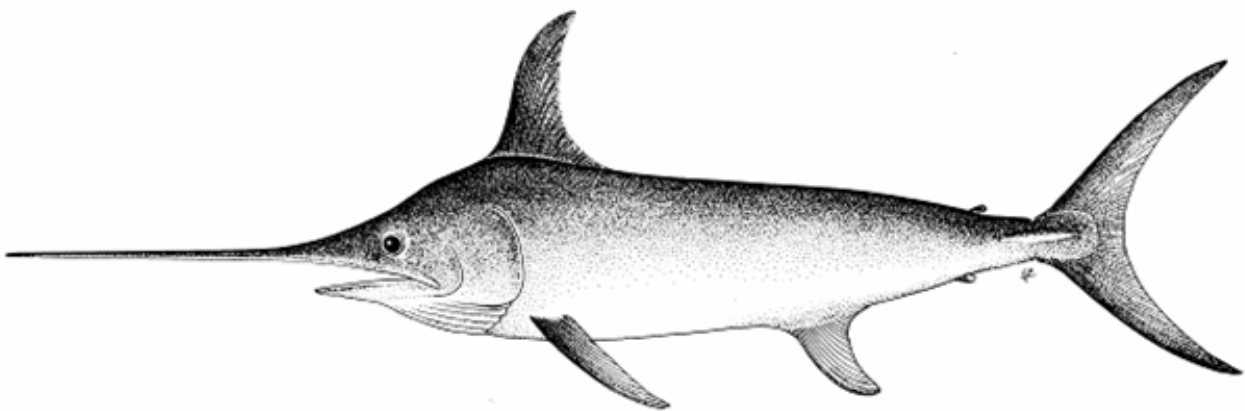




South-West Pacific Swordfish Assessment: 2005-6 Objectives and Preliminary Results



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Abstract

This paper is primarily intended as a brief overview of progress on SW Pacific swordfish (*Xiphias gladius*) stock assessment, which will hopefully stimulate discussion for further development. The South-West Pacific Swordfish fishery has undergone a number of substantial changes over the last decade. The swordfish catch (in numbers) over the last 10 years have been almost double the previous 25 year period, with large increases in Australian, New Zealand and Pacific Island Nation catches, and declines in the Japanese catch. Australian inshore catch rates have declined substantially, and the fishery has responded with a progressive expansion further offshore. Given the general perception that swordfish are a highly migratory, straddling stock, we expect that events of local concern probably need to be interpreted in the context of a broader regional model of population dynamics. In this paper, we outline the available fisheries and biological data that we will draw on for an integrative assessment, and present a number of hypotheses about swordfish spatial and temporal dynamics. Initial results are presented from fitting Multifan-CL to observations of swordfish catch in numbers, effort and catch-at-size, disaggregated into 20 fishing fleets in 7 regions, operating quarterly from 1952-2004. These preliminary results are presented to illustrate the methodology, and should not be interpreted in the context of management advice. The inferences are sensitive to arbitrary assumptions, and predicated on accepting some model predictions that are not entirely compatible with the data or our preconceived ideas about the stock dynamics. Some of the plausible hypotheses about migration dynamics that we would like to test cannot be accommodated within the existing Multifan-CL framework (notably site fidelity on foraging grounds and sex-specific population characteristics). Over the next 12 months, we plan to extend this analysis to include a broader range of alternative data interpretations and assumptions. This will be conducted in parallel with simulation testing, using a swordfish simulator to evaluate and compare estimator performance of different integrative assessment models, including different configurations of Multifan-CL and CASAL.

Introduction

This paper represents a report on progress in relation to a SW Pacific swordfish stock assessment project that will be completed over the next 12 months. Since about 1997, regional swordfish catches have increased dramatically, Australian inshore catch rates have declined substantially, and the Australian fleet has progressively moved further offshore (Campbell and Hobday 2003). These rapid and potentially worrying changes in the nature of the fishery have raised concerns for regional fisheries managers, and provide much of the impetus for an assessment at this time. Various swordfish assessments have been undertaken around the world (e.g. Kleiber and Yokawa 2002 in the north Pacific, Hinton and Maunder 2005 in the south-east Pacific) but have always proved highly uncertain (e.g. Sun et al. 2003). In the SW Pacific, serious problems include:

- Stock units are potentially difficult to define due to the continuous population structure and potentially highly migratory dynamics. There may be site fidelity on foraging grounds, effectively resulting in a sub-population structure even if there is a single spawning stock.
- SW Pacific swordfish are harvested in mixed-species fisheries, overlapping with tropical tuna species to the north, and temperate tunas to the south. Swordfish have been largely a by-catch species for much of their exploitation history, and the historical data collection procedures were often inferior to that for target species. Changes in targeting practices and fishery efficiency over time have not been well quantified, making it difficult to quantify the relationship between catch rates and relative abundance.
- There has been limited fisheries independent research on swordfish abundance; conventional and electronic tagging has been minimal and abundance surveys non-existent.
- Swordfish show substantial sexual di-morphism, and the spatial distribution of the sexes seems to vary considerably. There could also be sex differences in fishery vulnerability and natural mortality.

Despite these problems, there has also been an increase in SW Pacific swordfish research in recent years, including biological studies of size and growth (Young and Drake 2001), reproductive dynamics (Young and Drake 2002), and genetics (Reeb et al 2000). Campbell and Dowling (2003) initiated a Management Strategy Evaluation (MSE) to compare alternative management procedures in the face of uncertainty for the Australian East Coast fishery. The work outlined here is in many respects an extension of the MSE work. We expect to use the assessment results primarily in relation to the quantification of uncertainty about the status and dynamics of the stock. This will be used to assist in the development of robust management procedures, whether or not the formulation occurs within a formal MSE framework. This paper provides a brief overview of:

- history of the swordfish fishery and data

- spatial and fishery unit definitions, and the process by which they were derived
- alternative assumptions about population structure and migration dynamics
- assessment models to be used for parameter estimation (Multifan-CL, CASAL, plus the swordfish operating model used for simulation testing)
- an outline of a simulation project to evaluate estimator performance
- specifications and results from a preliminary application of Multifan-CL, including some problems encountered to date
- outline of the workplan over the next 12 months

We present this working paper in the hope of stimulating constructive feedback for the next phase of this project, scheduled to conclude around June 2006.

History of the SW Pacific swordfish fishery

We have defined the SW Pacific swordfish fishery as the region bounded by the equator and 50S and 140E to 175 W (Figure 1). The distant water Japanese longline fleet has recorded swordfish catches in the SW Pacific region since 1952 (Figure 2). The Japanese catches increased steadily till about 1970, then remained fairly constant until 1997, when the Japanese fleet was denied access to Australian and New Zealand territorial waters. The Japanese catch declined steadily since then, while Australian and New Zealand longline catches increased to more than make up the difference. Catch in numbers from about 1997-2002 have been roughly double the mean of the 1970-96 period. Total catches have dropped considerably in the last two years (partly in response to rising bait and fuel costs, and dropping swordfish prices).

Swordfish were generally considered a by-catch species until the late 1990s. Beginning in 1997, swordfish became a main target species in Australia, and seemingly New Zealand. The catch composition by area (Figure 3) indicates that the catch increases over the last decade are largely attributed to Areas 2,3 (Aus) and 5 (NZ). During this latter period, the technological efficiency in swordfish targeting increased dramatically (at least for the Australian fleet), but the fishery never lost its mixed species character, with many boats reportedly switching opportunistically between swordfish, yellowfin and bigeye. The Pacific Island Nation Catch has also increased in recent years, but remains a small portion of the total.

SW Pacific Swordfish Area and Fleet definitions

Figure 1 illustrates the 7 region spatial domain defined for the SW Pacific swordfish population and fleets that we have chosen for preliminary assessment trials. The 20 fisheries are defined in Table 1, based on the following considerations:

- Areas tend to represent units that are relatively homogeneous with respect to the fishing fleet (for a given nation).
- Area 2,3 and 4 represent the main fishing grounds for the Australian Mooloolaba fleet. They were partitioned to recognize the progressive offshore

expansion of the fleet over the last decade, and the serial depletion inshore inferred from catch rates.

- The Australian fleet was split into fisheries 7-11 (before 1997), and 17-20 (1997 onwards), to account for the swordfish targeting that began around 1997. This allows the separate treatment of catchability (and potentially selectivity) in relation to the targeting change. However, the actual shift in the fishery was not as abrupt as this temporal split suggests, and needs to be considered in more detail.
- The Area 7 catch (south New Zealand) is very small in comparison to the other areas, however, the catch size distribution in this area is distinct, with very large fish consistently reported in the southern fisheries that are primarily targeting Southern Bluefin Tuna. The actual split in North-South targeting practices seems to differ in the NZ domestic and charter fleets, such that the boundary between area 5 and 6 was defined as 40S for the NZ charter fleet, and 42S for the NZ domestic fleet.
- The spatial units have boundaries that are not exactly as illustrated. In some cases, small amounts of catch and effort have been moved into adjacent areas with similar fleet or catch characteristics to keep the number of fisheries manageable.

Data

This section is intended only as a superficial overview of the available data. Some data are illustrated in relation to the preliminary results from the Multifan-CL fitting in Figures 9-15.

Catch in Numbers

At this time, we have obtained catch data from Australia, Japan and New Zealand from the source nations, and Korean, Taiwanese and Pacific Island Nations from the Secretariat of the Pacific Community. Data from Australia and New Zealand extend into 2004, while the others end in 2003. In attempting to take advantage of the most recent Australian data up to the end of 2004, we have assumed that the catch of the other fleets is equal to the catch from exactly one year earlier. We do not have any EU data, but expect this to be a minor and temporary oversight. Similarly recreational data has not been considered. Discarding mortality has not been considered, although the catch distributions of some fleets suggest that discarding of small fish probably has occurred.

Fishing Effort and Catch Rates

Catch and effort series provide the most informative source of data for most pelagic assessments, under the usual assumption that CPUE is proportional to abundance (or some other quantifiable relationship exists between effort, fishing mortality and abundance) for at least some of the fleets. We expect to use the effort series from Australia, Japan and New Zealand in this manner. However, interpretation of catch

rates in mixed stock fisheries is difficult (Unwin et al. 2005) (see section on CPUE interpretation below).

Catch-at-size

The Australian longline fleet has good weight sampling data from processors since 1997. However, only a subset of this data can be directly allocated to specific fishery regions. Japanese size frequency data was collected intermittently historically. From around 1980 to 1997, observers in the Australian EEZ, have provided considerable additional size data for Japanese boats, and the two data series have been merged into a single time series in the regions of overlap. Japanese size data is aggregated into spatial units that do not align with our regional structure, and some mis-allocation will have occurred as a result. The New Zealand observer program provides good size frequency data for Japanese vessels chartered in NZ waters. There is additional size frequency data from the NZ domestic fishery, but the coverage is much lower. For our initial MFCL analysis, we used only weight data for Australia, and length data for Japan. The analysis was nominally based on New Zealand length data, but a number of independent weight samples were converted to lengths to boost the sample size. Various conversion factors had to be applied to get standard mass and length units across fisheries. Size data was not directly used for other DWF and PIN nations.

Tags

There have been relatively few swordfish tagged in this region, with recapture rates of around 1-2 %. To date, the results from pop-up satellite tags, and recovery of conventional tags from combined scientific and recreational programs number less than 10. None of them provide evidence of large-scale movements (more than a couple hundred km), although direct evidence of large movements have been seen in other populations (Sedberry and Loefer 2001). Tags will not play a role in the assessment, but we may test the effectiveness of tagging data in the simulation studies, to evaluate the potential usefulness in an assessment.

Conceptual Models of SW Pacific Swordfish Population and Fleet Dynamics

There is no direct evidence to distinguish among a number of alternative migration dynamics hypotheses that appear to be at least qualitatively consistent with the available data. We outline a number of alternatives below, with relevant arguments.

Population Structure:

1. There is a single stock spawning annually off NE Australia.
 - This is the region where the majority of mature fish have been observed (however, these studies have largely been restricted to Australian observer data to date, with a disproportionate sampling effort in this region)
 - From observer records of gonad condition, there is no indication of spawning in NZ waters

2. Significant spawning may also occur in the tropics considerably eastward of this region, as part of one continuous, or multiple distinct stocks.
 - Swordfish larvae have been reported in sporadic surveys directly north of New Zealand (Far Seas Fishery, 1985)
 - There has been little biological work done in this eastward region to confirm an absence of spawning
 - Genetic studies indicate that swordfish populations are not homogeneous across the Pacific (Reeb et al 2000), but differences are relatively small across the South-Pacific and fine resolution studies have not been done within the SW Pacific.

Foraging Populations:

1. The stock is a single homogeneous population with all individuals of the same age having equal probabilities of undertaking the same random or seasonally directed migrations from the same point in space and time.
 - There is no evidence of sub-population structure within this region based on genetic studies to date
2. The stock is divided into sub-populations through genetics or chance plus prior experience, such that there is a high degree of site fidelity on foraging grounds.
 - There appears to be considerable sustained depletion in the Australian in-shore fishing grounds, while catch rates in other areas do not show this depletion. This suggests that the swordfish population does not rapidly re-distribute over large distances, but on its own, this is not necessarily inconsistent with a slowly diffusing homogeneous population.
 - Limited tag recoveries do not show evidence of large migration of individuals (but irrespective of which view is more correct, presumably large migrations must occur in relation to spawning and juvenile dispersal).

Sex variability:

Biological studies indicate substantial differences between males and females in relation to size-at-age (females generally observed to be larger for a given age) (Young and Drake 2001) and distribution. Females are more likely to be caught further south, in the colder waters off the South Island of New Zealand. It follows that there are also differences in migration patterns, and we should not be surprised if there are differences in natural mortality and vulnerability to fishing gear, but there is little direct evidence to quantify this.

Fishery Catchability, Selectivity and CPUE interpretation:

The domain that we have defined for the model covers several regions with considerable bio-physical variability, and it seems unlikely that fishery catchability (and perhaps selectivity to a lesser extent) would be very homogeneous across

regions, even for the fleets that are ostensibly targeting swordfish. Oceanographic and pelagic ecosystem characteristics differ considerably from the warm tropical north to the cool temperate south. Part of the intent of working in a spatially disaggregated context is to make the regions as homogeneous as possible. However, when models are highly over-parameterized, there is a temptation (or necessity) to assume that a number of fishery characteristics are shared among regions. The interpretation of catch rates is always complicated by the confounding of availability (regional abundance) and catchability (e.g. efficiency of the fleet related to set depth or the prevalence of light sticks). Both of these factors probably vary seasonally, and spatially, particularly in temperate waters. We will attempt to standardize the effort series of Australia, Japan and New Zealand to account for whatever factors for which there are data, and which are beyond the scope of the assessment model dynamics.

For the Japanese longline fishery, we have attempted to account for spatial effects within regions, and set depth variability as inferred from the hooks per basket proxy using GLM-based standardization (Campbell 2005). In the first instance, we also included a year-quarter interaction term. We debated the inclusion of other factors in the effort standardization process as well, but it is not clear that we want to remove all these signals from reaching the assessment model. Ideally, we would like to remove the noise associated with catchability variation, but we want signals related to age structure and abundance variability to be passed along to the assessment model. The Japanese standardization was only conducted on the more detailed data available for 1971 onward, and it is assumed that Japanese effort characteristics prior to 1971 were similar to the 1971-5 period.

For the preliminary fitting, we have included standardized catch rates from Australia from only 1997 onwards (corresponding to the period of swordfish as the dominant target species). GLM-based standardization included several gear effects and targeting as recorded in logbooks (Campbell 2005). This standardization seemed to change the CPUE interpretation for some fleets in a manner that is consistent with our understanding of the fishery development. However, differences in mean catch rates among regions were sensitive to the actual factors selected for the standard, and these shifting means have potentially important consequences for constant catchability assumptions invoked in the assessment model. This will be examined in more detail. In the first instance, we have assumed that the Australian serial depletion is a real signal, and given the Australian fleets, from 1997 onward, the highest weighting in the model.

We did not consider the NZ domestic effort series to be informative (i.e. we attempted to estimate changes in catchability for fishery 12, as for the PIN nations and Australian fleets prior to 1997). We expect this to change in relation to an analysis of NZ catch rates (e.g. Unwin et al 2005).

