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Final project report on South-West Pacific Swordfish (*Xiphias gladius*) Stock Assessment 1952-2007

WCPFC-SC5-2009/GN-IP-2

Dale Kolody[1], Robert Campbell[2], and Nick Davies[3]

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[1] CSIRO Marine and Atmospheric Research, Hobart, Australia
[2] CSIRO Marine and Atmospheric Research, Aspendale, Australia
[3] NIWA, Ruakaka, New Zealand

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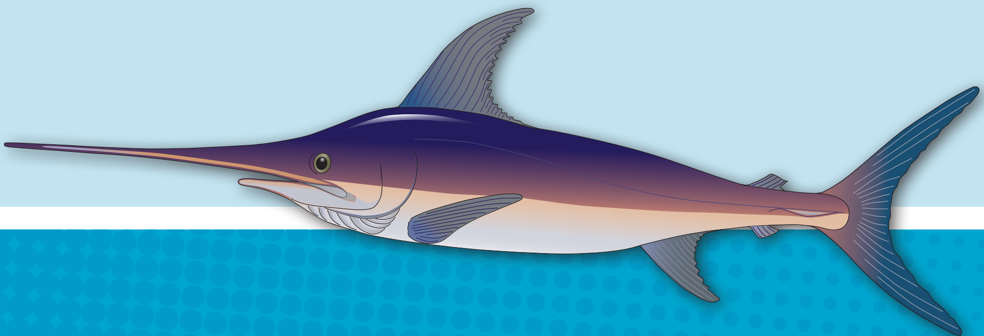

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South-West Pacific Swordfish *(Xiphias gladius)* Stock Assessment 1952-2007

December 2008

Dale Kolody – CSIRO Marine and Atmospheric Research, Hobart, Australia
Robert Campbell – CSIRO Marine and Atmospheric Research, Aspendale, Australia
Nick Davies – NIWA, Ruakaka, New Zealand

NIWA
Taihoro Nukurangi

Australian Government
Australian Fisheries Management Authority

Western and Central Pacific Fisheries Commission

Australian Government
Department of Agriculture, Fisheries and Forestry

South-West Pacific Swordfish (*Xiphias gladius*) Stock Assessment 1952-2007

Dale Kolody
CSIRO Marine and Atmospheric Research, Hobart, Australia

Robert Campbell
CSIRO Marine and Atmospheric Research, Aspendale, Melbourne, Australia

Nick Davies
NIWA, Ruakaka, New Zealand

December 2008

Final report for the funding agencies

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SUMMARY

This report documents the rationale and process for the swordfish (*Xiphias gladius*) stock assessment in the southern region of the Western and Central Pacific Fisheries Commission (WCPFC) convention area undertaken in 2008. This stock assessment was instigated at the request of the WCPFC in relation to Conservation and Management Measure (CMM) 2006-03, which stipulated constraints to the number of fishing vessels permitted to target swordfish in the WCPFC convention area, south of 20°S. CMM 2006-03 was reviewed at the Commission meeting in 2008 in relation to this updated assessment, and subsequently replaced by CMM 2008-05.

Details of the assessment are provided in a series of attached papers that were submitted to the Stock Assessment Specialist Working Group (SA-SWG), a subsidiary body of the Scientific Committee of the Western and Central Pacific Fisheries Commission (WCPFC-SC) in 2008. Attachment 1 provides the primary reference for the assessment modelling methodology and stock status summary. Attachments:

1. Kolody, D., Campbell, R. and Davies, N. 2008. A MULTIFAN-CL Stock Assessment of South-Pacific Swordfish 1952-2007. WCPFC-SC4-2008/SA-WP-6 (Revision 1)

2. Campbell, R. 2008. Data summary pertaining to the catch of swordfish by longline fleets operating in the southern WCPO. WCPFC-SC4-2008/SA-IP-3.

3. Campbell, R., Unwin, M., Davies, N. and Miyabe, N. 2008. Swordfish CPUE trends across the southern WCPO. WCPFC-SC4-2008/SA-IP-4.

4. Kolody, D. and Davies, N. 2008. Spatial structure in South Pacific Swordfish Stocks and Assessment Models. WCPFC-SC4-2008/SA-IP-2.

5. Anon. 2008. Report of the Southern WCPO Swordfish Assessment Workshop (convened 16-18 April, 2008, Secretariat for the Pacific Community, Noumea, New Caledonia). WCPFC-SC4-2008/SA-IP-1.

6. CMM 2008-05. WCPFC Conservation and Management Measure 2008-05. Conservation and management of swordfish.

To help provide an independent review of the assessment process, the authors of this report convened a workshop at the Secretariat of the Pacific Community (SPC) in Noumea 16-18 April 2008 (summarized in attachment 5). International swordfish biologists and assessment experts were invited to review the fisheries data, biological research, and the assessment modelling approach. A number of working papers were produced in support of the workshop and these are listed in Attachment 5. Overall, the workshop was recognized as a very useful exercise to facilitate communication among parties interested in the assessment. Unfortunately, none of the Distant Water Fishing nations were able to attend, though scientists from the European Union did submit a number of working papers.

The assessment represents a collaborative effort between scientists from Australia and New Zealand. Parallel assessment modelling software was employed (MULTIFAN-CL and CASAL), to minimize the impact of model specification and/or software errors. Several hundred models were fit to the data, with a range of alternative plausible biological and statistical assumptions explored to illustrate the current level of uncertainty in this fishery. The assessment was originally intended to cover the entire southern region of the WCPFC convention area (0-50°S; 140°E -130°W) for the period 1952-2007. However, the data were not sufficient to quantify the interactions between the fishery and the swordfish population in the South-Central Pacific (SCP 175°W-130°W), and the available evidence suggested that the SCP population was probably not strongly mixing with the South-West Pacific (SWP 140°E-130°W). As a result, the main quantitative focus of the assessment is on the SWP region only.

While the SWP stock status estimates from the CASAL and MULTIFAN-CL models were broadly similar, there were some unresolved concerns about the reliability of the CASAL function minimization, and it was decided that the MULTIFAN-CL results would provide the basis of the 2008 assessment advice. From the 192 models that were judged to be plausibly consistent with the data and prior expectations for the SWP swordfish population, it was concluded that the fishery has had a significant impact on the population, but there was a high probability that the SWP stock was currently not in an overfished state (B(current)>BMSY) and that current effort levels were probably not over-exploiting the stock (F(current)<FMSY). The available data did not suggest that the SCP fishery was having a sizeable impact on the population, however, the data were not considered to be very reliable. Given that the catch histories are similar in the SCP and SWP, this preliminary and qualitative observation about the SCP stock status should be interpreted with caution.

Data and research priorities for further reducing assessment uncertainties are discussed for both the SWP and SCP swordfish populations in the attached working papers. Notably, it is recognized that the swordfish population structure in the SWP, SCP and the broader Pacific Ocean remains poorly understood, and the interpretation of commercial catch rates as relative abundance indices would benefit from disclosure of operational level data from all fleets. For effective management of these populations, we encourage the pursuit of simulation-tested harvest strategies, which are based on pre-agreed decision rules, and designed to be robust to the major uncertainties to the extent possible.

INTRODUCTION

Background to the 2008 assessment

The first formal stock assessment for South-West Pacific (SWP) swordfish was presented to the Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee (SC) in 2006. The presentation consisted of 2 Methods Specialist Working Group (ME-SWG) working papers (Kolody et al 2006a, and Davies et al 2006), and a synthesis of results for the Stock Assessment Specialist Working Group (SA-SWG) (Kolody et al 2006b). Subsequent to the SC, a final report to the funding body was produced, which we recommend as a single reference for the final assessment (Kolody et al. 2006c).

The 2006 assessment was used as the basis for WCPFC Conservation and Management Measure (CMM) 2006-3, which stipulated constraints to the number of fishing vessels permitted to target swordfish in the convention area, south of 20˚S. While the assessment was positively received at the WCPFC ME-SWG and SA-SWG (WCPFC 2006A), the validity of the assessment was debated during the negotiation of CMM 2006-3 (EC 2006, ANZ 2006) at the subsequent Commission meeting, with none of the stock assessment analysts present. It was recognized that the stock assessment contained many uncertainties and would benefit from additional research. Thus the 2008 assessment was requested by the Commission in relation to the CMM:

> *6. The Commission will review this measure in 2008, on the basis of advice from the scientific committee, following their consideration of an updated swordfish stock assessment that improves the understanding of stock structure and assesses the status of swordfish throughout its range and distribution in the South Pacific Ocean.*

The process for obtaining the updated assessment was agreed at the 2007 Commission meeting (Anon. 2007):

> *72. Some CCMs raised questions regarding a planned assessment of southwest Pacific swordfish. Australia proposed that this will be a full assessment led by Australia and NewZealand on behalf of the Commission, peer reviewed by SPC, and submitted to SC4 for further review and consideration of management actions. Scientists from all CCMs are encouraged to contribute relevant data analyses and biological insight to the assessment, and an informal workshop is being held at SPC in April 2008 to facilitate this exchange of ideas.*

A swordfish assessment workshop was convened at the Secretariat of the Pacific Community (SPC) in Noumea (16-18 April 2008), to review the assessment data, new research and the assessment approach. Swordfish biologists and assessment experts were invited from various WCPFC member nations and other regional and international organizations. A number of working papers were produced in support of the workshop (including several from sources other than the assessment team).Overall the workshop was recognized as a useful exercise to facilitate communication among interested parties and to review the fisheries data, biological research, and the assessment modelling approach. A report from the workshop, and revised versions of several of the working papers were submitted to the WCPFC-SC in 2008.

Scientists from Australia and New Zealand collaborated on the 2008 assessment through independently funded projects. The specific objectives of the Australian component of the project are listed below, however, much of the work was a joint effort with co-authorship on most of the project deliverables:

Project Objectives

1. Collate and review the fisheries and biological data required for the stock assessment of swordfish in the southern WCPFC convention area.
2. Update the most plausible ensemble of swordfish assessment models using the methods from 2006.
3. Pursue refinements to modelling methodology to incorporate additional information and attempt to address limitations identified as a result of the 2006 assessment. A workshop will be convened to identify and debate the scientific issues, and swordfish and assessment experts from WCPFC members and cooperating non-members and elsewhere will be invited to attend. Specific analytical tasks include:
    i. Include 2-3 years of additional fisheries data from all fleets. This includes new catch size and sex composition data from the recent NZ observer and port sampling programs, and the full data set from the expanding Spanish fishery;
    ii. Revisit the spatial domain of the assessment in relation to the broader management needs of the WCPFC, to include the South-Eastern region of the WCPFC convention area;
    iii. Revisit migration hypotheses with respect to recent satellite tag deployments and conventional tag recoveries from Australia and New Zealand; and
    iv. Review the methodology used to estimate SW Pacific swordfish maturity, and age-size relationships in relation to other international swordfish populations.

4. Summarise the status of the SW pacific swordfish stock and projected implications of future harvesting.
5. Report stock assessment results to the WCPFC - SC in 2008 (and final report to domestic funding bodies subsequently).

PROJECT OUTPUTS

Annotated bibliography of working papers

The following is an alphabetical list of documents produced partially or wholly under this project (WCPFC-SC = Western and Central Pacific Fisheries Commission – Scientific Committee):

I. Anon. 2008. Report of the Southern WCPO Swordfish Assessment Workshop (convened 16-18 April, 2008, Secretariat for the Pacific Community, Noumea, New Caledonia). WCPFC-SC4-2008/SA-IP-1.
    - Includes workshop review and discussion of available data, biological research, assessment issues, description of key Pacific Island swordfish fisheries, and the workplan for the 2008 assessment.

- Attachment 5 of this report

II. Campbell, R. 2008. Data summary pertaining to the catch of swordfish by longline fleets operating in the southern WCPO. WCPFC-SC4-2008/SA-IP-3
  - Describes the available catch, effort and size composition data by fleet and sub-region within the southern WCPFC convention area.
  - A preliminary version of this report was circulated at the April workshop
  - Attachment 2 of this report

III. Campbell, R., Unwin, M., Davies, N. and Miyabe, N. 2008. Swordfish CPUE trends across the southern WCPO. WCPFC-SC4-2008/SA-IP-4.
  - Discusses the calculation and trends of nominal and standardized effort (and CPUE) series from various fleets in the South Pacific.
  - A preliminary version of this report was circulated at the April workshop
  - Attachment 3 of this report

IV. Davies, N., Bian, R., Kolody, D., Campbell, R. 2008. CASAL Stock Assessment for South-West-Central Pacific Broadbill Swordfish 1952-2007. Final Research Report for Ministry of Fisheries Research Project SWO200701 Objective 4. N.Z. Ministry of Fisheries, Wellington. 83 p.
  - This represents the final version of the CASAL stock assessment.
  - A preliminary version of this report was circulated as WCPFC-SC4-2008/SA-WP-7.

V. Kolody, D. 2008. Exploratory update of the 2006 South-West Pacific swordfish Multifan-CL assessment.
  - A preliminary update of the 2006 swordfish assessment presented to the April 2008 workshop. Results are superceded by document 6.

VI. Kolody, D. and Davies, N. 2008. Spatial structure in South Pacific Swordfish Stocks and Assessment Models. WCPFC-SC4-2008/SA-IP-2
  - Discusses the available data used to derive the spatial structure of the South Pacific swordfish population, including results of genetic analyses, tagging studies, the relative homogeneity of fisheries, CPUE and catch size composition data.
  - A preliminary version of this report was circulated at the April 2008 workshop
  - Attachment 5 of this report

VII. Kolody, D., Campbell, R. and Davies, N. 2008. A MULTIFAN-CL Stock Assessment of South- Pacific Swordfish 1952-2007. WCPFC-SC4-2008/SA-WP-6 (Revision 1)
  - This working paper details the modelling approach and provides the basis for the management advice as provided to the WCPFC-SC
  - Attachment 1 of this report

VIII. Kolody, D., Davies, N. and Campbell, R. 2008. Review of issues in the 2006 SW Pacific swordfish assessment.
  - Overview of assessment uncertainties and issues presented to the April 2008 workshop.

Assessment presentation to the Australian Eastern Tuna and Billfish Fishery Resource Assessment Group

The updated swordfish assessment was presented to the ETBF RAG in July 2008. Results are currently being used to represent the current stock status and uncertainty in an ongoing project to develop robust harvest strategies for the ETBF fishery (FRDC project "*Integrated evaluation of management strategies for tropical multi-species long-line fisheries*", Principle Investigator Campell Davies).

Assessment presentation to the WCPFC-Scientific Committee

A synthesis of the MULTIFAN-CL and CASAL assessments was presented to the SA-SWG at the fourth Scientific Committee of the WCPFC in Aug 2008. The analyses concluded that the population structure of swordfish in the South Pacific remains uncertain, and different spatial boundaries were investigated. Key points are highlighted in relation to the different geographical regions below.

South-West Pacific (SWP) stocks

A summary plot comparing key stock status reference points from the Multifan-CL and CASAL model results is illustrated in Figure 1. The plot suggests that the CASAL results are somewhat less optimistic than MULTIFAN-CL on average, with some particularly pessimistic outliers.

The assessment analysts agreed that the MULTIFAN-CL and CASAL results were broadly compatible, but that the MULTIFAN-CL results would form the basis of the advice to the WCPFC for the following main reasons:

- The CASAL results were affected by function minimization problems to a large and unknown degree. For both the CASAL and MULTIFAN-CL approaches, a large number of models were fit to the data using an automated process that did not include routine testing of the reliability of the function minimization. When a sample of the models were individually tested for minimization reliability, the CASAL results often yielded substantially different estimates, depending on the initial parameter values. This was discovered too late to be corrected for the WCPFC-SC. In contrast, the MULTIFAN-CL results proved to be very robust to the initial parameter specifications (and the procedures used to control the intermediate phases of the function minimization process). We cannot be certain that the MULTIFAN-CL software always identified the global minimum, however, this is true for virtually all complicated stock assessment models. In this case, we can at least conclude that the MULTIFAN-CL function minimization process performed better than CASAL.

- The CASAL model used a "weightless" specification (Davies et al. 2008), which means that the stock-recruitment is based on numbers, rather than the more conventional spawning biomass. This has implications for the dynamics and reference point calculations, and presumably explains an additional part of the divergence in the estimates shown in Figure 1.

