact that 45% of the annual catch for garfish was landed from March - May, whereas the period from December-January contributed only 9.5% to the annual landings.



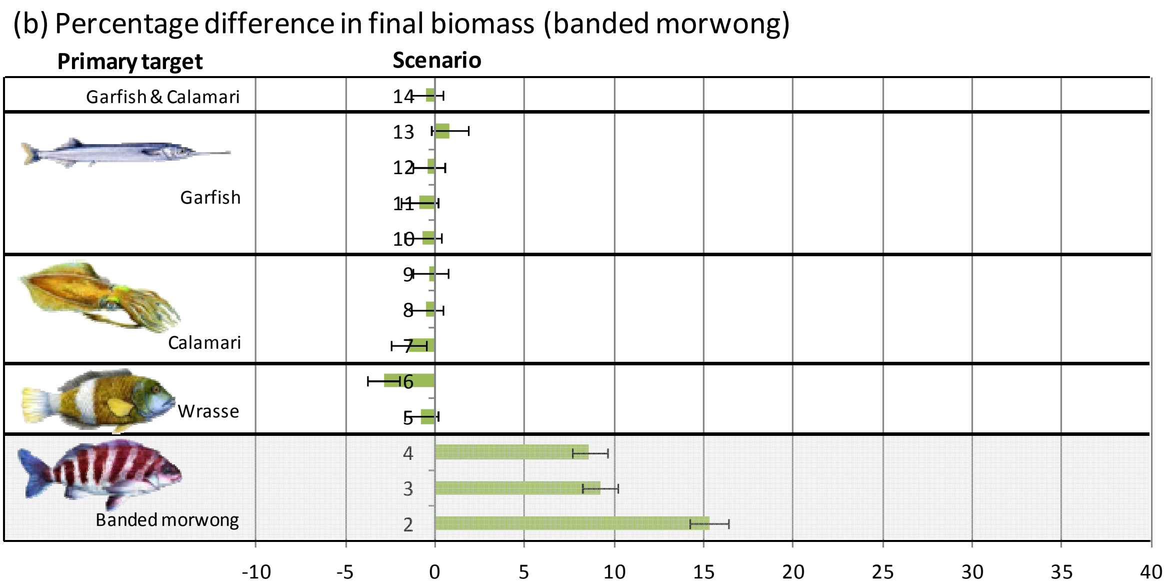
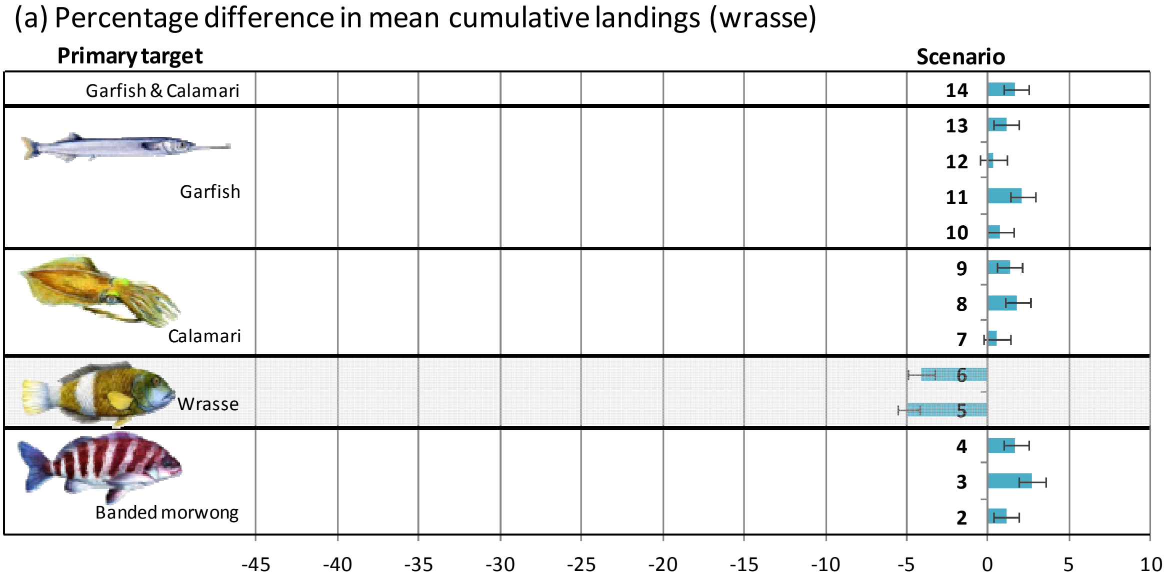


Figure 7.12: Difference in (a) mean cumulative landings from 2009 - 2028 and (b) mean final average biomass in 2028 for banded morwong from 200 simulations for all scenarios. Comparisons are expressed as the % difference to the Base Case (Scenario 1), error bars represent the relative Standard Error of Difference (SED). Primary target is the species primarily affected by the management change.



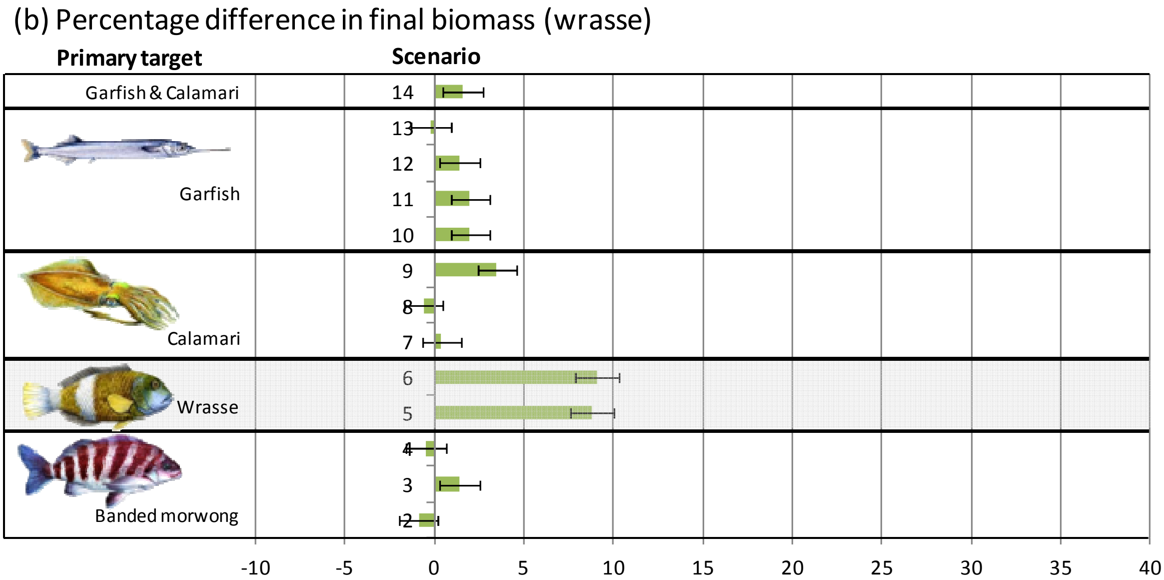


Figure 7.13: Difference in (a) mean cumulative landings from 2009 - 2028 and (b) mean final average biomass in 2028 for wrasse from 200 simulations for all scenarios. Comparisons are expressed as the % difference to the Base Case (Scenario 1), error bars represent the relative Standard Error of Difference (SED). Primary target is the species primarily affected by the management change.

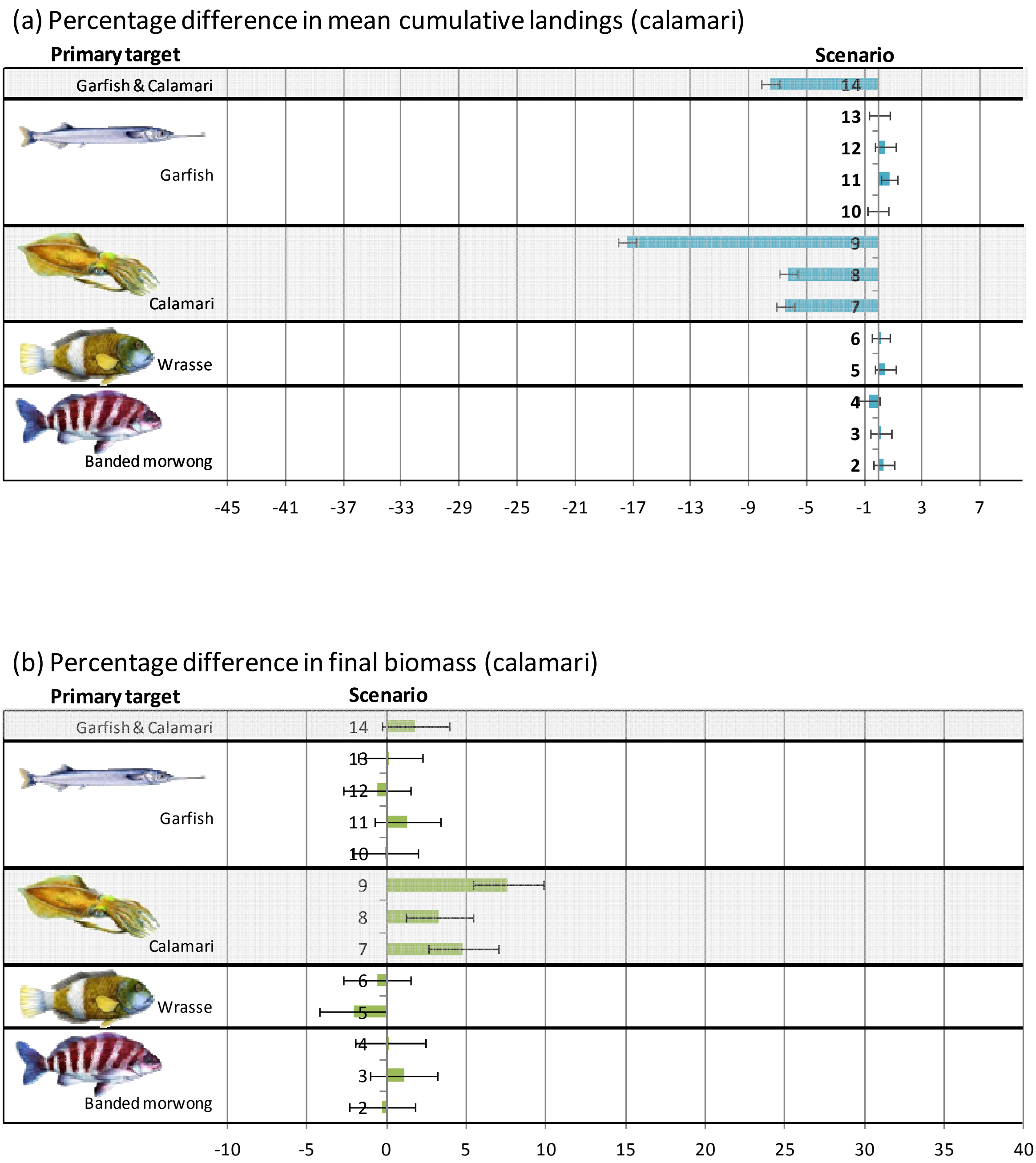
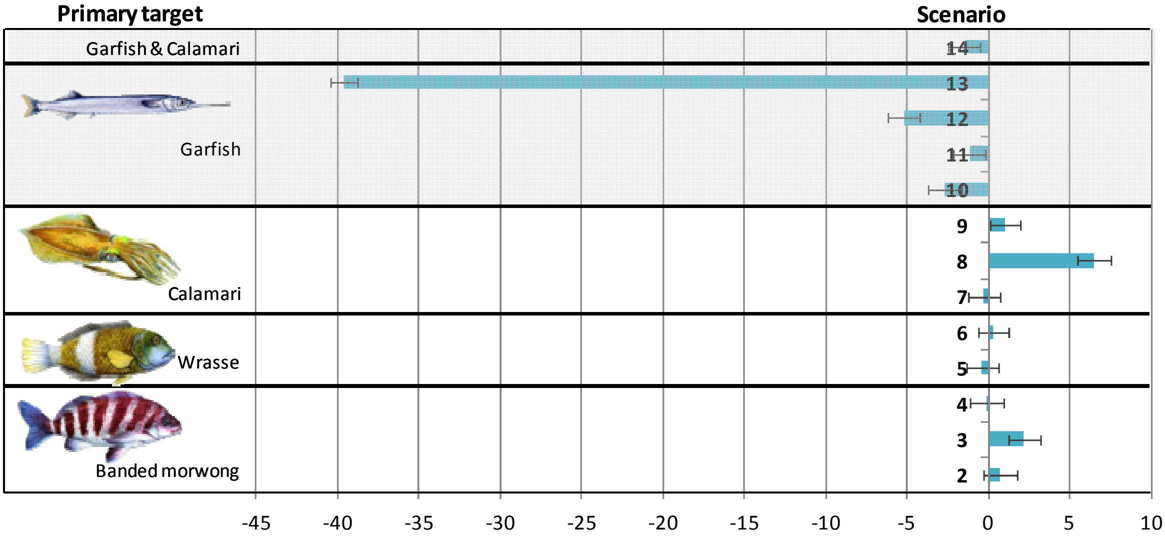


Figure 7.14: Difference in (a) mean cumulative landings from 2009 - 2028 and (b) mean final average biomass in 2028 for calamari from 200 simulations for all scenarios. Comparisons are expressed as the % difference to the Base Case (Scenario 1), error bars represent the relative Standard Error of Difference (SED). Primary target is the species primarily affected by the management change.

(a) Percentage difference in mean cumulative landings (garfish)



(b) Percentage difference in final biomass (garfish)

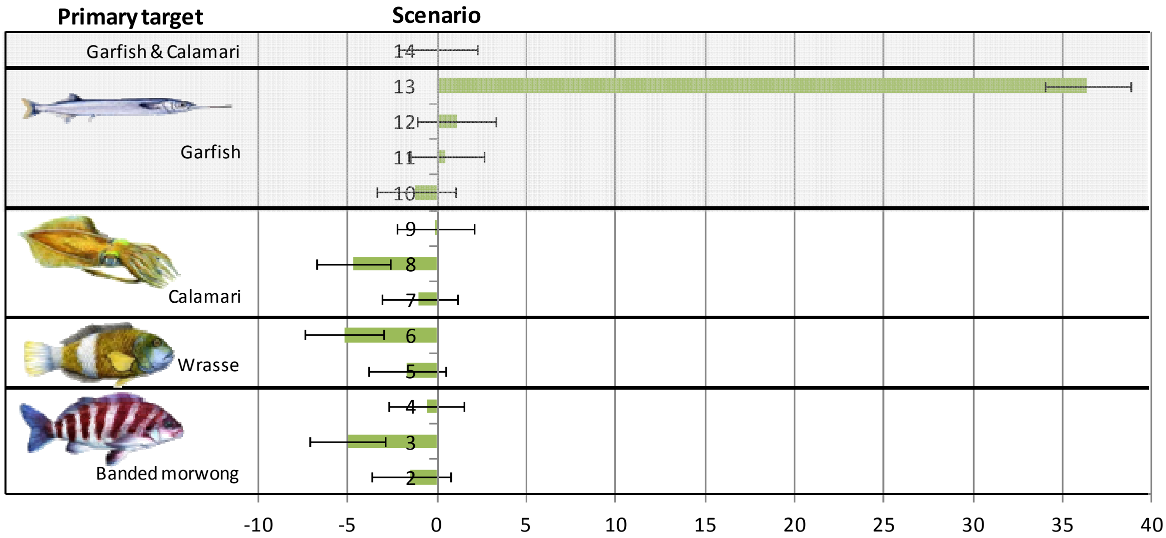


Figure 7.15: Difference in (a) mean cumulative landings from 2009 - 2028 and (b) mean final average biomass in 2028 for garfish from 200 simulations for all scenarios. Comparisons are expressed as the % difference to the Base Case (Scenario 1), error bars represent the relative Standard Error of Difference (SED). Primary target is the species primarily affected by the management change.

