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Overview of Current Approaches for South West Pacific Swordfish Assessment: Are the Methods Applicable for the Indian Ocean?

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Abstract

This paper provides a brief overview of a number of approaches that are currently under investigation for SW Pacific broadbill swordfish stock assessment. It is hoped that this will provide a helpful background for discussions about assessment options for Indian Ocean tuna.

In recent years, some areas of the SW Pacific fishery have shown worrying signs of depletion and this has provided the impetus for domestic Australian management action and considerations for wider management in the South Pacific region under the auspices of the Western and Central Pacific Fisheries Commission. East coast Australian stock assessment for swordfish has historically focused on data-based indicators of catch rates and size frequency data. In the last couple years, a range of model-based assessments have been pursued to provide advice toward different management-related questions. At the simplest level, estimators of depletion and renewal have been applied to the inshore Australian fishery, in an attempt to quantify harvest rates that can be sustained without causing further decline in inshore CPUE. Spatially-structured surplus production models have been used in an attempt to link local Australian dynamics with the greater SW Pacific population. Complicated assessment models (Multifan-CL and CASAL) are being used to integrate all of the fisheries and biological data in a manner that can represent many of the relevant processes, describing age-, sex-, and area-specific details of the sub-populations and their links through migration. Concurrent with the development of assessment models, simulation testing is being undertaken to evaluate the performance and reliability of different approaches. These models will be used to formulate advice related to policies for meeting local and regional management objectives. However, it is recognized that the stock assessment methods might not deliver information at the level of precision that will be required to satisfy competing fisheries management objectives, in which case we encourage the pursuit of management strategies that are robust to the major uncertainties.

Introduction

Catches in the SW Pacific swordfish fishery (defined as Areas1-5 in Figure 1) have increased rapidly over the last 10 years (Figure 2), with declining catch rates observed in some core areas (Figure 3). The assessment process in Australia to date has mostly focused on descriptive analyses of spatio-temporal changes in domestic fishing effort, catch numbers, catch size frequencies and catch rates. Concerns about the economic and biological sustainability of the fishery have become an immediate concern, and it is recognized that management actions disruptive to the status quo probably need to be undertaken. It would obviously be desirable if these management decisions were based on some explicit understanding of the dynamics of the fishery, and several initiatives related to swordfish population modeling have been recently undertaken to attempt to address the questions of concern for managers. While none of these methods are perfect, it makes sense to base decisions on precisely defined analytical methods that can be iteratively repeated, updated and improved as new and better data are collected. This paper represents a roadmap to the population modeling approaches that are currently under consideration. Technical details are omitted, but references are provided. The types of data and assumptions involved are discussed, and it is hoped that this might form a helpful basis for discussion of options worth pursuing in the context of Indian Ocean swordfish assessment.

History of the SW Pacific swordfish fishery

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. The Japanese catch has declined steadily since then, while Australian and New Zealand longline catches increased to more than make up the difference. Pacific Island Nation, Taiwanese and Korean catches have also increased in recent years, but remain a small portion of the total. The Spanish fleet reported the results of exploratory swordfish fishing for the first time in 2004. Catch in numbers from about 1997-2002 have been roughly double the mean of the 1970-96 period. Swordfish were generally considered a by-catch species until the late 1990s. Beginning in the 1990s, swordfish became a main target species in Australia, and seemingly New Zealand. During this latter period, the technological efficiency in swordfish targeting increased dramatically (for the Australian and New Zealand fleets), but the Australian fishery never lost its mixed species character, with many boats reportedly switching opportunistically between swordfish, yellowfin and bigeye. Total catches in Australia and New Zealand have dropped considerably in the last two years (partly in response to rising bait and fuel costs, and dropping swordfish prices).

SW Pacific Swordfish Data and data-based Fisheries Indicators

The by-catch nature of the swordfish fishery throughout most of its history tends to mean that the fisheries data quality and biological research lag behind some of the other pelagic fisheries in the region. The fisheries data includes:

- Total catch in numbers. We have little information about discarding, but it may have been substantial, particularly in the early years.

- Catch rates from Australia, New Zealand and Japan. Auxiliary information on gear deployment allows for CPUE standardization with varying degrees of success. Additional CPUE data from PIN nations, Korea and Taiwan has only been considered qualitatively to date. Strong seasonal periodicity suggests movement in relation to changing water temperatures and/or spawning migrations.

- Australian size sampling from fish processors has been very thorough for the last several years. The New Zealand charter fleet has 100% observer coverage with excellent size measurements from this small portion of the fleet. Size sampling has been undertaken in other fleets, but the sample sizes are generally small and sporadic over time.