We expect that multiple approaches to catch rate standardization will form a key element of the final assessment.

Assessment Model Selection

It is not clear what level of model abstraction will lead to the best management advice for swordfish. In the first instance, we are using pre-existing software with suitable

flexibility to accommodate most of the structural features that we expect to be important. Final choice of software and structural assumptions will be made in relation to examination of diagnostics and simulation testing as described below. A range of plausible models will probably be represented in our final assessment synthesis, in an attempt to express the considerable uncertainty expected.

Multifan-CL (e.g. Fournier et al 1998, Kleiber et al 2003) was originally developed primarily for the assessment of tropical tuna fisheries and can handle much of the structural detail and types of data that are available for swordfish assessment. The preliminary results that we present below were generated from the April 2005 version. The structural flexibility and efficient numerical optimization make it a powerful tool that we expect will play a central role in the final results. As the software currently stands, we recognize the following limitations, but cannot comment on how important they will ultimately prove to be:

- All individuals in the same region of the same age are equally likely to migrate in the same direction. This precludes the inclusion of multiple sub-populations as defined by distinct spawning populations or site fidelity on foraging grounds.
- There is no sex dis-aggregation (but we understand that sex dis-aggregation will be implemented in a future release within the timeframe of this project)
- The stock and recruitment relationship assumes the aggregate mature biomass from all regions contributes to spawning (mature swordfish have only been observed in a small portion of the tropical SW Pacific)

We also plan to use the CASAL assessment framework (e.g. Bull et al 2003), which uses a similar automatic differentiation procedure for parameter estimation as Multifan-CL, and has similar structural flexibility. Unlike Multifan-CL, CASAL can currently partition populations on the basis of sex and stock. But this software does not have the extensive history of applications to pelagic fisheries assessment, and we are curious how it will compare with Multifan-CL in the assessment and simulations.

We also expect to fit simple production models using spatially-aggregated population assumptions with standardized catch rate indices spanning the whole SW Pacific. The role of these models will be further investigated in relation to the simulation studies. We do not expect that these simple models will be adequate for addressing issues related to localized depletion and renewal, or the quantification of uncertainty. However, depending on how simulation and application results compare with the more complicated models, these models may play a valuable role in communicating results to stakeholders.

Simulation testing of Assessment models

It seems to be an unfortunate and inescapable fact that stock assessment models often produce poor inferences despite a basis in sophisticated statistical theory and good agreement between model predictions and observations. Part of this relates to the inevitable arbitrary assumptions that are required to make a tractable estimator (e.g. Schnute and Richards 2001). Often (usually, in our experience), inferences are highly sensitive to these assumptions and the data are not sufficiently informative to

distinguish among alternative assumptions. As a substantial part of the swordfish assessment, we will be evaluating and comparing assessment model performance on the basis of simulated data (e.g. Kolody et al. 2004, Sibert 2004). A swordfish simulator will be used to generate simulated data in accordance with the basic assumptions of how the fishery dynamics work in the assessment models. These simulated data are then analyzed using the assessment models, and the known simulation dynamics are compared with the estimator inferences (e.g. on the basis of common reference points).

The Virtual Stock Model Simulator (VSM) software (Kolody et al 2004) is being parameterized to represent plausible SW Pacific swordfish dynamics. The model was not originally designed with a built-in capacity for statistical inference, but it is conditioned to real observations using several somewhat independent and ad hoc processes. Notably, a genetic algorithm is being used to estimate seasonal migration dynamics, assuming in the first instance that Japanese longline CPUE is proportional to abundance (equal catchability among regions). We hope to generate a few simulation scenarios with alternative assumptions potentially including:

- stock structure (homogeneous vs: foraging grounds site fidelity)
- contrast in overall depletion
- sex-specific size, growth, migration, mortality and selectivity
- natural mortality
- the relationship between localized CPUE and abundance
- stock and recruitment relationship

We hope that this will provide important feedback on the interpretation of our assessment results in relation to: 1) if our assessment model assumptions are good, how well do the estimators perform? (e.g. can we estimate the current level of depletion?) 2) what are the implications of getting different assumptions wrong? (e.g. do we really gain anything from adding sex dis-aggregation to the assessment?) And 3) how would the collection of additional data influence assessment performance in the future? (e.g. how many tags would we have to release to be confident in our assessment?). Simulation testing is very useful for demonstrating the potential limitations of an assessment model in a well-defined situation, but it is worth emphasizing that they cannot prove that an assessment model will perform well in a real application. Like assessment models, the simulator operating models are arbitrary and potentially poor representations of the real world.

Preliminary Application of Multifan-CL to SW Pacific Swordfish

Reference Case Assumptions

A reference case assessment model was defined for illustrative purposes. We do not necessarily consider this case to be any better than a number of other scenarios that we have explored to date, and do not consider the analysis to be sufficiently comprehensive to be interpreted as management advice at this time. But it is sufficient to qualitatively illustrate a number of recurring inferences and problems that

have been encountered. The reference case was based on the following assumptions (and terminology from Kleiber et al 2003):

- The model is dis-aggregated into 7 Regions (Figure 1) and 20 fishing fleets (Table 1)
- Population dynamics are iterated on a quarterly timestep 1952-2004, in the following sequence:
 1. Initialize population
 2. Age incrementation
 3. Growth
 4. Recruitment
 5. Migration
 6. Natural and fishing Mortality (Baranov equations)
 7. (return to 2)
- Single stock
- Sex-aggregated
- Initial Population Structure: assumed to be unexploited in 1952, with independent age-specific deviations from mean levels estimated
- Twenty annual age-classes with recruitment defined at age-class 1 (0-1 year old) and a plus group accumulator at 20+.
- Size: (see Figure 4)
 - Multifan-CL assumes normally distributed length-at-age. Mean length-at-age is fixed at the mean of the male and female growth curves from (Young and Drake 2004); variances on length-at-age are estimated with very weak priors.
 - All masses refer to trunked mass, related to lengths from East Australia fisheries observations
- Maturity: 50% maturity at age-class 11 (Figure 5), as a simple approximation to Young and Drake (2002)
- Natural mortality: assumed to decrease exponentially with age, with an additional spawning-related component proportional to maturity (Figure 6)
- Migration: occurs at the beginning of each quarter, between all adjacent areas indicated in Figure 11. Age-specific migration co-efficients are estimated with a linear dependency. Population is homogenous in the sense that all individuals of age a , in quarter q and region r , have equal probability of migrating in a given direction. Migration parameters are specified with a weak prior on 0 (no migration). Separate migration parameters are estimated for each quarter. Movements are calculated using the implicit method, which provides a stable movement pattern (e.g. avoids large oscillations of

populations between adjacent regions when movement in both directions is high, see Kleiber et al 2003).

- Selectivity: an age-based, 5 parameter cubic spline function is used for each fishery, with a length-based constraint limiting the amount of variability among similar-sized age classes.
 - Japanese fisheries 1-6 plus 13 (Japan A7 plus NZ charter) and 14-16 (PIN fisheries, size data unavailable) are all assumed to have the same time-invariant selectivity
 - Australian fisheries 7-11 and 17-20 (no size data for the latter) are all assumed to have the same time-invariant selectivity
 - NZ fishery 12 selectivity is estimated on its own

- Catchability and effort deviations:
 - Japanese fisheries 1-6 plus 13 (NZ charter) are all assumed to have the same constant catchability
 - Australian fisheries 7-11 and 17-20 are all assumed to have the same constant catchability
 - Others are all independently estimated, with temporal variability (changes occurring every 2 years, CV ~ 0.1)
 - Effort deviation weightings = 10 (CV~0.22) for all fleets except Australian 7-11 which have weighting = 100 (CV~0.07 with square root transformation downweighting observations with lower effort)

- Recruitment Dynamics
 - Recruitment occurs annually in quarter 1, with 90% allocated to A1-3
 - Annual recruitment deviations are fairly tightly constrained (CV ~ 0.1)
 - Beverton-Holt Stock Recruitment curve (weak prior on moderate steepness of 0.6)
 - Total SSB is included in calculation, irrespective of what area the adults are in

- Data-based objective function terms:
 - Total catch fit (lognormal observation errors assumed CV ~ 0.07)
 - Catch-at-length (Multifan robustified likelihood assumed, effective sample size = number samples/10)
 - Catch mass frequencies (Multifan robustified distribution assumed, effective sample size = number samples/10)
 - effort deviations (lognormal errors with variance defined in catchability above)

Comments on Parameter Estimation

Using the batch processing script in Appendix 1, Multifan-CL completes a successful minimization in ~ 2 h using a 3 GHz Pentium PC. Relaxing constraints related to constant catchability/selectivity across fisheries increases the probability of failed convergence or a crash of the mfclopt executable, but many of these problems can be overcome with increased analyst intervention.

Estimated Dynamics

The following comments are considered only in relation to the MPD parameter estimates.

Figure 7 illustrates the estimated annual historical biomass for all regions. The total biomass appears to be fairly uniformly distributed among regions, with the greatest total biomass in (the spatially large but relatively low density) Area 1. The fairly large biomass in areas 6 and 7 (all ages, and especially adults in area 7) seems doubtful, given the low catches in these areas. The total biomass appears to have declined for the first ~10 years, increased for ~30, and then declined for ~10. The comparison between fished and unfished biomass (i.e. the biomass predicted to have occurred without any harvesting) (Figure 8) suggests that much of the biomass fluctuation can be attributed to temporal trends in recruitment variation. But fishing mortality does play a role in the biomass decline, particularly in the most recent years (Figure 9). The reference point estimates suggest that the overall exploitation rate has been approaching $F(MSY)$ in recent years, but biomass has remained above $B(MSY)$ throughout (not shown). The estimated stock recruitment relationship suggests that there is a high degree of compensation, but visual inspection of the scattered points suggests that this estimate is poorly determined (not shown).

The highest fishing mortality rates are estimated in Areas 2, 5 and 7 (Figure 10). We have serious doubts about the estimates for area 5 in particular, where some ages classes exceed an instantaneous fishing mortality rate of 3 in some quarters. The fact that the biomass estimates for these highly exploited times and regions does not show a very high depletion indicates that the highly exploited age classes are a small portion of the total and/or migratory processes lead to rapid renewal.

Figure 11 illustrates the seasonal migration patterns for fish of age 5 and 15. The largest migrations (in proportions of local fish) tend to be into and out of the southern regions (5-7). This is consistent with the idea that the temperate sub-populations undergo seasonal migrations. Figure 12 illustrates how a particular age-class becomes re-distributed over time. Recruits starting from any area redistribute themselves fairly similarly after about 5 years. Area 7 seems to be very unattractive for fish younger than age 10, and becomes a sink for fish older than about 15.

Quality of agreement between model predictions, prior expectations and observations

Initial trials in formulating the swordfish model have revealed a number of recurring problems.

CPUE Inconsistencies

It is unlikely that the model can adequately fit all the different CPUE series as relative abundance indices. This is not surprising given the 50 year history of the fishery, with poorly quantified mixed species targeting practices, and a poor record of technological changes in gear efficiency. In the reference case, we made the rather strong assumption that all Australian fleets had identical and constant catchability, as did the Japanese fleets for Areas 1-7 (plus NZ charter Area 7). It seems unlikely that

the tropical and temperate regions should have the same catchability, and this constraint will need to be revisited.

The Japanese CPUE series were often poorly fit for extensive time periods (Figure 13). We expect that this reflects gradual changes in swordfish catchability that our standardization cannot address. We are particularly doubtful of the Japanese CPUE prior to 1970, as this was a period of fishery expansion, with poor data, and was not included directly in the standardization process applied from 1971-2003. A different treatment of the pre-1971 period might have a large effect on the biomass trend estimated in the early part of the fishery (i.e. the decline estimated to have occurred even if the effect of fishing was removed).

We interpret the recent Australian catch rate drops in Areas 2 and 3 (fisheries 8 and 9) as a strong depletion signal that we are interested in reproducing, but this was only achieved in the model predictions (Figure 13) when the effort deviations on the Australian fisheries were weighted higher than the other fisheries. Even with the higher weighting, the Area 2 depletion was not estimated to be as extreme as observed, and a side effect was a reluctance of the model to fit the total catch removal series very well for these fisheries (Figure 15) (this was not an issue for other fisheries).

The New Zealand domestic fleet in Area 5 (fishery 12) is estimated to have increasing efficiency for most of its history (Figure 14). While qualitatively plausible given the reported increase in the use of light sticks, we cannot comment on the magnitude of the change at this time.

Figure 13 suggests that the model can explain much of the seasonal CPUE periodicity with estimated migration dynamics. This is particularly evident in fisheries 9 and 11, while fisheries 12 and 20 seem to have the right phase, but the amplitude is not large enough. However, as discussed below, the movements are not entirely consistent with our preconceived notions of annual spawning migrations.

In the assessment, regional CPUE is essentially a mean density estimator which is converted to abundance, assuming that the density applies to the whole region. However, within each region there is a diversity of swordfish habitat and a patchy fish distribution. In many cases, sporadic fishing in some regions probably represents an unusual fish distribution, rather than an unusual effort distribution. We need to consider carefully how to extrapolate into regions that are not fished, and how to assign relative areas of homogeneous density, when they probably have little relation to the fishery areas as defined on a map.

Catch Size Composition

There is a considerable amount of catch-at-size data for some portions of the swordfish fishery, but we have generally not found this information as informative as one might hope. The data do show some “modal progression” signals in consecutive size frequency distributions (e.g. Figure 16), but these are not as strong as we often see in tuna fisheries. Catch size frequency composition is a result of the combined size-at-age, local abundance, natural mortality and fishery selectivity across multiple age classes. In the reference case, we assumed that we knew size-at-age and natural

mortality, and that selectivity was constant over time and identical for similar fisheries. Size-at-age is in fact the only thing that we are confident about, and we know that our approximation is poor in so far as we have ignored the considerable sexual di-morphism. But the model still has enough flexibility to fit the size composition data fairly well (at least relative to most of the CPUE series). In some cases, the fit to the size composition is not great, and we attribute this to several factors, including: 1) small observation sample sizes and/or non-random sampling might not adequately represent the catch, 3) selectivity in the fishery might change over time (i.e. with targeting changes), 4) the model might not have enough flexibility in the migration dynamics to adequately partition the age classes spatially (i.e. linear changes in migration dynamics with age might be a poor approximation of spawning migration, or interannual variability is more important than the seasonal effects that we estimate, or site fidelity dominates), 5) the sexual dimorphism (and spatial partitioning by sex) might not be adequately described with a sex-aggregated model, or 6) recruitment variability was highly constrained (to prevent erratic model behavior in the early time series when there are no size data).

Figure 17 and Figure 18 show the time-aggregated length and mass fit details. In most cases, we can see that the observed length distributions tend to be broader than the predictions. This could indicate several things. The model predictions might not be capturing the interannual variability in migration or selectivity that inflates the variance on the observations. Or the model might be failing to capture the platykurtic distributional characteristics that could arise as a result of sexual di-morphism. Further evidence for this idea might be evident in area 7; Fishery 13 (Japan and New Zealand Area 7) has a unique and exceptionally large catch size distribution, and observers indicate considerably more females than males in the catch. The predicted catch at length is smaller than the observed size frequency in a manner that is at least qualitatively consistent with a compromise growth curve that fails to describe a predominantly female population.

In a spatially aggregated model, we generally expect the temporally variable size frequency data to provide information about recruitment and fishing mortality effects on the age structure, but this spatially dis-aggregated context, we also attempt to extract information about migration. We attempt to visually summarize these signals by presenting the quarterly mean sizes predicted and observed for the various fisheries (Figure 19). In these seasonal plots we expect to see the combined effects of recruitment (causing a shift to smaller incoming individuals), growth (all individuals get larger over time) and migration. Migration could cause a seasonal shift toward either smaller individuals (immigrating young fish and/or emigrating old fish) or larger individuals (immigrating old fish and/or emigrating young fish). These summary plots provide a quick way of looking for agreement in predicted and observed size classes by quarter, but potentially mask signals that might be evident in detailed size frequency plots (e.g. Figure 16). From these plots we note that the observed mean sizes are much more variable than the predicted, which presumably indicates sampling error, plus greater interannual variability in processes related to migration and selectivity in the real world. There are obvious discrepancies in the predicted and observed seasonal mean sizes in some cases (fisheries 3, 7 and 10), but overall they do not seem too bad.