8. DISCUSSION

8.1 Characterisation of the fleet structure

The Tasmanian scalefish fishery is highly diverse with a large number of fishing gear types and target species, and as many as 35 identified fishing tactics and 20 vessel groups. A categorisation of the vessel groups indicated a broad spectrum from specialists to generalists, with highly variable trends in participation and catch returns over the years.

The main purpose of this analysis was to improve the understanding of the structure and complexity within the Tasmanian scalefish fishery. The approach of using step-wise multivariate analyses to identify target species, fishing tactics and finally vessel groups proved to be valuable for defining groups with similar characteristics. Being cognisant of the limitations for the interpretation of the results from a descriptive analysis (e.g. Pelletier and Ferraris 2000, Ulrich and Adersen 2004), the characteristics of these groups are mainly indicative. Expert knowledge was required for some user-defined and somewhat arbitrary (as opposed to statistically-based) choices of the appropriate number of clusters, and alternative groupings could be possible (however, see also Clarke et al. 2008).

Since the results of such an analysis cannot be extrapolated beyond the investigated dataset and the intention of this study was to describe the whole Tasmanian scalefish fishery, all Tasmanian logbook records were included. The inclusion of vessel-fishers with low number of records had arguably only a minor influence on the overall conclusion of the analyses, but highlighted the existence of a relatively large number of vessel-fishers across most vessel groups that reported little fishing activity and small catches. While it may not bear much meaning for individual vessel-fishers with low numbers of records to be classified into particular vessel groups with the expectation that they will conduct similar fishing activities in the future, it can be assumed that the overall trend of a high number of vessel-fishers returning only small amounts of catches across vessel groups will continue for some time.

Consequently, the number of 'influential' vessel-fishers, i.e. those with large numbers of records and relatively high catches in each vessel group, is actually much smaller than the total numbers indicated in Table 7.3. In fact, taking time into consideration, only 10% of the 1675 vessel-fishers across all vessel groups had reported more than 20 records and were still active at the end of the study period in 2008/09.

The vessel groups in the four broad categories have seen substantial changes over the years of the study from 1995/96 - 2008/09, driven by changes in the licensing system and resource availability. In the deepwater category, the major restructure of the licensing system in 1998 and subsequent changes in 2001 resulted in a sharp decline in participation and catches reported in the Tasmanian logbooks. After the restructure, most vessels of these vessel groups essentially reported only shark bycatch in Tasmanian waters and striped trumpeter catches mainly outside Tasmanian waters. Since many vessels were still active in Commonwealth waters, Tasmanian logbook records provided only a limited insight into their overall activity.

Similarly, the specialist vessel group VG_AJ_GouldSquid consisted of vessels that were also mainly active in Commonwealth fisheries and only moved opportunistically into Tasmanian waters to fish for Gould squid when the species appeared in large numbers and market prices were high. The other main specialist vessel groups were dominated by a small number of vessel-fishers in highly regulated niche fisheries with specialised permits for particular gear types and one or two target species. Despite being small groups, some recorded considerable catches over the study period.

The intermediate and generalist categories were a major feature of the Tasmanian scalefish fishery. Vessel groups of these categories practiced strongly-interlinked fishing tactics and were characterised by increasing flexibility in target species and fishing tactics. Some fishers of these groups were also active in the rock lobster and abalone fisheries or earned an income from alternative employment (Bradshaw 2005). The high level of flexibility was based on a number of factors. Financial return from a single fishing tactic or one targeted species was generally low, while little capital was needed to enter the fishery and switch between strategies. Fishing vessels were small (often only dinghies of less than 6 m length), and alternative fishing gear types could be easily accommodated since most require only a simple hauler that can be mounted on almost any vessel and used to retrieve a number of gear types. In addition, the low financial reliance on fishing for fishers with an alternative income source provided them with a high degree of freedom to pursue fishing activities that were not necessarily economically successful (see Chapter 17).

However, this level of flexibility has created conflicts over fishing access where fisheries management attempted to protect fish stocks from overfishing. Generally, management decisions since 1998 have followed a trend away from open and equal fishing access towards specialist fishing rights (Ziegler and Lyle 2010). With specialist access licences either for catch or effort, fishery management has attempted to control the large overcapacity of actual and potential (latent) fishing effort. The licensing restructure in 1998 removed some of the overall overcapacity from the fishery by limiting gear allowances for the general fishing licence that all vessels have to hold, and by introducing a number of additional species or gear-specific licences. For example, new species-specific licences were required to catch live banded morwong and wrasse. Subsequently, fisheries management addressed concerns about fish stock status by restricting catch or access to fishing areas, particularly for species such as calamari, banded morwong, wrasse, and garfish (Ziegler and Lyle 2010). For calamari, the number of fishers was limited on the main spawning aggregations in the South-East and East in 2008 after the species had been heavily targeted over these spawning grounds. For banded morwong, a total allowable catch (TAC) system was introduced in 2008 due to concerns about stock status and potential expansion of catch levels.

Access rights to fishing areas, and gear and catch allocation to fishers has generally been granted on the base of their individual catch history (A. Sullivan, pers. comm.). Consequently, fishers that had specialised in a fish species before restrictions came into place were more likely to qualify for access or a substantial catch allocation. In contrast, generalist fishers largely missed out because they had frequently switched their activity and rarely built up consistent catch histories for the main species over the years. While some generalist fishers and indeed many fishers of the intermediate category have reduced their fishing activity or left the fishery altogether, many have reacted to lost access to species or fishing grounds by switching their fishing tactics (P. Ziegler, unpubl. data). Thus, by reducing overfishing of one species, fisheries management often simply relocated fishing effort to other gear types, species and fishing locations.

Unfortunately, opportunities to diversify fishing activities have diminished concurrently with the introduction of many specific licences, because many alternative species have become rarer. Fish species such as blue warehou, bastard trumpeter, striped trumpeter and barracouta were caught in large quantities in Tasmanian waters in the 1990s, but catches have been depressed since then as a result of overfishing by Commonwealth and State fishers (Ziegler and Lyle 2010). Consequently, fishing pressure in open areas and on the few remaining relatively unrestricted species such as garfish has increased substantially.

So far, the Tasmanian fisheries management has not had the required information to account for effort shifts between different components of the fishery when considering management changes. In order to move away from single-species decisions to such a more integrated fisheries management approach, the fleet dynamics and its impact on individual fish species needs to be well understood. This analysis of the structure and linkages within the Tasmanian fishery is an important first step in this direction and has allowed identifying the components of the fishery that may be affected by future management decisions.

8.2 Characterisation of fishers' behaviour

The estimated parameters of the random utility model characterising the behaviour of fishers were generally in agreement with the indicative results from the fishers' interviews. In the interviews, seasonality of fish availability was rated high as an important decision factor for the timing, location and type of fishing operation. Strong seasonal patterns in fishing activity were supported by the RUMs with positive values and high significance of the variable for the effort distribution in the same month of the previous year. However, based on the effort distribution of fishing tactics in the previous month, fishers were likely to switch fishing tactics in the short-term (between months) and particularly for the fishing tactics SJ_Calamari and DN_Garfish. This result indicated that due to low specialisation level of vessels, fishers readily adapt their fishing activity and follow species availability, but that the seasonal patterns are consistent over the years. Particularly banded morwong and calamari are known for strong seasonal patterns in fish availability and consequently targeting by fishers with peaks for banded morwong from December - February and in May after the spawning season closure, and for calamari from October - December during spawning (Ziegler and Lyle 2010). In contrast, fish availability tends to be less distinct between months for wrasse and garfish.

Following fish availability, fishers were highly aware of the economic considerations and adapt their fishing activity to maximise their income. With the exception of DN_Garfish, fishers tended to choose the same fishing tactics rather than to switch to another when the total VPUE in the previous month was high. Retaining VPUE instead of revenue in the model indicated that fishers seem to account not only for the revenue from the catch, but also for the days fishing. This could be a reflection of direct fishing costs for e.g. fuel incurred by fishing or indirect opportunity costs for the time that could have been spent earning income from another activity. However, better data on fishing costs would be required to properly evaluate the relative importance of the different underlying drivers.

Not surprisingly, the VPUE of the total catch was more relevant than that of the target species alone. Fishers that target banded morwong, wrasse, calamari and garfish tend to be highly diversified, opportunistic and often multi-species focused (see Chapter 7.1). While they may target a particular species, the catch of other species is an important part of the consideration of fishing tactic choice and contributes substantially to the total income from a fishing trip.

The fishing tactics targeting wrasse by fish trap or hand line were preferably chosen by fishers that spent less time in the scalefish fishery. The number of days fished in the previous one or twelve months appeared to be unimportant for the other fishing tactics with the exception of DN_Garfish where short-term (1-month) and long-term (12-month) trends stood in opposition to each other. Further analysis is required to determine whether this is a real trend or maybe an artefact of the small sample size of records for which this fishing tactic was actively chosen.

Fishers choosing GN_BMW, SJ_Calamari and DN_Garfish tended to be younger, while fishers choosing HL_Wrasse tended to be older. Based on the interviews, a younger fisher age could indicate a higher level of risk taking for possibly unpredictable levels of returns from these fishing tactics. The observed trends could be also caused by the fact that it is easier for (young) fishers entering the scalefish fishery to target calamari and garfish. Fishing for these species is allowed with holding only a general fishing licence, while targeting banded morwong and wrasse requires an additional species-specific licences which needs to be available for sale and can be costly. All fishing tactics with the exception of FP_Wrasse were also more likely to be applied from small vessels.

The RUMs predicted the choices of fishing tactics of the fitted data set very well. The proportion of correct predictions was also high for the validation period from 2007 - 2008 which may not be surprising given that no major management changes had occurred between the data fitting and the validation periods. Further model validation could now be done, using the additional years of data available since 2008 and evaluating the power of the model to predict fishing tactics after major changes in management arrangements, particularly the introduction of the banded morwong TAC and the calamari licence in the South-East and East of Tasmania.

8.3 Characterisation of the fishery and stock dynamics in ISIS-Fish

The ISIS-Fish model appeared to be a useful platform to study potential impacts of single-species management actions on complex interactive small-scale finfish fisheries. The model allowed representing many processes of fish stocks and the fishery that are important in multi-species fisheries. However, fully parameterising a multi-species multi-gear fisheries simulation model such as the ISIS-Fish model requires relatively long time-series and comprehensive data sets on species biology and population dynamics. As a consequence, ISIS-Fish model applications for small-scale fisheries that are complex but comparatively data-limited require many substantial trade-offs between the available information and the level of complexity that is represented in the model.

In this study, the model was restricted to the main area of the fishery, four key fish species and a subset of the fishing fleet that was active within the area. This model thus represented a higher level of complexity in regards to fish species and fishing fleet than previous studies that have used the ISIS-Fish model framework (Drouineau et al. 2006, Lehuta et al. 2010, Marchal et al. 2011). However, many aspects of the fleet dynamics were too complex to be modelled and required simplifications. For example, average values were used for fishing strategies, effort per fishing blocks for fishing tactics or vessel composition in vessel groups, and fishing zones with homogenous fishing effort were large. Beside the main fishing tactics, there was also a large number of other fishing tactics used in this fishery to catch some or all four key species. With the intention to simulate all effort targeted at the key species in the model, these fishing tactics were retained but summarised in one single fishing tactic FT_Other, with strong assumptions e.g. about gear selectivity.

Sparse information on species biology and current stock status let to the decision to keep the ISIS-Fish model spatially simple with only one single population per species. For species such as banded morwong and wrasse, the assumption of one single population was likely to be incorrect since adult move little once they settle on a reef (Murphy and Lyle 1999), although individual banded morwong populations may be linked at the recruitment level due to a 6-month larval phase (Wolf 1998). Discrepancies between the stock biomass and landings data for banded morwong, wrasse and garfish that were estimated by the stock assessment model and simulated by the ISIS-Fish model may at least be partly explainable by the assumption of one single population across the whole model area. Nevertheless, despite these spatial and other assumptions, the model was able to capture the essential dynamics of the species studied. Higher spatial complexity with more populations for banded morwong and wrasse along the coast may improve the stock dynamics in the simulation model, but would also require more detailed information on fish movement and stock biomass and status for these populations.

Despite the substantive simplifications of species and fishery dynamics in this study, there were some interesting results which could prove to be important to the management of the fishery. The single-species management decisions had relatively small but nevertheless measurable effects on landings and biomass of the target species as well as on other species in the fisheries. Our model simulations indicated that while single-species management actions affected predominantly the target species, they also affected the landings and biomass of non-target species just as strongly as some management actions intended for the non-target species alone.

Generally, the effects of changes in management strategies on biomass and landings of non-target species were small. This result was not unexpected given the low level of gear specialisation in this fishery where effort is often spread over a variety of fishing tactics in a given month. Only drastic management measures such as a 25% overall reduction in banded morwong fishing effort or a 6-months closure for garfish resulted in strong signals in landings and biomass of both target and non-target species.

As expected, the changes in landings and biomass for non-target species were stronger when the redistribution of effort was forced to one specific fishing tactic instead of all the active fishing tactics for that vessel group. While static changes to fishing strategies were assumed in this model rather than dynamic changes based on statistical predictions of fishers' behaviour such as those estimated by the characterisation of fishers' behaviour (see Chapter 7.2) or in other studies (Holland and Sutinen 1999, Vermard et al. 2008, Marchal et al. 2009), the results provided an indication of the magnitude of effects that can be expected if all fishing effort is redistributed within the fishery, without fishers reducing their fishing activity altogether and increasing their periods of inactivity.

Management actions in multi-species fisheries tend to lack coordination, where individual management actions targeting a single fish species or a fishing method are implemented independently, without consideration of their impacts on the rest of the fishery. While the effect of a single management action on non-target species may be weak, the cumulative effects of several decisions over time are expected to lead to more substantial changes in the effort distribution of a fishery. Using a simulation framework such as the ISIS-Fish model, concomitant or sequential management actions over time could be simulated to assess the potential for changes in populations and fishing effort due to cumulative effects.

This study was primarily a feasibility study to investigate whether the ISIS-Fish model can be used to simultaneously simulate the stock dynamics of several species that are targeted by a number of vessel groups with interlinked fishing tactics. Our initial results indicated that the ISIS-Fish model can be parameterised to this effect despite the data limitations inherent to small-scale fisheries. However, before further increasing model complexity and draw strong conclusions from the results presented here, sensitivity analyses are required to investigate the impact of assumptions and model parameters such as recruitment variability, growth, natural mortality, catchability, and gear selectivity on model result. This would allow the identification of the most sensitive parameters in the model, as well as changes in the systems dynamics brought about by the implementing a given management action (Lehuta et al. 2010).

9. BENEFITS AND ADOPTION

Fishers and fishery managers from Tasmania will benefit directly from this study through an improved understanding of fishery-wide consequences when managing multi-species and multi-gear fisheries. The analyses and results from this study will provide a valuable tool in informing future management decisions and providing direction for the fishery in the upcoming review of the Tasmanian scalefish fishery management plan.

In addition, it is anticipated that there will be similar benefits for industry and fishery managers in other jurisdictions if they adopt approaches like those developed in this study.

This project has demonstrated that analyses of fleet structure and fleet dynamics can be conducted relatively easily and provide valuable information about potential effort changes within the fishery when considering management changes. However, to ensure a long-term sustainable and economically viable future, fisheries management needs to define clear objectives towards which fishers and fish populations of each multi-species fishery should be managed. The high level of diversity and complexity in many scalefish fisheries with numerous fishing activities, gear types and fish species captures, implies that there may be hard decisions to be made with regards to effort allocation, access and catch levels, if these fisheries are to be proactively rather than reactively managed or even simply monitored.