Additional data from directed research includes:

- Studies of length-at-age, weight length relationships and sexual dimorphism (Young and Drake 2004)

- Reproductive studies suggest spawning only in tropical waters near North-Eastern Australia, but may suffer from spatial coverage bias (Young and Drake 2002)

- Larval surveys are in general agreement with the view of a single spawning region in the SW Pacific (Far Seas Fisheries 1985)

- Genetic studies suggest that the SW Pacific stock mixes somewhat with the South Central and Indian Ocean stocks, but very little with North Pacific stocks (Reeb et al 2000)

- From several hundred tag releases in recent years, <1% have been recovered to date, and none have indicated long distance movement

The Australian East Coast Tuna and Billfish fishery Resource Assessment Group (ETBF-RAG) has routinely used summaries of catch rates and catch size frequency distributions to monitor the status of the local swordfish stock (e.g. Campbell 2005). These data-based summaries involve considerable analytical effort spent in catch rate standardization. The examination of catch rates and size frequency distributions can be interpreted in relation to changes in abundance, population age/sex composition and fleet dynamics over time, and allow inferences about local depletion, seasonal migration dynamics and oceanographic effects on swordfish distributions. Basson and Dowling (2006) describe preliminary work on a project to evaluate the information content of indicators for data poor situations, and will likely find application in the SW Pacific and Indian Ocean assessment processes in the future.

Data-based indicators, in the sense that the term is used here, can potentially provide a good view of the status of the stock in many respects. For example, a good CPUE series might provide an excellent indication of stock numbers historically. In many cases, it appears that stock assessment models simply follow the CPUE trend (and in fact if they do not, it is probably a cause for concern). However, indicators do not have much capacity to synthesize data into a predictive framework for quantifying the interactions between fish stocks and fishing fleets. The modeling process allows us to articulate concise quantitative assumptions about stock dynamics, evaluate whether or not the assumptions are consistent with the various observations, and provide management advice within an internally consistent predictive framework. Of course the predictive value of the models is greatly reduced when the data are uninformative, or if the assumptions about the stock dynamics are poor. We expect that data-based indicators will continue to inform the swordfish stock assessment process in parallel with model developments, but the remainder of this paper focuses on the modelling.

Spatial considerations of SW Pacific Swordfish Dynamics

Swordfish are one of the most widely distributed pelagic species, and the degree to which individuals migrate and sub-populations mix potentially has important implications for fisheries management. If the fish are relatively stationary, and recruit to the local population, then assessment and management initiatives can be localized, as fishing activities in adjacent regions will have little direct effect on the area of interest. In a fast mixing, homogenous population, all fisheries will tend to show similar trends in abundance. With rapid mixing, exploitation in relatively distant regions can have a large impact on local abundance. Management actions obviously need to consider the larger region in this case. Assessment activities should also incorporate data from the larger region. However, with very rapid mixing, it is perhaps not especially critical where the relative abundance indices are calculated or where exactly the catch is removed from, as local processes will largely parallel the larger area. Our perceptions of the SW Pacific swordfish populations suggest an intermediate mixing situation which is more difficult to deal with than either of the two extremes.

The spatial units that have been defined for stock assessment purposes (Figure 1) represent a trade-off between the desire to partition the population into relatively homogenous units, while still maintaining tractable estimators. Most stock assessments operate on a spatially-aggregated structure, and this may be tested as an option for SW Pacific swordfish as well, however there are two main reasons why we have gone down the route of spatial partitioning from the beginning. First, there is no consistently reliable index of abundance that spans the whole region and time of interest. Unlike many of the pelagic fisheries assessment in the WCPO, we have less confidence in the widespread Japanese longline CPUE series relative to other localized series (Australian and potentially New Zealand), for which we have better data for catch rate standardization. Thus any aggregate abundance index is going to represent a patchwork of indices stitched together with various assumptions about fleet-specific and seasonal catchabilities. Ignoring implications of spatial heterogeneity and shared catchability among fleets will result in a simple averaging through the middle of several time series with conflicting trends. Retaining the distinct spatial structure of the different series maintains the focus on the critical assumptions involved in translating from local to regional abundance estimates. The second reason for using spatial structure relates to the type of advice that might be provided. There is limited capacity to describe how the different fisheries are going to affect one another if it is assumed that they all have an equivalent effect on the whole regional population. We have reason to suspect that substantially different interpretations of swordfish movement dynamics might be consistent with the available data, but if they are not explicitly modeled, we cannot compare the alternatives. When nations consider the merits of different management intitiatives in a unilateral or multilateral context, they will prefer want to be aware of the implications of movement.