Migration Parameterization

The reference case model reproduces many of the signals in the observations that we were hoping to explain with seasonal migration, but the inferences are not entirely consistent with our pre-conceived expectations. Fish are estimated to rapidly mix and diffuse across all regions, while we tend to assume (from tags if nothing else) that they have a degree of site fidelity on foraging grounds. The estimated migration dynamics of the age 15+ fish are very counter-intuitive. They show a tendency to get stuck in the area 7 retirement home, with less than a third participating in the annual spawning migration once they arrive. It is conceivable that swordfish do not spawn every year, but alternatively this could be a (recurring) problem with the migration parameterization (an artifact perhaps linked to selectivity and mortality assumptions as well).

There may be other problems in relation to migration as well. While seemingly very flexible, quarterly movements through multiple adjacent regions is required for spawning migrations from distant areas. This might not provide an adequate representation of migration if it is actually a very fast, short duration event.

We have some hope that the use of informative priors will be useful for exploring alternative migration dynamics scenarios in Multifan-CL, but experience with operating model parameterization has suggested that the manual imposition of sensible scenarios in a complicated spatial model can be a tedious and counter-intuitive process.

Sensitivity Analyses

It appears that Multifan-CL will probably be able to produce a reasonable fit to the observations that we consider to be most informative. The reference case model represents typical results over a range of rather arbitrary model specifications. We were pleasantly surprised that moderate tinkering with a number of model features (e.g. alternative natural mortality schedules, relative weighting of catch-at-size and CPUE data) did not cause dramatic changes in some of the aggregate reference point estimates, but other assumptions (e.g. the poorly determined stock recruitment curve) suggested considerably different dynamics (Figure 20). However, even though the aggregate dynamics initially appear fairly robust to a number of assumptions, the sub-region dynamics are much more sensitive. For example, alternative assumptions about the small but distinct Area 7 can have a large effect on the estimated migration and population distribution. Failure to adequately explore alternative model structures could result in a serious misrepresentation of uncertainty, and the provision of poor advice in relation to depletion and renewal processes of specific sub-regions of the fishery.

SW Pacific Swordfish 2005-6 Workplan

- Implement alternative catch rate interpretations, including standardized effort for New Zealand
- Implement an assessment with CASAL, or some other framework that can accommodate spawning migrations plus foraging grounds site fidelity

- Condition the VSM operating model and generate simulated data sets corresponding to alternative population dynamics assumptions
- Evaluate and compare assessment models on the basis of simulated data
- Explore the structural and statistical uncertainty of the assessment in an overall synthesis across models
- Provide management advice on the basis of the overall synthesis, including an updating of MSE recommendations

Acknowledgements

Thanks to David Fournier, John Hampton and Pierre Kleiber for making Multifan-CL publicly available (plus documentation and supporting visualization software which was used for some these plots), and for providing the additional critical insight required to get things running. Thanks to the countless people that have collected the fisheries data over the years, and the individuals and institutes that have collated and provided this data.

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Table 1. SW Pacific swordfish fishery definitions. Areas in brackets indicate a small amount of catch and effort moved across a boundary.

Fishery Number	Area Number	Fishing Nation(s)
1	1	Japan (plus other DWF)
2	2	Japan (plus other DWF)
3	3	Japan (plus other DWF)
4	4	Japan (plus other DWF)
5	5	Japan (plus other DWF)
6	6	Japan (plus other DWF)
7	1	Australia (1997+)
8	2	Australia (1997+)
9	3	Australia (1997+)
10	4 (5)	Australia (1997+) plus
11	6	Australia (1997+)
12	5 (6)	NZ Domestic
13	7 (6)	NZ charter and Japan
14	1	Pacific Island Nations
15	3	Pacific Island Nations
16	4 (5)	Pacific Island Nations
17	1	Australia (pre-1997)
18	2	Australia (pre-1997)
19	3	Australia (pre-1997)
20	6	Australia (pre-1997)

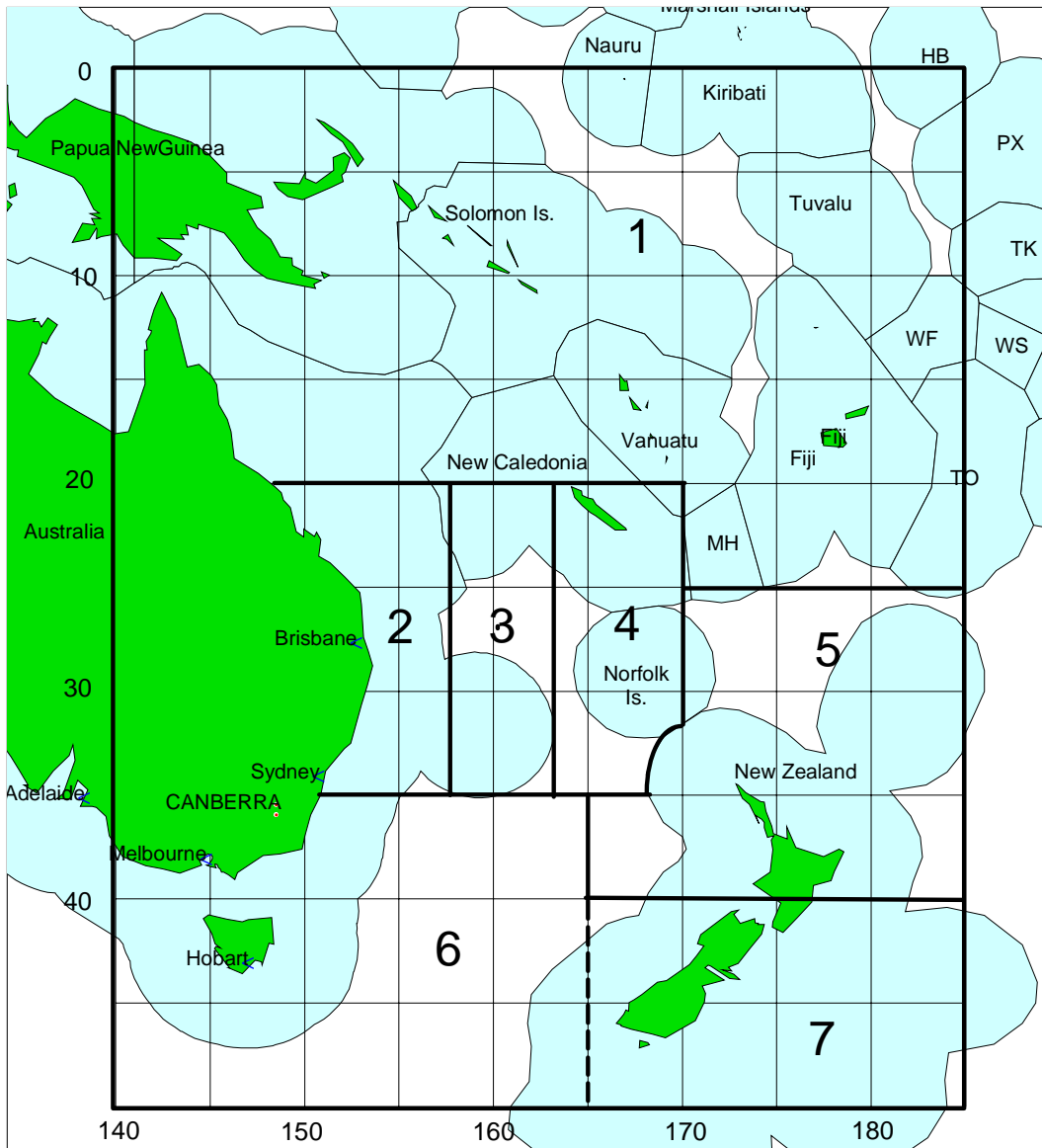


Figure 1. SW Pacific swordfish model spatial domain indicating approximate regional boundaries

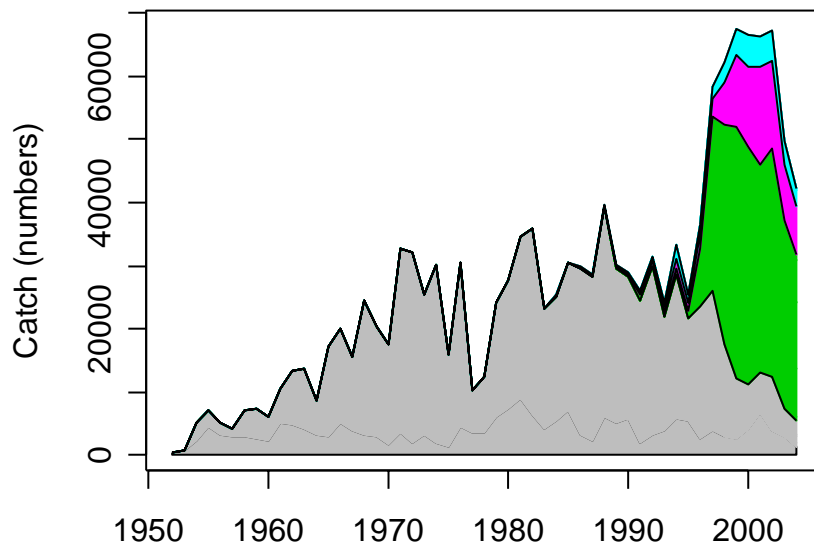


Figure 2. Catch history of SW Pacific swordfish (missing 2004 values assumed the same as 2003). Colours roughly correspond to nation groupings, ascending from bottom: Japan (plus NZ charter area 7 and other DWF), Australia, New Zealand (domestic), Pacific Island Nations.

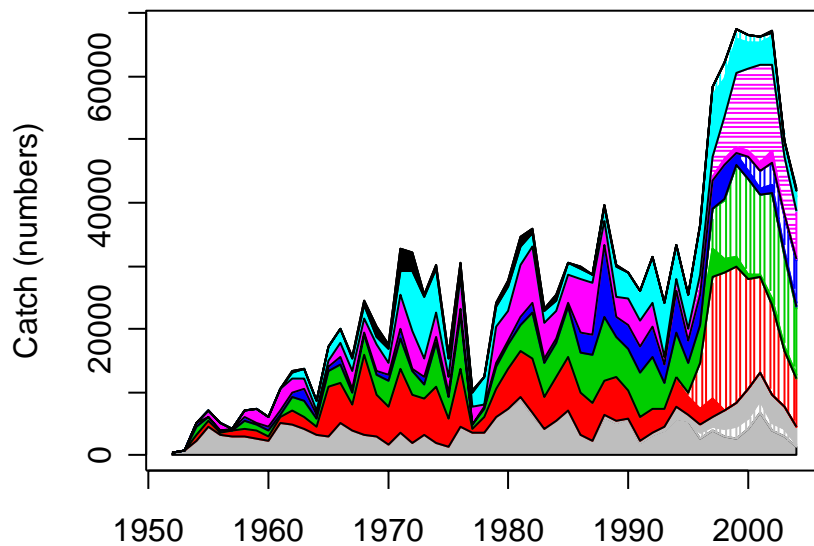


Figure 3. Catch history of SW Pacific swordfish (missing 2004 values assumed the same as 2003). Different colours correspond to the 7 regions in Figure 1, ascending from Area 1 at the bottom to Area 7 (thin black band) at the top. Vertical lines indicate Australian fisheries, horizontal indicates New Zealand domestic, solid colours everything else (predominantly Japan).

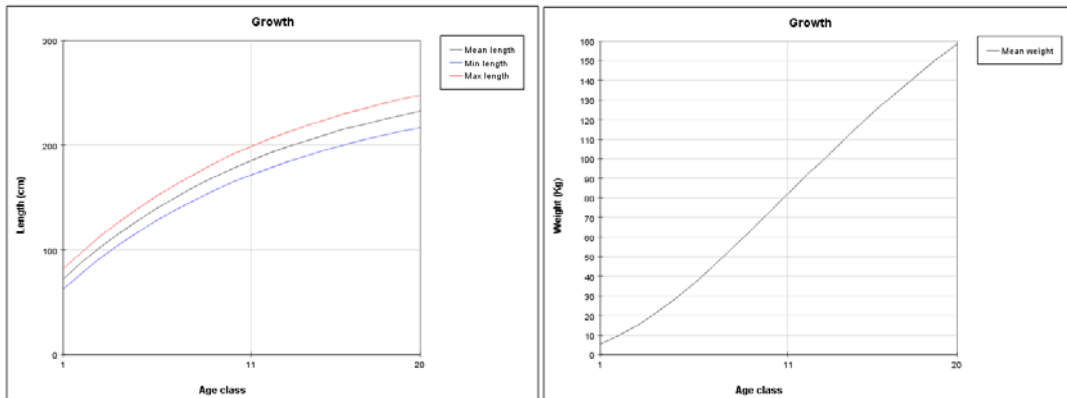


Figure 4. Swordfish size-at-age (orbital fork length and trunked mass) assumed in the Multifan-CL reference case analysis.

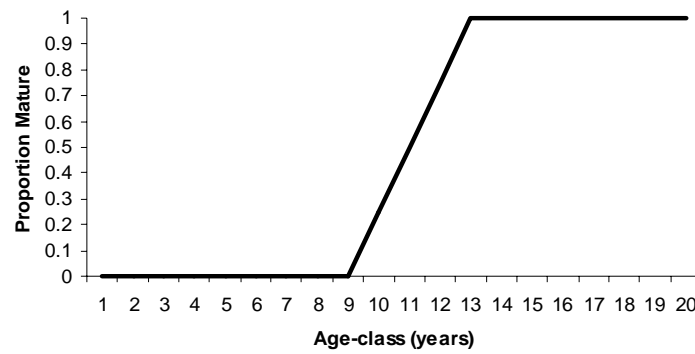


Figure 5. Assumed swordfish maturity.

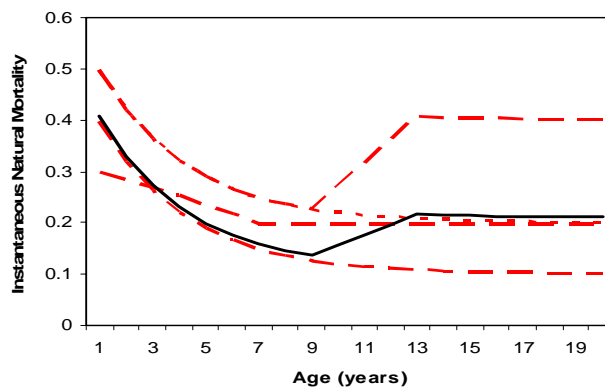
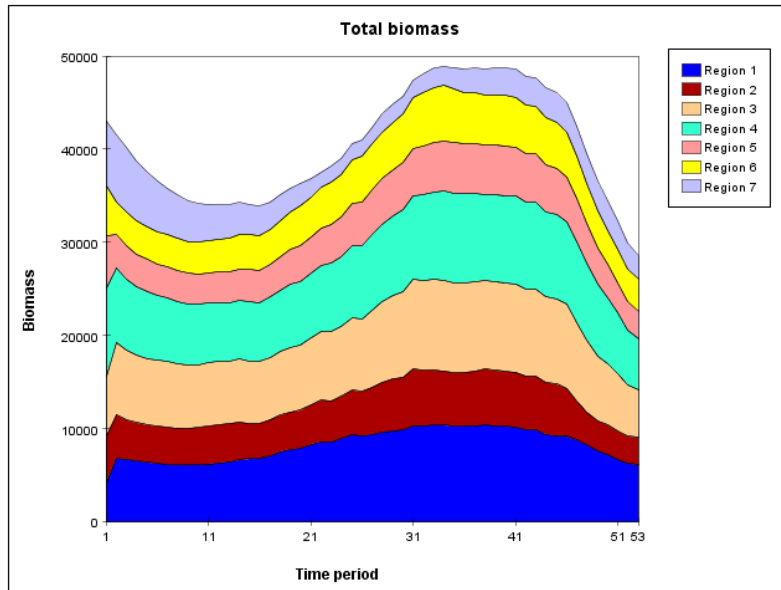


Figure 6. Assumed swordfish natural mortality (solid line), with some alternatives considered (broken lines).