The stock status estimates are described in Attachment 1. Relative to the 2006 SWP assessment, the most recent stock status estimates from the 2008 assessment are more optimistic. This is consistent with expectations given the large reductions in catch and effort observed in recent years. Relative to MSY, the biomass and fishing mortality reference points from the 2006 and 2008 assessments exhibit very similar measures of central tendency (i.e. for 2004, the last year of data in the first assessment), however the uncertainty appears to be greatly reduced in 2008. The reduced uncertainty is attributed to: i) 2-3 additional years of data improve the precision of recent cohort strength estimates, ii) reduced catches plus increasing catch rates have interrupted the "one-way trip" history of the fishery, such that these time series may now provide more informative contrast with which to estimate productivity, and iii) the spatial structure of the model was revised in relation to insight gained from the 2006 assessment and recent tagging studies.

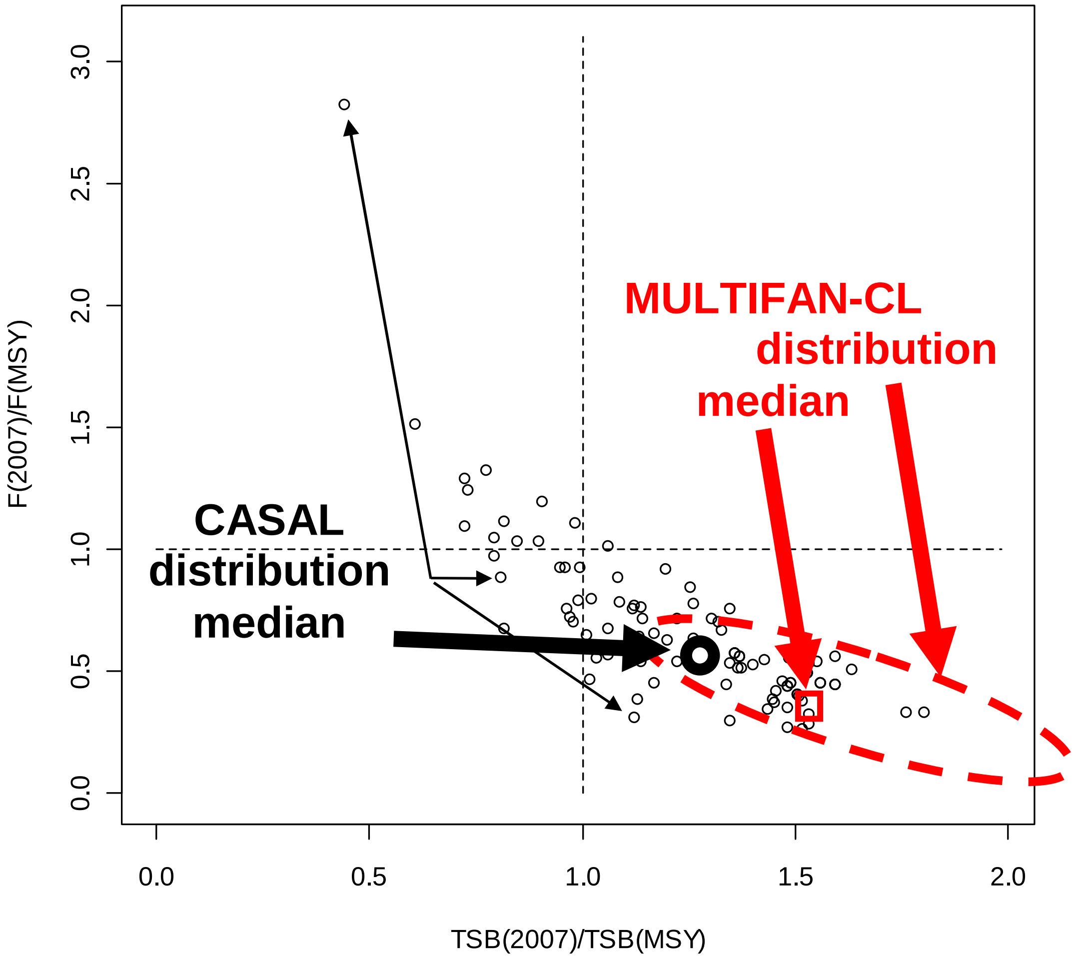

Figure 1. A comparison of MSY-related stock status reference point estimates for the MULTIFAN-CL and CASAL models. CASAL results show Maximum Posterior Density estimates for 103 individual model results (small black circles) and the median (large circle), while the broken red ellipse shows the envelope that encompasses the 192 MULTIFAN-CL results and the square marks the median.

South-Central Pacific (SCP) stocks

Various attempts were made to model the dynamics of the combined SWP and SCP stocks using both MULTIFAN-CL and CASAL. There was also an attempt to conduct an assessment only on the SCP using CASAL. These efforts were not considered to be successful, primarily because of the poor quality and quantity of data in the SCP region. The available data did not provide much evidence for a sizable fishery impact on the SCP stock. However, given that the catch histories are similar in the SCP and SWP, this preliminary and qualitative observation about the SCP stock status should be interpreted with caution.

Feedback from the WCPFC

The SA-SWG accepted the assessment as the basis for the stock status summary, and emphasized specific data concerns (WCPFC 2008):

- *"...the SA-SWG recognized that there is still uncertainty surrounding stock structure of swordfish in the southern Pacific Ocean that impacts on the interpretation of stock assessment results."*
- *"The SA-SWG noted the importance of carefully examining operational factors that may influence catchability and encouraged full data disclosure from all parties and participation in future activities (such as the open workshop) looking to address these issues further."*

The SA-SWG noted the following points in relation to management advice:

- *"...the available data (CPUE, genetics, etc.) suggest limited mixing between the southwest and the south-central Pacific. The implications are that management responses in each area may be different. The SASWG also noted that until this issue is resolved, it is more precautionary to manage on the basis of two separate stocks in the South Pacific."*
- *"A suggestion was made that, given the lack of a formal assessment in the south-central Pacific, a precautionary approach would be to constrain fishing mortality to recent levels until better understanding of fishing impacts in that region can be determined."*

The WCPFC Scientific Committee made two management recommendations for swordfish:

- *"The SA-SWG reviewed the second regional assessment undertaken for swordfish in the southwestern Pacific region. This assessment indicated an increase in stock abundance in recent years and the model projections predict further increases at current levels of fishing mortality. Plausible assessment results indicate that overfishing is not occurring and the stock is not in an overfished state. However, due to uncertainty in the assessment, the SA-SWG recommended there be no further increase in catch or effort in order to keep the stock above its associated reference points."*
- *"The SA-SWG recommended that there be no increases in fishing mortality for southcentral Pacific swordfish as a precautionary measure, given the lack of a formal assessment. Constraining fishing mortality to current levels is recommended until there is a better understanding of fishing impacts in the south-central Pacific stock and the relationship between this stock and other South Pacific stocks is more certain."*

Swordfish management was debated at the subsequent Commission meeting. Key points are extracted from WCPFC (2009):

- "Some Members considered that the assessment did not indicate any problem with the stock, since the stock was neither overfished or in an overfished state and that the current measures in place (CMM 2006-03) could be rolled over in its present format. Other developing State and participating territory CCMs expressed concerns about a rapid increase in effort and catch in the south west Pacific swordfish which may adversely impact their development aspirations in the fishery."

- "Some CCMs stated that the fact that a stock was not determined to be overfished or subject to overfishing was not a suitable basis for taking no management action. They noted that the objective of the Commission is for the long-term conservation and sustainable use of fish stocks and that this requires that management action is taken before stocks are overfished and is consistent with good fisheries management and the precautionary approach."

The Commission adopted CMM 2008-05 (attachment 6 of this report) for swordfish, replacing CMM 2006-03. In addition to limiting the number of vessels permitted to fish swordfish south of 20°S, the new measure also restricts the catch permitted by each nation in this region.

ACKNOWLEDGEMENTS

This project was jointly funded by DAFF, AFMA and CSIRO (Australia), the WCPFC , and indirectly through collaborative arrangements, NIWA and the New Zealand Ministry for Agriculture, Fisheries and Forestry. We are grateful to many people that contributed data, analysis, constructive criticism and software to various components of this project. David Fournier, and the Multifan-CL development team provided the main assessment software. John Hampton, Simon Hoyle and Adam Langley provided useful suggestions to the assessment and software. Naozumi Miyabe, Peter Williams, and Martin Unwin provided much of the data and supporting analyses for CPUE standardization. Chris Wilcox, Karen Evans, Toby Patterson, John Holdsworth, Tim Sippel and Michael Hinton provided unpublished data related to swordfish movement and population genetics. Andre Punt, Peter Ward, Malcolm Haddon, Campbell Davies and Sung Kwon Soh provided helpful suggestions on earlier drafts of some components of this report. Participants in the swordfish assessment workshop and ETBF Resource Assessment Group provided valuable insight into local swordfish fisheries.

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LIST OF ATTACHMENTS

1. Kolody, D., Campbell, R. and Davies, N. 2008. A MULTIFAN-CL Stock Assessment of South- Pacific Swordfish 1952-2007. WCPFC-SC4-2008/SA-WP-6 (Revision 1)

2. Campbell, R. 2008. Data summary pertaining to the catch of swordfish by longline fleets operating in the southern WCPO. WCPFC-SC4-2008/SA-IP-3.

3. Campbell, R., Unwin, M., Davies, N. and Miyabe, N. 2008. Swordfish CPUE trends across the southern WCPO. WCPFC-SC4-2008/SA-IP-4.

4. Kolody, D. and Davies, N. 2008. Spatial structure in South Pacific Swordfish Stocks and Assessment Models. WCPFC-SC4-2008/SA-IP-2.

5. Anon. 2008. Report of the Southern WCPO Swordfish Assessment Workshop (convened 16-18 April, 2008, Secretariat for the Pacific Community, Noumea, New Caledonia). WCPFC-SC4-2008/SA-IP-1.

6. CMM 2008-05. WCPFC Conservation and Management Measure 2008-06. Conservation and management of swordfish.

Attachment 1. A MULTIFAN-CL Stock Assessment of South-Pacific Swordfish 1952-2007. WCPFC-SC4-2008/SA-WP-6 (Revision 1).(90p.)

SCIENTIFIC COMMITTEE
FOURTH REGULAR SESSION

11-22 August 2008
Port Moresby, Papua New Guinea

A MULTIFAN-CL STOCK ASSESSMENT OF SOUTH-WEST PACIFIC SWORDFISH 1952-2007

WCPFC-SC4-2008/SA-WP-6
(REVISION 1)

Dale Kolody[1], Robert Campbell[2], Nick Davies [3]

[1]CSIRO Marine and Atmospheric Research, Hobart, Australia
[2]CSIRO Marine and Atmospheric Research, Aspendale, Australia
[3]Secretariat of the Pacific Community, Noumea, New Caledonia

WCPFC-SC4-2008-SA-WP-6 (REVISION 1*)

* This paper is a revision of the original submission 23 Aug 2008. The quantitative stock status summary remains unchanged, however, the presentation has been expanded and some errors corrected.

A MULTIFAN-CL Stock Assessment of South-West Pacific Swordfish 1952-2007

Dale Kolody [1]
Robert Campbell [2]
Nick Davies [3]

[1]CSIRO Marine and Atmospheric Research, Hobart, Australia
[2]CSIRO Marine and Atmospheric Research, Aspendale, Australia
[3]Secretariat of the Pacific Community, Noumea, New Caledonia

Executive Summary

This paper describes a stock assessment for broadbill swordfish (*Xiphias gladius*) in the Southern region of the WCPFC convention area (0-50°S; 140°E -130°W) for the period 1952-2007 (including constant catch projections to 2017). The previous assessment (covering the period up to 2004) considered only the South-West Pacific (SWP) with an eastern bound of 175°W. The inclusion of the South-Central Pacific (SCP) in 2008 was in response to a request from the Commission to revisit WCPFC Conservation and Management Measure (CMM) 2006-3, which limits swordfish fishing effort in the southern WCPFC convention area, south of 20°S. There was a two-tiered approach to the assessment this year. The SWP was given the highest priority, because the evidence suggests that the population in this region may form a reasonably discrete sub-population, and there is compelling evidence to indicate that the population has declined due to fishing. A combined assessment on the SWP-SCP region was attempted as a lower priority because i) the available data in the SCP are poor, and ii) there is little evidence to suggest a strong link between the two populations (and it is plausible to assume that the SCP might be more closely linked with the north-central and/or south-east Pacific).

In the SWP, swordfish have been taken primarily as by-catch in the Japanese tuna longline fisheries since the 1950s, with reported annual catches fluctuating around 2000 *t* over the period 1970-1996. Japanese catches declined since the late 1990s, when the targeted Australian and New Zealand longline fisheries rapidly developed, with total annual catches averaging around 4000 *t* from 1997-2002. Catches have declined from 2002-2007, with total catches in 2006-7 now around the levels observed prior to 1997. Fiji, Papua New Guinea, Vanuatu and New Caledonia have reported the largest catches among the Pacific Island nations. Standardized catch rates declined substantially for all the major fleets during the period from around 1999-2004. Since 2004, there has been a substantial increase in the Australian and New Zealand catch rates, however, the increase is not as evident in the Japanese fleet. Mean size composition has declined in the well-sampled Australian fishery since the mid 1990s. Most of the swordfish catch in the SWP is taken in the region between 20-40°S.

The magnitude of the SCP swordfish catches has been comparable to the SWP since around 2000. Unlike the SWP, the majority of the swordfish in the SCP have been taken as by-catch in the equatorial tuna longline fisheries. Japanese SCP swordfish have been primarily a by-catch species since the early 1950s, and Korean catches began in the mid-1970s. Taiwanese fleets have taken substantial catches since ~2000. Beginning in 2004, the Spanish fleet has rapidly expanded, and this targeted fishery recorded the largest catches of all nations in the SWP-SCP in 2006. French Polynesia, Cook Islands and Vanuatu represent the majority of the SCP Pacific Island catches. There is no compelling evidence for changes in size composition in the SCP catches, however, size data are limited. Swordfish catch rates observed in the SCP suggest that swordfish abundance is stable or increasing in recent years. However, the operational level data available for conducting catch rate standardization analyses are limited, and some conflicting trends suggest that targeting changes are affecting CPUE trends for at least some of the fleets.

Major changes from the 2006 assessment include:

- Two-three years of additional data, which includes informative contrast in catch levels and CPUE in the SWP
- Simplification of the spatial structure within the SWP
- Quantification of swordfish mixing rates on the basis of recent Pop-up Satellite Archival Tags (PSAT) and conventional tagging studies
- Correction of catch data from NZ (~25% of landings were omitted in 2006)
- Additional size composition data (NZ port sampling from 2006-7, Spanish observer data from 2004)
- Exploration of alternative growth curves and maturity schedules, in light of evidence of methodological variability among laboratories
- Exploration of models that include the SCP population

This paper describes a quantitative stock assessment using MULTIFAN-CL software, while parallel comparative work was undertaken with CASAL (WCPFC-SC4-2008/SA-WP-7). The SWP assessment involved a substantial exploration of model uncertainty, with 768 model specifications proposed. All SWP models were age-structured (ages 0-19+), sex-aggregated, iterated on a quarterly timestep (1952-2007), spatially-disaggregated into two roughly equal longitudinal units, with 11 fisheries and 4 informative effort series. The varying model assumptions in the uncertainty 'grid' were explored in a balanced factorial design with:

- 2 stock recruitment curve steepness priors (0.65, 0.9)
- 2 diffusive mixing assumptions (0.05, 0.1 per quarter)
- 8 growth rate / maturity / mortality options
- 2 recruitment deviation options (SD of log-normal deviates = 0.1, 0.5)
- 2 sample size down-weighting options for catch-at-size likelihoods (1/5, 1/20)
- 3 relative weighting options for CPUE indices (fleets weighted differently)
- 2 selectivity constraint options

From this combination of models, 192 (defined as the Most Plausible Ensemble - MPE) were judged to be plausibly consistent with the data and prior expectations of the swordfish fisheries and biology.

The SWP stock status summary represents a synthesis of the results from all 192 models, from which we reach the following conclusions (estimates represent the median and range of the Maximum Posterior Density (MPD) estimates; it is shown in the text that the parameter estimation error for any individual model is much less than the uncertainty among models):

1) We consider relative biomass estimates for recent years to be the most reliable reference points, because they are the most closely linked to the highest quality data, and are reasonably robust to the alternative model assumptions explored. In 2006, Total Stock Biomass (TSB) was considered to be more reliable than Spawning Stock Biomass (SSB) reference points. However, given the recognition of additional uncertainty in growth rates in 2008, it is not clear that the TSB estimates are more robust than SSB. The Maximum Posterior Density results from the plausible model ensemble indicate:

- TSB(2007)/TSB(1997): median = 0.69, range = (0.55 – 0.83).
- SSB(2007)/SSB(1997) = 0.58 (0.42 – 0.71).