10. FURTHER DEVELOPMENT

The focus of this project has been the development and evaluation of methods and tools to improve the understanding and management of cross-species implications of management arrangements. In the analysis of fleet structure, all Tasmanian logbook records were included, because the intention of this study was to describe the entire Tasmanian scalefish fishery and the results of such an analysis cannot be extrapolated beyond the investigated dataset. To provide results which are directly relevant to a proposed management change, future work could include the application of the same statistical methods to logbook data in the most recent year. Subsets of the already analysed data set could also be investigated, e.g. to evaluate how the fleet structure has changed in the past with the introduction of particular management actions.

The analysis of fishers' key drivers for their choice of fishing tactics focused on a subset of the fishery from 2000 - 2008. The developed models correctly predicted a high proportion of the fishing tactics, however the conditions for fishing were very similar between the fitting (2000 - 2006) and validation periods (2007 - 2008). Since 2008, the management of two fished species has significantly changed, namely a TAC system with individual transferable quotas (ITQs) has been introduced for banded morwong, and a species-specific licence has been introduced for calamari in the South-East and East of Tasmania. Validating the RUMs on data from the period after these management changes would be in important next step to confirm the power of the model to correctly predict fishing tactics. This would facilitate the adoption of the RUMs by fisheries management to anticipate future effort changes. In addition, this analysis could also be adapted to address other particular questions raised by proposed management actions, including those for fisheries in other jurisdictions (see Chapter 19).

The results from this project indicated that the ISIS-Fish model can be parameterised to predict the effects of effort displacement on fishery and fish population dynamics even in data-limited situations. However, sensitivity analyses are required to investigate the impact of assumptions and uncertainty in model parameters such as recruitment variability, growth, natural mortality, catchability, and gear selectivity on model results. This would allow the identification of the most sensitive parameters in the model, as well as changes in the systems dynamics brought about by the implementing a given management action (Lehuta et al. 2010).

Further scenarios of altered management or environmental conditions for the fish species included in the model can be simulated with the existing model application. While the effect of a single management action on non-target species appeared to be weak, the cumulative effects of several management decisions over time are expected to lead to more substantial changes in the effort distribution of a fishery. Using the same model, concomitant or sequential management actions over time could be simulated to assess the potential for changes in fishing effort and populations due to cumulative effects.

The ISIS-Fish model framework is considered to be suitable for some fisheries applications in other Australian States (see Chapter 19). For example, the model framework could be used to investigate issues of resource allocation between commercial and recreational sectors and the effects of management changes affecting the respective sectors.

11. PLANNED OUTCOMES

The planned outcomes for this project are an improved understanding of cross-species implications when changing management arrangements, thus advancing the sustainable management of coastal multi-species fisheries around Australia.

This study has provided statistical tools that can be used to analyse the structure and dynamics of fishing fleets. Based on these analyses, it is now possible to identify linkages between different components of a fishery and quantify potential effort shifts should regulatory or environmental conditions change. The ability to account for the expected displaced effort is a critical first step in transforming the common single-species management approaches in multi-species fisheries to a more integrated approach.

Using these methods, this study has provided an overview of the Tasmanian fishing fleet structure over the last 15 years and clearly highlighted the importance of intermediate and generalist fishers in the Tasmanian scalefish fishery. The study also quantified the importance of underlying drivers for some of the fishers' decisions that will help estimating the level of potential effort shifts within the Tasmanian scalefish fishery.

The management decision support tool in form of the ISIS-Fish model application that was developed in this study combines fleet and population dynamics by simulating both components simultaneously. This tool can not only predict the future catch for each fishing fleets represented in the model, but importantly also the development of the stock biomass over time. This tool is therefore a powerful addition to the approaches available to management and can provide valuable information to the consideration of a management decision.

Through a workshop, this project has raised awareness in Tasmanian fisheries managers and fishing industry, and scientists from other States of the methods available and potential approaches to identifying and assessing the effects of effort shifts within multi-species and multi-gear fisheries. The methodological approaches and results will also be presented at the Tasmanian Scalefish Fishery Advisory Committee (SFAC) and published in peer-reviewed journals (for the characterisation of the fleet structure, see Ziegler 2012).

12. CONCLUSIONS

Management actions in multi-species fisheries tend to target single fish species or individual fishing methods independently, without thorough consideration of impacts on other components of the fishery. A more holistic approach to multi-species and multi-gear fisheries assessment and management was needed that allows identifying and quantifying the effects of effort shifts between different components of a fishery on fleet and fish populations as a response to changes in management arrangements and resource availability.

The specific objectives of this study were to develop methods to identify and quantify linkages within a multi-species and multi-gear fishery, and evaluate whether the ISIS-Fish model framework could be developed into a management decision support tool to estimate the effects of effort shifts on fishery and fish population dynamics. The Tasmanian scalefish fishery was chosen as the study case due to its high complexity with many gear types being used to target and catch a large number of fish species.

The results from this study and discussions from the Workshop that was held as part of the extension strategy of this project (see Chapter 19) indicate that the methods developed here are very useful for identifying and quantifying inter-linked components of a fishery. This is a crucial first step for research and management when trying to anticipate and estimate potential effort shifts, since not all fishers are expected to shift their fishing effort as a response to management changes. Some fishers have a high level of specialisation in a particular fishing activity and are unlikely to engage in other fishing activities (see also Steer 2009). As a consequence, the level of 'latent effort' in the fishery, i.e. the capacity and willingness of fishers to increase their fishing activity or shift their effort to other fishing activities as a response to a management change, is situation-specific.

The ISIS-Fish model framework is a powerful simulations tool for predicting the effects of effort displacement on fishery and fish population dynamics. The results of this study indicated that the model can be parameterised to this effect even in data-limited situations inherent to most small-scale fisheries in Australia. For the Tasmanian situation, the effects of effort shifts had relatively small but nevertheless measurable effects on landings and biomass of the target species as well as on other species represented in the model. The impact on non-targeted species were in some cases just as strong as management actions intended directly at these species.

However, the Tasmanian model application has also highlighted the limits of this model approach when the complexity of fleets and fish populations represented in the model is high and the level of information available is low. Due to the many assumptions required for the parameterisation of stock biomass, stock productivity and the fishery, the predicted effects of fishing on the biomass of all four species were highly uncertain. Consequently, the model framework is likely to be inappropriate in situations when very little is known about the fished species, such as for the numerous bycatch species caught in some of Australia's fisheries.

The ISIS-Fish model framework appears to be suitable for relatively simple applications or in situations with abundant fishery and species data, including some fisheries in other Australian States. In addition, the ease of the model to include different fishing fleets or fishing sectors, including e.g. the recreational sector, and the potential to evaluate the individual impacts of these fleets on the fish stocks, means that the model could also be used to investigate issues on resource allocation between sectors and the effects of management changes on recreational fishing activities.

Choosing the ISIS-Fish model framework has a number of advantages and disadvantages that became evident during the project (see Chapter 19) and should be considered when choosing an appropriate model approach. Advantages include the open source code and the free availability of the model framework, and the high flexibility to represent many processes important to multi-gear and multi-species fisheries including economic aspects. The flexibility of ISIS-Fish is balanced by its high level of complexity which requires a substantial time commitment to develop an ISIS-Fish model application and adapt it to the specific situation. Nonetheless, the time commitment may still be less than coding a completely new model framework. Java as the model coding language will be seen by many scientists as a disadvantage since Java is not frequently used elsewhere in fisheries research (although there is an unsupported R version of ISIS-Fish). In addition, model runs tend to be slow and produce large outputs. There is a good support network, and reported model bugs are usually fixed in the next release version. The user-group email list is a valuable source of help and often provides prompt responses to technical or coding issues. However, the frequent use of French in model documentations and support is a concern and could be a substantial disincentive for the uptake of the ISIS-Fish model framework in other States.

Based on the results from this project, we recommend the following steps when considering a management change in a multi-species fishery:

(1) Evaluate if strongly-interlinked components of the fishery (or whole fisheries) are affected by the management change and if there could be potential effort shifts, e.g. with an analysis of fleet structure.

(2) If there is an identified potential for effort shifts, quantify the likely effects of the management change on fishing effort and fleet dynamics, e.g. with an analysis of fishers' behaviour.

(3) If an appropriate multi-species (and multi-gear) model such as an ISIS-Fish model application is available or could be developed, evaluate and quantify the effects of the management change on fishery and fish population dynamics through simulations.

The analysis of the fleet structure in Step 1 can be conducted relatively easily with most existing logbook data and should be completed for any multi-species multi-gear fishery. It can be updated quickly for a snapshot of the most recent or relevant fishing period, and provide an indication of which fishers and fishing activities could be affected by a proposed management change. The analysis of the fleet dynamics in Step 2 builds upon the fleet structure analysis and is more complex. However, once the fleet dynamics analysis has been conducted, it is easily updated and can quantify the extent of the likely responses to a management change. The model application in Step 3 requires a substantial time commitment and whether it should be attempted depends *inter alia* on the level of knowledge about the fish species. In reality, such a simulation model will only add valuable information to the consideration of a management decision, if the level of uncertainty around the fleet and fish population dynamics is acceptable such that the simulation results are considered to be relevant.

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14. APPENDIX 1: INTELLECTUAL PROPERTIES

The research of this project is for the public domain. The report and any resulting manuscripts are intended for wide dissemination and promotion. All data and statistics presented conform to confidentiality arrangements.

15. APPENDIX 2: STAFF

The following table lists project staff involved in the project:

Name	Organisation
Dr Philippe Ziegler	IMAS, AAD
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16. APPENDIX 3: R-CODE FOR FLEET STRUCTURE ANALYSES

16.1 Analysis of fleet structure

```
#####################################################################
#### Required Libraries
library(MASS)
library(fpc)
library(lattice)
library(ca)


#####################################################################
#### 1. Determine Target Species
#####################################################################

#### Load and check data
setwd("mydata/")
ff <- read.table("Data1_Logbook.txt",sep=",",header=T)
nrow(ff)
head(ff)
#      Month Year Vessel Client Region Gear Effort FishA FishB FishC FishD FishE
#    1    11 2000      2    632     R2   GN      1    13     0     0   412    78
#    2    11 2000      2    632     R1   GN      7    45     0     0   552    59
#    3     3 2004      3    653     R1   SJ      1     9   201     0    31     0
#    4     4 2004      3    653     R1   SJ      1     0    17     0    20     2
#    5    11 2007      5    316     R2   FP      1   122    94    20     0   188
#    6     1 2007      7    664     R1   FP      6    23     0     0   178    65

levels(as.factor(ff$Gear))
a <- which(colnames(ff) == "FishA")
b <- which(colnames(ff) == "FishE")


#### Assessment by gear type: Do this for each gear type
geartype <- "GN"
ff0 <- subset(ff,Gear == geartype)

#### Prepare data
## Remove empty columns (if present)
ff1 <- ff0[,c(rep(T,a-1),colSums(ff0[,a:b])>0)]
b <- ncol(ff1)
print(paste("Number of Observations: ",nrow(ff1),sep=""))
## Transform the data to relative values (if required)
ff2 <- ff1
ff2[,a:b] <- ff2[,a:b]/rowSums(ff2[,a:b])

##### Principal component analysis PCA
pc <- princomp(ff2[,a:b])
print(summary(pc))
# Investigate results
plot(pc,type="l")
biplot(pc,xlabs=rep(".",nrow(ff2)))
#xyplot(pc$scores[,2]~pc$scores[,1]|ff2$Year,pch="o",as.table=T)

##### Hierarchical ascending clustering HAC
dd <- dist(pc$scores)            # Euclidian distance
cl <- hclust(dd,method="ward")   # "single","complete","average","centroid","ward"

#### Select Method to determine appropriate number of clusters:
## E.g.: Variance explained (R2): Vector with partitioning to 1-20 clusters
varexp <- vector(mode = "numeric", length = 20)
for (nc in 1:20) {
```

```
     cltree   <- cutree(cl,k=nc)
     Euclid   <- sqrt(rowSums(pc$scores^2))
     overallSS  <- sum((Euclid-mean(Euclid))^2)
     groups   <- as.data.frame(cbind(Euclid,cltree))
     partialSS  <- matrix(0,nrow=nc)
     for (i in 1:nc) {
          gr <- subset(groups,cltree==i)
          partialSS[i] <- sum((gr$Euclid-mean(gr$Euclid))^2)
     }
     r2 <- 1-(sum(partialSS)/overallSS)
     varexp[nc] <- r2
}
print(varexp)
plot(varexp)


#### Number of clusters
## Based on 'ellbow' point, choose appropriate number of clusters
nclust <- 7
cltree <- cutree(cl,k=nclust)
ff0$cltree <- cltree
## Plot tree and clustering boxes
plclust(cl,xlab ="", main = paste("Cluster Analysis for ",geartype,sep=""))
rect.hclust(cl, k = nclust, border = "red")          # border=border colour
print(paste("Number of clusters: " ,nclust,sep=""))
print(paste("Variability explained with the clusters(r2): ", round(varexp[nclust],
     digits=3), sep=""))


#### Summarise clusters
## Method a: Table of Catch sums per Cluster
clstats <- aggregate(ff1[,a:b],by=list(ff0$cltree),sum)
print(round(clstats,0))
## Method b: Centroids (similar to catch summaries)
haccentr <- as.matrix(aggregate(ff2[,a:b],list(cluster=cltree),mean))
print(haccentr)
## Method c: K-means
km <- kmeans(ff2[,a:b],nclust)
ff0 <- cbind(ff0,km$cluster)
print(xtabs(~ cltree + kmclust, data = ff0))
## Plot results
par(windows(width=7,height=9))
par(mfrow=c(4,2))
for (k in 1:nclust) {
    barplot(as.matrix(clstats[k,c(-1)]),las=2, main=(paste("Cluster ",k,sep="")))
    # barplot(haccentr[k,c(-1)],las=2, main=(paste("Cluster ",k,sep="")))
     # barplot(km$centers[k,],las=2, main=(paste("Cluster ",k,sep="")))
     par(mtext(paste("Results for ",geartype,sep=""),side=3,line=-
     1.5,outer=TRUE,font=2,col="black",cex=1.2))
}

## Assign meaningful names to target species, such as:
if(geartype == "GN") {
     gearGN <- ff0
     gearGN$Target[cltree %in% c(2,3)] <- "FishE"
     gearGN$Target[cltree==1] <- "FishC"
}
## Do this for all gear types (e.g. by creating gearFP, gearHL and gearSJ) and
     combine objects
out <- rbind(gearGN,gearFP,gearHL,gearSJ)
write.csv(out,file="Data2_Target.txt",row.names = T,na = "",quote = FALSE)
```

```
##################################################################
#### 2. Determine Fishing Tactics (or metiers)
##################################################################
ff <- read.table("Data2_Target.txt",sep=",",header=T)
head(ff)

a <- which(colnames(ff) == "FishA")
b <- which(colnames(ff) == "FishE")
ff$Region <- ordered(ff1$Region,levels=c("R1","R2","R3"))

#### Assessment by gear: Do this for each gear type
geartype <- "GN"
ff0 <- subset(ff,Gear == geartype)


#### 2.1 Data mining: Simple Correspondence Analysis to examine membership by year
# Target species by Year
tab <- xtabs(~Year+as.vector(Target), data=d1)
biplot(corresp(tab,nf=2))
# Target species by Region
tab <- xtabs(~Region+I(as.vector(Target)), data=d1)
biplot(corresp(unclass(tab),nf=2))
# Target species by Month
tab <- xtabs(~Month+I(as.vector(Target)), data=d1)
biplot(corresp(unclass(tab),nf=2))


#### 2.2 Multiple Correspondence Analysis MCA
## mjca does automatic transformation of Burt matrix into indicator matrix
     depending on lambda specification.
## mjca needs columns containing the factors (as is already the case here).
## Thus, creation of matrix with just the columns and the records as individuals
     without reshaping.
## mjca has default lambda = "adjusted" (Burt matrix adjusted for inertia)
## but this does not sum up to 100% inertia, therefore here lamda = "burt" chosen
## (Decomposition of eigenvalue of Burt matrix, see Nenadic & Greenacre 2007)

## You may wish to add Year to this analysis, or do the analysis annually
ffm    <- data.frame(Target=I(as.vector(d1$Target)),Region=I(as.vector(d1$Region)))
ffm$Month <- d1$Month

multca <- mjca(ffm,nd=3,lambda="burt")
multca
plot(multca,dim=c(1,2),what=c("none","active"),labels=c(1,2))
summary(multca)


#### 2.3 Cluster analysis of MCA results
# Select no of axes based on Eigenvalues (where the curve starts to flatten out)
naxes <- 10
ddd <- dist(multca$rowcoord[,1:naxes]) # Axes number based on multca Eigenvalues
#ddd <- dist(multca$rowdist)           # Euclidian distance
ccl <- hclust(ddd,method="ward")       #"single","complete","average","centroid",
     "ward"

# Search manually for appropriate cluster number
nclust <- 5
cltree <- cutree(ccl,k=nclust)
#plclust(ccl,xlab ="", main = paste("Cluster Analysis for ",gear,sep=""))
#rect.hclust(ccl, k = nclust, border = "red")

## Plotting by cluster
ffm$cltree   <- cltree
ffm$RegionMonth <- paste(ffm$Region,format(ffm$Month,width=2),sep="")
tab <- xtabs(~as.vector(ffm$Target)+ffm$RegionMonth+ffm$cltree)
barplotting1(tab,nclust)
```

```
## Plotting by RegionMonth
tab <- xtabs(~as.vector(ffm$Target)+ffm$RegionMonth)
par(windows(width=12,height=6))
par(mfrow=c(1,1))
par(mai=c(1.3,1,0.3,0.2))
barplot(as.matrix(tab[,]),cex.names=0.75,las=2,legend.text=T,ylab="Number of
      records",font.lab=2)

## Cluster size
xtabs(~ffm$cltree)   # Size by cluster
xtabs(~ffm$Target)   # Size by species


## Assign meaningful names to fishing tactics (or metiers), such as:
if(geartype == "GN") {
      metierGN <- ffm
      metierGN$Metier[cltree %in% c(1,2)] <- "Metier1"
      metierGN$Metier[cltree==3] <- "Metier2"
}
## Do this for all gear types (e.g. by creating metierFP, metierHL and metierSJ)
      and combine objects
out <- rbind(metierGN,metierFP,metierHL,metierSJ)
write.csv(out,file="Data3_Metier.txt",row.names = T,na = "",quote = FALSE)



#####################################################################
#### 3. Determine Vessel Groups
#####################################################################

d <- read.table("Data3_Metier.txt",sep=",",header=T)
head(d)

## PCA chosen (rather than MCA) because interest is in the relative proportion of
      metiers
## (MCA uses absolute numbers)

#### Table with number of fishing strategies per vessel & data transformation
d0 <-  xtabs(~d$Vessel + d$Metier)
head(d0)
d1 <- d0/rowSums(d0)

#### 3.1 Principal Component Analysis PCA
pc <- princomp(d1)
biplot(pc,xlabs=rep(".",nrow(d1)))
summary(pc)
plot(pc,type="l")

#### 3.2 Hierarchical ascending clustering HAC
dd <- dist(pc$scores)             # Euclidian distance
cl <- hclust(dd,method="ward")    #"single","complete","average","centroid","ward"

## Select Method to determine appropriate number of clusters:
## E.g.: Variance explained (R2): Vector with partitioning to 1-60 clusters
NoCl <- 60
varexp <- vector(mode = "numeric", length = NoCl)
for (nc in 1:NoCl) {
      cltree <- cutree(cl,k=nc)
      Euclid <- sqrt(rowSums(pc$scores^2))
      overallSS <- sum((Euclid-mean(Euclid))^2)
      groups <- as.data.frame(cbind(Euclid,cltree))
      partialSS <- matrix(0,nrow=nc)
      for (i in 1:nc) {
       gr <- subset(groups,cltree==i)
       partialSS[i] <- sum((gr$Euclid-mean(gr$Euclid))^2)
      }
      r2 <- 1-(sum(partialSS)/overallSS)
      varexp[nc] <- r2
```

```
}
print(varexp)
plot(varexp,xlab="No of clusters", ylab="Variance described")


## Choose appropriate number of clusters
nclust <- 20
cltree <- cutree(cl,k=nclust)
# Plot
par(windows(width=14,height=7))
par(oma=c(0.0,0.0,0.0,0))
par(mai=c(0.8,0.8,0.6,0))
plclust(cl,xlab = "",ylab="", main = "Cluster Analysis for Vessels", labels =
     FALSE, axes=TRUE, hang=0.01)
title(ylab=list("Distance",cex=1,font=2),line=2.0)
title(xlab=list("Fishing vessels",cex=1,font=2),line=1.0)
rect.hclust(cl, k = nclust, border = "black")          # border=border colour
# abline(h=mean(rev(cl$height)[(nclust - 1):nclust]),col="black",lwd=2)   # Line at
     height of chosen cluster


## Summaries clusters by Method a: Table of sums of proportions spent in each
     metier
out <- cbind(d1,cltree)
clstats <- aggregate(out[,1:ncol(out)-1],by=list(cltree),sum)
print(round(clstats,0))


## Assign meaningful names to vessel groups, such as:
d$VG <- cltree[cltree = d$Vessel]
d$VesselGroup[d$VG == 1] <- "VesselGroup1"
d$VesselGroup[d$VG == 2] <- "VesselGroup2"

write.csv(d,file="Data4_VesselGroups.txt",row.names = T,na = "",quote = FALSE)
```