A



B

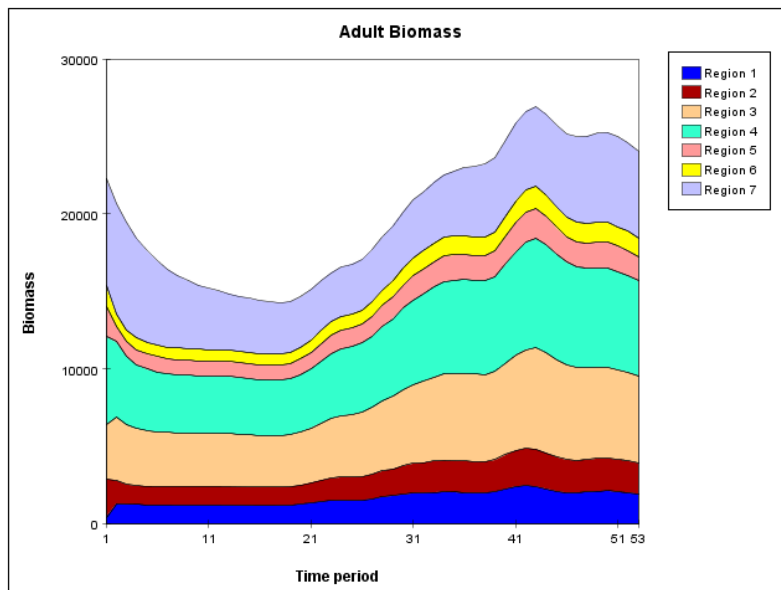
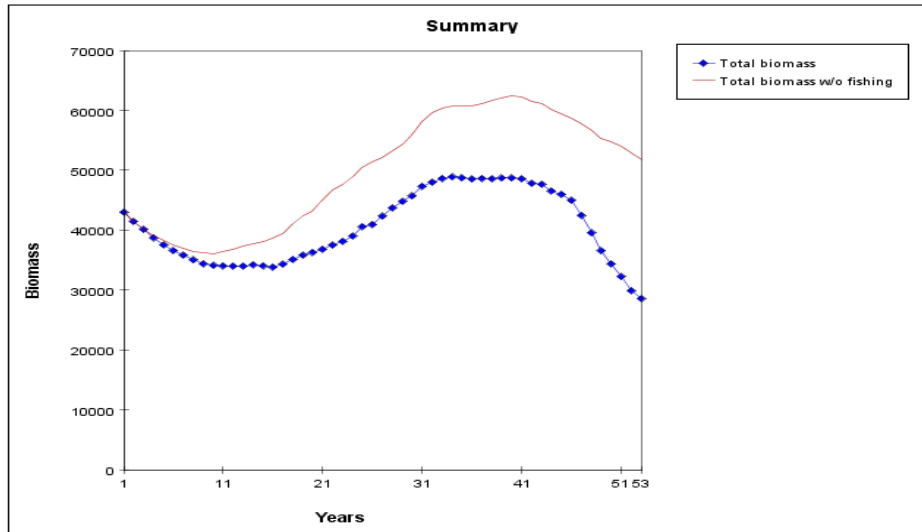


Figure 7. Reference case estimated swordfish Biomass by region (seasonal variability removed). Year 1 = 1952, Year 53 = 2004.

A



B

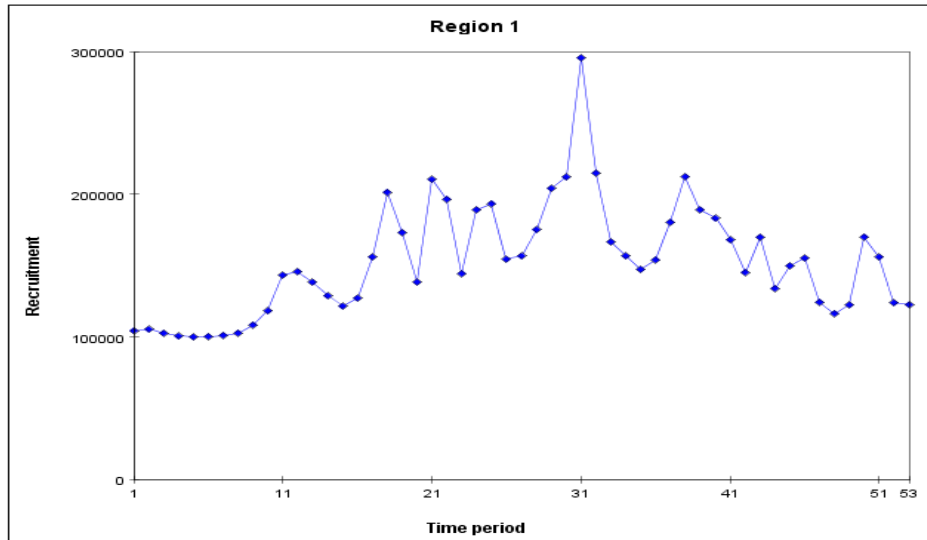


Figure 8. A) SW Pacific swordfish biomass estimated for Reference case, relative to that which would have occurred in the absence of fishing. B) Total recruitment time series. Year 1 = 1952, Year 53 = 2004.

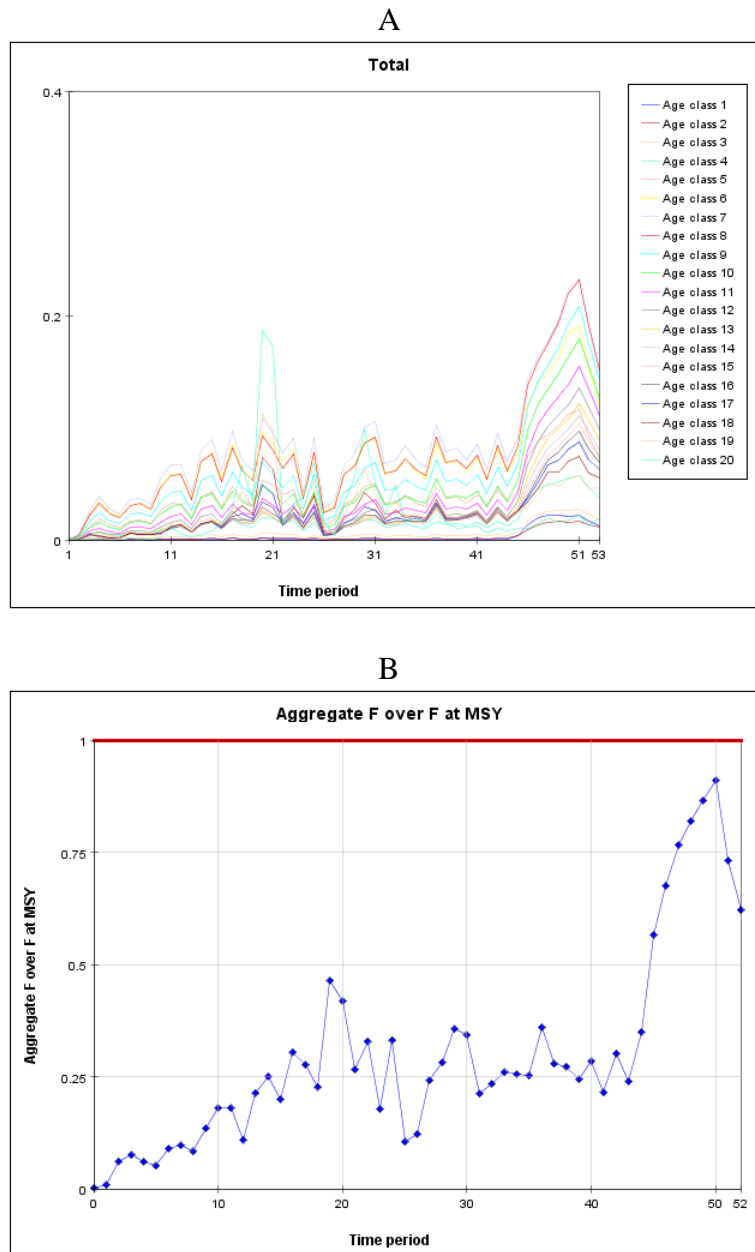


Figure 9. SW Pacific swordfish fishing mortality aggregate across regions, estimated for the reference case. A) Age-specific, B) Relative to $F(MSY)$. Year 1 = 1952, Year 53 = 2004.

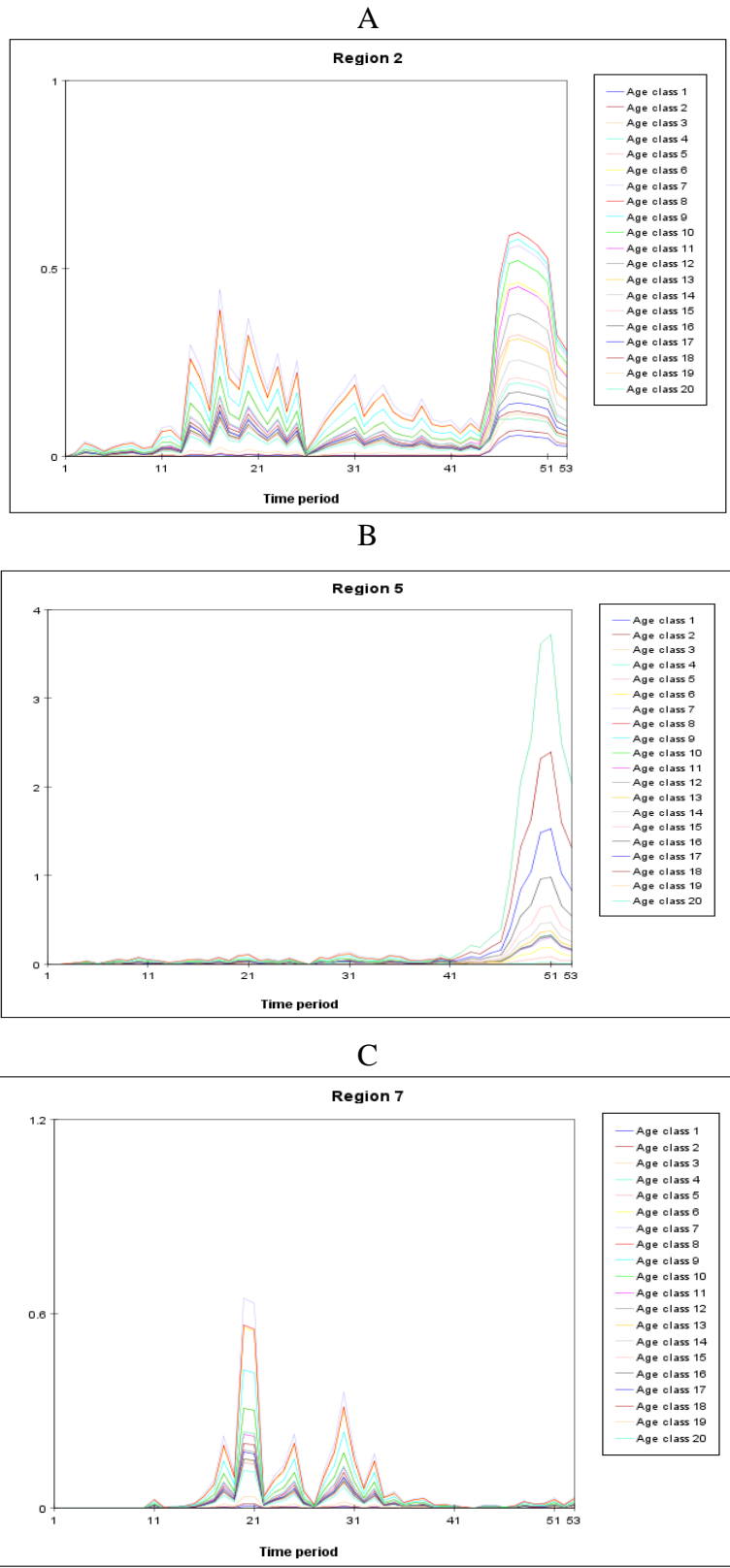


Figure 10. SW Pacific swordfish fishing mortality by age, for the three most highly exploited regions estimated for the reference case. A) Region 2, B) Region 5, C) Region 7. Year 1 = 1952, Year 53 = 2004.

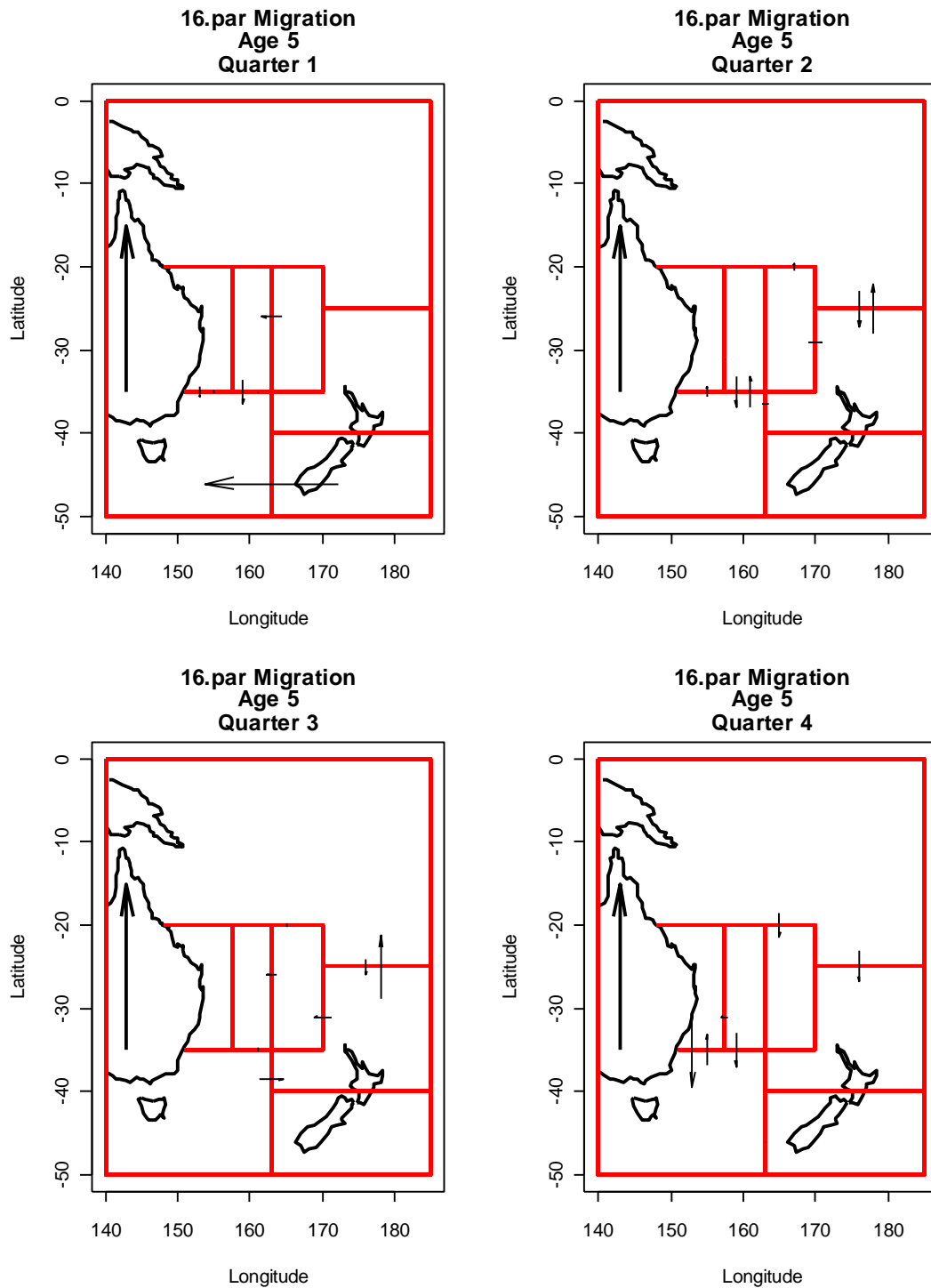


Figure 11. SW Pacific swordfish age 5 quarterly migration dynamics, estimated for the reference case. Arrows represent proportion of fish moving from a given region, the scale arrow on Eastern Australia represents 100%. (Age 15 on following page)