2) The ratio of TSB relative to the biomass estimated to have occurred in the absence of fishing (TSBNF) provides a measure of the fishery impact on the population that might be more meaningful than the biomass ratio at two points in time if the population has experienced non-stationary production dynamics (which many of these assessments suggest to some extent):

- TSB(2007) / TSBNF(2007) = 0.58 (0.45 – 0.79)
- SSB(2007) / SSBNF(2007) = 0.43 (0.31 – 0.63).

3) The data are not sufficient to estimate a stock recruitment relationship reliably, and most of the models explored suggest some form of long-term recruitment variability. This undermines the usefulness of the MSY-related reference points. However, in so far as these reference points have been calculated, all of the MPD estimates from the plausible model ensemble suggest that biomass (total and spawning) is above levels that would sustain MSY, and fishing mortality is below F(MSY).

- TSB(2007)/TSB(MSY) = 1.57 (1.22 – 2.06)
- SSB(2007)/SSB(MSY) = 1.98 (1.20 – 3.46)
- F(2007)/F(MSY) = 0.44 (0.18 – 0.67)

4) The stock projections (assuming deterministic future recruitment from the stock recruitment relationship, and constant catches at 2007 levels), suggest that rebuilding would be likely:

- TSB(2012) / TSB(2007) = 1.19 (1.03 – 1.54)
- SSB(2012) / SSB(2007) = 1.21 (0.91 – 2.07)
- TSB(2017) / TSB(2007) = 1.24 (1.05 – 1.64)

- SSB(2017) / SSB(2007) = 1.41 (0.94 – 2.30)
- TSB(2012) / TSB(MSY) = 1.89 (1.38 – 2.94)
- TSB(2017) / TSB(MSY) = 1.97 (1.43 – 2.99)

Overall, the 2008 SWP assessment yields results that are consistent with the results presented in the 2006 assessment. The uncertainty appears to be substantially reduced in 2008, in that the models are much more consistent in their stock status inferences and none of the models yielded results that were near the extremes that were judged to be plausible in 2006. There are two main factors likely contributing to this perception of reduced uncertainty. First, the 'one-way-trip' nature of the fishery has been interrupted, with recent declines in catch and effort resulting in stock rebuilding, such that the exploitation history now has informative contrast that improves the estimation of productivity. Second, the simplified spatial structure in the 2008 model reduces the flexibility for the model to create spatial refuges and 'cryptic biomass' reserves.

An attempted assessment on the combined SW and SC Pacific was undertaken, with a similar approach to the SWP, and an uncertainty grid of 144 models fit. However, none of the results were satisfying, for reasons that were anticipated during the 2006 assessment and discussed at the swordfish assessment workshop in April 2008 (WCPFC-SC4-2008/SA-IP-1). The nominal and standardized CPUE series from all the major fishing fleets in the SCP are either stable or show a continuous upward trend for the last several years (up to 20 or more) that has been sustained despite a rapid increase in catches. There is also a paucity of size composition data in the SCP. Thus there are no informative signals in either the CPUE or size composition data with which to quantify the fishery impact on the SCP stock. If it is assumed that the SCP CPUE indices provide reasonable relative abundance indices, then all of the models estimate a trend in increasing recruitment for most of the duration of the SCP fishery. In many cases, the models estimate very low stock recruitment curve steepness (i.e. a linear relationship between spawning biomass and abundance), with the paradoxical suggestion that both biomass and recruitment are increasing over time, despite very low MSY and chronic overfishing relative to MSY. In other cases, the models suggest that recruitment is stable or increasing, biomass is very high and the fishery catch is a negligible proportion of the stock. It is possible that the SCP is experiencing a long-term change in recruitment productivity, in which case none of these models are very helpful for predicting what will happen in the future. If this is true, it also suggests that the SCP swordfish population is not rapidly mixing with the SWP population, as the general CPUE trends in the two areas are in opposite directions despite a similar magnitude of catch removals. However, another plausible explanation for the increasing CPUE trends is a change in gear deployment practices in the SCP. One can never be confident that commercial effort standardization is effectively creating an unbiased relative abundance index, and this is particularly true in the SCP, where little operational data on setting procedures is available for the standardization analyses. The Taiwanese fleet in particular seems to have undergone a shift toward targeting swordfish. At present there is no compelling evidence to indicate that the SC Pacific swordfish fishery is over-exploiting the stock, but we do not consider the available data to be very convincing.

Data and research priorities for further reducing uncertainties are discussed for both the SWP and SCP swordfish populations.

1 Introduction

The first formal stock assessment for SW Pacific swordfish (*Xiphias gladius*) was presented to the Western and Central Pacific Fisheries Commission Scientific Committee (WCPFC-SC) in 2006 (spatial domain defined in Figure 1). The presentation consisted of 2 Methods Specialist Working Group working papers (Kolody et al. 2006a, and Davies et al. 2006), and a synthesis of results for the Stock Assessment Specialist Working Groups (Kolody et al. 2006b). Subsequent to the SC, a final report to the funding body was produced which we recommend as a single reference for the derivation of the final assessment (Kolody et al. 2006c). This paper represents an updated assessment that includes additional fisheries data and research that was not available in 2006. The WCPFC requested an update to the swordfish assessment in 2008, as one of the conditions associated with WCPFC Conservation and Management Measure 2006-3 (CMM06-3), which prescribes limits to the number of vessels allowed to target swordfish in the convention area south of 20°S. The Commission is planning to review CMM06-3 in relation to the new assessment.

The 2008 assessment attempts to address a number of concerns that were raised during and since the 2006 assessment, including:

1) The spatial domain is revisited in relation to the spatial domain of CMM06-3 (see Figure 1).

2) The 2006 MULTIFAN-CL assessment did not produce convincing estimates of migration within the South West Pacific, and this problem is revisited in relation to the revised spatial structure and new observations from Pop-up Satellite Archival Tags (PSATs) and conventional tagging.

3) Some comparative work on methods for estimating swordfish ages indicates that there is much greater uncertainty than was previously recognized. This has implications for growth rate, maturity and natural mortality assumptions.

These and other issues are discussed in section 3.2.

A swordfish assessment workshop was convened at the Secretariat of the Pacific Community (SPC) in Noumea (16-18 April 2008), to review the assessment data, new research and the assessment approach. Swordfish biologists and assessment experts were invited from various WCPFC member nations and other regional and international organizations. A number of working papers were produced in support of the workshop, and many of these have been revised for submission to the WCPFC-SC in 2008. A summary of the workshop discussions, and an agreed workplan for the assessment are included in Anon. (2008).

While this paper only describes the MULTIFAN-CL results, parallel work with CASAL was also undertaken in 2008 (Davies et al. 2008). A comparison and synthesis of the two approaches is planned for the WCPFC Stock Assessment Specialist Working Group.

1.1 Fishery History

For the purposes of this assessment, two main fishery regions are defined, the South-West Pacific (SWP) and the South-Central Pacific (SCP) (Figure 1). These regions are further subdivided into 4 areas and several sub-areas (zones) that were used to define homogenous fishery units (Figure 2). The swordfish catch history in the 4 areas are illustrated in Figure 3. Figure 4 separates the catch by area into the major fishing fleets. In this region, swordfish are caught almost exclusively by longliners. They are caught from the equator to around 50°S, with the highest catch rates and targeted fisheries between 20-40°S. Catches north of 20°S tend to be by-catch in tropical tuna fisheries, while catches south of 40°S tend to be predominantly very large females taken as by-catch in the Southern Bluefin Tuna (SBT) fishery.

In the SWP, swordfish have been taken primarily as by-catch in the Japanese tuna longline fisheries since the 1950s, with reported annual catches fluctuating around 2000 *t* over the period 1970-96. Japanese catches declined since the late 1990s, when the targeted Australian and New Zealand longline fisheries rapidly developed, with total annual catches averaging around 4000 *t* from 1997-2002. Catches have declined from 2002-7, with total catches in 2006-7 now around the levels observed prior to 1997. Fiji, Papua New Guinea, Vanuatu and New Caledonia have reported the largest catches among the Pacific Island nations. Standardized catch rates declined substantially for all the major fleets during the period from around 1999-2004. Since 2004, there has been a substantial increase in the Australian and New Zealand catch rates, however, the increase is not as evident in the Japanese fleet operating in the same general areas. Mean size composition has declined in the well-sampled Australian fishery since the mid 1990s.

SCP swordfish catches were lower than the SWP historically, but increased rapidly starting in the late 1990s and have been of comparable magnitude to the SWP since around 2000. Unlike in the SWP, SCP catches have not declined appreciably in recent years. The majority of the swordfish in the SCP have been taken as by-catch in the equatorial tuna longline fisheries. Japanese SCP swordfish have been landed since the early 1950s, and the Korean fleet began operating in the mid-1970s. Taiwanese fleets have taken substantial catches since ~2000. Beginning in 2004, the Spanish fleet has rapidly expanded, such that this targeted fishery recorded the largest catches of all nations in the combined SWP and SCP in 2006. French Polynesia, Cook Islands and Vanuatu represent the majority of the SCP Pacific Island catches. There is no compelling evidence for changes in size composition in the SCP catches, but available catch-at-size data are limited. Swordfish catch rates observed in the SCP suggest that swordfish abundance is stable or increasing in recent years. However, the operational level data available for conducting catch rate standardization analyses are limited, and some conflicting trends suggest that targeting changes are affecting CPUE trends for at least some of the fleets (notably Taiwan).

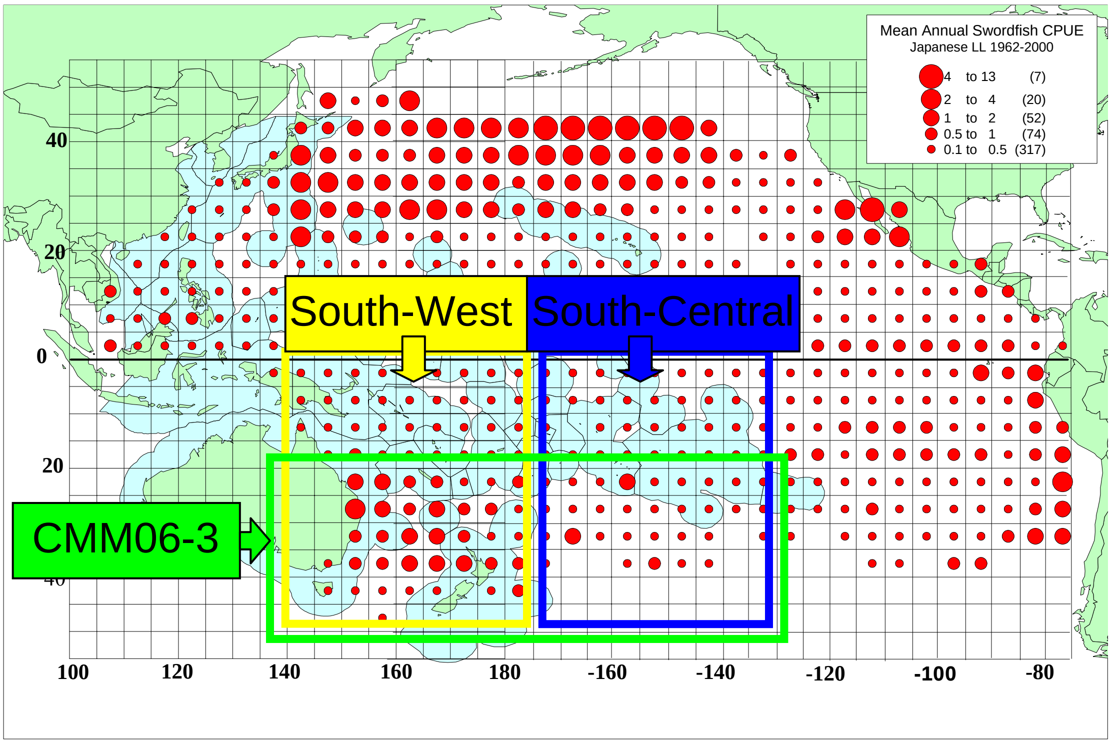


Figure 1. The South-West Pacific (SWP) and South-Central Pacific (SCP) regions as defined in the swordfish assessment, shown in relation to the region defined for Conservation and Management Measure 06-3. The boxes are superimposed on a map of mean nominal Japanese catch rates (1962-2000) which is thought to provide some indication of the relative abundance of swordfish throughout the Pacific.

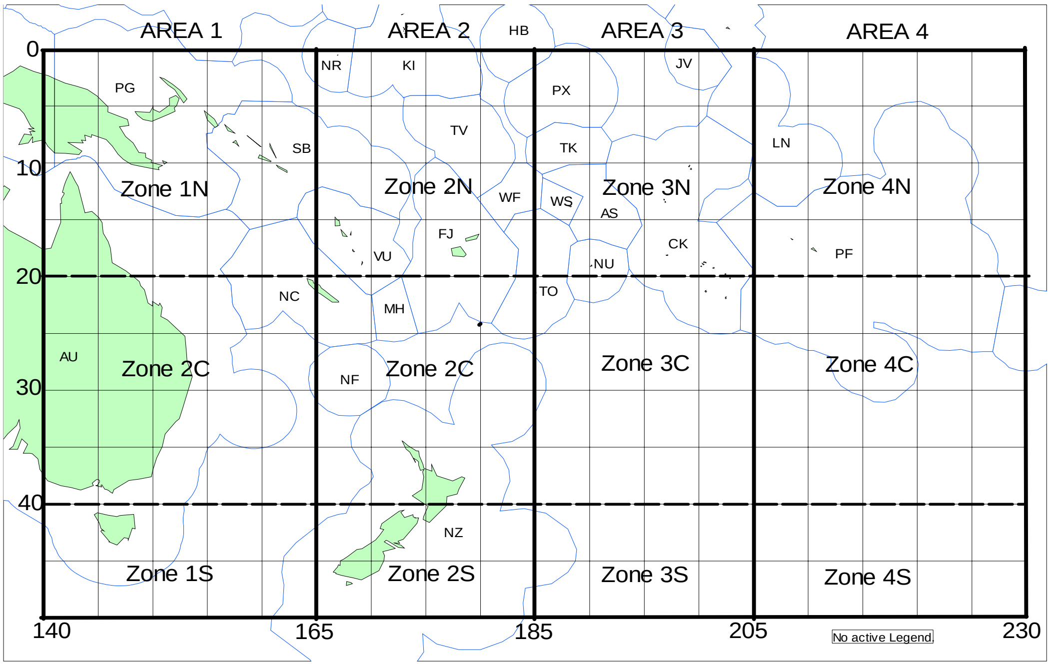
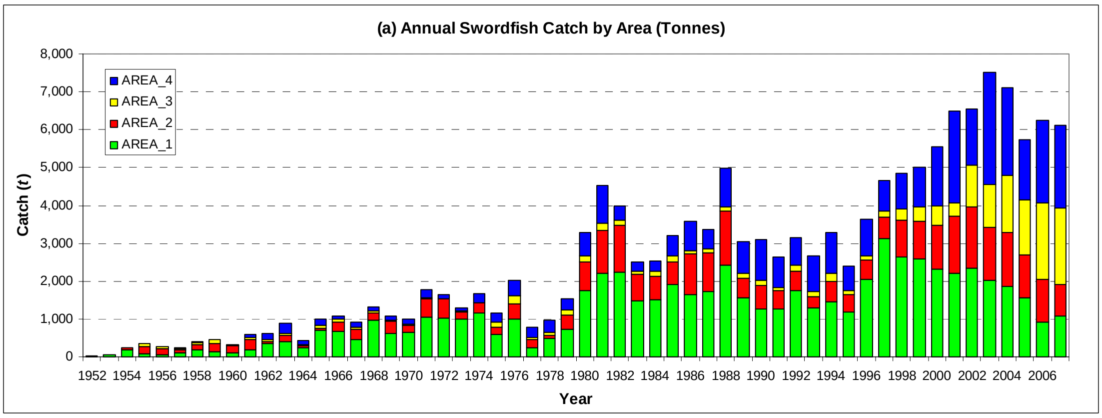


Figure 2. Spatial structure used in the 2008 southern WCPFC swordfish assessment. N, C and S refer to the North, Central and Southern zones of each area and are used to define fisheries. Areas 1-2 are referred to as the South-West Pacific (SWP); areas 3-4 are referred to as the South-Central Pacific (SCP) and combined areas 1-4 are referred to as the South-West/South-Central Pacific (SWP-SCP).