We attempted to define homogenous units on the basis of fishing fleet distributions, catch size characteristics, CPUE trends and perceived biological activities (i.e. spawning vs foraging). Swordfish are caught throughout the Pacific Ocean, and there is genetic evidence of substantial mixing through the south Pacific, the Eastern Pacific and the North Pacific. At one extreme, one could attempt to model the whole Pacific Ocean stock, as has been attempted for Pacific bigeye tuna in recent years. However, as the project grew out of an immediate need for Australian and New Zealand management advice, there was an obvious need to focus attention on the SW Pacific. While the genetic studies suggest that there is relatively low mixing across the equator in the Western Pacific, it is more difficult to justify an Eastern boundary for this stock. The definition of 175 W for this boundary reflects the eastern extent of the New Zealand domestic fishery, and a substantial decline in CPUE in the distant water fishing nation fleets at this point. It is also a point perceived to be about half-way between suspected southern hemisphere spawning areas (on the basis of larval distributions).

There are substantial catches of swordfish East of 175 W, but they tend to be in more equatorial waters, and not contiguous with the high catch and CPUE regions of the SW Pacific. Defining a spatial region of the South Pacific that also encompasses the South-Central region would lead to two problems. First, the central South Pacific region is contiguous with high catch and CPUE regions immediately to the North and East, which would lead to an argument for further expansion into the northern hemisphere and beyond the bounds of the WCPFC convention area. Second, CPUE in the South-Central region is based only on the DWF fleets, for which we currently do not have detailed data for standardization. The nominal CPUE series in this region indicates an increasing trend that is the opposite of the SW Pacific region (and is suggestive of an increase in swordfish targeting much like Australia and New Zealand experienced in the 1990s).

A further consideration of the spatial dynamics of swordfish arises in relation to the manner of the mixing of the stock. We refer to two possibilities as the homogenous population, and the foraging site fidelity with the difference illustrated schematically in Figure 5. The homogenous population refers to a spatial structure in which all individuals in a given region (of the same age and sex) have the same probability of migrating to another region irrespective of their prior experience. The foraging site fidelity model assumes that fish that recruit to a particular region tend to remain in that region, leaving only to spawn, and then returning to the same foraging site. Foraging site fidelity is not as extreme as having fully independent stocks because we assume that spawning and recruitment processes are still linked across the sub-populations. The homogenous population is most commonly assumed in pelagic fisheries models, however, it might be difficult to reconcile both seasonal migration and localized depletion without some form of site fidelity. Whether it matters for management purposes is not clear.

Contrast in the different assessment approaches

The different assessment approaches under development for SW Pacific swordfish are compared briefly in Table 1.

There is a recognition that the more detailed and 'realistic' assessment models do not necessarily provide better inferences than simpler models, and this is likely to be especially true when data are sparse or poorly understood. Although somewhat counter-intuitive, this result stems in part from what is often referred to as the bias-variance trade-off: in an assessment context, simple models tend to aggregate over non-homogenous population units (e.g. ignore age-structure) and lead to an imperfect representation of the real population with unavoidable biases due to structural rigidity. In contrast, the complicated models attempt to represent population processes in dis-aggregated units that potentially provide a close approximation to a real population (e.g. age-, sex-, fleet- and spatial dis-aggregation) and do not suffer from the structural rigidity of the simpler models. However, the data required to estimate the parameters in these models are insufficient, so the overall estimator performance suffers from a high variance. There is usually some intermediate level of model complexity that will provide the best performance for a given purpose. Unfortunately, there is usually no way to know where exactly this optimum is located, and it can be instructive to compare assessments based on a range of models. By pursuing multiple approaches, we gain confidence in the results that are consistent across analyses, and we are more likely to be aware of alternative plausible interpretations that should be considered in developing robust management plans.

Multifan-CL and CASAL were chosen as flexible assessment products with a substantial assessment track record. They seemed to cover the key aspects of the feature set potentially required for this stock, there are probably others that would be equally appropriate.

Depletion Estimator: Quantifying local immigration and emigration off Eastern Australia

In 2005, Australian managers sought an interim measure to stop the decline of swordfish catch rates in the In-shore Australian fishery. Wilcox and Bravington (2005) presented a depletion estimator based on the simple assumption that the in-shore Australian fishery was a small, relatively dynamic portion of a vastly larger, relatively static (in terms of total numbers) stock. The estimator assumes that a constant number of fish flow into the Mooloolaba grounds every year, and a constant proportion of those not caught in the local fishery flow out every year.