16.2 Analysis of fishers' behaviour

```
#####################################################################
#### Load required packages
library(VGAM)
library(mlogit)
library(SOAR)
library(lattice)


#####################################################################
#### RUM Variables
#### Choice-specific variables
# per_effort_m  % effort (fishing days) spent in this fishing tactic in previous
     month
# per_effort_y  % effort (fishing days) spent in this  fishing tactic in same month
     of previous year
#### Individual-specific variables
# VPUE_total    Revenue per day achieved from all species caught by the fisher
#                          with the same fishing tactic in the previous month
# FDaysMonth N fishing days in previous month
# FDaysYear  N fishing days in previous 12 months
# ClientAge
# VesselLength
#### Variables to make conditional logit for VPUE:
# GN_BMW, FP_Wra, HL_Wra, DN_Gar, SJ_Cal, XX_Oth
```

```
##################################################################
#### Set working directory and load data
setwd("mydata/")
FD   <- read.csv(file="Data_FD.txt")
row.names(FD) <- FD$X
FD   <- FD[,-1]
head(FD,12)

   id   mode choice per_effort_m per_effort_y FDaysMonth FDaysYear VPUE_total
1   1 GN_BMW  FALSE            0            0          4        19   156.6748
2   1 FP_Wra   TRUE           70            0          4        19   156.6748
3   1 HL_Wra  FALSE            0            0          4        19   156.6748
4   1 SJ_Cal  FALSE           30            0          4        19   156.6748
5   1 DN_Gar  FALSE            0            0          4        19   156.6748
6   1 AOther  FALSE            0            0          4        19   156.6748
7   2 GN_BMW   TRUE            0            0          9        67   220.4192
8   2 FP_Wra  FALSE            0           18          9        67   220.4192
9   2 HL_Wra  FALSE           23            0          9        67   220.4192
10  2 SJ_Cal  FALSE           44            0          9        67   220.4192
11  2 DN_Gar  FALSE           33            0          9        67   220.4192
12  2 AOther  FALSE            0           82          9        67   220.4192

   ClientAge VesselLength GN_BMW FP_Wra HL_Wra SJ_Cal DN_Gar XX_Oth
1         34         12.0      0      1      0      0      0      0
2         34         12.0      0      1      0      0      0      0
3         34         12.0      0      1      0      0      0      0
4         34         12.0      0      1      0      0      0      0
5         34         12.0      0      1      0      0      0      0
6         34         12.0      0      1      0      0      0      0
7         48          9.0      1      0      0      0      0      0
8         48          9.0      1      0      0      0      0      0
9         48          9.0      1      0      0      0      0      0
10        48          9.0      1      0      0      0      0      0
11        48          9.0      1      0      0      0      0      0
12        48          9.0      1      0      0      0      0      0


##########################
#### Select and convert data for fitting the models
yall    <- c(2000, 2008, 9)       # All years: First & last years, number of years
yselect <- c(2000, 2006, 7)       # Years to fit RUMs (2007-08 used for predictions)
seldat  <- FD[FD$Year %in% seq(yselect[1],yselect[2]),] # Data for fitting models
dat     <- mlogit.data(seldat,choice="choice",shape="long",alt.var ="mode",
     chid.var="ID")
# mlogit.data turns each record into:
#       id   mode choice  then all the other variables ...
#    1   1 GN_BMW  FALSE
#    2   1 FP_Wra   TRUE
#    3   1 HL_Wra  FALSE
#    4   1 SJ_Cal  FALSE
#    5   1 DN_Gar  FALSE
#    6   1 AOther  FALSE
#    7   2 GN_BMW   TRUE
#    8   2 FP_Wra  FALSE
#    9   2 HL_Wra  FALSE
#    10  2 SJ_Cal  FALSE
#    11  2 DN_Gar  FALSE
#    12  2 AOther  FALSE

## If choice variable is not turned into a logical automatically, do it here:
dat$choice    <- as.logical(dat$choice)
## Data for validation
seldat        <- FD[FD$Year %in% seq(yselect[2]+1,yall[2]),] # Validation data
seldat$id     <- as.integer(as.factor(seldat$id))
preddat       <- mlogit.data(seldat,choice="choice",shape="long",alt.var ="mode",
     chid.var="ID")
preddat$choice <- as.logical(preddat$choice)
```

```
##########################
#### mlogit models
#### Examples
## General formula:
## mlogit(choice ~ choice-specific (generic coefficient)
##               | individual-specific
##               | choice-specific (alternative specific coefficients), data)
m1a  <- mlogit(choice~ 1 | FDaysMonth + FDaysYear + ClientAge + VesselLength +
                           I(GN_BMW*VPUE_total) + I(FP_Wra*VPUE_total) +
                           I(HL_Wra*VPUE_total) + I(DN_Gar*VPUE_total) +
                           I(SJ_Cal*VPUE_total) + I(XX_Oth*VPUE_total)
                          | per_effort_m + per_effort_y,
                           reflevel="AOther",na.action=na.exclude, data= dat)
summary(m1a); AIC(m1a)
# Drop e.g. VesselLength
m1b  <- mlogit(choice~ 1 | FDaysMonth + FDaysYear + ClientAge +
                           I(GN_BMW*VPUE_total) + I(FP_Wra*VPUE_total) +
                           I(HL_Wra*VPUE_total) + I(DN_Gar*VPUE_total) +
                           I(SJ_Cal*VPUE_total) + I(XX_Oth*VPUE_total)
                          | per_effort_m + per_effort_y,
                           reflevel="AOther",na.action=na.exclude, data= dat)
summary(m1b); AIC(m1b)

## Likelihood ratio test
lrtest(m1a,m1b)

## Extract results
coef(m1a)                               # Coefficients
summary(m1a)$CoefTable[,"Std. Error"]   # Std Error
summary(m1a)$CoefTable[,"Pr(>|t|)"]     # Probabilities


#### Possible alternative: Nested models
m1a  <- mlogit(choice~ 1 | FDaysMonth + FDaysYear + ClientAge + VesselLength +
                           I(GN_BMW*VPUE_total) + I(FP_Wra*VPUE_total) +
                           I(HL_Wra*VPUE_total) + I(DN_Gar*VPUE_total) +
                           I(SJ_Cal*VPUE_total) + I(XX_Oth*VPUE_total)
                          | per_effort_m + per_effort_y,
                           nests=list(bmw_wra=c("GN_BMW","HL_Wra","FP_Wra"),
                                      cal_gar=c("SJ_Cal","DN_Gar"),
                                      other=c("AOther")), un.nest.el=TRUE,
                           reflevel="AOther", na.action=na.exclude, data= dat)
summary(m1a); AIC(m1a)



###############################################################
## Test for IIA properties - Independence from Irrelevant Alternatives
## Using the following model:
ff <- mFormula(choice~ 1 | FDaysMonth + FDaysYear + ClientAge  + VesselLength
                         | per_effort_m + per_effort_y)

ff1  <- mlogit(ff, data=dat);summary(ff1)  # Full model, then alter subsets
ff1a <- mlogit(ff, data=dat,
                    alt.subset=c("GN_BMW","FP_Wra","HL_Wra","DN_Gar","SJ_Cal"))
ff1b <- mlogit(ff, data=dat,
                    alt.subset=c("GN_BMW","FP_Wra","HL_Wra","DN_Gar","AOther"))
ff1c <- mlogit(ff, data=dat,
                    alt.subset=c("GN_BMW","FP_Wra","HL_Wra","SJ_Cal","AOther"))
ff1d <- mlogit(ff, data=dat,
                    alt.subset=c("GN_BMW","FP_Wra","DN_Gar","SJ_Cal","AOther"))
ff1e <- mlogit(ff, data=dat,
                    alt.subset=c("GN_BMW","HL_Wra","DN_Gar","SJ_Cal","AOther"))
ff1f <- mlogit(ff, data=dat,
                    alt.subset=c("FP_Wra","HL_Wra","DN_Gar","SJ_Cal","AOther"))
```

```
## Hausmann-McFadden Test for IIA (independence of the irrelevant alternatives)
mcf <- list()
mcf[[1]] <- hmftest(ff1,ff1a)
mcf[[2]] <- hmftest(ff1,ff1b)
mcf[[3]] <- hmftest(ff1,ff1c)
mcf[[4]] <- hmftest(ff1,ff1d)
mcf[[5]] <- hmftest(ff1,ff1e)
mcf[[6]] <- hmftest(ff1,ff1f)

macfadden <- matrix(0,ncol=2,nrow=length(unique(dat$mode)),
                    dimnames=list(unique(dat$mode),c("Statistic S","p-value")))
for (ii in 1: length(unique(dat$mode))) {
     macfadden[ii,1] <- mcf[[ii]]$statistic
     macfadden[ii,2] <- mcf[[ii]]$p.value
}



#########################################################
#### Predictions:
#### 1. How many were predicted correctly in the fitted data 2000-2006?
# Actual metiers:
met_obs <- dat$mode[dat$choice==TRUE & (!is.na(dat$VesselLength))]
     # Account for the NAs of VesselLength that were excluded in calculations
# Fitted metiers (with best model, here m1a)
fits <- fitted(m1a,outcome=FALSE)
met_fit <- rep("NA",nrow(fits))
for (ii in 1: nrow(fits)) {
     met_fit[ii] <- colnames(fits)[which(fits[ii,] == max(fits[ii,]))]
}
# Combine and compare
mets <- cbind(obs=as.character(met_obs),fits=met_fit)
xtabs(~fits, data=mets)
xtabs(~obs, data=mets)
cbind(rbind(xtabs(~fits+obs, data=mets),xtabs(~obs, data=mets)),c(xtabs(~fits,
     data=mets),nrow(mets)))
# % correct predictions for fitted data set
aa  <- xtabs(~fits+obs, data=mets)
aa1 <- aa[row(aa) == col(aa)]
aa2 <- round(aa1 / xtabs(~obs, data=mets)*100,0)
c(aa2,Total=round(sum(aa1)/nrow(mets)*100,0))



#### 2. How many were predicted correctly in the validation data 2007-2008?
## 1. Create model for validation data set with similar formula as best fitted
     model
m1a  <- mlogit(choice~ 1 | FDaysMonth + FDaysYear + ClientAge + VesselLength +
                           I(GN_BMW*VPUE_total) + I(FP_Wra*VPUE_total) +
                           I(HL_Wra*VPUE_total) + I(DN_Gar*VPUE_total) +
                           I(SJ_Cal*VPUE_total) + I(XX_Oth*VPUE_total)
                          | per_effort_m + per_effort_y,
                           reflevel="AOther",na.action=na.exclude, data= preddat)
## If you want, check power of model predictions with the same code as above
## predict does not seem to work:
# apply(predict(m1a, newdata=preddat, returndata=FALSE),2,mean)
## Alternative: replace coefficients, then estimate predictions manually
p1a$coefficients <- m1a$coefficients    # Replace coefficients in prediction model
X     <- model.matrix(p1a)
alt  <- index(preddat)$alt
chid <- index(preddat)$chid
eXb  <- as.numeric(exp(X %*% coef(p1a)))
SeXb <- tapply(eXb, chid, sum)
P    <- eXb / SeXb[chid]
P    <- matrix(P, ncol = length(unique(preddat$mode)), byrow = TRUE)
colnames(P) <- unique(preddat$mode)
#apply(P, 2, mean)
```

```
## Compare predicted with observed
p_fits <- rep("NA",nrow(P))
for (ii in 1: nrow(P)) {
     p_fits[ii] <- colnames(P)[which(P[ii,] == max(P[ii,]))]
}
# Combine and compare
p_obs <- preddat$mode[preddat$choice==TRUE & (!is.na(preddat$VesselLength))]
pmets <- cbind(obs=as.character(p_obs),fits=p_fits)
xtabs(~fits, data=pmets)
xtabs(~obs, data=pmets)
cbind(rbind(xtabs(~fits+obs, data=pmets),xtabs(~obs, data=pmets)),c(xtabs(~fits,
     data=pmets),nrow(pmets)))
# % correct predictions for validation data set
aa  <- xtabs(~fits+obs, data=pmets)
aa1 <- aa[row(aa) == col(aa)]
aa2 <- round(aa1 / xtabs(~obs, data=pmets)*100,0)
c(aa2,Total=round(sum(aa1)/nrow(pmets)*100,0))
```

17. APPENDIX 4: INDUSTRY SURVEY

17.1 Industry survey

The objectives of the industry survey was to characterize the key drivers for fishing activities and fishers' responses to changes in regulatory, environmental and market conditions of the Tasmanian multi-species and multi-gear scalefish fishery. The identified variables were used in the subsequent analyses of the fleet dynamics by random utility models (RUMs).