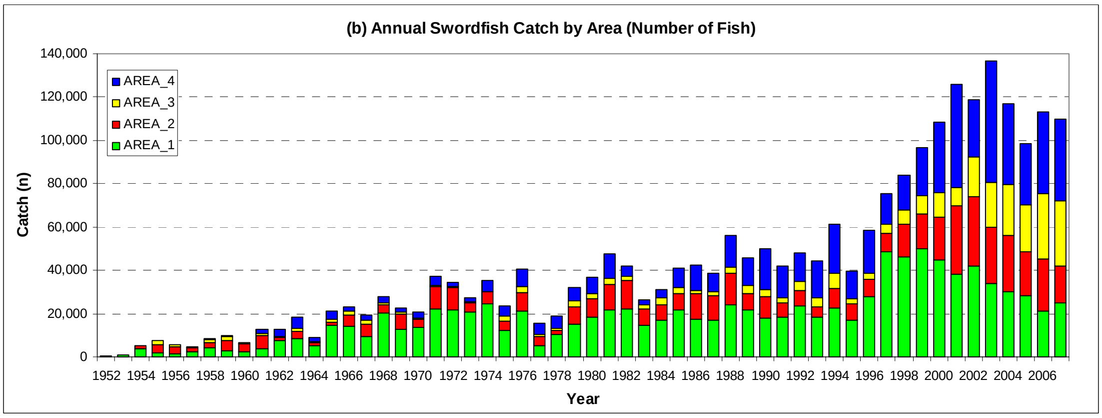


Figure 3. Total swordfish catch in mass (top panel) and numbers (bottom panel) for swordfish in the combined South-West and South-Central Pacific 1952-2007 (note that the 2007 data are incomplete for some fleets and assumed to be equal to 2006 levels). Areas are illustrated in Figure 2.

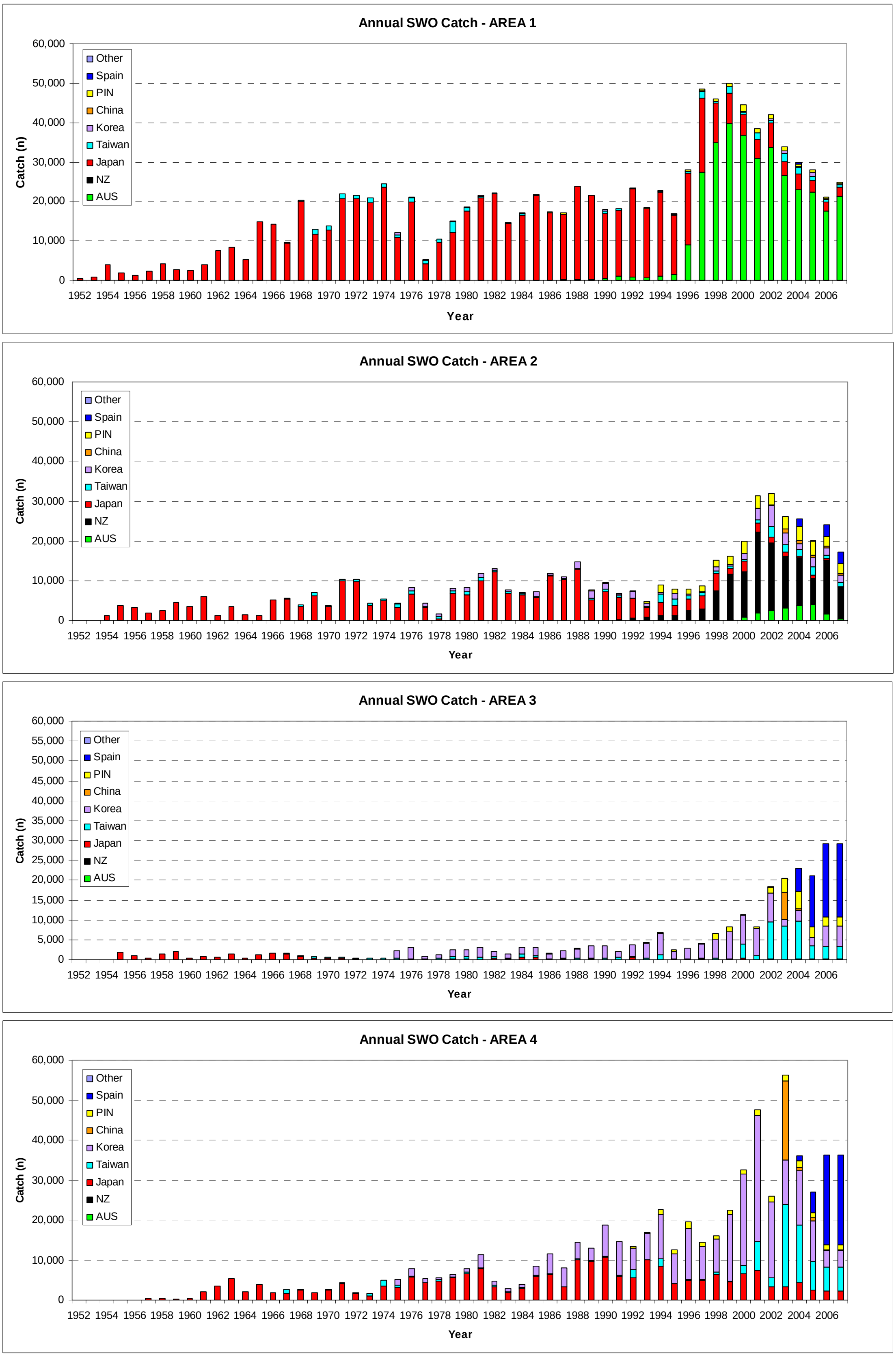


Figure 4. Swordfish catch history (numbers) in the South-West (areas 1-2) and South-Central (areas 3-4) Pacific by fishing nation. Areas are illustrated in Figure 2.

1.2 Swordfish Biology

Swordfish are one of the most widely distributed pelagic species, distributed globally, and observed from 50°N to 50° S and at all longitudes in the Pacific Ocean. Japanese longline catch rate distributions suggest three large, relatively high density areas, the North-West, South-West and Eastern Pacific (Figure 1). In contrast, spawning distributions (as inferred from larval surveys, Nishikawa et al. 1985, and maturity studies, e.g. Young and Drake 2002, Mejuto et al. 2008a) tend to suggest spawning only in tropical and sub-tropical areas, though with conspicuous absence from the Western Pacific equatorial region, and the coastal regions of North and South America. The degree to which individuals migrate and sub-populations mix potentially has important implications for fisheries management, but the effective stock structure is poorly understood. Genetic studies indicate that there is not uniform gene flow among Pacific swordfish populations. Reeb *et al.* (2000) suggest a broad “ ⊃ ”-shaped connectivity pattern, such that the SW and NW Pacific populations are the most distinct from each other, with central and eastern populations intermediate between the two. Alvarado Bremer et al. (2006) concluded that the SE Pacific population was genetically distinct from the NE and SW. There was additional evidence to suggest that the SCP represented a population intermediate between the SW and SE, but it was recognized that sample sizes in the SCP region were not sufficient to be conclusive (Michael Hinton, IATTC, Pers. Comm.).

In recent years, PSAT and opportunistic conventional tagging programs in the SWP have begun to provide direct information about the movement of individuals (Karen Evans and Chris Wilcox, CSIRO, pers. comm.; Holdsworth et al. 2007; Kolody and Davies 2008). Tagging seems to confirm that swordfish undergo directed seasonal migrations between temperate foraging grounds and tropical spawning grounds, but it remains unclear how much site fidelity individuals maintain between these migrations.

Swordfish are sexually dimorphic and seem to have different spatial distributions (e.g. Young and Drake 2002, Mejuto et al 2008a). Potential sexual differences in other life history characteristics are largely unknown (e.g. migration patterns, natural mortality, etc.).

There have been a number of studies on swordfish growth rates and maturity in the SWP (e.g. Young and Drake 2002, 2004; DeMartini et al. 2000, 2007; Mejuto et al. 2008a; Valeiras et al. 2008). However, recent comparative work on methods used among laboratories has suggested that there remains a large degree of uncertainty about some of the basic biology of this species (Young et al. 2008).

2 Data

2.1 Fishery Data

The total catch (in numbers) and size composition data for most fleets were provided from the SPC database. Analyses involving effort standardization of Japanese, Australian and New Zealand fleets were conducted with additional fine-scale data with the cooperation of individuals from the respective countries. The following briefly overviews the assessment data used in 2008. Much more detailed summaries and analyses of the catch, effort and size composition data are provided in Campbell (2008), and catch rate standardization analyses are detailed in Campbell et al. (2008).

2.2 Catch Data

Swordfish catches are commonly reported in numbers and are illustrated by area and fleet in Figure 3 and Figure 4. The catch data used in the SWP assessment data are essentially the same as used in 2006, with the following exceptions:

- Three additional years of data were obtained for most fleets. Australian and New Zealand catch and effort data included 2007 (except the last quarter in the case of NZ), all other fleets included only 2006 (2006 may be incomplete for some fleets). Missing catch data from 2007 was assumed to be identical to 2006; no substitution was made for missing effort.
- In 2006, logbook data was used to estimate the New Zealand catches and this resulted in a bias approximately 25% lower than the estimates provided through the quota management system. Quota management data were used in 2008.
- There remains some uncertainty about the separation of NZ domestic and charter fleet catch data (which might mean that the NZ domestic catch is over-reported by 1-2%). This does not affect the size composition data.
- The New Zealand domestic fishery instigated a comprehensive port sampling program in 2006, which resulted in a large number of size composition samples in 2006-7 relative to previous years.

As swordfish have historically been a by-catch species, there may be catch reporting problems related to discarding, but we have no evidence to suggest that this is an important problem in this fishery.

2.3 Effort and CPUE Data

Pelagic fisheries stock assessment models are generally dependent on the use of catch rates from commercial operations as relative abundance indices. If catch rates cannot be effectively standardized to remove the effects of factors that are confounded with abundance, then the relative abundance indices will likely not be reliable, and one cannot have much confidence in the assessment model results. For targeting fleets, there is always the possibility that efficiency is increasing in ways that are not recorded in logbooks. Equivalently, by-catch fleets might be changing their operations in ways that incidentally change swordfish catchability. In the SWP and SCP assessments, data were only obtainable from three nations with which it was considered possible to attempt estimating informative abundance indices – Japan, Australia, and New Zealand. Important operational level data was either not available for other nations, or the spatial and temporal coverage of the fleets was not sufficient to provide an informative index.

Standardized effort series were used in the assessment on a quarterly time-step. Annual CPUE trends (seasonality removed for clarity) for the SWP are shown in Figure 5. From these plots, the Australian and New Zealand fleets suggest very similar relative abundance trends in areas 1 and 2, with similar declines from 1997-2003, and similar increases from 2003-7. In contrast, the Japanese fleets show a continuous (though noisy) decline from 1997-2006. It is not clear which of the trends is closer to reality, and this is discussed further in section 3.2.14.

Standardized Japanese catch rates from areas 1-4 are shown in Figure 6. Unlike the SWP (areas 1-2), the SCP (areas 3-4) catch rates suggest stable or increasing trends. This is further suggested by the Taiwanese and Korean nominal catch rates (Figure 7). The Taiwanese catch rates in particular show a rapid increase starting ~2000, which suggests a major targeting shift toward swordfish.

We note that standardized catch rates for the Spanish fleet for 2004-6 are provided in Mejuto et al. 2008b, and appear to be stable over this period. Unfortunately, the spatial structure used in this CPUE analysis extended beyond the assessment domain, and there were concerns about the validity of the analytical methods used to account for targeting (Anon. 2008). However, the Spanish fleet represents a promising source of information for future CPUE analyses, and we encourage greater collaboration in the future.

The April 2008 assessment workshop (Anon. 2008) revealed that logbook data from the Taiwanese fleet has been recorded at Pago Pago historically, and this operational level data may be obtainable through collaborative studies with the U.S.A. in the future.

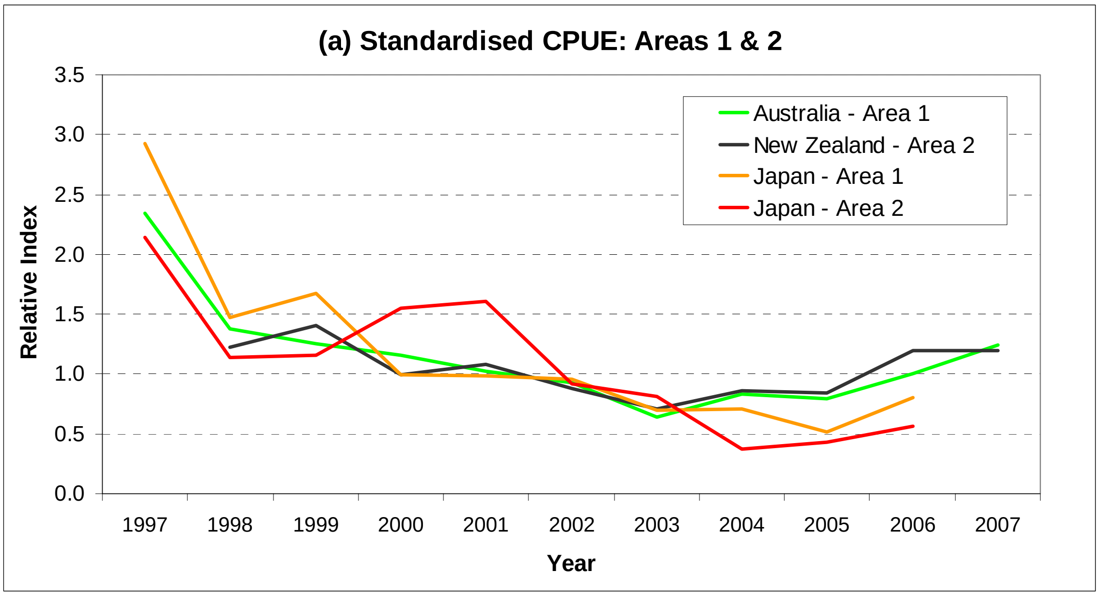


Figure 5. Comparison of standardized catch rates for South-West Pacific fleets from 1997-2007 for the central zone of areas 1 and 2 as defined in Figure 2 (normalized to a mean of unity).

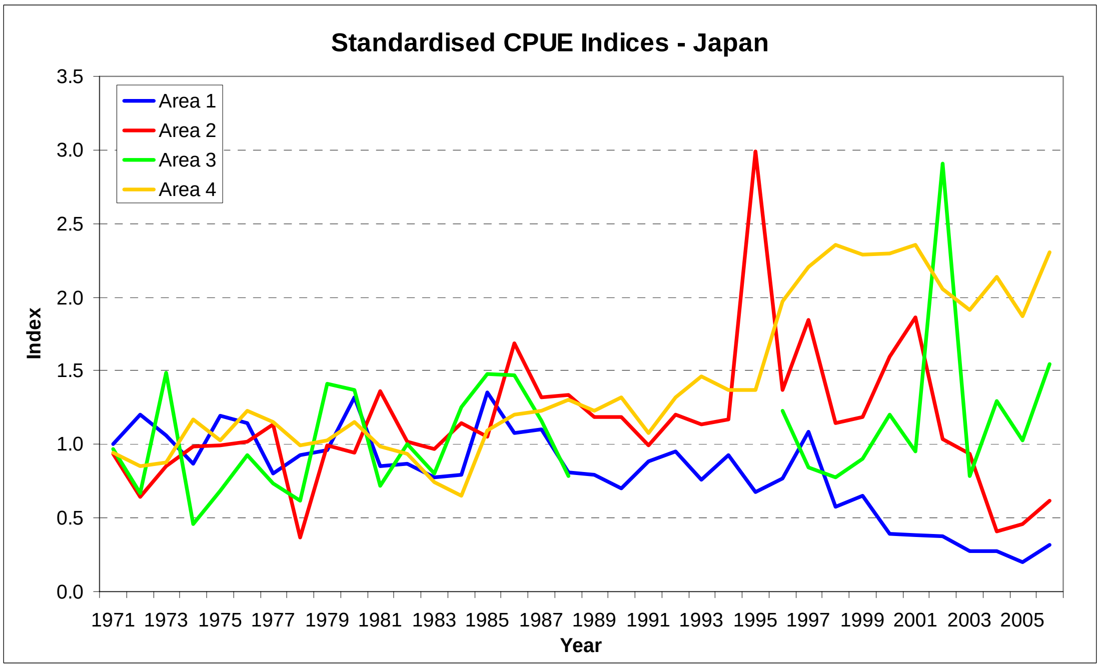


Figure 6. Comparison of standardized catch rates for the Japanese fleet for Areas 1-4 (normalized to a mean of unity).