Advantages:

- Simple to implement and understand
- Requires only total catch (numbers) and CPUE data from the immediate area of interest

Disadvantages:

- The assumed constant immigration rate is not likely to be valid if abundance outside the area of interest is changing over time (e.g. either because the area of interest reflects a non-trivial component of the larger stock, or other fisheries outside the core area of interest are substantially impacting the stock)
- (Plus other issues relevant to the SDPT below)

Spatially-disaggregated Pella-Tomlinson Surplus Production Model (SDPT)

SW Pacific swordfish life history parameters are poorly quantified, and the data with which they might be estimated within an integrated assessment model are probably not sufficiently informative to produce reliable estimates. The Spatially-Disaggregated Pella-Tomlinson Production model (SDPT) was developed because it can represent the gross characteristics of the production dynamics of a range of life history strategies, albeit with a poor representation of transient age structure changes. Given that the available data do not provide much indication of trends in catch sizes, selectivity that varies among fleets, or large-scale recruitment fluctuations, this seems like a system that might be well represented by an age-aggregated model.

The original SDPT estimator was implemented in a 3 region structure, in a manner that focused on the localized dynamics of the Australian east-coast fishery, but explicitly included links to a larger dynamic SW Pacific population (Figure 4A). This model was iterated on an annual time-step assuming that seasonal migration was much less important than net diffusive movements among adjacent regions.

The SDPT estimator was subsequently extended to include an arbitrary spatial structure, seasonal migration and an arbitrary sub-stock structure. The sub-stock structure was implemented to explore foraging site fidelity models. All of the model structures in Figures 4 and 5 have now been implemented.

Advantages:

- Relatively simple to implement and understand
- Admits the ecological concept of surplus production in a simplified form
- Includes seasonal and long-term diffusive migration dynamics
- Can compare foraging site fidelity and homogenous population scenarios

Disadvantages:

- It is notoriously difficult to estimate the stock production parameters for Pella Tomlinson production models, however, life history traits can be used to bound plausible scenarios. While this is generally considered a weakness, the highly dis-aggregated models tend to suffer from an equivalent problem in the estimation of stock recruitment curves and natural mortality.

- The model cannot account for interannual variability in production (or migration) due to processes other than the level of depletion of the greater SW Pacific stock.

- SDPT cannot describe population heterogeneity due to age and sex structure (and corresponding issues of fishery selectivity), and ignores size data (potentially missing important information on declining fish size)

MultiFan-CL

Multifan-CL (e.g. Kleiber et al 2003) is a flexible integrative assessment modeling framework initially developed and routinely applied to the assessment of tuna species of the Western and Central Pacific Ocean (Kleiber and Yokawa 2002 attempt a North Pacific swordfish assessment). The SW Pacific swordfish implementation is spatially dis-aggregated (5-6 regions, see Figures 1, 5A) and age-structured. It is iterated on a quarterly time-step and attempts to describe seasonal migration. In principle, it is intended to estimate many parameters, including natural mortality, fishery selectivity, catchability, migration dynamics, annual recruitment variability and a stock recruitment relationship. Implementation details and preliminary results are described in Kolody et al (2005), but we note that some of the problems observed therein have been resolved by simplifying the spatial structure. The model will need to undergo further exploration and development before a comprehensive assessment is advanced by mid-year 2006. We expect that the assessment process will continue in subsequent years, in relation to the underlying uncertainties, evolving nature of the fishery and collection of new types of data (see tagging section below).

Advantages:

- Integrates all the available catch, CPUE and catch size frequency data from all fleets in the SW Pacific
- Includes dis-aggregation of the population into relatively homogenous units (i.e. fisheries with distinct characteristics, age structure and age-specific mortality, selectivity and migration). This detailed population representation should reduce parameter estimation biases due to the assumption of aggregate properties in non-homogenous system components.
- The direct link between data, model predictions and preconceived ideas about stock dynamics make for convenient comparisons and visualization of obvious inconsistencies
- Flexible structure potentially allows extensive uncertainty quantification through comprehensive sensitivity analyses. We have not seen this done to

date, but expect that it would be particularly worthwhile for defining plausible operating model scenarios for Management Strategy Evaluation.

Disadvantages:

- Computationally demanding, which limits the number of scenarios that can be explored. Because of the flexibility, multiple model structures might fit the data equivalently well, but this will not be recognized unless explicitly tested. Given the potential sensitivity to arbitrary constraints, there is a serious risk of under-representing uncertainty in these cases.

- Cannot explore foraging site fidelity migration scenarios.

- Current version does not include sex dis-aggregation (though it is reportedly under development by Otter Research and the SPC).