The survey specifically focused on:

- Past and present fishing activities
- Main fishing activities and factors that determine fishing activity choices
- Observed changes in the fishery over the past 15 years
- Impacts of management changes on fishing operation, and
- Perspectives on the future of the fishery.

For the survey, fishers were selected who were key operators in the South-East and East of Tasmania with a long and consistent catch history using graball nets, traps, handlines, squid jigs and dip nets to target banded morwong, wrasse, calamari, and garfish.

Between 25 June 2009 and 15 October 2010, thirteen scalefish fishers with a wide range of operational characteristics were interviewed. All interviewed fishers were keen to participate in the study and share their views about the fishery. Some fishers provided very detailed information about their operations including financial details (relative and absolute values). The interviews lasted up to 3.5 hours.

The survey provided interesting insights into the dynamics of the fishery, and helped to identify potential factors that may be important in driving fishers' decisions. However and perhaps not surprisingly, the results were difficult to quantify. The diversity of fishing operations was enormous, even amongst the main fishers that return the majority of the total catch of the key species. Consequently, a significantly larger sample size would have been needed to quantitatively analyse the interview results.

Important in the context of the study was the variety of driving factors and the financial gains from fishing. While few fishers seem to earn enough money from fishing alone, many had either incomes that were highly variable from year to year (depending on fish availability), or other occupations to supplement the income from fishing. The latter were either a part-time occupation besides fishing throughout the year or a seasonal occupation such as construction work in winter when the conditions for fishing are tougher and the catchability of fish is lower. In addition, other household members also often contributed to the total household income and helped to compensate for low income or losses from fishing activities. Therefore, income from fishing alone appeared to be a potentially insufficient measure when trying to infer fishing motivation, e.g. fishers do not necessarily exit the fishery immediately when suffering financial losses.

Despite the generally low incomes (when figures were given), keeping costs low was rarely rated high as an important decision factor for location and type of fishing operation. Rather, experience of fish availability, the weather, rotation of sites and avoiding seals (for gillnet fishers) were the main factors cited.

Interviewed fishers ranged from specialists targeting one or two species to generalists targeting a number of species. Changes in the fisheries management had different effects on fishing operations. Most fishers had reacted to restricted fishing access by changing fishing locations, gear or fished species. However, satisfying options were not always available, and mainly generalists complained about the diminishing opportunities to switch location, fishing gear and targeted species. Particularly in the East between Bicheno and St. Helens, fishing pressure on the few fish species that could be commercially and viably fished has been high. As a consequence, leaving the fishery was stated as the only option forward (one fisher in the survey had left the fishery recently). In the South-East, the number of fishable species is higher but general fishing pressure tends to be high as well and one surveyed fisher had ceased fishing after he lost access to his main target species due to a change in management arrangements.

When asked about their view on the state of the scalefish fishery and its management, fishers' opinions varied strongly. Latent effort was not considered a problem, except maybe for wrasse. Views were split on the licensing arrangements. Some of the interviewed fishers were happy with the current arrangements, while others expressed concerns especially regarding the specialist licenses which decrease the possibility for diversification. Fishers generally agreed on size limits although there were discussions whether the lower size limit for banded morwong was appropriate. Seasonal closures were well supported, but views varied widely on the duration of some of the current closures (e.g. for banded morwong and calamari). Few interviewed fishers supported spatial closures, stating that they displace effort and open up opportunities for poaching. Management approaches for banded morwong were the most contentious. Some expressed the views that the multiplication factor (to calculate the weight from the numbers of fish caught) and the quota system introduced in 2008 were inappropriate and that the net allocation should be equal for all licence types.

17.2 Survey questionnaire

1. Date and time

Data and time	Date and time

2. Profiling

Questions	Data
Client ID	Client ID
Name	Surname
	First name
Age	Age
Home town	Town
Years of industry experience	Years of industry experience

3. Current/usual fishing operation

Determine the spatial and temporal distribution of fishing activity

3.1. Vessel

Questions	Data
What type of vessel do you currently fish from?	Vessel mark/name Vessel type Length Tonnage Diesel/outboard Horsepower
Is your vessel owned, leased or chartered?	Owned/Leased/Chartered
When did you get this vessel?	Year
What is your role on board?	Skipper/Supervisor
What is the usual crew size including you?	Crew number

3.2. Fishing licenses

Questions	Data
What fishing licences and endorsements do you currently hold? Are these owned or leased?	Licence types and endorsements

3.3. Fishing gear and species

Questions	Data
In the past year: What fishing gears have you used and what fish species have you targeted (by month)?	Gear type Gear amount %time used Target species
Have you used multiple gear types per trip (by month)?	Y/N
Have you targeted multiple species together (by month)?	Y/N
What was your catch composition (% weight by month)?	Target species+ other species
Have you caught the target species (by month)?	Y/N
What did you do if not (by month)?	Action
When do you choose your target species?	Before/during trip
Have you changed target species during a trip?	Y/N

3.4. Fishing trips

Questions	Data
In the past year: Where have you fished?	Location Depth Distance offshore Port of departure Port of unloading
How far can you go with your vessel/car and vessel?	Distance with vessel Distance car and vessel
How much time have you spent fishing (by month)?	Duration of typical fishing trip % of total time spent steaming Number of days per month spent fishing
Have you fished as much as you can, e.g. weather allowing (by month)?	Y/N
Do you know of other vessels/fishers with similar fishing activities that yours?	Other vessels/fishers

4. Decision making

Questions	Data
In the past year: How important were the following factors for your choice of fishing location, target species and gear type? • Catch or CPUE from previous month • Catch or CPUE from previous year • Tradition • Potential for high catch (higher risk) • Maintaining some catch (lower risk) • Keeping costs low • Knowledge of fish availability • Information from other fishers • Weather • Tides • Distance from home port • Fuel price • Beach prices/market demands • Seals / mammal interactions • Other factors	1= Very important 2= Important 3= Less important 4= Not important 5= Don't know
Have these factors the same importance as in the past?	Increased/decreased importance Reasons

5. Economics: Income

Questions	Data
In the past year: What was the contribution to your total household income by: • Scalefish species (or total scalefish fishing) • Other fishing activities • Other activities	Income $ value or %
Where do you sell your catch (locally, interstate)?	Processor

6. Economics: Fishing costs

Questions	Data
What are your current annual costs for:	
• Fees and licences	Fishing licences Boat licences Mooring fees Other fees and costs (MAST, etc…)
• Vessel and infrastructure	Vessel maintenance Car and trailer maintenance (if applicable) Fish holding facilities maintenance (e.g. tanks) Insurance (e.g. vessel)

• Fuel	Travel on land ($ or average distance) Travel on water ($, average distance, or % of an average trip spent steaming) Fishing
• Running costs	Gear maintenance Bait Food for crew Other
• Crew share	Crew share
• Sales costs	Freight Commission

7. Fishing history

Determine strategic long-term decision making and changes in fishing operations
Fishing activities since 1995 with particular focus on how external changes have affected activities and how fishers have responded to these external changes.

Questions	**Data**
What has been your fishing history since 1995? Define periods of consistent fishing activity.	Vessels Role (skipper/supervisor) Crew number Licences Endorsement Gear type (by month) Gear amount % time Target species
During each period, did you catch your target species?	Y/N % weight of target species
During each period, what did you do when you did not catch your target species?	Actions
During each period, what were your fishing locations?	Locations (by month) Depths Ports of departure Port of unloading Trip duration % time spent steaming Number of fishing days per month Months without fishing
During each period, did you know of other fishers with similar fishing activities that yours?	Other vessels/fishers
During or at the end of each period, did any of following changes affect you?	Management changes Catch rates/fish availability Efficiency (e.g. GPS) Beach price/market preference/opportunity Operating costs (e.g. fuel price) New vessel Other

What impact did such a change have on your fishing activities at the time?	Buy new vessel Change fishing gear Change target species Change fishing location Diversified operation Increased non-fishing activities Bought more/another licence Other
Were other fishers affected similarly? How did they react?	Reactions of other vessels/fishers
Did other historical management changes (*not mentioned by the fisher*) affect you at all?	Reactions to these management changes
How would you react today to such changes?	Reactions today
Has your efficiency changed over time? How?	Y/N How/by how much Why

8. Current and future perspective

Questions	**Data**
Do you plan to fish in the same way in 5 or 10 years time?	Y/N
If not, what is your plan?	Plans
Where would you like to see the scalefish fishery in 5 or 10 years?	Future of scalefish fishery
Do you consider the current management arrangements as appropriate? If not, what are the problems and possible solutions?	Licensing Latent effort Gear allocation Size limits Spatial closures Seasonal closures Other
Any other comments?	Comments

18. APPENDIX 5: PARAMETERS OF THE TASMANIAN ISIS-FISH MODEL

18.1 Population dynamics sub-model

The biological parameters of the four fish species represented in the model were as specified below.

18.1.1 Banded morwong

Banded morwong (*Cheilodactylus spectabilis*) inhabits rocky reefs down to 50 m depth, with females and juveniles inhabiting shallower sections of the reef while males dominate in deeper sections (McCormick 1989b, 1989a). Both juveniles and adults undergo limited movements, which are generally restricted to within 5 km of the release site (Murphy and Lyle 1999). Since there is no information on population movement rates or the stock structure of banded morwong, one closed banded morwong population was assumed in the model.

Table 18.1 shows the life-history characteristics that were used in the model (taken from Ziegler et al. 2007b, Ziegler and Lyle 2010). Banded morwong is a long-lived species (maximum estimated ages of 93 years for females, 96 years for males, Ewing et al. 2007). Growth rates are sex-specific with males growing to larger sizes than females. In the model, a two-sex length-based model was used to represent the banded morwong population dynamics. The choice of a length-based model over an age-based model was the result of restrictions in ISIS-Fish, which currently allows sex separation only in a length-based model. However, the length-based model essentially behaved like an age-based model, where each length class represented only one age class. The population was structured in 15 length classes per sex (L_2 - L_{16}), where L_2 corresponds to 2-year old mature individuals and L_{16} is a plus-group. Growth followed a Schnute-Richards growth function (Ziegler et al. 2007a):

$$L = L_{\infty}\left(1 + \alpha^{(-at^{c})}\right)^{-1/b}$$

where L is the length in mm, L_{∞} is the average maximum length for the species, t is the age in years, and α, a, b and c are constants. The most recent parameter estimates from 2007 were used here.

The weight-at-length relationship was specified as:

$$W = aL^{b}$$

where W is the weight (g), and a and b are constants. Various levels of natural mortality M were evaluated by testing values from 0.05 (Murphy and Lyle 1999) to 0.3 to match the estimated population biomass with the biomass from the stock assessment model. Based on these results, a natural mortality of M =0.07 was assumed for all sizes.

A season in ISIS-Fish is defined as a series of consecutive months corresponding to an event in the life cycle. Three seasons were defined in the model for banded morwong: January (change of length class for all individuals), February - May (recruitment of L_2 individuals and reproduction, Murphy and Lyle 1999) and June - December.

No stock-recruitment relationship has been established for banded morwong, therefore recruitment to L_2 individuals from 1998 - 2008 (Figure 18.1), as well as initial population numbers by length class to initiate the model runs (Table 18.2) were estimated from an integrated statistical catch-at-age stock assessment model (Ziegler and Lyle 2010). For simulations from 2009 onwards, annual recruitment was randomly sampled from a log-normal distribution with μ = 11.08 and σ = 0.47 that was estimated from the historic annual recruits from 1998 - 2008 (Table 18.1).

18.1.2 Wrasse

The blue-throated wrasse (*Notolabrus tetricus*) and purple wrasse (*N. fucicola*) exhibit strong differences in their life-history characteristics. The blue-throated wrasse is a protogynous hermaphrodite (i.e. developing into female before changing to male; Smith et al. 2003) while the purple wrasse is a gonochoristic species (i.e. sex is fixed at maturity, Hardwood and Lokman 2006). However, the two species were not represented separately in the ISIS-Fish model, because the two wrasse species have been rarely differentiated in fishing logbooks until 2008, and therefore the species-specific catch history was unclear. Because the growth estimation and sex-change mechanism for blue-throated wrasse in Tasmania are highly uncertain and the sex-specific growth estimates from other Australian populations (Victoria) are similar to those for purple wrasse (Smith et al. 2003, Welsford 2003), a common growth function was assumed for both species in a 'wrasse' species group (Table 18.1).

Similar to banded morwong, one closed wrasse population was assumed for the whole model area, since there is no information on the stock structure of wrasses and wrasse movement between reefs is limited (Barrett 1995b). Wrasses can live up to 24 years (Welsford 2003), but few individuals older than 16 years of age are caught (Ewing 2004). The population in the model was structured into 15 age groups (A_2 - A_{16}), where A_2 corresponds to 2-year old individuals and A_{16} is a plus-group (Table 18.2). Growth (in cm) followed a von Bertalanffy growth function (Welsford and Lyle 2005):

$$L = L_\infty\left(1 - exp^{-k(t-t_0)}\right)$$

where L_∞ is the average maximum length for the species, k is the growth efficient, and t_0 is the hypothetical age at length zero.

Table 18.1: Species life-history and population characteristics as represented in the ISIS-Fish model, with the type of population model, parameters of the length-at-age and length-weight relationship, natural mortality M, annual recruitment with mean μ and standard deviation σ of the lognormal distribution, and estimated catchability coefficients.