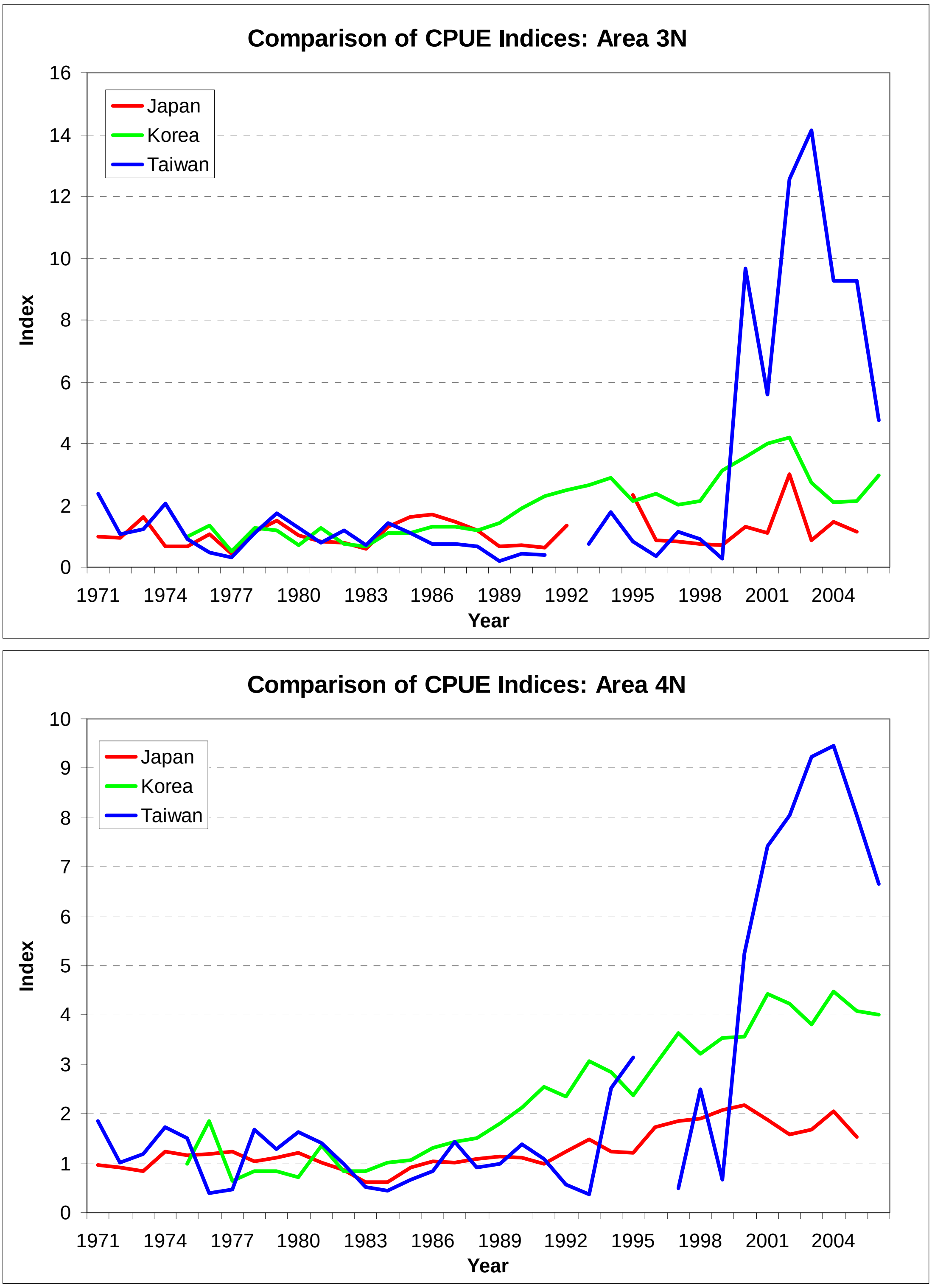


Figure 7. Comparison of DWF nominal catch rates from the South-Central Pacific (the northern zones of Areas 3 (top panel) and 4 (bottom panel)). Areas are defined in Figure 2.

2.4 Size Composition Data

Swordfish catch-at-size is not well sampled for many of the fleets in the assessment area (e.g. Figure 8). Australia has samples about 70% of the domestic catch since 1997, and New Zealand implemented a comprehensive port sampling program in 2006. With the exception of the short time series of the Spanish fleet, there is very little sampling from the SCP. In July 2008, the assessment team became aware that additional Spanish size data from 2005-6 had been provided to the SPC, but these data were not loaded into the SPC database, and hence were not provided in time for inclusion in the assessment. The absence of these data are not expected to make much difference to the current assessment because the 2004 Spanish data were included (which informs the selectivity estimation), and the mean size composition in these data has not changed noticeably in 2005-6.

Figure 9 illustrates trends in mean size composition over time. The Australian fleet is the most heavily sampled, and shows strong evidence for continuously declining sizes over time. When partitioned on a finer spatial scale, there are patterns in size composition evident within the Australian fishery, however, there is no evidence that the overall declining size trend is a result of a trend in the spatial distribution of effort (Campbell 2008).

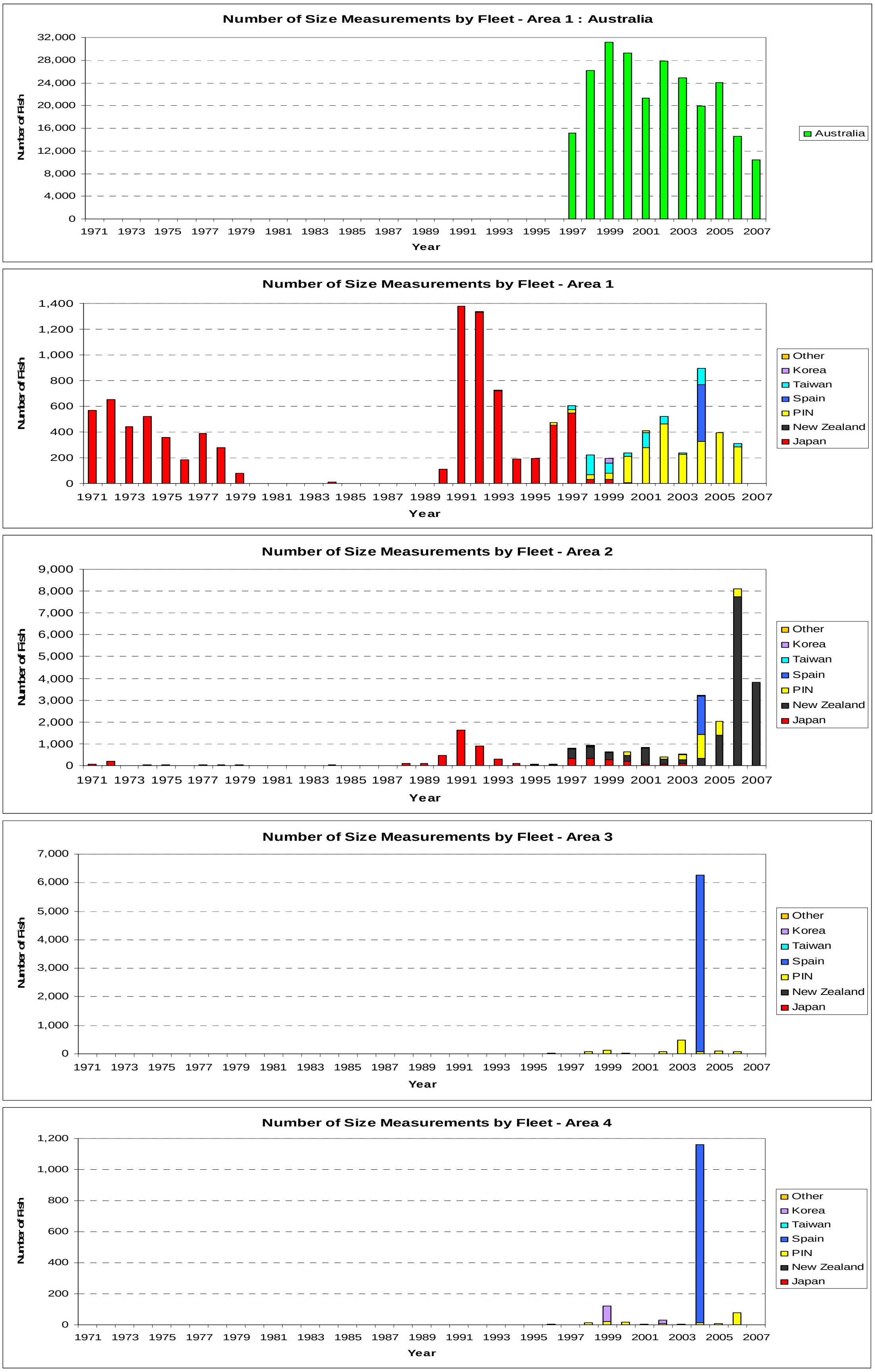


Figure 8. Sample sizes for catch-at-size sampling in the SWSC Pacific by nation. Australian sizes are in mass, all others in length (note that scales differ by area).

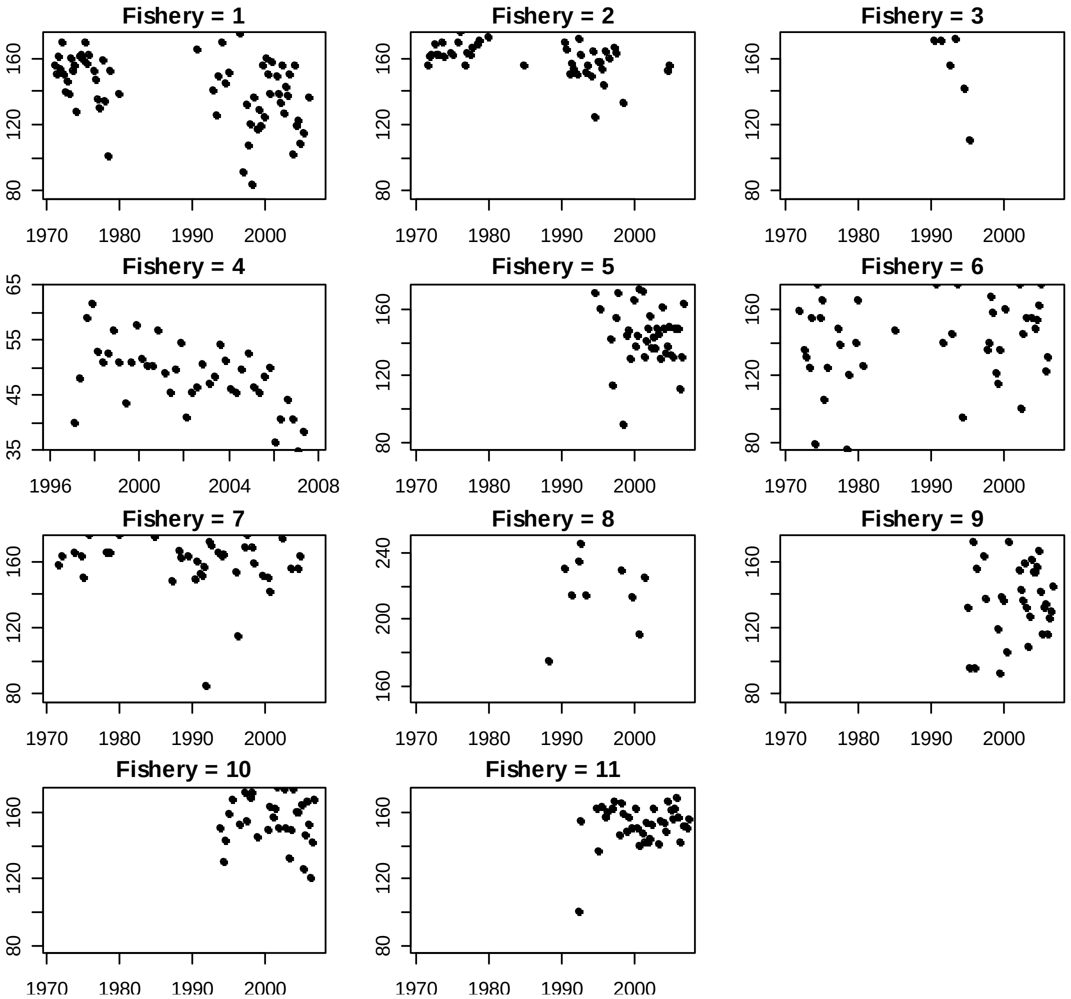


Figure 9. Mean size composition of swordfish catches over time for SWP fleets. Note that the Y-axis scales differ for fishery 4 and 8 relative to the others. Fishery 4 (Australian area 1) is in trunked mass (kg), all other plots are in length (cm).

2.5 Fisheries independent research data

Fisheries independent swordfish research has yielded important insight in three areas since 2006:

- A number of PSAT tags have been deployed by Australia and New Zealand, providing inferences on short term movements, and a few conventional tags have been recovered with longer durations at liberty (up to 6 years) (Figure 10). Tag inferences are discussed in the sections relating to spatial structure and migration assumptions below (3.2.1 and 3.2.10).

- Spatial patterns of catch characteristics in the Spanish fleet have yielded some interesting insights about population demographics. These are discussed further in the section on spatial assumptions (3.2.1) below.

- A comparison of swordfish age estimation methods has revealed substantive differences among labs that do not seem to be resolvable without further research to directly validate the interpretation of fin spine annulus counts. This has important implications for other assumptions as well and is discussed in the sections relating to growth, maturity and mortality assumptions below (3.2.7-3.2.9).

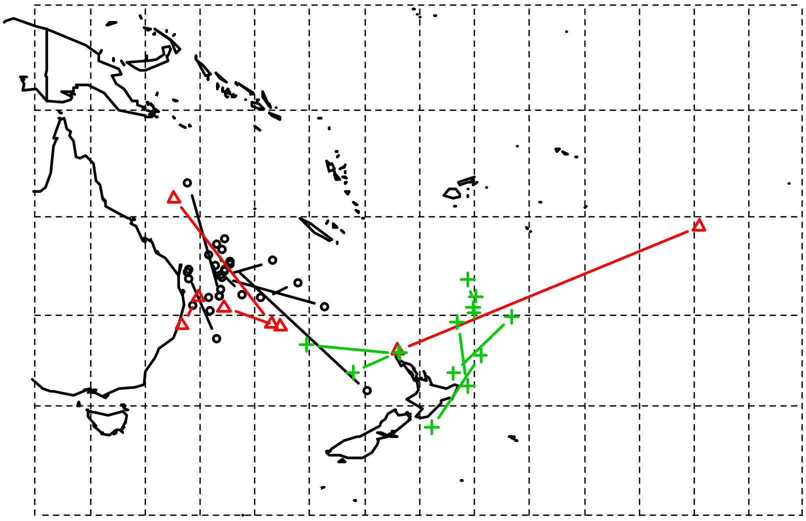


Figure 10. Release and pop-off (or recapture) points for Australian (black circles) and New Zealand (green "+") PSAT tags and conventional tags (red triangles), for tags at liberty between 60 days and 6 years (Figure 8 from Kolody and Davies 2008)

3 Modelling Methods

Recognizing the fact that fisheries assessment problems are almost always over-parameterized (e.g. Schnute and Richards 2001), we would be reluctant to ever assign much credibility to any individual model result. In general, we view complicated integrative population models as tools for exploring the interactions among data and assumptions, identifying conflicts, quantifying robust patterns, and identifying major uncertainties and sensitivities.

3.1 MULTIFAN-CL Stock Assessment Software

Continuing with the general approach used in 2006, the 2008 swordfish assessment involved parallel modelling approaches to ensure a more robust final result. This paper describes the approach and results using MULTIFAN-CL, while Davies et al. (2008) describes an attempt at a CASAL (e.g. Bull et al. 2003) assessment.