CASAL

Similar to Multifan-CL, CASAL is a flexible, generic software package that attempts to integrate all of the available catch, effort and size data in an arbitrary spatial arrangement, with seasonal dynamics. Nick Davies (NIWA, NZ) is developing CASAL estimators to be applied to the same data and structure as the Multifan-CL model. At this time, the choice between CASAL or Multifan-CL is primarily driven by user familiarity, and the swordfish assessment will provide a practical basis for comparing user-friendliness and numerical performance. The CASAL swordfish implementation is currently not as well developed as the Multifan-CL version. CASAL currently has the advantages that it is in principle able to model sex-specific population characteristics and foraging ground site fidelity migration scenarios. In other respects, we expect similar advantages and disadvantages to Multifan-CL.

Assessment Results to Date

The assessment papers referred to in this text were primarily intended as methodological papers and progress reports to encourage feedback from other scientists, managers and industry. While preliminary, most of the results are consistent in indicating that the fisheries have had a substantial impact on the SW Pacific stock. Results compatible with a more traditional assessment format will be tabled at the WCPFC-SC in Aug 2006, and will represent a synthesis of results from the approaches discussed in this document. The main problems that we are facing, roughly in order of priority, include:

- Interpretation of CPUE series as relative abundance indices
- Migration dynamics and stock structure
- Stock recruitment relationships
- Natural mortality

All of these models seemingly have the ability to generate predictions that fit the available observations reasonably well, however the estimated model parameters are often not in agreement with our prior expectations of the stock dynamics. This is most evident for the migration dynamics, in which the timing and direction of movement is often counter-intuitive given our pre-conceived notions of spawning migration. The simulation testing and further comparison of models will help to illustrate whether or not the alternative plausible migration models are likely to have important management implications.

Management Strategy Evaluation

We recognize that the preceding stock assessment approaches alone might not provide results that are sufficiently precise to meet joint objectives of biological conservation and optimal economic utilization. Alternative solutions may be required to develop robust management strategies, potentially including formal Management Strategy Evaluation. Campbell and Dowling (2003) describe a possible approach to MSE for SW Pacific swordfish. One of the outcomes of this work was the recognition that the MSE operating model needs to be more closely linked to a thorough assessment process, as the management procedures need to be tested in relation to the best estimates of stock dynamics and associated uncertainty. Thus we tend to view the MSE approach as complementary to stock assessment rather than an independent alternative solution that can entirely bypass the problems of stock assessment.

Simulation Testing

An integral part of the SW Pacific swordfish assessment involves the use of simulation studies (e.g. Kolody et al 2004). In actual assessment applications, we rarely acquire much feedback about the performance of our methods, because we never know what the real state of the world was. By using simulation models to create plausible fisheries data, we are able to compare model estimates with the known population characteristics of the simulator. This helps us to identify the limitations of different assessment approaches and potentially compare the value of collecting alternative types of data to improve assessments. For SW Pacific swordfish, we have developed a simulator that represents alternative plausible swordfish populations, with which we will compare different Multifan-CL, CASAL and production model estimators. This will in turn be used to inform the actual assessment applications.

Swordfish Tagging in the SW Pacific

Given the potential importance of migration in understanding swordfish dynamics, a number of tagging initiatives have been undertaken in the South Pacific. Australia has released several hundred conventional tags and 2 P-SAT tags. Several more P-SATs are being released in 2006, plus a handful of GPS tags. New Zealand intends to release a similar number of P-SATs this year. Additional collaborative proposals have been put forward for tagging programs in more eastern regions of the South Pacific (Cook Islands and Easter Island) and there are plans for tag releases in the North Pacific. These studies should provide important information about alternative movement hypotheses. Similar initiatives are encouraged in the Indian Ocean and CSIRO Marine and Atmospheric Research would be interested in exploring collaborative opportunities in the region.

Genetic Studies

Genetic studies of swordfish population links are also being pursued among several institutions with samples from across the Pacific Ocean.

Conclusions

1. SW Pacific swordfish stock assessment is problematic because of the large uncertainties in the interpretation of CPUE as a relative abundance index, complicated migration dynamics (without direct tagging observations), and the paucity of catch size sampling data. Most of these features are shared with Indian Ocean swordfish stocks and pelagic fisheries in general, and common approaches may be developed across systems.

2. We are using a range of approaches for stock assessment, including data-based indicators, production models and fully integrated assessment models. A key part of our assessment will be the synthesis of results across approaches to identify consistent inferences, and a thorough description of both model and statistical uncertainty. Whether or not a similar effort is justified in the Indian Ocean at this time is a topic for discussion, but it would certainly be possible to further explore data-based indicators and it would be feasible to apply production models at the March 2006 IOTC-WPB meeting, if the available data show general consistency with production model assumptions.