<table>
<tr><th>Species</th><th>Population model</th><th>Length-at-age</th><th>Length-weight</th><th>Natural mortality M</th><th>Annual recruitment</th><th>Catchability q</th></tr>
<tr><td>Banded morwong</td><td>Two-sex length-based model (15 classes each)</td><td>Schnute-Richards growth function
L in mm, t in years
<table>
<tr><th>Parameter</th><th>Females</th><th>Males</th></tr>
<tr><td>$L\infty$</td><td>442</td><td>516</td></tr>
<tr><td>α</td><td>51.4</td><td>0.1</td></tr>
<tr><td>a</td><td>18.8</td><td>2.3</td></tr>
<tr><td>b</td><td>3.3^{e-7}</td><td>$3.3e^{-3}$</td></tr>
<tr><td>c</td><td>0.05</td><td>0.33</td></tr>
</table></td><td>W in g, L in mm
<table>
<tr><th>Parameter</th><th>Females</th><th>Males</th></tr>
<tr><td>a</td><td>$3.563e^{-5}$</td><td>$3.729e^{-5}$</td></tr>
<tr><td>b</td><td>2.875</td><td>2.852</td></tr>
</table></td><td>0.07</td><td>$\mu = 11.08$
$\sigma = 0.47$</td><td>$9.25e^{-5}$</td></tr>
<tr><td>Wrasse</td><td>Age-based model (15 classes</td><td>Von Bertalanffy growth function
L in cm, t in years
$L_\infty = 44.7$
$K = 0.085$
$t_0 = 3.23$</td><td>W in g, L in cm
$a = 0.0161$
$b = 3.0407$</td><td>0.02</td><td>$\mu = 13.09$
$\sigma = 0.36$</td><td>$2.44e^{-4}$</td></tr>
<tr><td>Calamari</td><td>Length-based model with 1 classes</td><td>$L = 300$ mm</td><td>W in g, L in mm
a = 0.0008
b = 2.427</td><td>0.80</td><td>$\mu = 11.99$
$\sigma = 0.29$</td><td>$q_1 = 7.00e^{-5}$
$q_2 = 2.50e^{-4}$
$q_3 = 7.00e^{-4}$
$q_4 = 24.50e^{-4}$</td></tr>
<tr><td>Garfish</td><td>Age-based with 8 classes</td><td>Von Bertalanffy growth function
L in cm, t in years
$L_\infty = 34.3$
$K = 0.54$
$t_0 = -0.23$</td><td>W in g, L in cm
a = 0.0011
b = 3.4403</td><td>0.60</td><td>$\mu = 14.09$
$\sigma = 0.43$</td><td>$5.31e^{-5}$</td></tr>
</table>

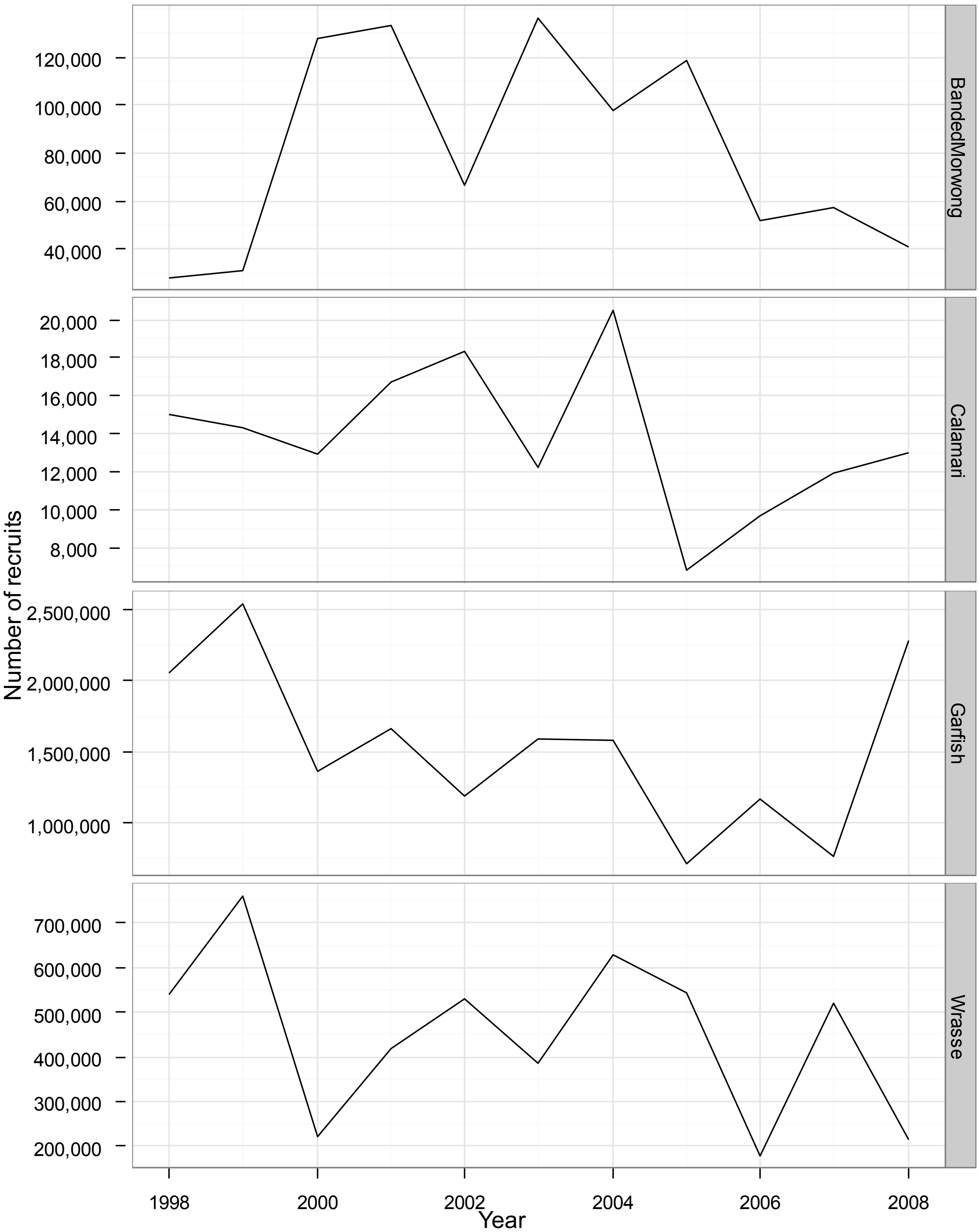

Figure 18.1: Number of recruits from 1998 - 2008 for banded morwong, calamari, garfish and wrasse estimated by the external stock assessment model.

Table 18.2: Initial population numbers at age (*A*) or length (*L*) class in 1998 estimated by the external stock assessment model and used in the ISIS-Fish model for banded morwong, wrasse and garfish. 'N/A' is not applicable to the species, + denotes a plus-group.

Class	Banded morwong		Wrasse	Garfish
	Females	Males		
A_1/L_1	N/A	N/A	N/A	0
A_2/L_2	31,007	31,007	0	918,129
A_3/L_3	28,046	28,046	366,276	372,772
A_4/L_4	18,628	18,774	225,700	75,100
A_5/L_5	29,961	29,377	443,575	42,319
A_6/L_6	32,139	28,627	198,628	19,304
A_7/L_7	11,823	10,391	161,999	8,126
A_8/L_8	10,885	10,801	255,289	1,658
A_9/L_9	9,679	11,722	144,477	N/A
A_{10}/L_{10}	10,245	5,451	28,538	N/A
A_{11}/L_{11}	6,832	5,423	33,951	N/A
A_{12}/L_{12}	7,333	6,757	64,348	N/A
A_{13}/L_{13}	2,433	12,596	46,907	N/A
A_{14}/L_{14}	4,773	11,252	0	N/A
A_{15}/L_{15}	5,310	3,961	0	N/A
A_{16+}/L_{16+}	241,623	171,775	2,088	N/A

A weight-at-length relationship was established based on 1508 male and female purple wrasse records collected on the east coast of Tasmania in the early 1990's (Barrett, unpublished data). A natural mortality of M = 0.20 was assumed for all ages (Smith et al. 2003). Three seasons were defined for wrasse following Welsford (2003): July (change of age class for all individuals), August - January (reproduction and recruitment of A_2 individuals, Barrett 1995a) and February - June. No stock-recruitment relationship has been established for wrasse, therefore recruitment to A_2 individuals from 1998 - 2008 (Figure 18.2), as well as initial population numbers by age class in 1998 to initiate the model runs (Table 18.2) were estimated from the external stock assessment model described above (Ziegler and Lyle 2010) and adapted for wrasse. For simulations from 2009 onwards, annual recruitment was randomly sampled from a log-normal distribution with μ = 13.09 and σ = 0.36 that was estimated from the historic annual recruits from 1998 - 2008 (Table 18.1).

18.1.3 Calamari

The southern calamari (*Sepioteuthis australis*) is a highly mobile species undergoing migrations between feeding and spawning grounds. The main spawning grounds on the Tasmanian east coast have a high degree of self-recruiting, but also supply recruits to other areas on the east coast. Recruits from these spawning grounds are therefore likely to mix (Ziegler et al. 2007b), and 98% of the calamari population on the east coast belong to a single genetic stock (Triantafillos and Adams 2001, Triantafillos 2004). In the ISIS-Fish model, one closed calamari population was assumed.

The life-history characteristics of calamari are dominated by extreme variability in growth and recruitment (Pecl et al. 2004). Combined with a maximum life-span of about one year, stock sizes in Tasmanian waters fluctuate strongly between years. Calamari are found throughout the year, but are mainly caught from August - December. These peak catches are based on the dominant cohort of calamari hatched during the main spawning season (September to December, Moltschaniwskyj and Pecl 2003), which subsequently dies off each year after spawning. Catches from January - July are linked to much smaller cohorts that mature and spawn during these months.

The lack of reliable estimates of growth, recruitment and adult stock size impeded a detailed representation of the population dynamics in the model. Instead, the population dynamics was simplified in the ISIS-Fish model (Table 18.1). Only one cohort was represented that recruited simultaneously in October and died in October the following year. To avoid any assumptions on growth, the entire cohort reached its average adult length of 300 mm instantaneously. Two seasons were defined: October (death of current cohort and recruitment of the new cohort) and the remainder of the year from November-September (presence of calamari). Variable catchabilities during the year simulated the changing presence of different cohorts and accessibility of calamari (see Chapter 18.2.1).

A weight-at-length relationship was established based on 634 calamari records collected on the east coast of Tasmania between 1996 and 2000 (G. Pecl, unpublished data). Calamari species have a high natural mortality (Boyle and Rodhouse 2005), and a value for natural mortality M = 0.8 was chosen in the model. Due to the absence of any strong relationship between stock size and egg production or recruitment in the following year, annual recruitment is modelled by an average recruitment with high random variability. For the historic recruitment from 1998 - 2008, calamari catches were assumed to equate to 50% of the population biomass (Figure 18.1). For simulations from 2009 onwards, annual recruitment was randomly sampled from a log-normal distribution with μ = 11.99 and σ = 0.29 that was estimated from historic recruitment (Table 18.1).

18.1.4 Garfish

The southern garfish (*Hyporhamphus melanochir*) is a pelagic species that occurs in estuarine and inshore waters around Tasmania. Parameters for the von Bertalanffy growth function (Jordan et al. 1998) and the weight-at-length relationship (Hartmann and Lyle 2011) are shown in Table 18.1. In the model, the population was structured by 8 age classes (A_1 - A_8), where A_1 corresponds to 1-year old recruits. Different levels of natural mortality M from 0.55 (Jones 1990) to 1 were tested in the model to calibrate the estimated population biomass with the biomass estimates from the external stock assessment model that was adapted for garfish (Ziegler and Lyle 2010). Based on these results, a natural mortality M = 0.60 was assumed for all ages.

Three seasons were defined for garfish: October - January (reproduction and recruitment of A_1 individuals, Jordan et al. 1998), February - August (presence of fish in SSE, Jordan et al. 1998) and September (change of age class for all individuals). No stock-recruitment relationship has been established for garfish, therefore recruitment to A_1 individuals from

1998 - 2008 (Figure 18.1), as well as initial population numbers by age class in 1998 to initiate the model runs (Table 18.2) were estimated from the external stock assessment model. For simulations from 2009 onwards, annual recruitment was randomly sampled from a log-normal distribution with μ = 14.09 and σ = 0.43 that was estimated from the historic annual recruits from 1998 - 2008 (Table 18.1).

18.2 Fleet dynamics sub-model

18.2.1 Vessel groups

Six vessel groups were retained (named after their dominant fishing tactics with a suffix 'VG'): VG_GN_BMW, VG_FP_Wrasse, VG_HL_Wrasse, VG_SJ_Calamari, VG_DN_Garfish, and VG_GN_Mixed. The average numbers of active fishing vessels during the most recent years from 2003 - 2008 were used for all years, although the number of active vessels in a given vessel group fluctuated from year to year (Table 18.3). During the study period from 1998 - 2008, the six vessel groups contributed to between 18% and 41% of the total scalefish catch (Table 18.4).

Table 18.3: Number of active vessels in each vessel groups from 1998 - 2008. The average numbers of active fishing vessels from 2003 - 2008 (marked in grey) was used in the model.

Year	VG_ FP_Wrasse	VG_ SJ_Calamari	VG_ GN_BMW	VG_ DN_Garfish	VG_ HL_Wrasse	VG_ GN_Mixed
1998	33	5	25	15	6	57
1999	40	13	28	24	4	63
2000	34	16	27	12	5	52
2001	31	14	25	12	4	40
2002	31	22	28	10	5	33
2003	30	31	22	8	4	38
2004	28	30	24	9	6	34
2005	27	23	20	9	5	26
2006	29	19	18	6	7	23
2007	28	26	19	5	8	25
2008	16	21	18	6	4	20
Average 2003-2008	**26**	**25**	**20**	**7**	**6**	**28**

Based on logbook data, two vessel types were defined for the model: small vessels less than 6 m in length that were assumed to perform only day trips of 8 hours, and large vessels more than 6 m in length that were capable of performing 5-day trips (120 hours). The proportion of vessel types within each vessel group varied to some degree from year to year, but there was a consistent dominance of a particular vessel type within a vessel group over time. For example, the vessel groups VG_GN_BMW, VG_SJ_Calamari and VG_DN_Garfish were always dominated by small vessels, while VG_FP_Wrasse and VG_HL_Wrasse were dominated by large vessels. In order to obtain a fixed proportion of each vessel type, the proportion of small and large vessels in the most recent years from 2003 - 2008 was averaged (Table 18.5). In the model, vessel types that constituted over 80% of a given vessel group were considered as the sole vessel type for that vessel group.

Table 18.4: Catch in tonnes and percentage contribution to the total scalefish catch (in brackets) from 1998 - 2008 for each vessel group.

Year	VG_ FP_Wrasse	VG_ SJ_Calamari	VG_ GN_BMW	VG_ DN_Garfish	VG_ HL_Wrasse	VG_ GN_Mixed
1998	111.3 (4.3%)	24.6 (0.9%)	103.7 (4.0%)	153.9 (5.9%)	24.7 (1.0%)	251.5 (9.7%)
1999	98.3 (3.2%)	49.2 (1.6%)	106.1 (3.5%)	131.2 (4.3%)	20.2 (0.7%)	267.5 (8.8%)
2000	106.9 (3.7%)	75.1 (2.6%)	85.9 (2.9%)	66.3 (2.3%)	24.4 (0.8%)	177.9 (6.1%)
2001	93.0 (4.5%)	68.5 (3.3 %)	77.3 (3.7%)	69.8 (3.4%)	25.1 (1.2%)	100.8 (4.8%)
2002	76.0 (5.4%)	122.6 (8.6%)	110.1 (7.8%)	63.4 (4.5%)	28.3 (2.0%)	159.2 (11.2%)
2003	75.7 (7.1%)	98.1 (9.2%)	86.5 (8.1%)	56.7 (5.3%)	16.7 (1.6%)	78.9 (7.4%)
2004	78.0 (6.4%)	128.9 (10.6%)	73.2 (6.0%)	78.4 (6.5%)	36.7 (3.0%)	76.1 (6.3%)
2005	65.3 (7.1%)	93.2 (10.1%)	71.2 (7.7%)	37.2 (4.0%)	32.5 (3.5%)	66.8 (7.2%)
2006	57.1 (5.9%)	96.4 (9.9%)	69.8 (7.2%)	43.2 (4.4%)	37.6 (3.9%)	76.5 (7.9%)
2007	51.6 (3.7%)	81.9 (5.9%)	89.0 (6.4%)	32.1 (2.3%)	45.6 (3.3%)	53.4 (3.8%)
2008	21.2 (1.8%)	105.2 (8.9%)	80.9 (6.9%)	211.0 (18.0%)	29.5 (2.5%)	39.5 (3.4%)

Table 18.5: Average proportion of small vessels and large vessels in each vessel groups averaged for the period 2003 - 2008.