MULTIFAN-CL (primarily developed by Otter Research, Ltd.) has a rich set of features tailored for pelagic fisheries assessment and a substantial track record of applications in a spatially-disaggregated context (e.g. Hampton and Fournier 2001). It is a flexible, integrative, numerically efficient, assessment modeling framework initially developed for, and routinely applied to, the assessment of tuna species of the Western and Central Pacific Ocean (e.g. Hampton et al. 2006a,b). Most technical specifications, dynamic equations and statistical assumptions are documented in Kleiber *et al.* (2005).

MULTIFAN-CL provides a flexible statistical framework and efficient function minimization routines to estimate model parameters and reference points derived from these parameters. Parameter estimation consists of minimizing an objective function including (negative log-) likelihood terms, prior probability distributions and smoothing penalties. In addition to estimating the Maximum Posterior Density (MPD), MULTIFAN-CL can calculate the statistical uncertainty associated with parameter estimates using the inverse-Hessian matrix and Delta-method normal approximation and likelihood profiles for many quantities of interest.

The swordfish models were fit in a series of 10 phases in which an increasing number of parameters were estimated in successive phases, with all free parameters fit in the last phase (see SWP bash script in Attachment 1). MULTIFAN-CL also invokes a number of internal strategies in the early stages of the minimization that are not well documented. Together, these processes seem to result in a robust minimization that rarely (in the 2008 swordfish applications) led to results that were identifiable as obviously implausible. However, we note that there were some strange results in the preliminary trials using the 2006 spatial structure with the new data in 2008 (Anon. 2008).

A number of tests were undertaken to examine the probability of MULTIFAN-CL finding alternative minima (for the SWP models). These included: i) altering the temporary F target in the initial phase of the minimization (1%, 10% (default), 50%), ii) Adjusting total population and recruitment scaling factors in the second phase of the minimization (by a factor of 0.1, 1 (default), and 10), iii) changing the number of iterations in the intermediate phases (though not the first or final phase) of the minimization (250 (default), 25, 3). In most cases, MULTIFAN-CL arrived at the same solution (to within 0.0001 likelihood units, and 4+ significant digits for the estimated quantities examined). From these trials, the only deviation resulted when the number of iterations in the intermediate phases were reduced to 1% (3 iterations) of the default setting. In this case, MULTIFAN-CL yielded a result that we would have concluded converged successfully (on the basis of the small gradients), though it is possible that the maximum iteration setting (5000) in the final phase was reached. In this case the minimum objective function value was ~10 likelihood units off of the best solution, and estimated quantities were within 4% of the best solution. It seems that the minimization is impressively robust under the conditions tested, and the results are plausibly consistent with the data. Hence we expect that the results are useful, whether or not the global minimum was always identified.

Each SWP swordfish model included 1977 estimated parameters. However, it is important to realize that most of these parameters are not really free parameters in the sense of some other models. The effort deviations account for the majority of parameters. If one were to use an equivalent model assuming that catch in numbers was known perfectly (which is essentially what these models are doing anyway), and treating the effort deviations purely as CPUE observation errors, then the number of estimated parameters is greatly reduced. In this particular model, additional parameters were either tightly constrained by priors (stock recruitment relationship), or bounds (growth curves), or related to future projections. The core dynamics of the SWP models are primarily driven by the following parameters:

- Recruitment deviations - 1 per year
- selectivity – 5 cubic spline nodes for each of 4 selectivity groupings
- catchability – mean plus seasonal deviations for each of 3 fleets with informative CPUE series (noting that catchability is shared for the two Japanese fleets)
- functional relationship of SD on length-at-age – 2 parameters

Thus the effective number of parameters for this group of SWP models is more like 93 than the official number of 1977.

MULTIFAN-CL is a complicated and continuously evolving piece of software, and as such, it is not surprising that code and documentation errors continue to be identified at regular intervals. The underlying dynamic equations as used in most applications seem to be stable, robust and consistent with similar software. This assessment was conducted with the same version of MULTIFAN-CL that was used in 2006 (16 Jun 2006 Windows build). While newer versions exist, there were implementation problems with the swordfish application that could not be resolved by the authors in time for the new version to be adopted for the 2008 assessment. SPC staff have indicated that developments and bug fixes since this 2006 release do not seem to have any substantive implications on the model features that were used in this assessment (John Hampton, SPC, pers. comm.). In July 2008, a bug was identified which affects model specifications in which the stock recruitment curve steepness exceeds 0.95 (Simon Hoyle, SPC, pers. comm.); this was not a problem for any of the results presented here.

3.2 Assessment Assumptions

This assessment is underpinned by the recognition that assessment models inevitably involve somewhat arbitrary constraining assumptions, and the stock status results may be highly sensitive to these assumptions (e.g. Schnute and Richards 2001). As such, we have made an effort to explore a large range of alternative combinations of plausible assumptions to provide an indication of the model selection uncertainty. In sections 3.2.1 - 3.2.13 we describe the assumptions, with an attempt to justify them. Multiple assumptions listed as bulleted points indicate that alternative assumptions were being tested. The manner in which the assumption combinations were combined is discussed 3.2.14 and summarized in Table 2 and Table 3.

3.2.1 Assessment Spatial Structure

Kolody and Davies (2008) review the evidence and arguments relevant to the spatial domain and internal structure adopted for this assessment. Further discussion is recorded in the April 2008 workshop report (Anon. 2008).

The overall assessment domain was derived after consideration of larval distributions, genetic connectivity studies, conventional and PSAT tag deployments, fishery characteristics (including distributions and seasonal patterns in catch, CPUE, and size composition) and the WCPFC request to encompass the broader South Pacific convention area in the assessment.

The SCP swordfish population is a data poor region with uncertain migratory links with adjacent regions in the Pacific. In 2006, it was recognized that the available data in the SCP would not likely provide any means for estimating the fishery impact on the population, whereas the SWP was recognized as being plausibly describable as a relatively discrete sub-population. In 2008, a formal attempt was made to estimate standardized catch rates, compile size composition data, and examine the SCP data in the context of an integrated assessment that included the combined SWP and SCP area. However, it was again recognized that the SCP was problematic and the 2008 swordfish assessment workshop (Anon. 2008) noted:

> *Given the lack of compelling evidence for a single stock across all 4 regions of the southern WCPO, and the lack of reliable swordfish abundance indicators in regions 3 and 4, the Workshop recommended that the primary focus of the 2008 assessment should be on the swordfish resource located in the southwest Pacific (Regions 1-2), and that additional sensitivity analyses should be undertaken to include regions 3 and/or 4 (with the northern zones excluded) if possible.*

Despite the latter recommendation from the workshop (i.e. to exclude the northern zones), the decision was made to include the northern zones in our exploration of the SCP. There does not seem to be any compelling biological justification for separating the northern and central zones, and further analyses indicated that the only standardized catch rates that were worth considering from the SCP at this time were generated from the Japanese fleets operating in the northern zones (Campbell et al. 2008).

The internal spatial structure of the swordfish assessment was substantially changed from that adopted in 2006. Problems with the spatial structure adopted in 2006 included:

1) The complicated spatial structure in 2006 was adopted to accommodate the differing trends in exploitation patterns, CPUE and size composition that seemed to be occurring within the SW Pacific. However, when the data were standardized and summarized at the pre-determined scale, evidence for divergent patterns within the SWP were much less apparent (and to some extent this may reflect an absence of adequate data rather than a truly homogenous population).
2) The 2006 model structure had considerable freedom to estimate migration (variable by area, season and age), but all of the movement estimates in 2006 were indirect inferences (i.e. no tagging). The model tended to estimate biologically questionable movement patterns (potentially including spatial and temporal refuges for 'cryptic biomass').
3) There was a confounding of seasonal catchability and seasonal migration that could not be resolved (i.e. seasonal CPUE patterns between fleets operating in the same area differed, such that it was not possible to conclude how much of the cyclic pattern actually represented migration).
4) The southern area (SBT-targeting) fishery has unique characteristics, such that it was difficult to link abundance between the northern and southern areas (e.g. through shared catchability), and the model estimates of abundance (or exploitation rates) in this area were often thought to be unrealistic.
5) Exploratory comparisons of homogenous mixing and foraging site fidelity models (using CASAL and production models, but not MULTIFAN-CL) indicated that both sets of migration assumptions seemed to be consistent with the data.

The new spatial structure (illustrated in Figure 2) is thought to be preferable to that used in 2006 because:

1) PSAT tags in the SW Pacific and elsewhere suggest that there are directed seasonal migrations between spawning and foraging grounds, and in the SWP this seasonal migration can be represented by seasonal catchability (and potentially selectivity), without the need to explicitly partition the areas.

2) PSAT and conventional tags provide a means for estimating east-west diffusive movement. While preliminary, these estimates are likely to represent an upper bound of mixing rates, and using these values directly in the assessment models provides a strong structural constraint to the dynamics. This is discussed under section 3.2.10.
3) The longitudinal stratification facilitates a direct comparison between the aggregate assessment results from the 2006 assessment and the SWP component of the 2008 assessment. It is easy to remove one or both of the more eastward extensions of the model domain in relation to new evidence.

The two-tiered approach to the assessment (i.e. Table 2 and Table 3) was defined in relation to the spatial stratification in Figure 2 and the fishery definitions in the following section:

- SWP assessment (A12F11, Table 2) consists of Areas 1-2 and fisheries 1-11
- combined SWP-SCP assessment (A14F18, Table 3) consists of Areas 1-4 and fisheries 1-18

3.2.2 Fishery Definitions

Table 1 defines the 18 fisheries used in the MULTIFAN-CL models of the SWP and SCP. The quality and amount of data varies considerably among fisheries and a number of smaller or similar fleets were aggregated (i.e. similarity assumed on the basis of catch size frequency distributions if possible). Only 6 fisheries were assumed to have informative CPUE series (adequately standardized effort); 4 in the SWP and 2 in the SCP. Many of the 18 fleets were assumed to have identical selectivity (shared parameters in the model estimation). Some of these fleets are active in the same area, and hence the fleets are effectively aggregated (but separable for the purposes of exploring management options). Campbell 2008 describes the size composition data for the available fleets, and illustrates that in most cases the catch size frequency distributions are either very similar or poorly sampled. An obvious exception is the southern (SBT-targeting) fleets which catch very large individuals. Some of the other southern fleets may represent a mixture of northern and southern characteristics. On this basis, 4 different selectivities were defined and estimated independently.

Table 1. SWP and SCP fishery definitions in the assessment models. Areas and sub-areas are illustrated in Figure 2. Selectivity and catchability groups identify fisheries with shared parameters (e.g. fishery 2 and fishery 7 both belong to catchability group 'A' and hence catchability parameters are shared in the model).

Fishery Number	Area	Sub-area (zone)	Catchability Group	Selectivity Group	Fishing Nation(s)
South-West Pacific					
1	1	N	n/a	a	Japan (plus other DWF)
2	1	C	A	a	Japan (plus other DWF)
3	1	S	n/a	b	Japan (plus other DWF)
4	1	N+C+S	B	a	Australia
5	1	N+C	n/a	a	Pacific Island Nations
6	2	N	n/a	a	Japan (plus other DWF)
7	2	C	A	a	Japan (plus other DWF)
8	2	S	n/a	c	Japan (plus other DWF)
9	2	N	n/a	a	Pacific Island Nations
10	2	C	n/a	a	Pacific Island Nations
11	2	C+S	C	d	New Zealand
South-Central Pacific					
12	3	N	A	a	Japan (plus other DWF)
13	3	C+S	n/a	a	Japan (plus other DWF)
14	3	N	n/a	a	Pacific Island Nations
15	3	C	n/a	a	Pacific Island Nations
16	4	N	A	a	Japan (plus other DWF)
17	4	C+S	n/a	a	Japan (plus other DWF)
18	4	N	n/a	a	Pacific Island Nations

3.2.3 Catch Rate Assumptions (effort deviations, catchability, and relative areas)

These types of stock assessment models tend to perform poorly in the absence of reliable relative abundance indices (e.g. as demonstrated with simulations in Kolody *et al.* 2004). It follows that we would also expect poor model performance if the abundance indices are poorly fit by the model (i.e. whether or not they are reliable). The conflicting recent trends in the Australia/New Zealand vs: Japanese CPUE trends (Figure 5) raises a problem in that (at least) one of them has to be somewhat wrong. To assume that they are both equally correct and diverging through observation error alone results in an averaging of series. We consider it more likely that one set of trends is probably more correct than the other, but we do not know which. Three alternative weighting scenarios were employed in the model uncertainty grid to reflect this situation:

- UA1 - Both series equally reliable
- UAJ - Australia/New Zealand more reliable than Japan
- UJA - Japan more reliable than Australia/New Zealand

The SD of the (natural log) effort deviations corresponding to these scenarios is listed in Table 2 and Table 3. These values are approximately equivalent to the CV of the CPUE observation error. Effort series for all other fleets were considered uninformative and set to missing.

In WCPO tuna assessments, catchability for the Japanese longline fleets is usually shared across areas. The shared catchability implies that the same CPUE in two different areas corresponds to an equivalent density (i.e. fish per unit of surface area) and allows the relative abundance of different regions to be linked. However, there is a further step involved in relating density to abundance. The (relative) area (or volume) of each region is required to interpret the relative density as relative abundance (i.e. number = density X area). However, fish are not usually homogenously distributed within a region, and the "effective" area of the fish distribution might be considerably different from the actual geographical area. Estimating the effective area of a region is problematic if the spatial and temporal coverage of the effort represents a small portion of the fish distribution. Fisheries-dependent data (and many surveys) are often plagued by inadequate coverage, which leads to philosophical debates about fish density in unfished areas. For the swordfish assessment in 2006, three relative area options were investigated, related to 1) the geographical surface area as defined on a map, 2) the maximum extent of the historically fished area, and 3) the maximum range in which swordfish were caught historically. The 2006 assessment was not very sensitive to these assumptions. Hence, in 2008, it was simply assumed that the relative areas for the purpose of CPUE applicability were equal among the 4 areas in Figure 2. The southern zones of the SCP might not have been fished as heavily as the SWP (because there are not significant numbers of SBT in the SCP), so we cannot be sure of the swordfish density in this region. However, swordfish density is not thought to be high in the southern regions of the SWP either, so this should not introduce a large error.

3.2.4 Fishery Selectivity Assumptions

Selectivity was assumed to be constant over time for all fisheries, and was parameterized as a cubic spline function with 5 nodes. The revised spatial structure was intended to account for migration using seasonally variable selectivity if required. However, this was not pursued, in part because 1) the model diagnostics examined did not show obvious biases relative to the size composition data that are available, and 2) the fisheries with good size composition data tend to have a strong seasonal pattern in catch anyway (i.e. if not many fish are being caught outside of the main season, the size bias in the off-season will not have much influence). In the 2006 assessment, it was found that assessment results were sensitive to alternative selectivity assumptions, and two options were again pursued in 2008 (Table 2 and Table 3):

- SM – selectivity non-decreasing with age
- SF – selectivity unconstrained (dome-shaped usually results in this case)

In 2006, the unconstrained models tended to prefer dome-shaped selectivity, however both assumptions could produce results that were plausibly consistent with the data (with the appropriate combination of other assumptions). There is evidence that swordfish have size-specific distributions (likely related to sex dimorphism), with larger individuals caught disproportionately in the south. In the revised spatial structure, selectivity is clearly influenced by availability, and the large fish in the southern zone would be expected to be less vulnerable to the fleets of the northern and central zones (for at least part of the year). Hence, we did not think it would be appropriate to impose a non-decreasing selectivity constraint on the northern and central fleets with the revised spatial structure. We did however explore the effects of the non-decreasing constraint on the southern SBT-targeting fleet (fishery 8, which catches only very large swordfish).

3.2.5 Catch-at-Size Sample Characteristics

MULTIFAN-CL assumes that length-at-age is normally distributed about the mean, and uses a robust likelihood term to reduce the influence of outliers when fitting the size frequency observations. Model predictions are based on an assumed mean growth curve described in section 3.2.7. The length-mass relationship was estimated from New Zealand observer data, and based on lower jaw fork lengths (cm) and trunked mass (kg): mass = 7.62e-7(length)$^{3.49}$.