3. Initiatives to develop management strategies that are robust to the major assessment uncertainties should be developed in parallel to the stock assessment process, with constructive dialogue among the relevant stakeholders in the wider region of the SW Pacific. It is likely that assessment uncertainties in the Indian Ocean will be at least as large as in the SW Pacific, and if there are worrying indicators of stock status, the process of developing robust management strategies should be pursued even if a reliable stock assessment seems unfeasible.

4. Most of the approaches that we are considering make indirect inferences about movement. Conventional and/or electronic tagging would be very helpful to constrain the range of plausible assumptions under consideration. We encourage these studies in all of the oceans.

5. Simulation testing will form a key part of the SW Pacific assessment process. We expect that this will provide much more general insight into broader pelagic fisheries assessment methods.

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Table 1. Comparison of assessment approaches for SW Pacific swordfish.

Approach (implemented by)	**Data-based Indicators** (CSIRO, NIWA,SPC and various national fisheries agencies)	**Mooloolaba Depletion Estimator** (CSIRO)	**SDPT** Spatially-disaggregated Pella Tomlinson Production Model (CSIRO)	**Multifan-CL** (Otter Research and SPC. Swordfish Implementation by CSIRO)	**CASAL** (NIWA, NZ)
Progress	Updated annually in recent years in Australian context	Completed in 2005	Various versions implemented, simplest documented	Preliminary version documented in 2005. Update in progress	Preliminary version in development
Purpose	Monitoring fishery trends	interim estimate of Australian catch that will likely not cause further CPUE decline	Monitoring Fishery Trends Quantified prediction of management effects on fishery	Monitoring Fishery Trends Quantified predictions of management effects on fishery Quantifying Uncertainty for potential use in development of robust Management Procedures	
Data Used in Model Fitting:					
Catch by fishery		Mooloolaba only	SW Pacific	SW Pacific (except Spain to date)	SW Pacific
Catch Rate Series		Mooloolaba only	a) Mooloolaba b-c) 3 Aus, 1 NZ, 1 Jpn	3 Australian 1 NZ 5 Japan	3 Australian 1 NZ 5 Japan
Size frequency		no	no	Length and mass	lengths
Model Structure:					
Number of fisheries		1	a) 3 b-c) 5	10-11	10-11
Spatial units		1	a) 3 b-c) 5	5-6	5-6
Time-step		annual	a) annual b-c) quarterly	quarterly	Quarterly or Semi-annual
Age-structure		no	No	yes	yes
Sex-structure		no	no	no (possibly 2006)	yes
Production dynamics		constant over time	Deterministic density-dependent	Age-specific Mortality and stochastic recruitment with SR function	Age-specific Mortality and stochastic recruitment with SR function
Migration dynamics and sub-stock structure		Confounded with Production	ab) homogenous c) foraging site fidelity	homogenous	homogenous or foraging site fidelity
Parameter Estimation:					
Number estimated		2-3	a) 7-12 b) ~65 c) ~25	400+ (~1500 with effort devs)	Likely less than Multifan-CL
MPD calc time		seconds	seconds	~60 minutes	?
Statistical Uncertainty Quantification		Hessian MCMC	Hessian (MCMC for simple cases)	Hessian	Hessian (MCMC doubtful)