Vessel type	VG_ FP_Wrasse	VG_ SJ_Calamari	VG_ GN_BMW	VG_ DN_Garfish	VG_ HL_Wrasse	VG_ GN_Mixed
Small	0.13	0.79	0.80	0.90	0.33	0.25
Large	0.87	0.21	0.20	0.10	0.67	0.75

Table 18.6: Gear parameters used in the model. Technical parameters describe the type of gear but were not used in calculations except where stated. Shown are gear standardisation factor (Std. factor), and gear selectivity *S* by fish length *L* or age *A*. Gear selectivity of a species that is not targeted is *S* = 0.

Gear	Technical parameter	Std. factor	Selectivity *S*		Source
Graball net (GN)	Mesh size *m*: 105-140 mm Net length: 150-1000 m	1.21	Banded morwong and wrasse	$S = \left(\frac{L}{\alpha k m}\right)^{\alpha} exp^{\left(\alpha - \frac{L}{km}\right)}$ *L* in cm α = -22.87 *k* = 0.0129 Mesh size *m* = 137	Ziegler et al. (2006)
Fish trap (FP)	Trap size mm: 2000Wx1000Dx2000L Min mesh size: 25 mm Max opening: 250 mm	4.81	Wrasse	$S = \frac{exp^{(a+bL)}}{1+exp^{(a+bL)}}$ *L* in mm a = -7.25 b = 0.039	Ewing (2004)
Hand line (HL)	1-2 hooks	1.08	Wrasse	$S = \frac{exp^{(a+bL)}}{1+exp^{(a+bL)}}$ *L* in mm *a* = -19.87 *b* = 0.077	Present study
Dip net (DN)	Mesh size: 20 mm Max diameter: 100 mm	1.00	Calamari Garfish	*S* = 1 *S* = 1	Present study
Purse seine (PS)	Net length: 600 m	8.32	Garfish	*S* = 0 for age = A_1 *S* = 1 for age ≥ A_1	Present study
Squid jig (SJ)	1-5 jigs	1.03	Calamari	*S*= 1	Present study
Other	N/A	3.63	BMW Calamari Garfish Wrasse	*S* = 1 *S* = 1 *S* = 1 *S* = 1	Present study

18.2.2 Selectivity parameters

Parameters of graball net length-specific selectivity *S* for banded morwong were taken from Ziegler et al. (2006) and assumed identical for wrasse (Table 18.66). Fish trap selectivity for wrasse was taken from Ewing (2004). Handline selectivity for wrasse was estimated by a logistic curve based on 189 length observations collected from research surveys in 2003 (G.P. Ewing, unpublished data).

Selectivity of dip net and purse seine for garfish was assumed to be *S* = 1, since whole fish schools are usually targeted and caught using these gear types. Selectivity for squid jig was also assumed to 1 since there was only one length class in the model. Selectivity for the "Other" gear type which included a variety of lines and nets with unknown selectivity, was assumed by default to be *S* = 1 for all species independent of age and length classes.

Gear standardisation factors, species target factors and vessel group technical efficiency were estimated using a generalised linear model (GLM) of monthly catch rate (CPUE) data. For each species, catch rate data was relative to the average catch rate for the species in the month to standardise across species.

The GLM model with a Gaussian error and an identity link function contained six factors, namely vessel group (*VG*), gear type (*Gear*), fishing year (*Year*), fishing month (*Month*), fishing block (*Block*), and an interaction term for fishing tactics and species (*FishingTactics:Species*):

$$\log(SdtCPUE) = \beta_0 + \beta_1 VG + \beta_2 Gear + \beta_3 Year + \beta_4 Month + \beta_5 Block + \beta_6 (FishingTactis{:}Species)$$

in which the coefficient β_1 corresponded to the vessel group technical efficiency (Table 18.7), β_2 to the gear standardisation factor (Table 18.6) and β_6 to the species target factor (Table 18.8).

The target factors β_6 for each species (*species*) were corrected for zero catches in the records:

$$corr\ \beta_{6_{Species}} = \frac{n_{ft\ Species}}{n_{ft\ Total}}\ \beta_{6_{Species}}$$

where $n_{ft\ Species}$ corresponds to the number of records with non-zero catches for the fishing tactic *ft* and fish species, and $n_{ft\ Total}$ is the total number of records with catch for at least one of the four species for the fishing tactic *ft*.

Table 18.7: Technical efficiency by vessel group.

Vessel group	Technical efficiency
VG_DN_Garfish	1
VG_FP_Wrasse	0.8610
VG_GN_BMW	1.1235
VG_GN_Mixed	1.0342
VG_HL_Wrasse	1.3446
VG_Other	1.1439
VG_SJ_Calamari	1.0453

Table 18.8: Species target factor by fishing tactics.

Fishing tactic	BMW	Calamari	Garfish	Wrasse
DN_Garfish	0	0.8916	14.2387	0
FP_Wrasse	0.0005	0.0148	0.0004	0.9900
GN_BMW	7.3003	0.0077	$8.0688e^{-05}$	0.1357
HL_Wrasse	0.0194	0.0022	0	5.0959
FT_Other	0.3223	0.1821	0.1355	0
PS_Garfish	0	0.0156	4.7608	0
SJ_Calamari	0	4.5951	0.0498	0

18.2.1 Fishing zones

The spatial distribution of fishing effort by fishing tactics differed between vessel groups (Figure 18.2). Accordingly, two fishing zones were defined for each fishing tactics: a 'main' fishing zone for the vessel groups using the fishing tactic preferentially, and a 'secondary' fishing zone for all other vessel groups using the fishing tactics as a side activity. To account for interannual variation in fishing zones, the effort per fishing blocks was averaged from 1998 - 2008 for each fishing tactic. Only fishing blocks which contributed 10% or more to the total effort for the fishing tactic were included in the fishing zone.

18.2.2 Historical fishing strategies

Table 18.9 to Table 18.16 describe the eight average fishing strategies from 2003 - 2008, i.e. the monthly allocation of fishing effort between fishing tactics as represented in the model.

18.2.1 Survival

Survival of discarded fish (e.g. capture and release of undersized or oversized fish, or fish that are accidently caught while subject to fishing closures) was taken in account in the model. Survival is used to obtain the number of surviving discarded fish, which is then used to update population numbers at each time step. Discard survival was set at s = 0.5 for garfish, s = 0.75 for wrasse, s = 0.80 for banded morwong and s = 0.30 for calamari based on estimations from Metcalf (2009).

18.2.1 Calibration for catchability

Catchability q in ISIS-Fish is defined as the probability that fish present in a zone during a season is caught by a unit of standardized effort (Mahévas and Pelletier 2004). No catchability data were available for any of the four selected species. Constant catchability was assumed for banded morwong, wrasse and garfish in all zones and for all age or length classes (Table 18.1). Catchability was calibrated using the monthly landing for the selected vessel groups from 1998 - 2005, as well as the estimated biomass from the stock assessment models for these species (1998 - 2002 for wrasse).

Due to the simplified model for calamari population dynamics, four different values for catchability were necessary to replicate the observed catch patterns. Catchability from January - April (q_1) was low, mimicking the absence of adults of the main cohort but the presence of smaller cohorts during this period. Increasingly higher catchabilities were estimated from May - July (q_2) mimicking the increasing presence of adults from the main cohort, and from August - October (q_3) when all the adults of the main cohort are present. Catchability was highest in the November-December period (q_4) when adults are concentrated on spawning grounds until dying (Table 18.1).

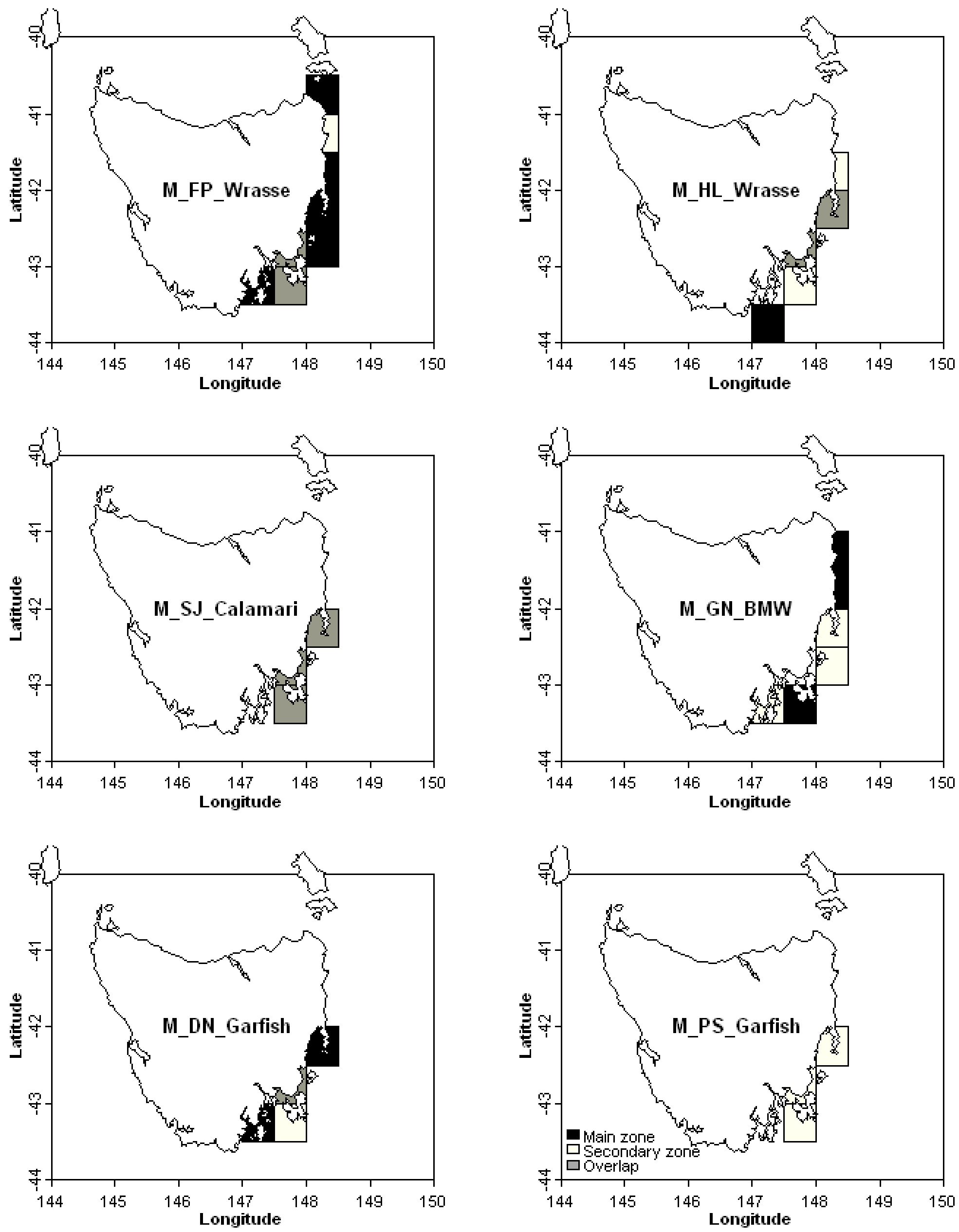

Figure 18.2: Fishing zones for selected fishing tactics. Main (black), secondary (white) and overlap between main and secondary (grey) fishing zones. 'BMW' is banded morwong, 'FP' is fish trap, 'HL' is hand line, 'SJ' is squid jig, 'GN' is graball net, 'DN' is dip net, and 'PS' is purse seine.

Table 18.9: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_HL_Wrasse and strategy S_HL_Wrasse. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 0.66	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.9471	0.9537	0.9593	0.9660	0.9591	0.9509	0.9745	0.9401	0.9651	0.9539	0.9644	0.9194
	GN_BMW	0	0.0026	0	0	0	0	0	0	0	0	0	0.0008
	DN_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	PS_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	SJ_Calamari	0.0116	0.0007	0.0031	0	0.0075	0	0.0020	0.0108	0.0063	0	0.0056	0.0530
	HL_Wrasse	0.0287	0.0344	0.0261	0.0243	0.0301	0.0407	0.0155	0.0284	0.0206	0.0261	0.0256	0.0169
	FP_Wrasse	0	0.0007	0.0046	0.0069	0	0.0065	0.0054	0.0169	0.0040	0.0146	0.0011	0
	FT_Other	0.0125	0.0079	0.0069	0.0028	0.0032	0.0019	0.0027	0.0038	0.0040	0.0054	0.0033	0.0100

Table 18.10: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_HL_Wrasse and strategy S_HL_Wrasse_out. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 0.34	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.9892	0.9881	0.9946	0.9944	1.0000	0.9222	0.9767	0.7849	0.9694	0.9588	0.9889	0.9516
	GN_BMW	0	0	0	0	0	0	0	0	0	0	0	0
	DN_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	PS_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	SJ_Calamari	0	0	0	0	0	0	0	0	0	0	0	0.0269
	HL_Wrasse	0	0.0030	0	0	0	0.0389	0.0072	0.1183	0.0139	0.0090	0.0056	0
	FP_Wrasse	0	0.0089	0.0054	0.0056	0	0.0389	0.0090	0.0699	0.0028	0.0215	0	0.0108
	FT_Other	0.0108	0	0	0	0	0	0.0072	0.0269	0.0139	0.0108	0.0056	0.0108

Table 18.11: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_FP_Wrasse and strategy S_FP_Wrasse. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 0.68	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.9200	0.9353	0.8732	0.9156	0.9273	0.9002	0.8982	0.9168	0.9247	0.9202	0.9175	0.9208
	GN_BMW	0.0023	0.0047	0	0	0	0.0019	0.0006	0.0009	0	0	0.0013	0.0015
	DN_Garfish	0	0	0	0	0.0003	0	0	0.0002	0	0	0	0
	PS_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	SJ_Calamari	0.0010	0.0004	0	0.0002	0.0019	0.0030	0.0012	0.0011	0.0012	0	0.0005	0.0052
	HL_Wrasse	0.0072	0.0076	0.0054	0.0035	0.0044	0.0011	0.0035	0.0066	0.0090	0.0108	0.0051	0.0050
	FP_Wrasse	0.0383	0.0320	0.0432	0.0450	0.0639	0.0765	0.0732	0.0611	0.0627	0.0623	0.0516	0.0408
	FT_Other	0.0313	0.0201	0.0782	0.0357	0.0022	0.0173	0.0234	0.0133	0.0025	0.0068	0.0240	0.0267

Table 18.12: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_FP_Wrasse and strategy S_FP_Wrasse_out. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 0.32	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.9098	0.9220	0.8943	0.9153	0.9435	0.9111	0.9289	0.9267	0.8958	0.8548	0.9204	0.9339
	GN_BMW	0	0	0	0	0	0	0	0	0	0	0	0
	DN_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	PS_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	SJ_Calamari	0.0018	0.0012	0	0.0007	0.0054	0.0083	0.0024	0.0040	0.0056	0	0	0.0131
	HL_Wrasse	0.0012	0	0	0	0	0	0.0006	0.0007	0	0	0	0.0015
	FP_Wrasse	0.0412	0.0387	0.0529	0.0465	0.0493	0.0667	0.0448	0.0517	0.0931	0.1416	0.0531	0.0269
	FT_Other	0.0460	0.0381	0.0529	0.0375	0.0018	0.0139	0.0233	0.0168	0.0056	0.0036	0.0265	0.0246