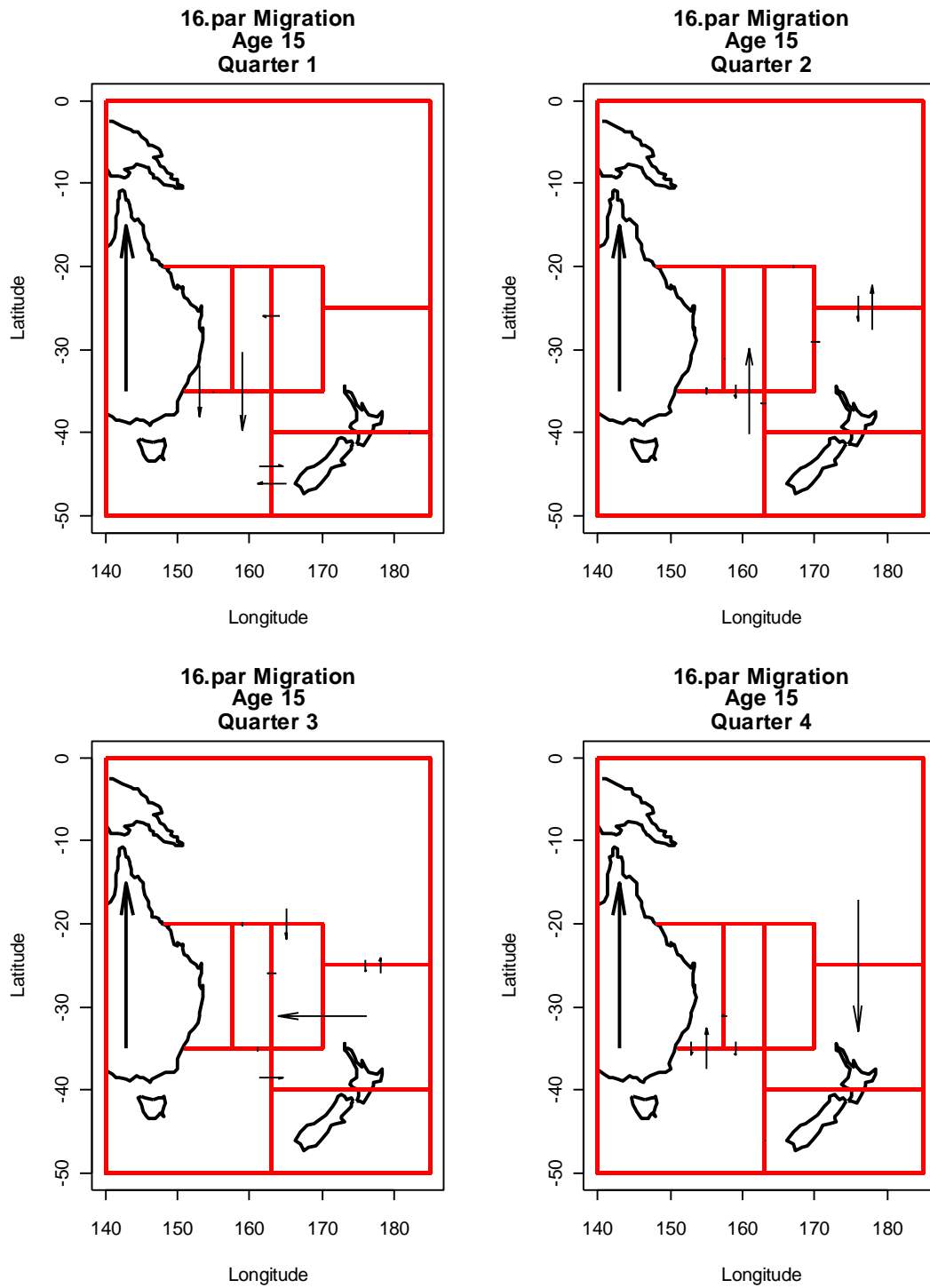


Figure 11 (cont.)

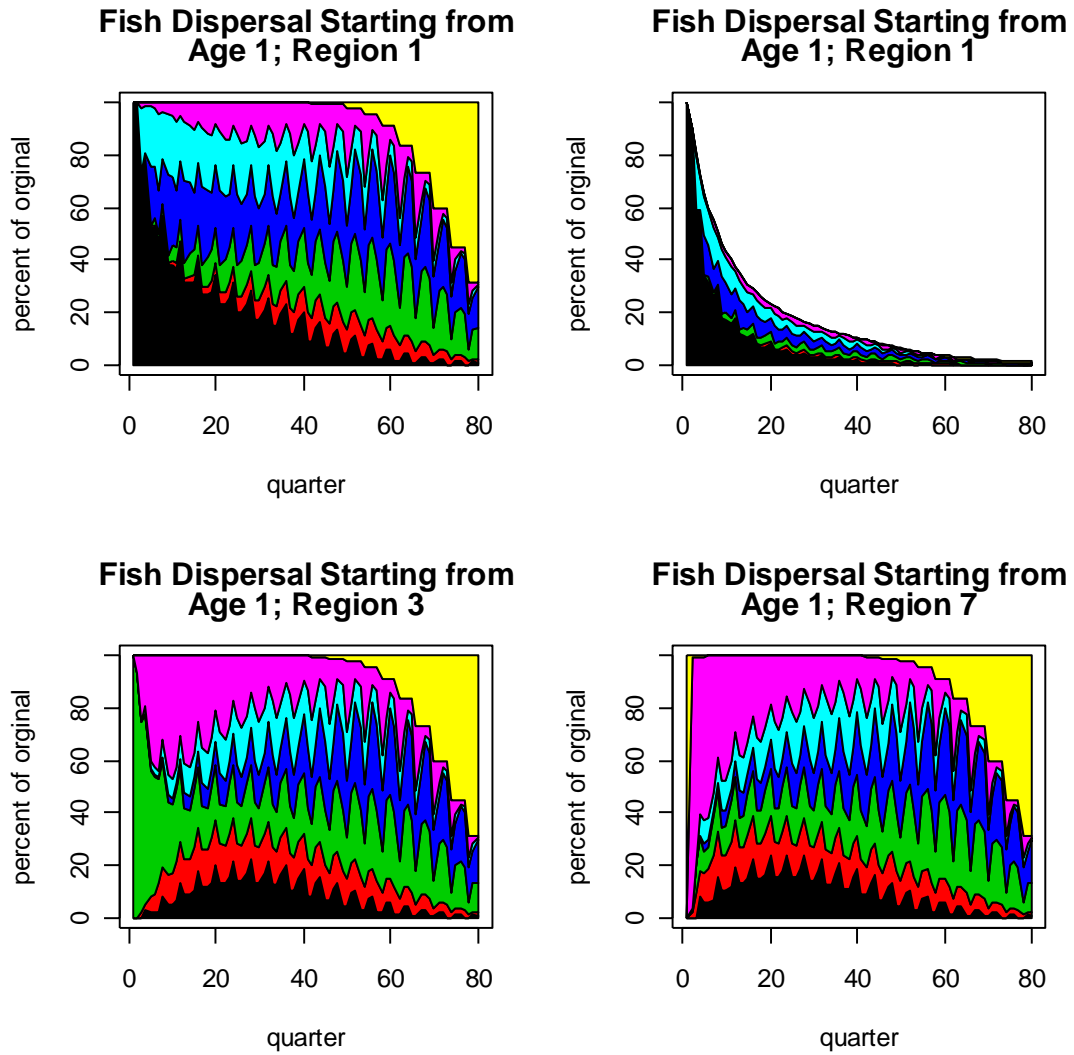
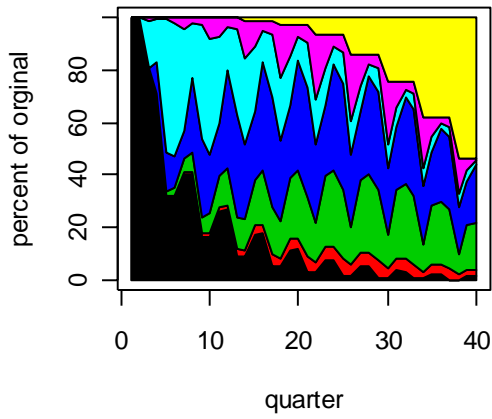
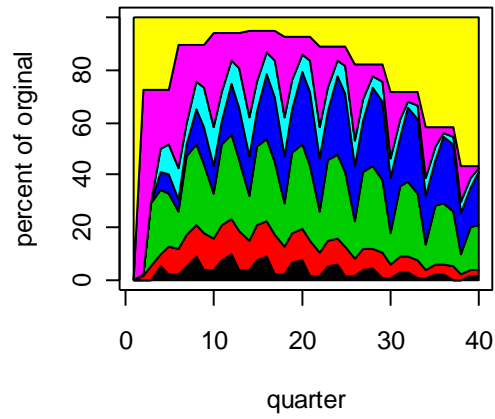


Figure 12. The (unfished) re-distribution of swordfish over time seeded at the indicated region and age-class. The upper right-hand panel includes the effects of natural mortality. Each coloured band represents a region, starting at region 1 in black at the bottom, ascending to region 7 in yellow.

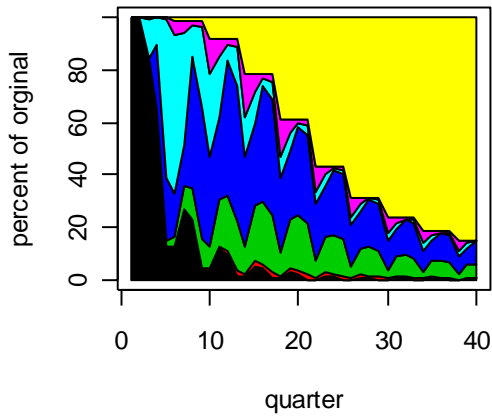
Fish Dispersal Starting from Age 10; Region 1



Fish Dispersal Starting from Age 10; Region 7



Fish Dispersal Starting from Age 15; Region 1



Fish Dispersal Starting from Age 15; Region 7

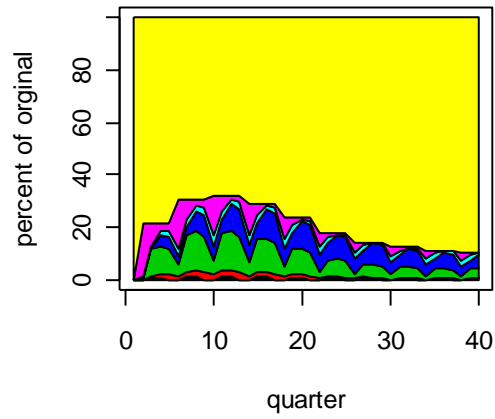


Figure 12 (continued)

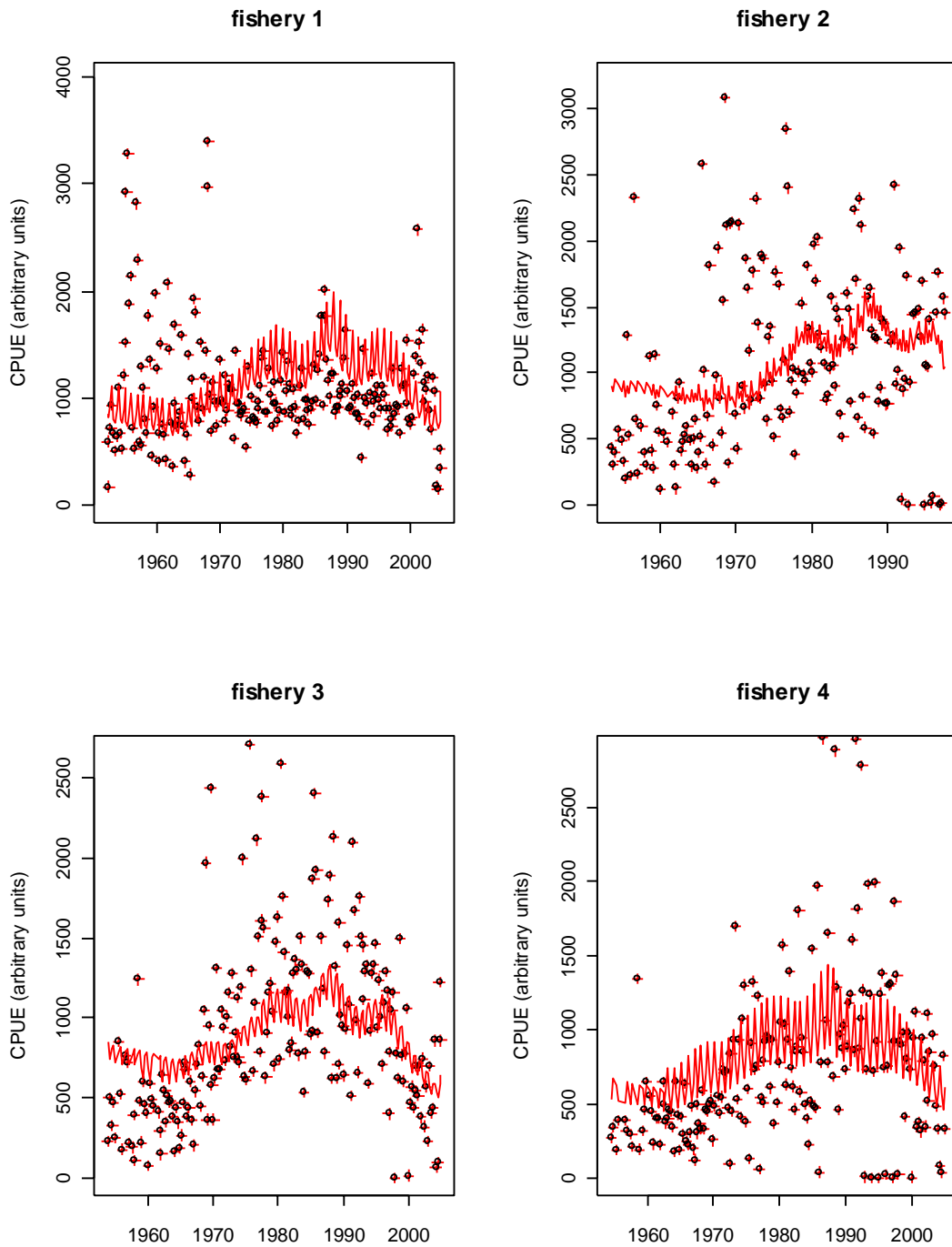


Figure 13. Predicted (lines) and observed (points) CPUE for the indicated fisheries for the reference case model fitting (scaled by the estimated catchability). Timesteps are quarterly from 1952-2004. Fisheries 1-11 and 13 have no catchability deviations, while the others have been standardized to account for the effects of catchability variation (but not effort deviations) in predictions and observations (+ symbols). The nominal observed CPUE (rescaled by mean catchability is indicated by the circles to give an indication of the catchability changes estimated.