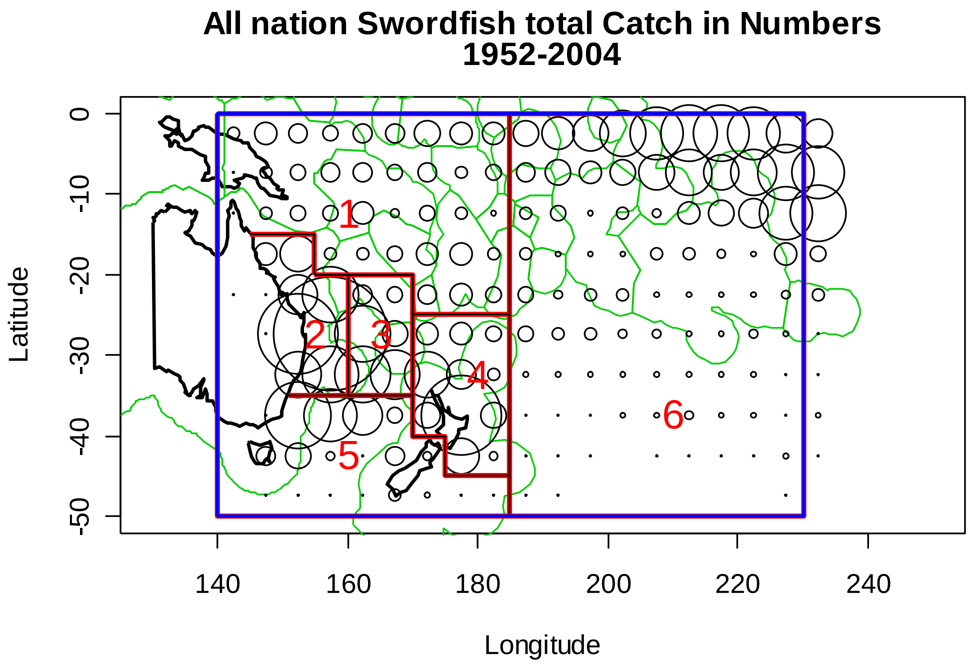


Figure 1. Spatial considerations in the development of the SW Pacific swordfish assessment. Regions 1-5 correspond to the core assessment area, where we have the best understanding of the fisheries data and biology. Area 6 will be incorporated as a sensitivity test. The area of the circles represents the relative catch in each 5X5 degree square summed over 1952-2004. Plots of average CPUE (not shown) suggest similar concentrations of swordfish in the South West and Equatorial-Central regions (but the pattern is less extreme).

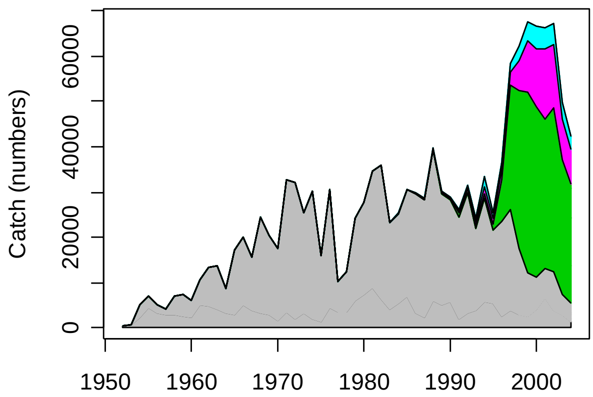


Figure 2. Catch history of SW Pacific swordfish (missing 2004 values assumed the same as 2003). Colours roughly correspond to nation groupings, ascending from bottom: Japan (plus NZ charter and other DWF), Australia, New Zealand (domestic), Pacific Island Nations.

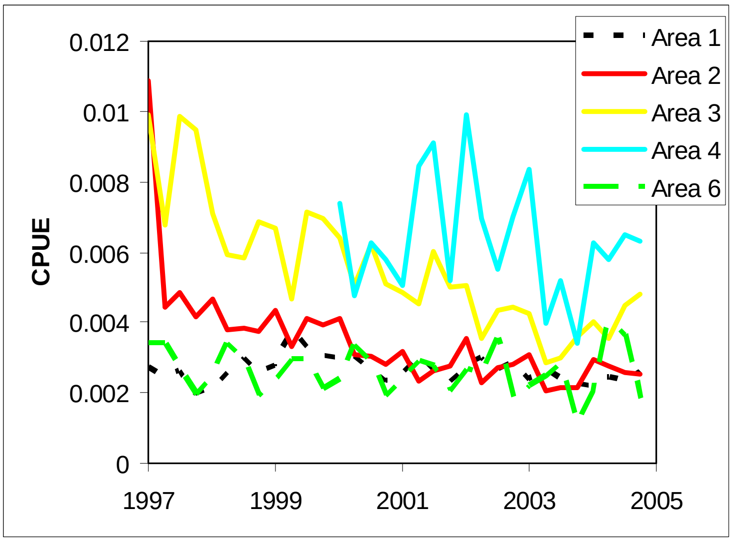
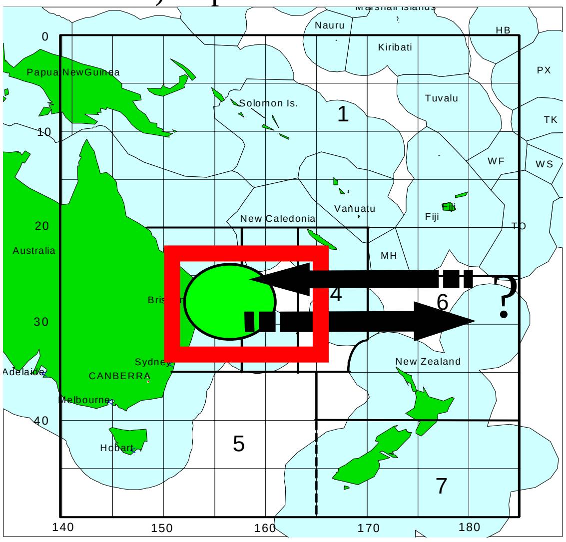


Figure 3. Standardized catch rates in the East Australian fishery, showing strong declining trends in the core area of the fishery (Areas 2 and 3 off Mooloolaba), and less obvious trends further offshore (Area 4), in the northern tropical region (Area 1), and the southern temperate region (Area 5) .