There are a number of reasons why it might not be appropriate to use the actual sample sizes from the length and mass frequency distributions as inputs to the model likelihood terms. In these models: i) the assumption of constant selectivity over time is probably not entirely valid (e.g. species targeting shifts probably have some effect on selectivity), ii) swordfish growth curves are currently highly uncertain (plus there are complicating factors of sexual dimorphism and within year growth) iii) many of the size samples are small and unlikely to be random samples from the whole fishery, iv) with respect to the mass data – different processors use different methods, resulting in differences of up to 10% suspected for the trunked mass. We considered 2 down-weighting schemes in the model uncertainty exploration (e.g. Table 2 and Table 3):

- ES5 - sample size = n/5
- ES20 - sample size = n/20

There is also a maximum sample size of 1000 implemented before the down-weighting is applied.

3.2.6 Stock Recruitment

Recruitment was assumed to occur once annually (quarter 1). A Beverton-Holt stock recruitment relationship was assumed, with all mature spawners contributing to the spawning biomass irrespective of area. Because of the general difficulty in reliably estimating stock recruitment curves, different levels of recruitment compensation were imposed in the model uncertainty grid via tightly constrained priors (e.g. MULTIFAN-CL beta distribution parameters 9000, 1000 for steepness 0.9). In 2006, 3 steepness (*h*) options were explored (Figure 11). All values were in reasonable agreement with the data (depending on the other model assumptions), but the higher values were considered more plausible on the basis of life history arguments, and signs of apparent stock recovery in other swordfish fisheries that experienced effort reductions (e.g. Ortiz 2005 describes rebuilding in the North Atlantic). Accordingly, only the two more productive values were considered in 2008:

- h65 - h = 0.65 (moderate degree of recruitment compensation)
- h90 - h = 0.9 (high recruitment compensation)

In the SWP models, the final MPD estimates tended to be slightly higher than the mode of the priors. In the combined SWP-SCP models, the MPD estimates were often very different from the mode of the priors as described in the results.

Two different assumptions were explored with respect to the magnitude of interannual recruitment variability:

- r1 – SD on the log recruitment deviation = 0.1 (CV ~ 10%)
- r5 – SD on the log recruitment deviation = 0.5 (CV ~ 50%)

The higher value is considered to be more plausible for pelagic fish populations in general. However, there was a concern that the relaxed recruitment constraint might result in highly irregular and misleading recruitment time series because of the small number of non-representative size samples. The constrained recruitment deviation assumption was tested as an alternative in the uncertainty grid, which would ensure that the recruitment time series was not unduly influenced by poor size sampling, and would yield results that conformed with stock recruitment assumptions. This of course raises the opposite concern, i.e. the imposition of a strong stock recruitment relationship which might not be supported by the data. The primary intent of exploring both options in the uncertainty grid was to find out whether the stock status results were sensitive to this assumption.

In the SWP, recruitment was split equally between areas 1 and 2. In the combined SWP-SCP models, two options were explored for the distribution of recruitment:

- RS1 - Recruitment was split evenly among areas 1-4
- RS2 - The recruitment split among areas 1-4 was estimated with regional deviations over time estimated

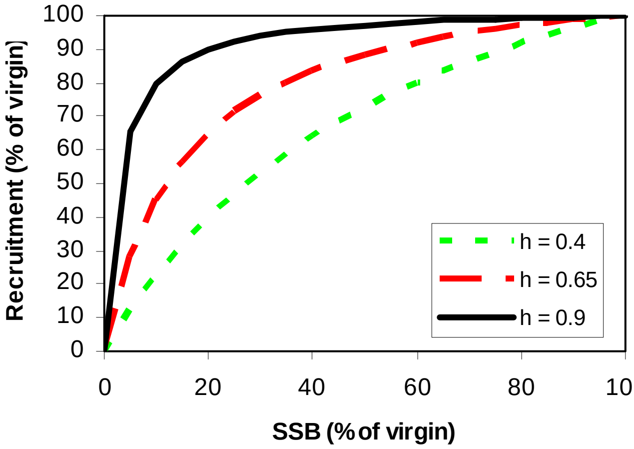


Figure 11. Three levels of stock recruitment curve steepness (*h*) assumed in the model uncertainty grid in 2006. Only the higher values *h* = 0.65 and 0.9 were used in 2008.

3.2.7 Growth Curves

Young et al. (2008) describe some recent work on the comparison of age-estimation methods from biologists at CSIRO (Australia) and NMFS (Hawai'i). On the basis of this work, it is appropriate to consider that SW Pacific swordfish may be growing and maturing at a rate that is much faster than had been assumed in 2006 (Figure 12). Without direct age validation studies, it remains unclear which method of interpreting fin spine counts is more appropriate. New growth curves have not been estimated for the Australian fin ray samples to date, however, visual inspection suggests that the Hawaiian growth curves described in DeMartini et al. (2007) seem to fit the alternative readings for the limited sample of Australian fin spines. The two alternative growth curves were applied in the assessment uncertainty grid. In each case, the mean of the male and female curve was used as fixed input. Variances on length-at-age were estimated in the overall fitting (from starting values that reflected the combined variance of males and females). Ignoring the sexual dimorphism that is know to occur in swordfish (and undoubtedly relates to other important life history characteristics like M) is a potential source of bias. However, given the overall uncertainty in growth rates at present, sex dimorphism is probably not the highest priority issue to resolve. These two growth curve assumptions were only considered in conjunction with specific maturity and mortality vectors, and are included in Table 2 and Table 3 as part of the combined growth/maturity/mortality assumptions defined in 3.2.9.

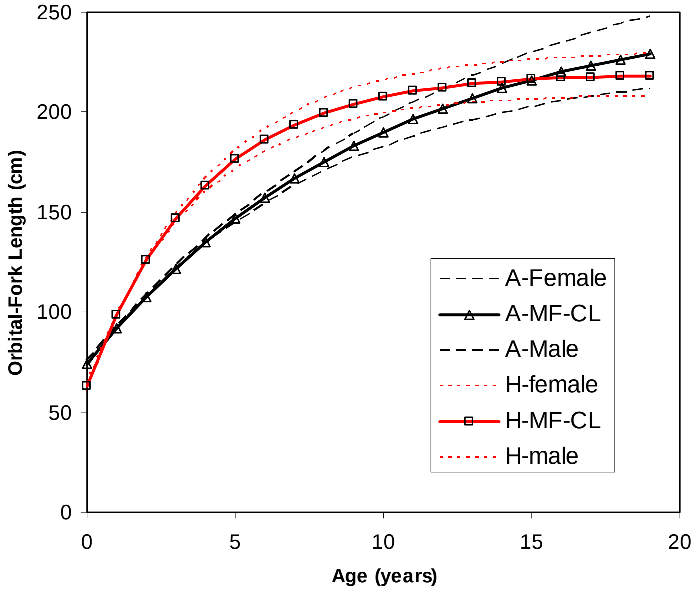


Figure 12. Swordfish growth curves estimated from Australian samples ('A' in the legend) from Young et al. 2008 and Hawai'ian samples ('H') from DeMartini et al (2006). Female (upper) and Male (lower) curves are shown for each, with the mean used in the assessment models (labelled "MF-CL"). Note that the model uses lower jaw fork length data while the figure illustrates the difference in orbital fork-length.

3.2.8 Maturity Schedules

Young et al. 2008 suggest that there are also methodological differences and uncertainties in the interpretation of swordfish maturity-at-size. However, the greatest uncertainty on maturity-at-age is attributable to the uncertainty in age estimation. The maturity assumption adopted in 2006 was derived from Young and Drake 2002. As an alternative maturity schedule assumption, we adopted one of the more extreme maturity interpretations used in other swordfish assessments (age of 50% maturity = 4 years) (Figure 13). These two maturity assumptions were only considered in conjunction with specific growth curves and mortality vectors, and are included in Table 2 and Table 3 as part of the combined growth/maturity/mortality assumptions defined in 3.2.9.

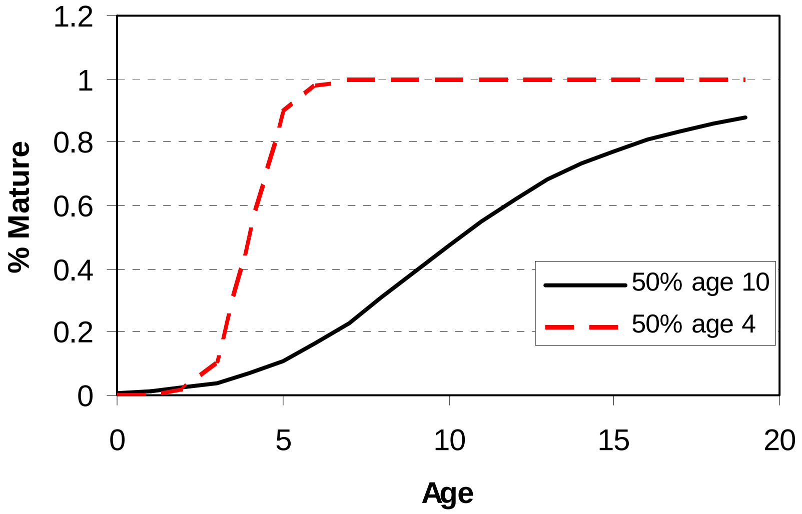


Figure 13. Alternative swordfish (female) maturity schedules assumed in the 2008 assessment. The 50% age 10 curve is taken from Young and Drake (2002); the 50% age 4 curve is qualitatively consistent with assumptions adopted in other assessments in the Atlantic and Eastern Pacific. Only the 50% age 10 value was used in 2006.

3.2.9 Natural Mortality

Given the difficulty in tagging swordfish, and the poorly validated methods of age estimation, it follows that natural mortality estimates are also highly uncertain. There are a broad range of M values assumed in other swordfish assessments worldwide, ranging from at least 0.2 – 05. In this assessment we attempted to span a range of options based on speculation about life history dependent factors.

A total of 8 vectors of M by age were examined, 4 corresponding to each of the two growth curve options described above. For each growth curve, two values of mean M were derived from Pauly (1980), which describes M from a number of species in relation to the k parameter from the von Bertalanffy growth equation, and the species temperature preferences. The temperature preferences used here correspond to the highest and lowest values (14.57, 22.83° C) identified for swordfish in Boyce et al. (2008). Note that the authors identify temperature preferences which have a much narrower range than the temperature tolerances identified in the same paper. This results in mean M values for slow growth curves of: 0.16 and 0.2, and for the faster growth curves: 0.31 and 0.38. For each value of mean M (mean over ages 1-15 years), two vectors of M by age were derived from the following:

$$M_a = 0.1 + (L_{\inf} / L_a)^{K_1} + K_2 \cdot Maturity_a ,$$

where:

$L_{\inf}$ = von Bertalanffy growth parameter

L_a = mean length-at-age

$Maturity_a$ = proportion mature at age

K_1, K_2 = somewhat arbitrary constants as indicated below.

This equation is simply intended to represent variation in *M* by age that is biologically plausible given what we know from other species, (e.g. tagging studies and observations of maximum age for Southern Bluefin tuna suggest substantial differences in M by age, Polacheck et al. 1998), and spawning (plus associated migratory activity) is generally a stressful process that might be expected to increase mortality. The magnitude of the curves was arbitrarily bounded with a maximum difference of M between ages of a factor of 1.5 (excluding ages 0 and 16+).

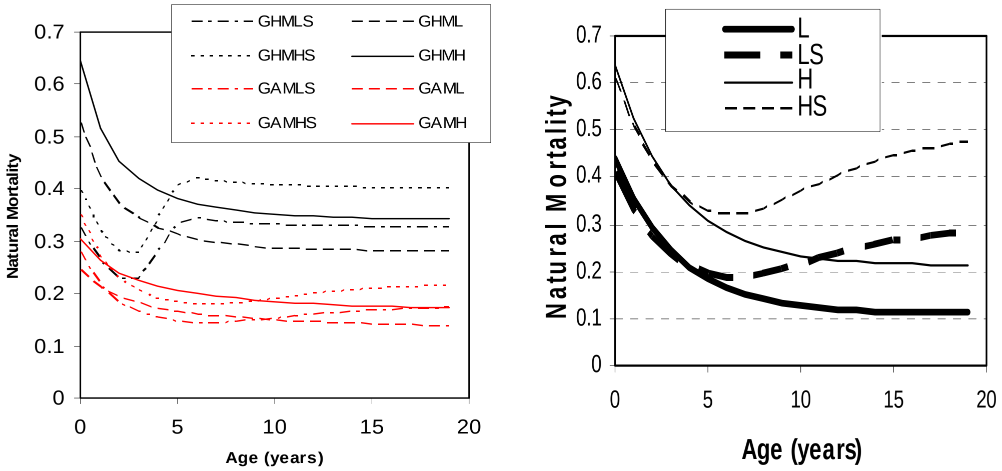


Figure 14. Natural mortality assumptions used in the 2008 assessment (left panel) and 2006 (right panel). Note that the upper 4 (GH) vectors in the left panel were assumed in relation to the faster growth curve, while the lower 4 (GA) vectors were assumed in relation to the slower curve. The *M* vectors assumed in 2006 are shown in the right panel for comparison.

Note that the GH mortality vectors were only assumed in conjunction with the fast growth curves and young age at maturity, while the GA vectors were only assumed in conjunction with the slow growth and older age at maturity. The intent of this large range was to be reasonably confident that realistic values were encompassed by the range explored, and to determine whether the assessment results are sensitive to the growth/maturity/mortality assumptions. In Table 2 and Table 3 these combined assumptions are defined:

- GAMH - Slow growth, 10+ maturity, relatively high *M*
- GAMHS -Slow growth, 10+ maturity, relatively high *M* with spawning effect
- GAML - Slow growth, 10+ maturity, relatively low *M*
- GAMLS - Slow growth, 10+ maturity, relatively low *M* with spawning effect
- GHMH - Fast growth, 4+ maturity, relatively high *M*
- GHMHS - Fast growth, 4+ maturity, relatively high *M* with spawning effect
- GHML - Fast growth, 4+ maturity, relatively low *M*
- GHMLS - Fast growth, 4+ maturity, relatively low *M* with spawning effect

The range of mortality assumptions used in 2006 was similar in magnitude to the range employed this year (mean *M* = 0.16, 0.24, 0.26, 0.41). However, in 2006 only one growth and mortality schedule was considered, and only the L and H mortality options (Figure 14) yielded results that were judged to be plausible.

3.2.10 Migration rates

A range of migration rate assumptions were explored in relation to the analysis of PSAT and conventional tags described in Kolody and Davies (2008). The migration rate estimates were derived from fitting a simple one dimensional diffusion model (with geo-positioning error) to the available PSAT and conventional tags. The estimates of longitudinal mixing were translated into bulk transfer coefficients appropriate to the swordfish assessment structure. Further analyses are expected to be undertaken in relation to the swordfish PSAT tags (Chris Wilcox, CSIRO, pers. comm.), however, given the small number of deployments to date there was not much justification for a more detailed analysis at this time.

In the SWP models, only the approximate upper and lower bounds estimated from the tag analysis were considered:

- D05 – Exchange of ~5% of fish per quarter between areas 1 and 2
- D10 – Exchange of ~10% of fish per quarter between areas 1 and 2

In the combined SWP-SCP models, a much more exploratory position was adopted to see if sensible results could be obtained, including the following range of options:

- D00 – Exchange of 0.1 % of fish per quarter between all adjacent areas
- D10 – Exchange of 10 % of fish per quarter between all adjacent areas
- DF – Migration rates between all adjacent areas were estimated as free parameters (constant with age)

3.2.11 Time period

The models were iterated on a quarterly time-step from 1952-2007. An additional 10 years of projections 2008-2017 were conducted, assuming that catch remained constant at 2007 levels (including the seasonal pattern). In MULTIFAN-CL, projections consist of extending the time series with an assumed future effort (or catch) time series, and the model estimates the missing catch (or effort) that corresponds to the provided values (with deterministic future recruitment driven by the stock recruitment relationship). A similar assumption about proportionate effort by fleet is used in the equilibrium yield (and MSY) calculations.

3.2.12 Age and Sex Structure

The modeled population consisted of 40 quarterly age classes (0-19.75+ in years); both sexes combined. Recruitment (age 0) was assumed to occur annually, in the first quarter.

3.2.13 Catch in Numbers Observation Errors

We assume that the total catches are essentially error free (approximate observation error CV ~ 0.07), although it is likely that some additional fishing-related mortality (e.g. discarding of small fish) has been overlooked. Given the weak size constraints imposed by the model, the predicted total catch in numbers tended to agree almost perfectly with the observations (not shown).