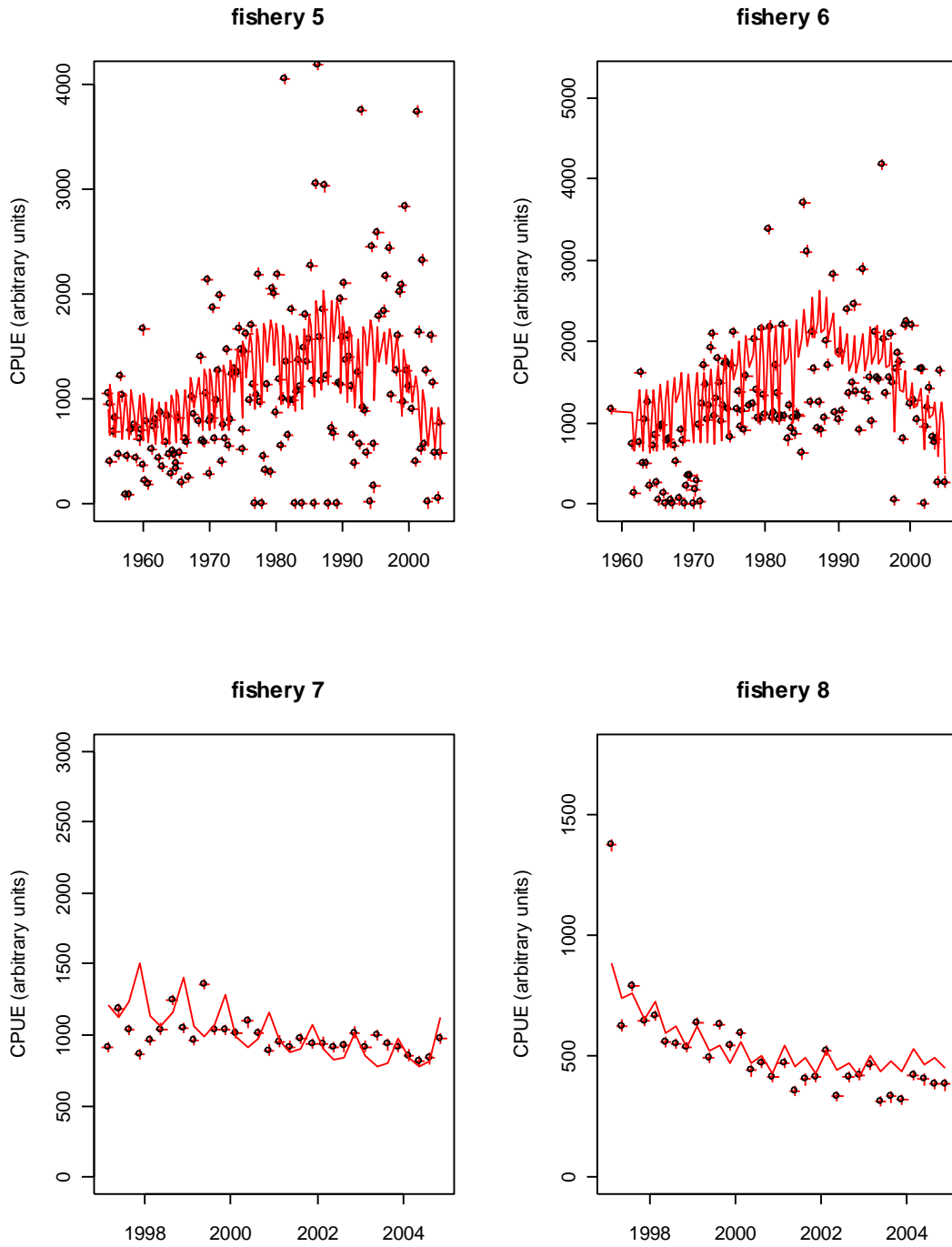


Figure 13. (cont.)

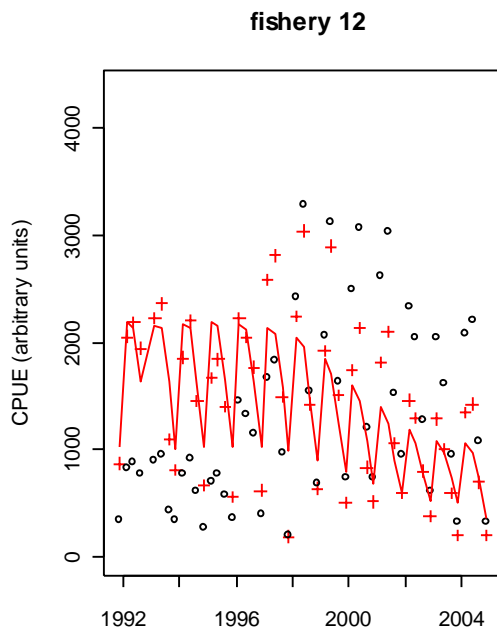
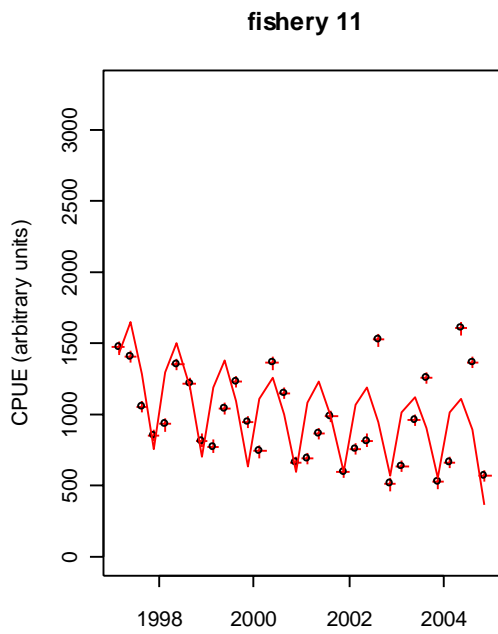
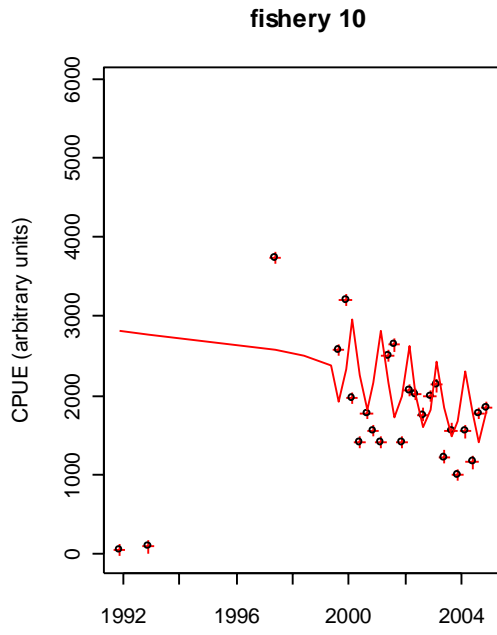
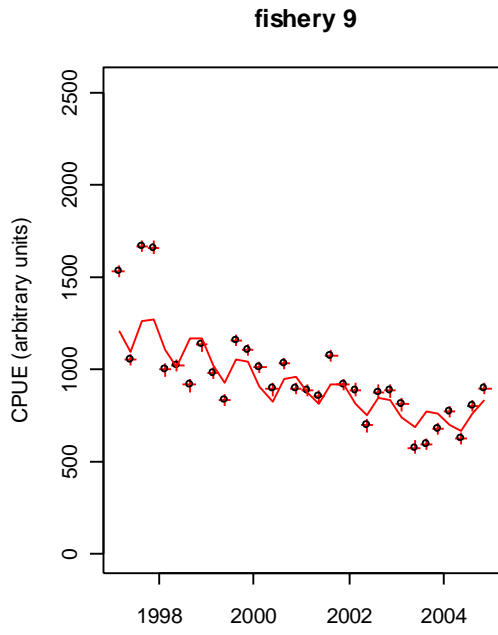


Figure 13. (cont.)

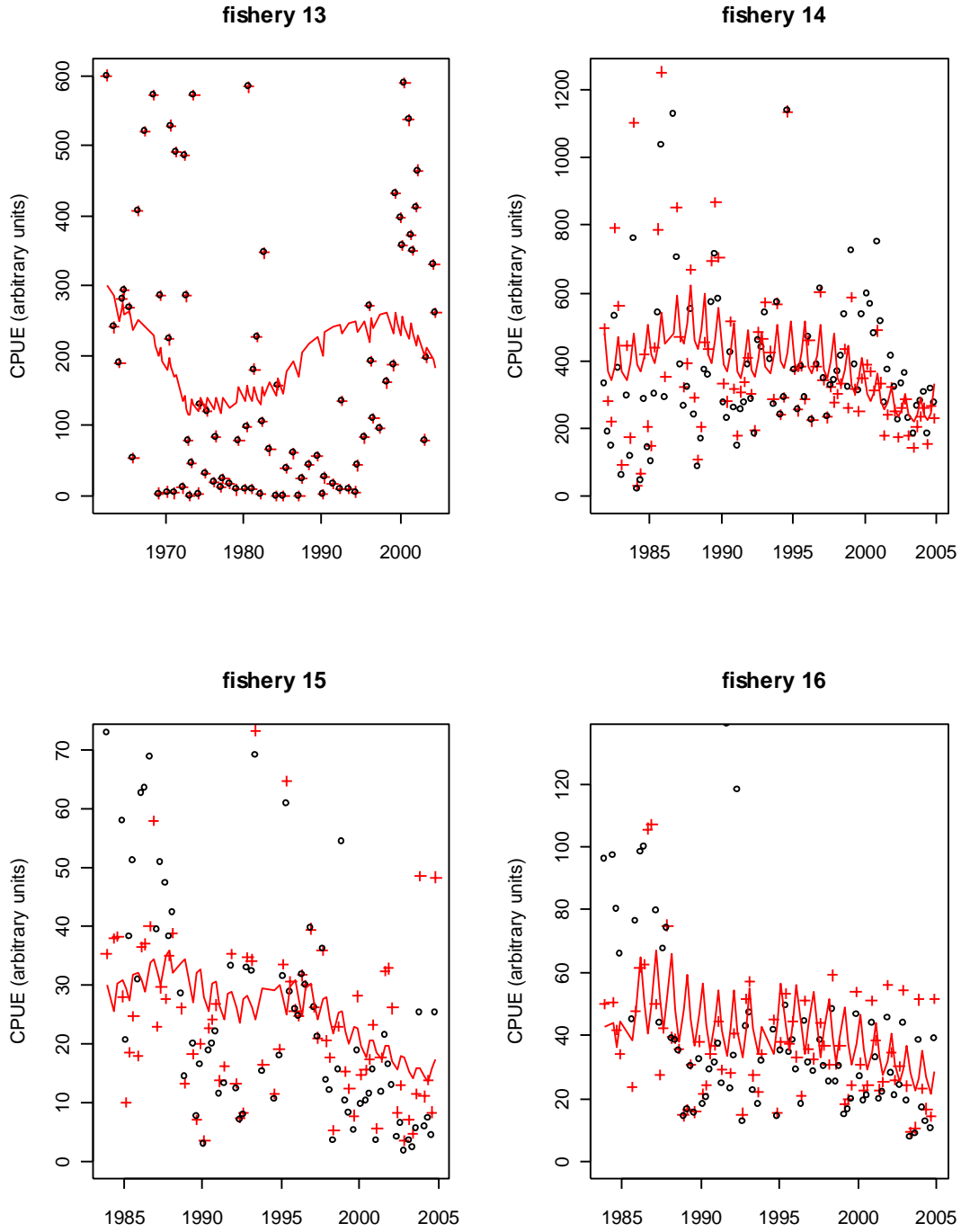


Figure 13. (cont.)

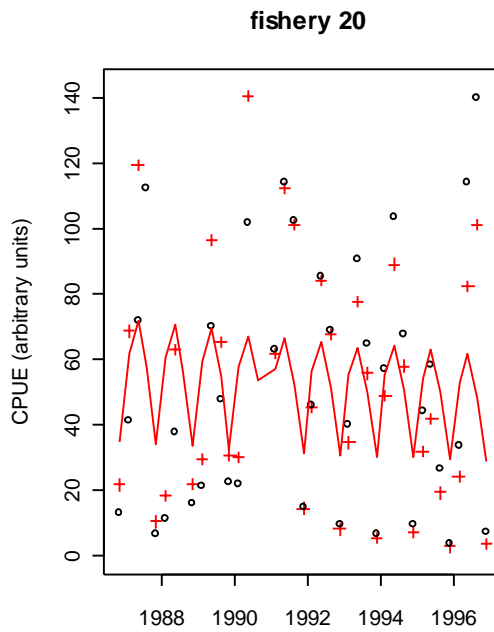
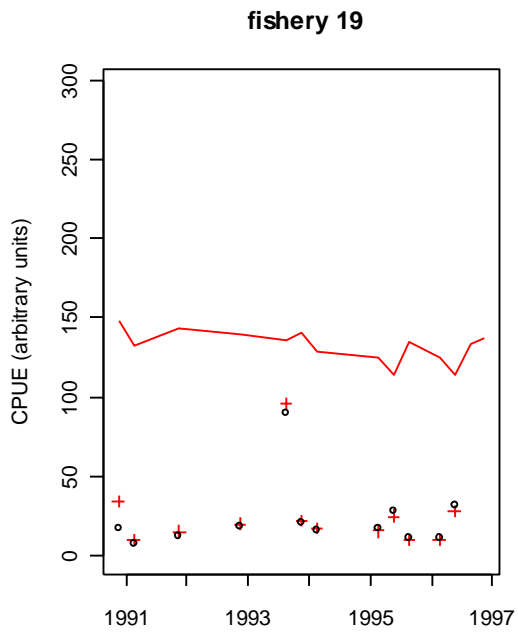
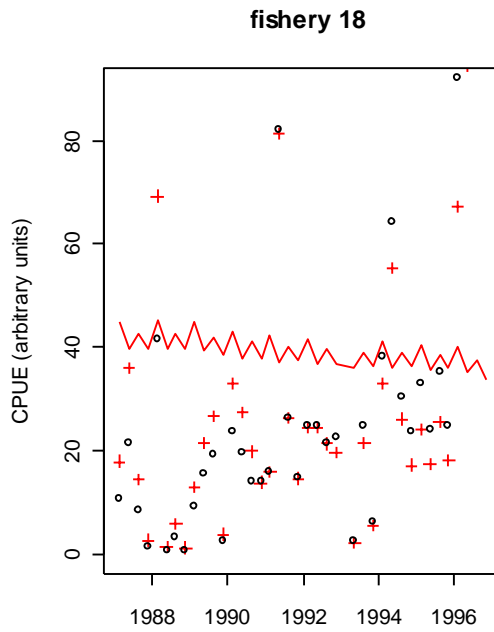
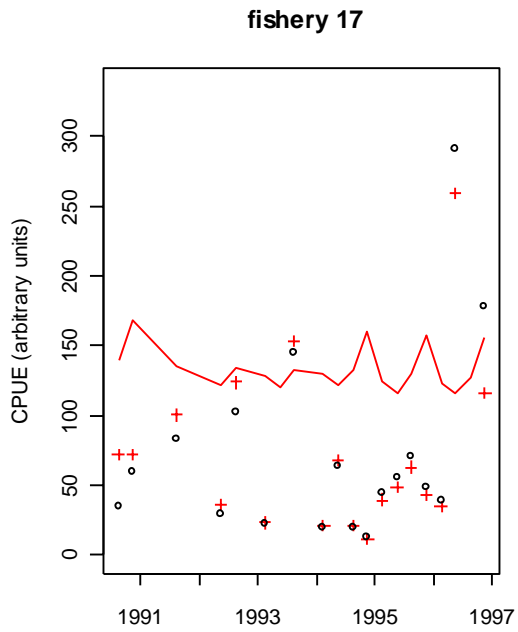


Figure 13. (cont.)