A) Depletion Estimator



B) 3 Area Version of the Spatially Dis-aggregated Production Model (SDPT)

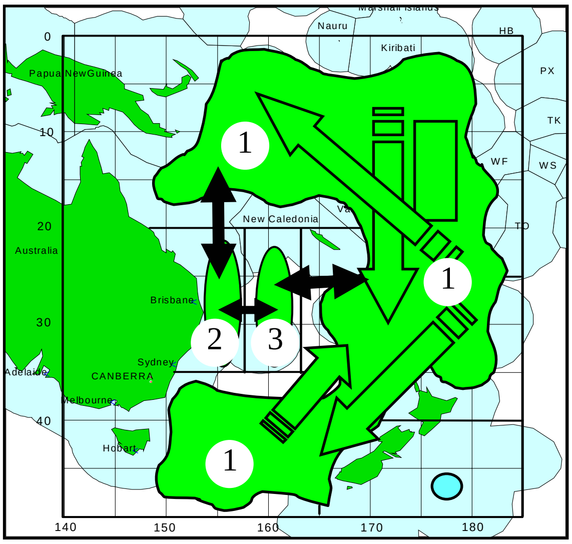
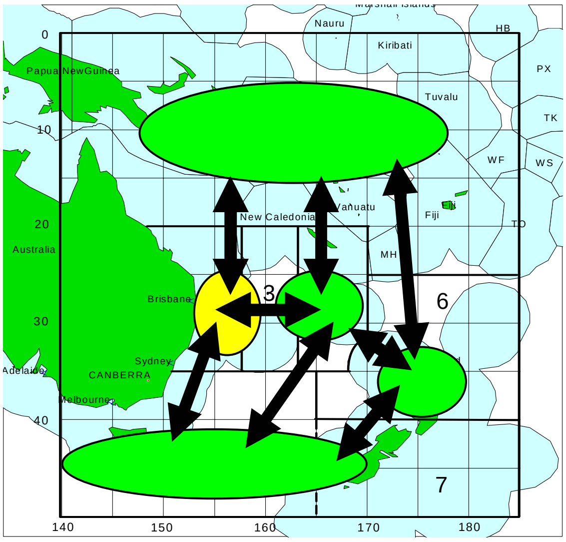


Figure 4. Cartoon spatial representation of interim assessment approaches for the Australian Mooloolaba grounds depletion estimators. Dark arrows indicate explicit movements, opaque shapes indicate explicit sub-populations.

A) Homogenous population spatial structure used in SDPT, Multifan-CL and CASAL



B) Foraging grounds site fidelity spatial structure used in SDPT and CASAL

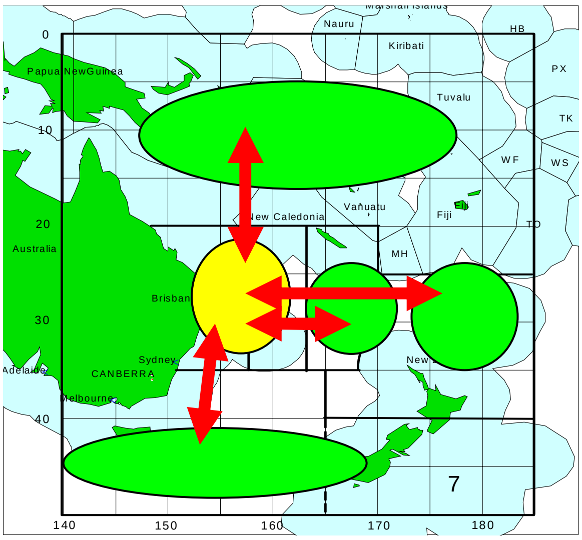


Figure 5. Cartoon spatial representation of the different SW Pacific assessment models discussed. Dark arrows indicate explicit movements, opaque shapes indicate explicit sub-populations (green indicates foraging grounds; yellow indicates spawning grounds).