Table 18.13: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_GN_BMW and strategy S_GN_BMW. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 1.00	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.8411	0.7970	0.9235	0.9156	0.8025	0.8519	0.8524	0.8344	0.8673	0.8559	0.8437	0.8449
	GN_BMW	0.1238	0.1673	0.0010	0	0.1339	0.0897	0.0850	0.1000	0.0732	0.0858	0.1034	0.1022
	DN_Garfish	0	0	0	0	0	0	0	0	0	0	0.0002	0
	PS_Garfish	0.0003	0	0.0002	0.0006	0	0.0004	0	0.0004	0.0002	0	0	0
	SJ_Calamari	0.0012	0.0014	0.0022	0.0044	0.0041	0.0041	0.0037	0.0037	0.0046	0.0029	0.0010	0.0095
	HL_Wrasse	0.0083	0.0088	0.0247	0.0278	0.0285	0.0257	0.0246	0.0308	0.0319	0.0274	0.0230	0.0133
	FP_Wrasse	0.0088	0.0086	0.0122	0.0133	0.0237	0.0187	0.0271	0.0256	0.0173	0.0186	0.0146	0.0067
	FT_Other	0.0163	0.0168	0.0362	0.0383	0.0073	0.0095	0.0072	0.0052	0.0056	0.0093	0.0142	0.0234

Table 18.14: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_GN_Mixed and strategy S_GN_Mixed. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 1.00	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.9575	0.9522	0.9435	0.9524	0.9610	0.9589	0.9772	0.9659	0.9731	0.9597	0.9609	0.9532
	GN_BMW	0.0006	0.0009	0	0	0	0.0003	0.0004	0	0.0009	0	0.0002	0.0002
	DN_Garfish	0.0003	0.0013	0.0021	0.0041	0.0020	0.0017	0.0004	0.0000	0.0003	0.0012	0.0011	0
	PS_Garfish	0.0008	0.0004	0.0064	0.0077	0.0074	0.0064	0.0029	0.0016	0.0003	0.0008	0.0010	0.0007
	SJ_Calamari	0.0011	0.0023	0.0014	0.0029	0.0054	0.0017	0.0013	0.0034	0.0022	0.0035	0.0016	0.0052
	HL_Wrasse	0	0	0	0	0	0	0	0	0	0.0029	0.0008	0
	FP_Wrasse	0.0011	0.0006	0.0004	0	0.0002	0.0022	0.0004	0.0020	0.0046	0.0045	0.0023	0.0012
	FT_Other	0.0387	0.0423	0.0461	0.0329	0.0240	0.0289	0.0175	0.0271	0.0185	0.0273	0.0320	0.0395

Table 18.15: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_DN_Garfish and strategy S_DN_Garfish. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 1.00	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.8656	0.8247	0.7590	0.7500	0.7536	0.8238	0.8280	0.8253	0.8357	0.8339	0.6841	0.7926
	GN_BMW	0	0	0	0	0	0	0	0	0	0	0	0
	DN_Garfish	0.0522	0.0701	0.1210	0.0903	0.0815	0.0746	0.0618	0.0565	0.0603	0.0382	0.0548	0.0307
	PS_Garfish	0	0	0	0	0	0	0	0	0	0	0	0
	SJ_Calamari	0.0366	0.0258	0.0430	0.0688	0.1022	0.0754	0.0833	0.1001	0.0810	0.0896	0.2127	0.1398
	HL_Wrasse	0	0	0.0027	0	0.0018	0.0016	0	0	0	0	0	0
	FP_Wrasse	0	0	0	0.0007	0	0	0	0	0	0.0006	0	0
	FT_Other	0.0457	0.0794	0.0744	0.0903	0.0609	0.0246	0.0269	0.0181	0.0230	0.0376	0.0484	0.0369

Table 18.16: Proportional monthly allocation of fishing effort between fishing tactics for vessel group VG_SJ_Calamari and strategy S_SJ_Calamari. ProportionVG is the proportion of the vessel group that practises this strategy.

	ProportionVG: 1.00	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fishing tactics	FT_Inactivity	0.8961	0.8610	0.8854	0.8626	0.8509	0.8856	0.9126	0.8882	0.8699	0.8683	0.8728	0.8944
	GN_BMW	0.0136	0.0105	0	0	0.0024	0.0010	0.0004	0	0.0042	0.0040	0.0066	0.0051
	DN_Garfish	0.0006	0.0014	0.0024	0.0068	0.0064	0.0030	0.0027	0.0016	0.0023	0.0027	0.0022	0
	PS_Garfish	0	0	0.0004	0	0	0	0	0	0	0	0	0
	SJ_Calamari	0.0330	0.0220	0.0215	0.0364	0.0540	0.0495	0.0384	0.0580	0.0625	0.0593	0.0637	0.0671
	HL_Wrasse	0.0087	0.0189	0.0159	0.0243	0.0253	0.0214	0.0164	0.0177	0.0180	0.0190	0.0111	0.0068
	FP_Wrasse	0.0047	0.0060	0.0063	0.0095	0.0127	0.0095	0.0081	0.0101	0.0142	0.0128	0.0063	0.0039
	FT_Other	0.0432	0.0803	0.0680	0.0605	0.0484	0.0300	0.0214	0.0244	0.0289	0.0339	0.0372	0.0226

19. APPENDIX 6: REPORT FROM 'WORKSHOP ON APPROACHES TO FISHERIES RESEARCH AND MANAGEMENT OF COASTAL MULTI-GEAR AND MULTI-SPECIES SCALEFISH FISHERIES'

A 1-day Workshop on 'Approaches to fisheries research and management of coastal multi-gear and multi-species scalefish fisheries' was held at the Institute of Marine and Antarctic Sciences (IMAS) in Taroona on 15 November 2012.

Participants:
Philippe Ziegler (IMAS and Australian Antarctic Division; workshop organiser)
Jessica André (IMAS)
Jeremy Lyle (IMAS)
Caleb Gardner (IMAS)
Klaas Hartman (IMAS)
Neil Stump (Tasmanian Seafood Industry Council)
Frances Seaborn (Tasmanian Department of Primary Industries and Water)
John Stewart (NSW Department of Primary Industries)
Wayne Sumpton (Queensland Department of Agriculture, Fisheries and Forestry)
Mike Steer (South Australian Research and Development Institute)
Dan Gaughan (WA Fisheries)

Apologies:
Paul Hamer (Victorian Department of Primary Industries)
Mark Grubert (NT Department of Primary Industry and Fisheries)

The workshop was held as part of the extension strategy of the FRDC project 2008/010 to distribute the findings of this project and discuss research and management approaches in coastal multi-gear and multi-species scalefish fisheries ('mixed fisheries') with fisheries scientists and managers from other States or Territories. With the exception of Victoria and the Northern Territories (both with late apologies), at least one representative from each State or Territory attended the workshop.

During the workshop, a series of presentation were given and discussed, including an introduction to the background and objectives of the project (Philippe Ziegler), and presentations on approaches and results from the FRDC project (on fleet structure and fishers' behaviour by Philippe Ziegler, on the ISIS-Fish model by Jessica André), and on approaches in Victoria (Paul Hamer in absence), New South Wales (John Stewart), Queensland (Wayne Sumpton), Western Australia (Dan Gaughan) and South Australia (Mike Steer).

The workshop participants were asked to address the following questions in their discussions:

- What research approaches are useful and worthwhile to quantify interactions of different components in mixed fisheries and to estimate effects of displaced fishing effort when conditions change (management arrangements, environmental conditions, market situation…)? How can the results be used for management?

- Should management decisions take into account these interactions and potential effects of displaced effort? If so, how can this be done?

Given the expertise present at the workshop, discussions focussed mainly on research aspects.

19.1 Analysis of fleet structure

The workshop participants agreed that the fleet structure analysis using multivariate statistical methods is a useful way to identify linkages between different components of a fishery or between fisheries, and to identify those fishers or vessels with a potential for effort shifts should regulatory or environmental conditions change. Identifying and quantifying the strongly inter-linked components of a fishery is a crucial first step for research and management for anticipating potential effort shifts, since not all fishers will shift fishing effort as a response to such changes. Some fishers have a high level of specialisation in a particular fishing activity and are unlikely to engage in other fishing activities (see also Steer 2009). As a consequence, the level of 'latent effort' in the fishery, i.e. the capacity and willingness of fishers to increase their fishing activity or shift their effort to other fishing activities, is situation-specific.

The participants discussed various technical aspects of the analysis, including the effects of expert knowledge. Expert knowledge is not only required to select the appropriate number of cluster when identifying fishing tactics or vessel group, but also e.g. for quality control to detect misspecifications of target species (e.g. barracouta may be an unlikely target species for graball nets) which may arise due to the type of the analysis (post-hoc target species analysis based on the species that have been caught instead of an analysis based on the species that was targeted when setting the gear).

Following the general overview analysis of the fleet structure as conducted in this study, future work could include snapshot analyses of the current fleet structure. Based on the developed methodology, the analysis can be easily reapplied to additional data including those from the present year. Subsets of the data can also be analysed and interpreted to e.g. evaluate how the fleet structure has changed with the introduction of particular management actions.

19.2 Analysis of fishers' behaviour

The workshop participants agreed that the approach and validated results from fishers' behaviour analyses is a useful tool for fisheries scientists and managers to predict possible effects of management changes in dynamic 'what-if' scenarios.

The workshop participants encouraged further analyses of fishers' behaviour to identify and quantify the underlying drivers of fishing decisions. Participants speculated that the high proportion of correct predictions during the validation phase was mainly achieved because the conditions for fishing were very similar between the fitting (2000 - 2006) and validation periods (2007 - 2008). However, the management of two fished species has significantly changed since 2008, namely for banded morwong with the introduction of a TAC and individual transferable quotas (ITQs), and for calamari with the introduction of a species-specific licence in the South-East and East of Tasmania. Validating the random utility model on data from the period after these management changes would be an important next step to confirm the power of the model to correctly predict fishing tactics.

19.3 ISIS-Fish model

Workshop participants recognised the potential of the ISIS-Fish model framework in predicting the effects of effort displacement on fishery catch distribution and fish population dynamics through simulations.

The results provided by the Tasmanian ISIS-Fish model were considered to be very valuable. However, this application has highlighted the limits of this model approach when the complexity of fleets and fish populations represented in the model is high and the level of information available is low. Due to the many assumptions required in its parameterisation, the results were considered to be highly uncertain. Consequently, the model framework is likely to be unsuitable in situations where very little is known about the fished species (e.g. for the numerous bycatch species caught in some of the fisheries).

The ISIS-Fish model framework was considered to be more suitable for simpler applications (addressing simpler questions) or in situations with more fishery and species data, including some fisheries in other States. In addition, the ease of the model to include different fishing fleets or fishing sectors, including e.g. the recreational sector, and the potential to evaluate the individual impacts of these fleets on the fish stocks, means that the model could be used to investigate issues on resource allocation between sectors and the effects of management changes on recreational fishing. Such applications would make the ISIS-Fish model framework also very attractive to a range of funding sources.

The workshop participants discussed general advantages and disadvantages of the ISIS-Fish model approach (Table 19.1). The flexibility of the ISIS-Fish model framework is balanced by the high level of complexity. The model's complexity requires a substantial time commitment to develop an ISIS-Fish model application, however this may still be less than coding a completely new model framework. Java as the model coding language was seen as a negative due to the unfamiliarity of most scientists with Java. Although there is a good support network, the workshop participants were concerned about the frequent use of French in model documentation and support. This issue was considered a substantial disincentive for the uptake of the model in other States.

Table 19.1: Advantages and disadvantages of the ISIS-Fish model approach.

Advantages	Disadvantages
Open-source and freely available at www.**isis-fish**.org	Data-intensive Complex, required substantial amount of time to understand and parameterise
Allow representation of many processes that are important to multi-gear and multi-species fisheries	Slow run times
Very flexible, new rules and analyses can be easily written	Coded in Java (and R), requires code adaptation in most cases, some bugs (usually fixed with next program update)
Good support network	Some of the model documentation and most support documentation (e.g. list server) are in French

19.4 Overview of other jurisdictions

The presentation on fishery assessments and management in other States and Territories provided a good overview over the different approaches used around Australia, and highlighted *inter alia*:

- The use of the term 'fishery' varies, and can either relate to the whole fishery (Tasmania and South Australia) or parts of the scalefish fisheries (e.g. Ocean Trap & Line fishery in NSW, Ocean beach net fishery in Queensland).

- Scalefish fisheries in many States are multi-species and multi-gear, some with substantial components of other commercial and recreational sectors.

- Assessments are usually performed by individual species, but often only the most valuable species or indicator species are assessed.

- Many States have a species classification system that defines the level of assessment. Assessments are generally conducted on a regular time interval.

- There is generally only a poor understanding of the fishing fleet dynamics.

- Management can be at species level or at the level of a fishery. The NSW Ocean Trap & Line fishery was used as an example for management of an entire fishery, where the size of the escape panel mesh of fish traps was set based on a multi-species yield-per-recruit analysis.

- In general, management is via input controls such as fishing licences, gear restrictions, size limits, and spatial and temporal closures.

- WA uses an EBFM framework for multi-species multi-sector fisheries to prioritise risk and optimise use of resources (groups of species based on broad habitat) at a bioregional level.

- The recreational sector is very important in all States. Many challenges to fisheries management in scalefish fisheries relate to the interaction between the commercial and recreational sectors.

19.5 Adoption of project methods and results in other jurisdictions

The workshop participants compared the different approaches taken by this project (Table 19.2) and discussed the potential benefits of their adoption in other States and Territories.

Since financial and personnel resources in most State Departments are stretched, a re-prioritization of work tasks would be required to do the type of work described in this project. However, methods for the analyses of fleet structure and fishers' behaviour have been developed in this project and are readily available. They could be adapted relatively easily to fisheries in other jurisdictions, potentially as part of student projects. ISIS-Fish model applications were considered to be substantially more complicated, and only achievable either as a student project or through an externally-funded project (with a minimum period of 18 months). In both cases, close collaboration with Jessica André was considered to be mandatory for the success of such a project due to Jessica's expertise with the ISIS-Fish model and her knowledge of the French language.

Table 19.2: Overview of project approaches.

	Industry survey of fleet structure and dynamics	Analysis of fleet structure	Analysis of fleet dynamics	Simulation
Method	Survey	Multivariate analyses	Random utility models	ISIS-Fish model
Platform	NA	Statistical package such as R, SAS etc.	Statistical package such as R, SAS etc.	Java, with supporting routines in R
Data requirements	Database to select and contact fishers	Logbook with catch composition (ideally trip-based)	Fishing fleet structure Economic data List of potential drivers (e.g. determined by survey)	Fishing fleet structure Biological parameters Population estimates (initial population numbers, recruitment) Fleet and Fishing gear parameters (target factor etc)
Outcome	Snapshot of fleet structure and dynamics	Historical fleet structure	Quantify drivers for fishers' choices of fishing tactics, fishing locations…	Simultaneous simulation of fleet and fish population dynamics
Use for predictions & management	Identification of fishery components that may be affected by effort displacement	Identification of fishery components that may be affected by effort displacement	Prediction of effort displacement based on dynamic drivers of fleet dynamics	Simulation of scenarios with prediction for catch and fish populations
Complexity	Low-medium	Low-medium	Medium	High
Effort	Medium	Low-medium	Medium	High
Uncertainty of results	Medium	Low-medium	Medium	High
Adoption in new situations (time requirement)	Adapt survey questions (medium)	Adapt existing model code (low)	Identify appropriate variables, and adapt existing model code (medium)	- New model (high) - New scenarios for existing model (medium)
Comments	Large sample size required for quantitative analysis			