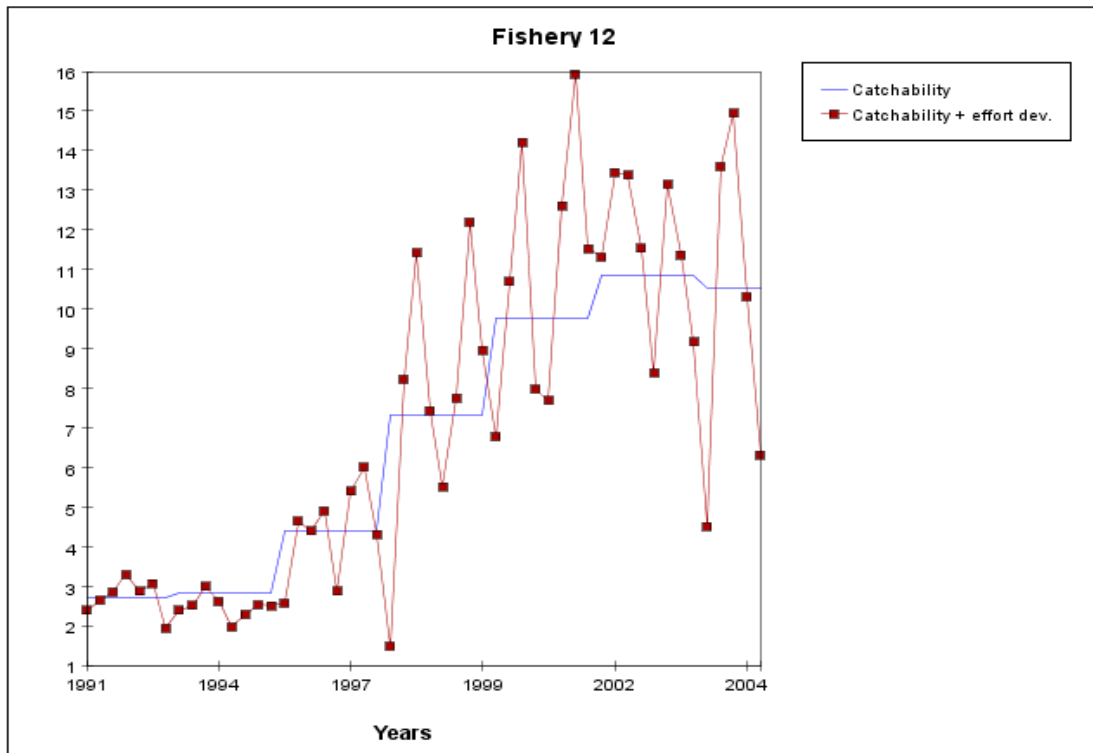
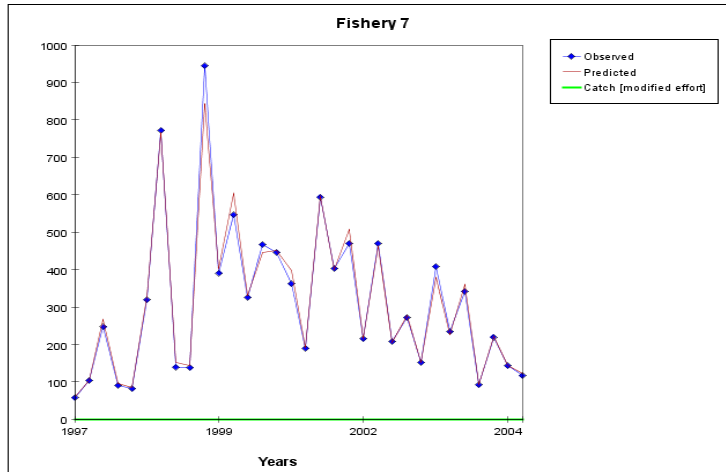
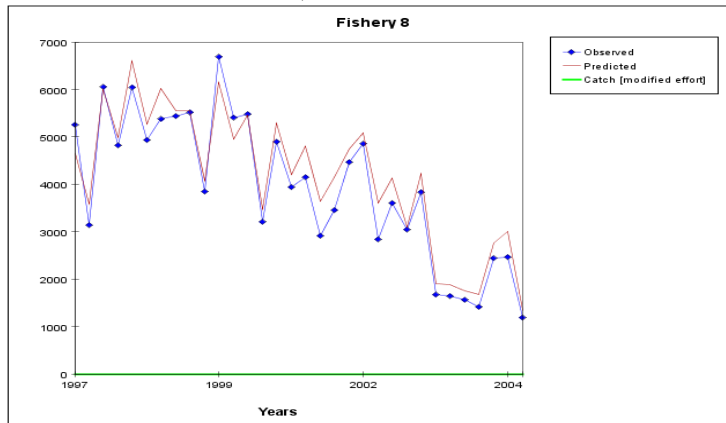


Figure 14. SW Pacific swordfish reference case estimated changes in catchability over time for fishery 12 (New Zealand domestic).

A) Aus Area 1



B) Aus Area 2



C) Aus Area 3

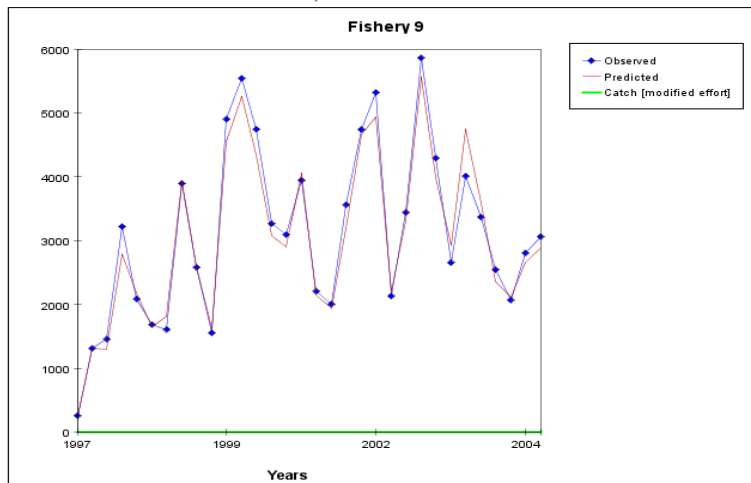


Figure 15. SW Pacific swordfish reference case predicted (lines) and observed (circles) catch for key Australian fisheries, indicates how attempting to force a fit to effort series causes the catch prediction to change.

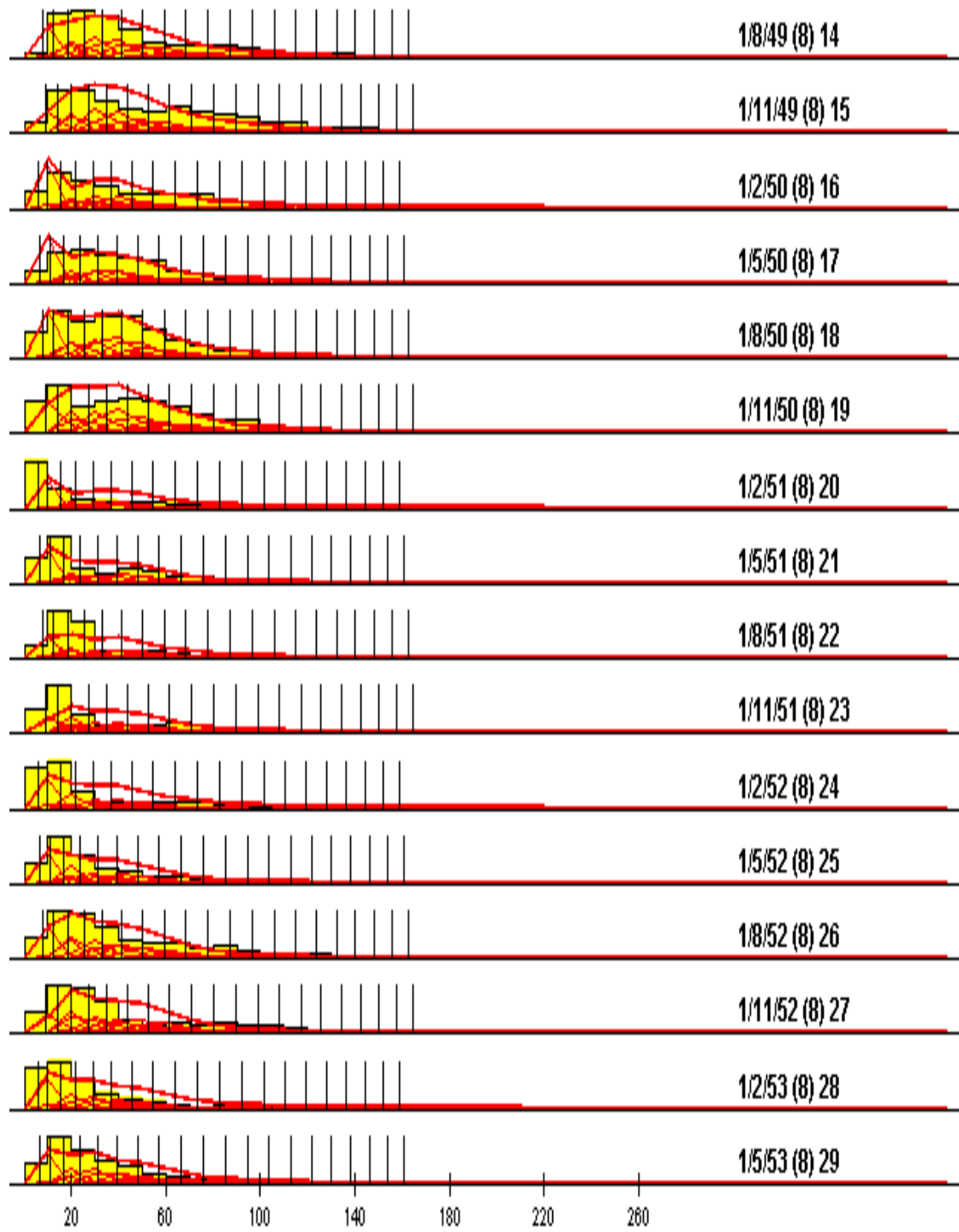


Figure 16. SW Pacific swordfish predicted (lines) and observed (histograms) catch mass (kg) frequency distributions from fishery 8 (Australia area 2). Quarterly observations from 2001-4.

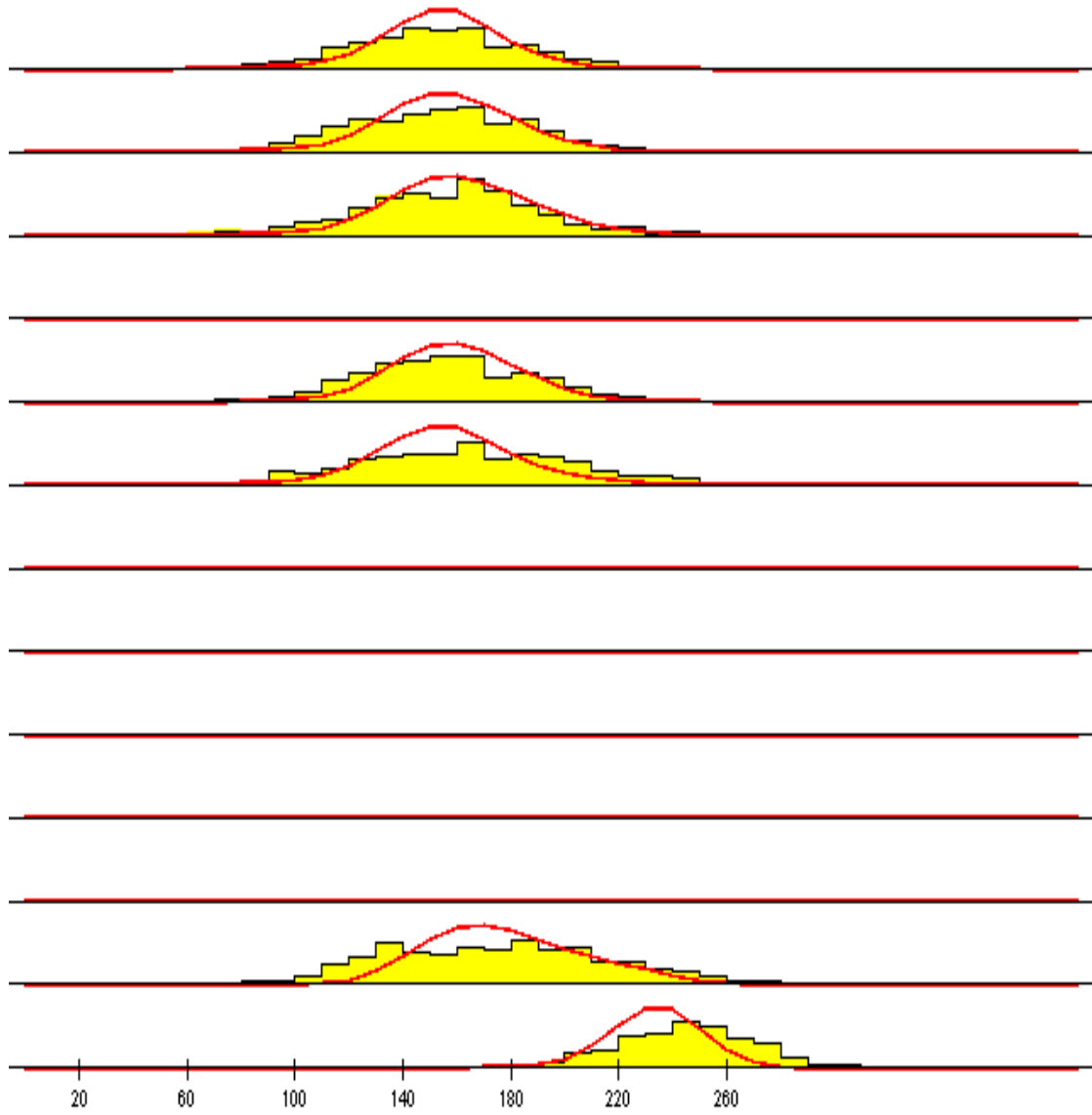


Figure 17. SW Pacific swordfish reference case predicted (lines) and observed (histogram) length frequency distributions (aggregated over time) for fisheries 1-13 (in sequence with 1 at the top).

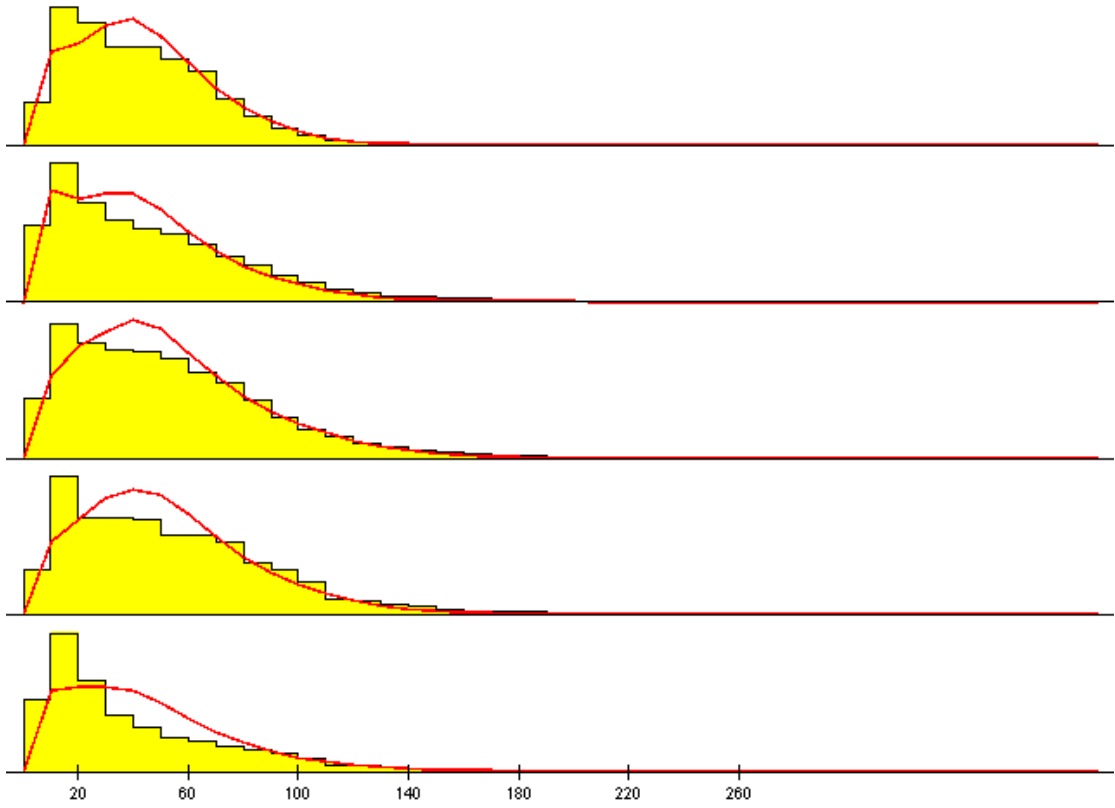


Figure 18. SW Pacific swordfish reference case predicted (lines) and observed (histogram) mass frequency distributions (aggregated over time) for fisheries 7-11 (in sequence, 7 at the top).

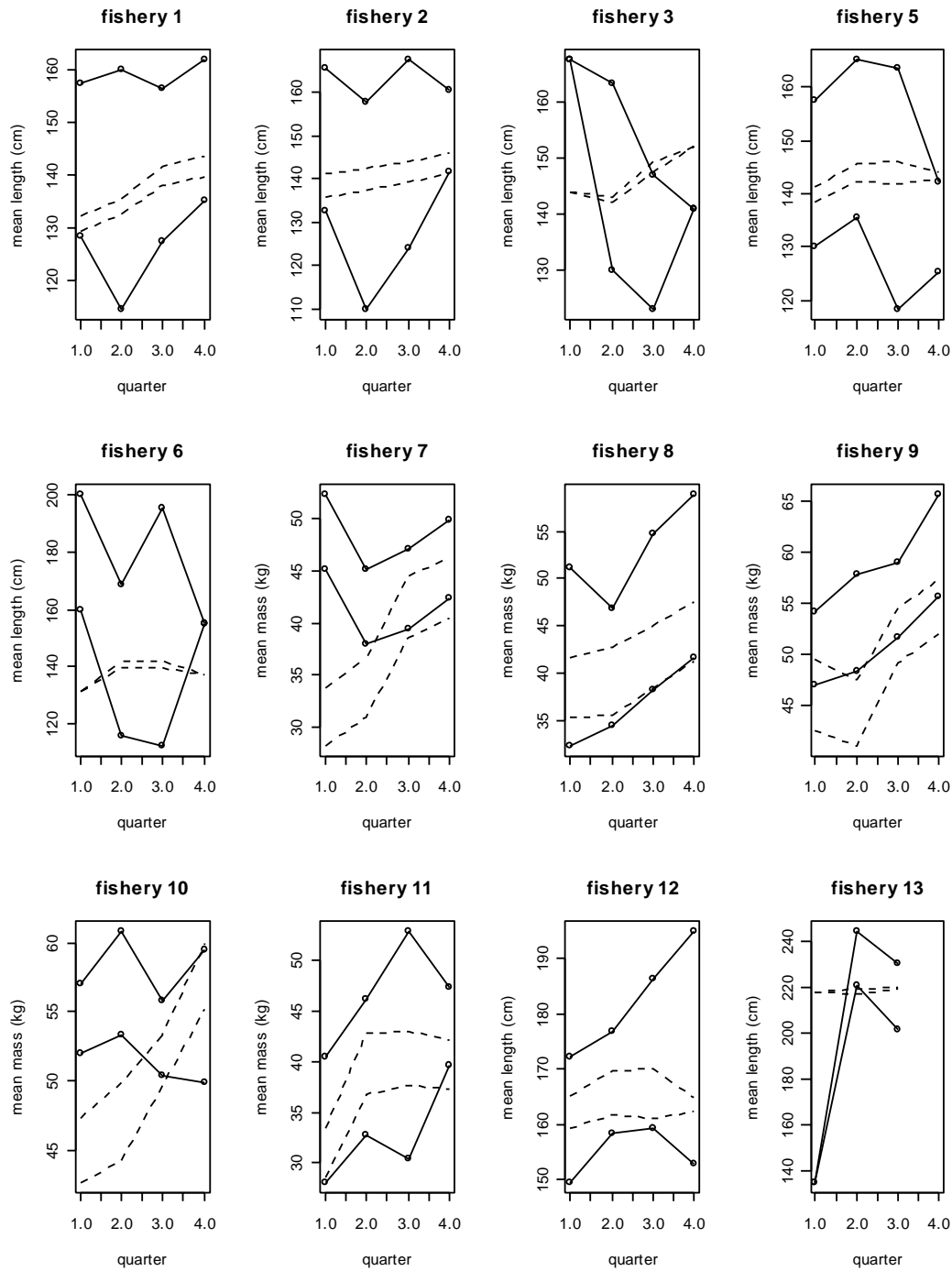


Figure 19. Predicted (broken lines) and observed (solid lines) mean catch-at-size distributions by season (aggregated over years). X-axis is quarter, Y-axis is the mean size. For each series, the bottom line is the lower 10 percentile of the annual means, upper line is the 90th percentile. Fishery definitions in Table 1. The plots are intended to illustrate the seasonal migration signal and noise in catch size distributions.

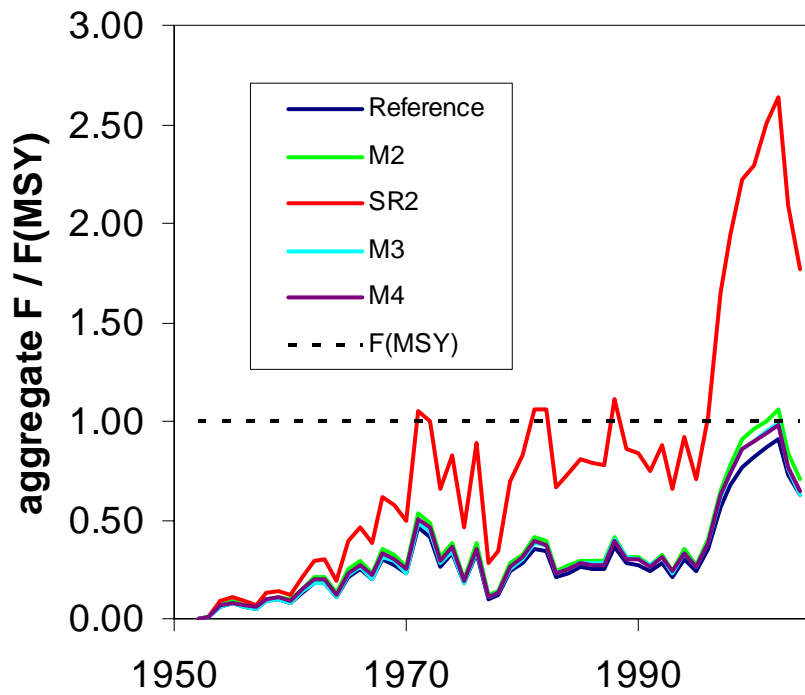


Figure 20. Fishing mortality estimates relative to $F(MSY)$ corresponding to some alternative model specifications. M refers to alternative mortality assumptions from Figure 6. SR refers to an alternative stock recruitment curve steepness assumption.

Appendix 1. The bash script used to conduct the Multifan-CL reference case swordfish assessment.

```
#!/bin/sh
#
#rm *.par
#-----
# PHASE 0 - create initial par file
# -----
#
#if [ ! -f 00.par ]; then
# mfclopt swo320.frq swo320.ini 00.par -makepar
#fi
# -----
# PHASE 1 - initial par
# -----
#
if [ ! -f 01.par ]; then
mfclopt swo320.frq 00.MFsize.MSpLo.AusandJapgroupedqandssel.par 01.par -file - <<PHASE1
2 113 1 # estimate initpop/totpop scaling parameter
1 32 3 # sets "a slightly faster initial control sequence" standard initial estimation scheme
1 141 3 # sets likelihood function for LF data to normal
2 57 1 # sets no. of recruitments per year to 1
2 94 1 2 95 10 # initial age structure based on M (assume virgin)
-999 26 2 # sets length-dependent selectivity option
-999 57 3 # use cubic spline for selectivity
-999 61 5 # number of parameters in cubic spline
# grouping of fisheries with common selectivity
-1 24 1
-2 24 1
-3 24 1
-4 24 1
-5 24 1
-6 24 1
-7 24 2
-8 24 2
-9 24 2
-10 24 2
-11 24 2
-12 24 3
-13 24 1
-14 24 1
-15 24 1
-16 24 1
-17 24 2
-18 24 2
-19 24 2
-20 24 2
-1 29 1 #group catchabilities deviations
-2 29 1 #group catchabilities
-3 29 1 #group catchabilities
-4 29 1 #group catchabilities
-5 29 1 #group catchabilities
-6 29 1 #group catchabilities
-7 29 2 #group catchabilities
-8 29 2 #group catchabilities
-9 29 2 #group catchabilities
-10 29 2 #group catchabilities
-11 29 2 #group catchabilities
-12 29 3 #group catchabilities
-13 29 1 #group catchabilities
-14 29 4 #group catchabilities
-15 29 5 #group catchabilities
-16 29 6 #group catchabilities
-17 29 7 #group catchabilities
-18 29 7 #group catchabilities
-19 29 7 #group catchabilities
-20 29 7 #group catchabilities
-1 60 1 #group catchabilities initial
-2 60 1 #group catchabilities
-3 60 1 #group catchabilities
-4 60 1 #group catchabilities
```

```

-5 60 1 #group catchabilities
-6 60 1 #group catchabilities
-7 60 2 #group catchabilities
-8 60 2 #group catchabilities
-9 60 2 #group catchabilities
-10 60 2 #group catchabilities
-11 60 2 #group catchabilities
-12 60 3 #group catchabilities
-13 60 1 #group catchabilities
-14 60 4 #group catchabilities
-15 60 5 #group catchabilities
-16 60 6 #group catchabilities
-17 60 7 #group catchabilities
-18 60 7 #group catchabilities
-19 60 7 #group catchabilities
-20 60 7 #group catchabilities
2 107 100 # turn on exploitation rate target
2 108 10 # set exploitation rate target as x% (Catch(numbers)/Rec(N))
PHASE1
fi
# -----
# PHASE 2
# -----
if [ ! -f 02.par ]; then
mfclopt swo320.frq 01.par 02.par -file - <<PHASE2
1 189 1 # write length.fit and weight.fit (obs. and pred. LF data)
1 190 1 # write plot.rep
1 149 500 # set penalty on recruitment devs to n/10 (500/10 ~ cv of 0.1)
1 1 500 # set max. number of function evaluations per phase
1 50 0 # set convergence criterion to 1E+0
1 12 0 # attempt to shut off mean first length growth estimation (overridden in phase 1 probably)
1 13 0 # attempt to shut off mean last length growth estimation (use priors instead)
1 14 0 # attempt to shut off k growth estimation
PHASE2
fi
# -----
# PHASE 3
# -----
if [ ! -f 03.par ]; then
mfclopt swo320.frq 02.par 03.par -file - <<PHASE3
2 70 0 # attempt to turn off recruitment time series variability among regions?)
2 71 0 # attempt to turn off recruitment distribution (related to above)
2 110 5 # penalty weight for rec deviations (related to above)
PHASE3
fi
# -----
# PHASE 4
# -----
if [ ! -f 04.par ]; then
mfclopt swo320.frq 03.par 04.par -file - <<PHASE4
2 68 0 # de-activate- estimate movement coefficients #manual says activates movement
2 69 0 # de-activate- sets generic movement option (now default) #manual says estimates movement params
-999 48 1 # activate selectivity estimation
PHASE4
fi
# -----
# PHASE 5
# -----
if [ ! -f 05.par ]; then
mfclopt swo320.frq 04.par 05.par -file - <<PHASE5
1 16 1 # estimate length dependent SD
PHASE5
fi
# -----
# PHASE 6
# -----
if [ ! -f 06.par ]; then
mfclopt swo320.frq 05.par 06.par -file - <<PHASE6
1 141 0 # sets likelihood function for LF data to mod chi2
PHASE6
fi
# -----
# PHASE 7
# -----
if [ ! -f 07.par ]; then

```

```

mfclopt swo320.frq 06.par 07.par -file - <<PHASE7
-1 10 0 # estimate catchability time series
-2 10 0 # estimate catchability time series
-3 10 0 # estimate catchability time series
-4 10 0 # estimate catchability time series
-5 10 0 # estimate catchability time series
-6 10 0 # estimate catchability time series
-7 10 0 # estimate catchability time series
-8 10 0 # estimate catchability time series
-9 10 0 # estimate catchability time series
-10 10 0 # estimate catchability time series
-11 10 0 # estimate catchability time series
-12 10 1 # estimate catchability time series on
-13 10 0 # estimate catchability time series
-14 10 1 # estimate catchability time series on
-15 10 1 # estimate catchability time series on
-16 10 1 # estimate catchability time series on
-17 10 1 # estimate catchability time series on
-18 10 1 # estimate catchability time series on
-19 10 1 # estimate catchability time series on
-20 10 1 # estimate catchability time series on
-1 23 999 # no do a random-walk step every 23+1 months
-2 23 999 # no do a random-walk step every 23+1 months
-3 23 999 # no do a random-walk step every 23+1 months
-4 23 999 # no do a random-walk step every 23+1 months
-5 23 999 # no do a random-walk step every 23+1 months
-6 23 999 # no do a random-walk step every 23+1 months
-7 23 999 # no do a random-walk step every 23+1 months
-8 23 999 # no do a random-walk step every 23+1 months\n
-9 23 999 # no do a random-walk step every 23+1 months\n
-10 23 999 # no do a random-walk step every 23+1 months\n
-11 23 999 # no do a random-walk step every 23+1 months\n
-12 23 23 # and do a random-walk step every 23+1 months
-13 23 999 # no do a random-walk step every 23+1 months
-14 23 23 # and do a random-walk step every 23+1 months
-15 23 23 # and do a random-walk step every 23+1 months
-16 23 23 # and do a random-walk step every 23+1 months
-17 23 23 # and do a random-walk step every 23+1 months
-18 23 23 # and do a random-walk step every 23+1 months
-19 23 23 # and do a random-walk step every 23+1 months
-20 23 23 # and do a random-walk step every 23+1 months
PHASE7
fi
# -----
# PHASE 8
# -----
if [ ! -f 08.par ]; then
  mfclopt swo320.frq 07.par 08.par -file - <<PHASE8
# -999 27 1 # estimate seasonal catchability for all fisheries
-7 13 -100 # effort dev weighting (neg = sqrt transformed)
-8 13 -100 # effort dev weighting (neg = sqrt transformed)
-9 13 -100 # effort dev weighting (neg = sqrt transformed)
-10 13 -100 # effort dev weighting (neg = sqrt transformed)
-11 13 -100 # effort dev weighting (neg = sqrt transformed)
PHASE8
fi
# -----
# PHASE 9
# -----
if [ ! -f 09.par ]; then
  mfclopt swo320.frq 08.par 09.par -file - <<PHASE9
PHASE9
fi
# -----
# PHASE 10
# -----
if [ ! -f 10.par ]; then
  mfclopt swo320.frq 09.par 10.par -file - <<PHASE10
  2 68 1 # on estimate movement coefficients #manual says activates movement
  2 69 1 # on sets generic movement option (now default) #manual says estimates movement params
# 2 33 1 # estimate mean natural mortality rate
PHASE10
fi
# -----
# PHASE 11

```

```

# -----
if [ ! -f 11.par ]; then
  mfclopt swo320.frq 10.par 11.par -file - <<PHASE11
  2 88 1      # activate parameters
  2 89 1      # and estimate age-dependent movement
PHASE11
fi
# -----
# PHASE 12
# -----
if [ ! -f 12.par ]; then
  mfclopt swo320.frq 11.par 12.par -file - <<PHASE12
  # 2 73 1      # estimate age-sepdependent M
  # 2 77 1      # estimate age-sepdependent M second diff pen (default=25)
  # 2 78 1      # estimate age-sepdependent M first diff pen (default=5)
  # 2 79 10     # estimate age-sepdependent M dev from mean pen (default=10)
  2 145 1      # estimate Beverton Holt SRR with small penalty
  2 146 1      # SRR parameter active
  2 147 1      # recruitment lag is 1 quarter
  2 148 24     # base F is average over last 24 quarters (MSY stuff)
  2 155 4      # base F average does not include last 4 quarters (MSY stuff)
  2 153 4      # parameters of beta distribution defining prior for
  2 154 6      # steepness - mode = 0.6, sd
PHASE12
fi
# -----
# PHASE 13
# -----
if [ ! -f 13.par ]; then
  mfclopt swo320.frq 12.par 13.par -file - <<PHASE13
  1 1 1000     # set no. function evaluations
  1 50 -6      # set convergence criterion to 1E+n
PHASE13
fi
# -----
# PHASE 14
# -----
if [ ! -f 14.par ]; then
  mfclopt swo320.frq 13.par 14.par -file - <<PHASE14
  2 107 0      # off- turn on exploitation rate target
  2 108 0      # off- set exploitation rate target as x% (Catch(numbers)/Rec(N))
  1 1 3000     # set no. function evaluations
  1 50 -6      # set convergence criterion to 1En
PHASE14
fi
# -----
# PHASE 15
# -----
if [ ! -f 15.par ]; then
  mfclopt swo320.frq 14.par 15.par -file - <<PHASE15
  # -100000 1 1 # estimate
  # -100000 2 1 # time-invariant
  # -100000 3 1 # distribution
  # -100000 4 1 # of
  # -100000 5 1 # recruitment
  # -100000 6 1
  # -100000 7 1
PHASE15
fi
# -----
# PHASE 16
# -----
if [ ! -f 16.par ]; then
  mfclopt swo320.frq 15.par 16.par -file - <<PHASE16
  -999 55 1    # compute biomass with catchability for all fisheries set to 0
PHASE16
fi

```