3.2.14 Assessment Model Uncertainty Grids

South-West Pacific

Table 2 summarize the combinations of assumptions in the SWP uncertainty grid. In the SWP, a balanced design of 7 assumption combinations was proposed:

(hxx) X (Dxx) X (Gxx) X (rxx) X (ESxx) X (Uxx) X (Sxx)
= 2 X 2 X 8 X 2 X 2 X 3 X 2 assumptions
= 768 models

The unconstrained selectivity assumption SF tended to estimate non-decreasing selectivity for the southern fleet, so it seemed redundant to retain both the SM and SF assumptions in the uncertainty grid. The SM assumption was dropped, and a total of 384 models were fit.

South-Central Pacific

Table 3 summarize the combinations of assumptions in the SCP uncertainty grid. The SCP assessment was conducted after the SWP assessment, and a different set of assumptions was explored, with increased number of options for migration and recruitment variability, and a reduced number of options for Growth/Maturity/Mortality, catch-at-size down-weighting and selectivity constraints:

(hxx) X (Dxx) X (Gxx) X (RSxx) X (rxx) X (ESxx) X (Uxx) X (Sxx)
= 2 X 3 X 2 X 2 X 2 X 1 X 3 X 1 assumptions
= 144 models

Table 2. Abbreviations and model assumptions used in the SW Pacific model uncertainty grid. The full cross of factors results in a grid of 768 models; removal of the ES20 and SM options resulted in the final grid of 192 models.

Scenario Abbreviation	**Definition**
Spatial Definition	
A12F11	Areas 1-2 (South-West Pacific), 11 fisheries
Beverton-Holt Stock Recruitment Relationship steepness (h)	
h65	h prior mode = 0.65 (beta prior parameters = 6500, 3500)
h90	h prior mode = 0.90 (beta prior parameters = 9000, 1000)
Migration Rates	
D05	Migration to/from adjacent regions ~ 0.05 per quarter (all ages)
D10	Migration to/from adjacent regions ~ 0.10 per quarter (all ages)
Growth / Maturity / Natural Mortality	
GAMH	Slow growth, 10+ maturity, relatively high M
GAMHS	Slow growth, 10+ maturity, relatively high M with spawning effect
GAML	Slow growth, 10+ maturity, relatively low M
GAMLS	Slow growth, 10+ maturity, relatively low M with spawning effect
GHMH	Fast growth, 4+ maturity, relatively high M
GHMHS	Fast growth, 4+ maturity, relatively high M with spawning effect
GHML	Fast growth, 4+ maturity, relatively low M
GHMLS	Fast growth, 4+ maturity, relatively low M with spawning effect
Recruitment variability	
r1	likelihood term ln(SD) = 0.1
r5	likelihood term ln(SD) = 0.5
Catch-at-Size Likelihood Assumptions	
ES05	input sample size downweighted by factor of 1/5 (1000 maximum)
(ES20*)	input sample size downweighted by factor of 1/20 (1000 maximum)
CPUE Likelihood Assumptions	
UA1	all informative CPUE series weighted with CV ~ 10%
UAJ	Australia/New Zealand CV ~ 10%; Japan CV ~ 25%
UJA	Australia/New Zealand CV ~ 25%; Japan CV ~ 10%
Selectivity Constraints	
SF	all selectivities unconstrained
(SM**)	fishery 8 selectivity non-decreasing; all others unconstrained

* The input effective sample size ES20 model dimension always resulted in very poor fits to some of the size frequency distributions and was removed from the SWP Most Plausible Ensemble (see 4.1.1)

**Partial application of the SM assumption in the uncertainty grid suggested that it was frequently (possibly always) redundant (i.e. the unconstrained selectivity of fishery 8 was estimated to increase with age), and hence this dimension was dropped.

Table 3. Abbreviations and assumptions used in the South-West-South-Central (SWSC) Pacific assessment uncertainty grid of 144 models.

Scenario Abbreviation	Definition
Spatial Definition	
A14F18	Areas 1-4 (South-West and South-Central Pacific), 18 fisheries
Beverton-Holt Stock Recruitment Relationship steepness (h)	
h65	h prior mode = 0.65 (beta prior parameters = 6500, 3500)
h90	h prior mode = 0.90 (beta prior parameters = 9000, 1000)
Migration Rates	
D00	Migration to/from adjacent regions ~ 0.0001 per quarter (all ages)
D10	Migration to/from adjacent regions ~ 0.10 per quarter (all ages)
DF	Migration to/from adjacent regions estimated (variable with age)
Growth / Maturity / Natural Mortality	
GAML	Slow growth, 10+ maturity, relatively low M
GHMHS	Fast growth, 4+ maturity, relatively high M with spawning effect
Recruitment Spatial Distribution	
RS1	Recruitment is split evenly among areas
RS2	Recruitment distribution is split among areas is estimated, constant over time
Recruitment variability	
r1	likelihood term ln(SD) = 0.1
r5	likelihood term ln(SD) = 0.5
Catch-at-Size Likelihood Assumptions	
ES05	input sample size downweighted by factor of 1/5 (1000 max)
CPUE Likelihood Assumptions	
UA1	all informative CPUE series weighted with CV ~ 10%
UAJ	Australia/New Zealand CV ~ 10%; Japan CV ~ 25%
UJA	Australia/New Zealand CV ~ 25%; Japan CV ~ 10%
Selectivity Constraints	
SF	all selectivities unconstrained

4 Results and Discussion

Several hundred models were fit in the course of this assessment. The MULTIFAN-CL software converged successfully in all cases (i.e. very small final gradients attained). While we cannot be certain that global minima were always identified, there was fairly consistent behaviour among models, and no evidence of predictions that were grossly unexpected given the model specifications (at least for the SWP results which were examined in much greater detail than the combined SWP-SCP results). Results and discussion are separated for the two assessments in the following.

4.1 South-West Pacific Assessment

The following sections present: i) a brief description of the model selection process, in which the Most Plausible Ensemble of models was defined from the SWP uncertainty grid, ii) a detailed review of two models with stock status estimates at the extreme optimistic and pessimistic ends of the distribution (defined by MSY), iii) a stock status summary of results from the Most Plausible Ensemble of models, iv) a comparison of the relative importance of model selection uncertainty and parameter estimation uncertainty in the assessment and v) A comparison between stock status estimates from the 2006 and 2008 assessments.

4.1.1 Defining plausible models from the SWP uncertainty grid

There is always an element of subjectivity in the formulation and selection of models, and different analysts will have different priorities with respect to what they consider most important. While theoretical statistical measures (e.g. AIC, BIC) can provide some guidance in the model selection process, these measures should be used cautiously when statistical assumptions are known to be violated. Furthermore, these indices are not applicable when fundamental characteristics of models differ (e.g. different data are included in the model, or sample sizes are manipulated to account for non-random sampling). By using the model selection process defined below, we do not resolve the need to make arbitrary decisions or guarantee that the best decisions are made. However we would argue that it is useful to explicitly define plausibility criteria because 1) they allow a large number of models to be compared rapidly and consistently, and 2) the selection criteria are openly available for criticism and debate. As in 2006, we focused on three initial diagnostics:

1) We describe the quality of fit to the CPUE series on the basis of the degree of agreement between predictions and observations (i.e. independent of the assumed variance of the effort deviations) using the Root Mean-Squared Error. For fishery *f*:

$$RMSE_f = \sqrt{\tfrac{1}{N}\sum \left(\ln(CPUE_f^{predicted} / CPUE_f^{observed})\right)^2}$$

It is usually the case in these models that CPUE RMSE increases due to a systematic lack of fit in the form of a temporal trend in residuals (as opposed to random noise). While we are probably most interested in the systematic lack of fit, the two are usually strongly positively correlated (although this might not be true if there is a seasonal component for the CPUE variability that is poorly described).

2) To compare the quality of fit between predicted and observed size frequency distributions, we use the Effective Sample Size (ESS), which is independent of the assumed sample sizes (and catch-at-size likelihood term) in the assessment model objective function (McAllister and Ianelli 1997). For fishery f, the ESS is defined:

$$ESS_f = \frac{1}{T}\sum_t^T \left(\frac{\sum_l p_{f,t,l}(1-p_{f,t,l})}{\sum_l (o_{f,t,l} - p_{f,t,l})^2} \right),$$

where:

$p_{f,t,l}$ = proportion of predicted catch in size bin *l* at time t in fishery f, and

$o_{f,t,l}$ = proportion of observed catch in size bin *l* at time t in fishery f.

This value can be interpreted as the truly random sample size that would on average yield a quality of fit between predictions and observations as that which resulted. Note the unfortunate confounding of terms, in that "effective sample size" is also the term used to describe the manipulation of assumed sample sizes for size frequency likelihoods. We use "input ES" to refer to model input assumptions, and "output ESS" to refer to model output diagnostics.

3) In 2006, it was observed that the ESS was not very useful for fisheries with very small sample sizes. Sometimes vastly different fishery selectivities could be estimated which resulted in very similar output ESS diagnostics. However, large differences were apparent between predicted and observed mean sizes that were strongly indicative of a model problem (e.g. we are very confident that the New Zealand charter fleet catches predominantly very large fish, and would not consider model results plausible if this effect is not captured by the model). Hence the mean size bias for fishery *f* was used as third model diagnostic:

$$meanSizeBias_f = \tfrac{1}{T}\sum_{t=1}^{T}(\overline{L}_t^{\Pr edicted} - \overline{L}_t^{Observed}).$$

Note that residuals cancel out in this index (but should be captured in the ESS index), as this index is intended to describe major biases.

The relationship between the quality of fit diagnostics and the various assumptions in the SWP uncertainty grid are illustrated in Figure 15-Figure 17. Figure 15 illustrates that the fit to the Australian fishery (4) CPUE is most sensitive to the CPUE weighting assumption. Not surprisingly, down-weighting the fit to the Australian CPUE relative to the Japanese CPUE reduces the CPUE RMSE for the Australian series somewhat (i.e. assumption UJA vs: UA1 or UAJ). Figure 16 illustrates that the quality of fit to the Australian size composition data (measured by the output ESS) is greatly decreased by down-weighting the assumed effective sample sizes (input ES assumption ES5 vs: ES20). Figure 17 illustrates that the catch-at-size distributions are badly biased for at least one of the fleets with the ES20 assumption, especially when combined with the slow growth curve (GA) assumptions.

On the basis of these plots, it was decided to remove all of the ES20 assumptions from the model uncertainty grid. The sources of the variance in quality of fit diagnostics associated with the other assumptions in the uncertainty grid are less severe, and do not seem to provide any obvious justification for reducing the grid further.

Table 1 compares model diagnostics for the SWP uncertainty grid for all models with the ES20 assumption and all models without the ES20 assumption. The latter combination of models is hereafter referred to as the Most Plausible Ensemble (MPE).

In the 2006 assessment there were a number of additional implausible results identified for individual models that did not detract from a high quality fit to the data. In particular, some formulations estimated dubiously large spawning biomass or very high exploitation rates in the southern (SBT-targeting) region. These problems were not observed with the revised spatial structure adopted in 2008. However, the selectivity of fisheries 3 and 11 (Japanese Area 1 South and New Zealand domestic) were suspicious in that they tended to be bimodal to some extent (see section 4.1.2). This might be credible for the southern Japanese fishery (3), as it is difficult to properly partition the northern (primarily yellowfin/bigeye-targeting) and southern (SBT-targeting) fleets. One can speculate about the plausibility of the bimodal New Zealand domestic fleet selectivity, however given that it was almost ubiquitous and identified late in the process, no attempt was made to explore the issue further.

It was notably unexpected that the 8 growth/maturity /mortality assumptions all seemed to have rather similar outcomes in terms of the quality of the model fits to the data, although the fast growth options seem to be somewhat better in the MPE (Figure 18). This is probably the result of i) the relatively poor size sampling data for most fleets, and ii) the lack of clearly defined modes in the catch composition (possibly exacerbated by sex dimorphism and size/sex-dependent seasonal migrations within fisheries). There is obviously a lot of flexibility for the models to trade-off growth and natural mortality and fishery selectivity, and we would not expect the model to be able to reliably estimate growth and mortality in this fishery. This emphasizes the need to explore the full range of this biological uncertainty in the assessment.

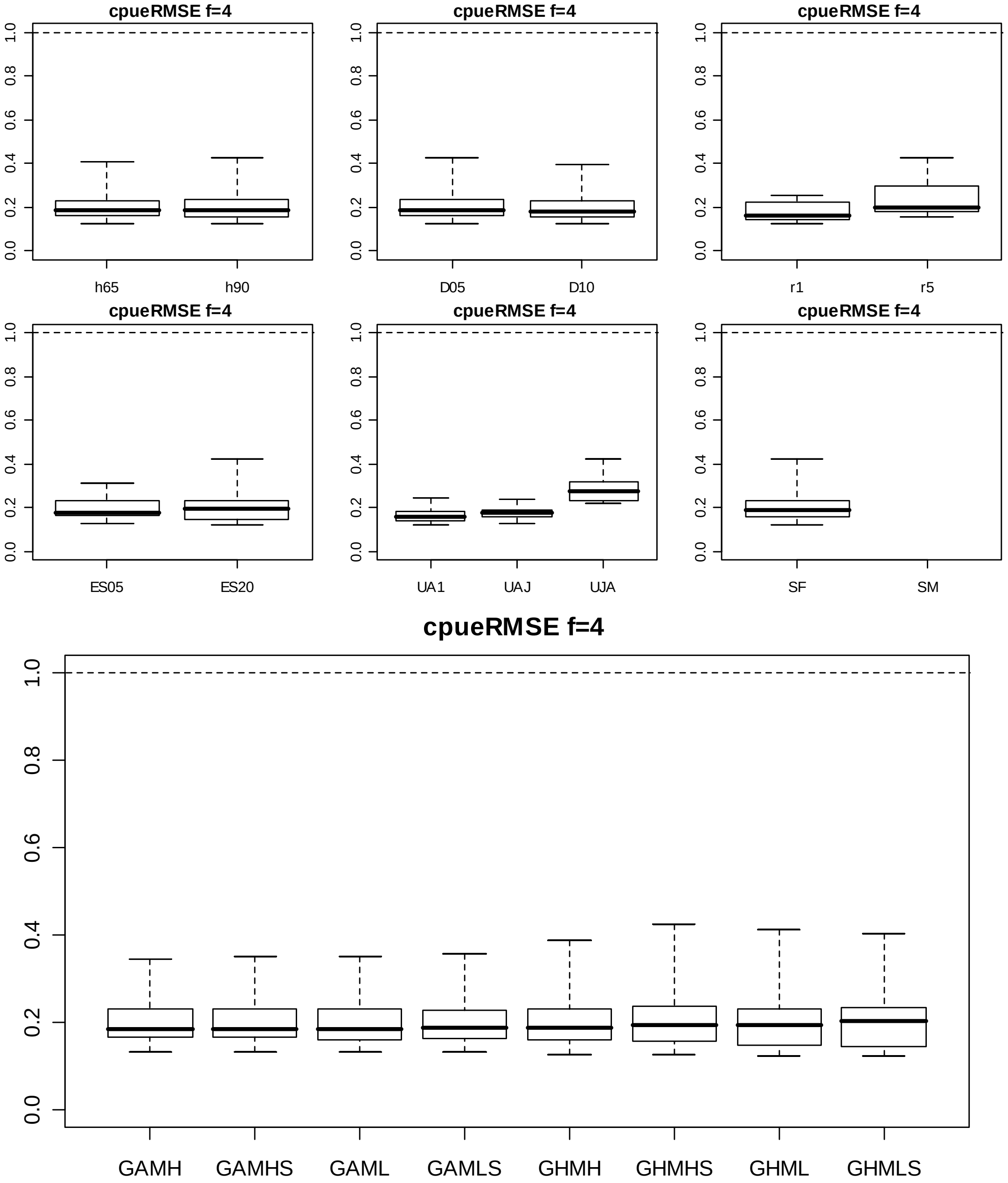


Figure 15. Illustration of how the various assumptions in the uncertainty grid (Table 2) affect the MPD model fit to the Australian longline fishery (fishery 4) CPUE. Y-axis is the RMSE. Each panel contains results from 384 models, partitioned according to individual model factors from the uncertainty grid (boxplots indicate 0, 25, 50, 75 and 100 percentiles).

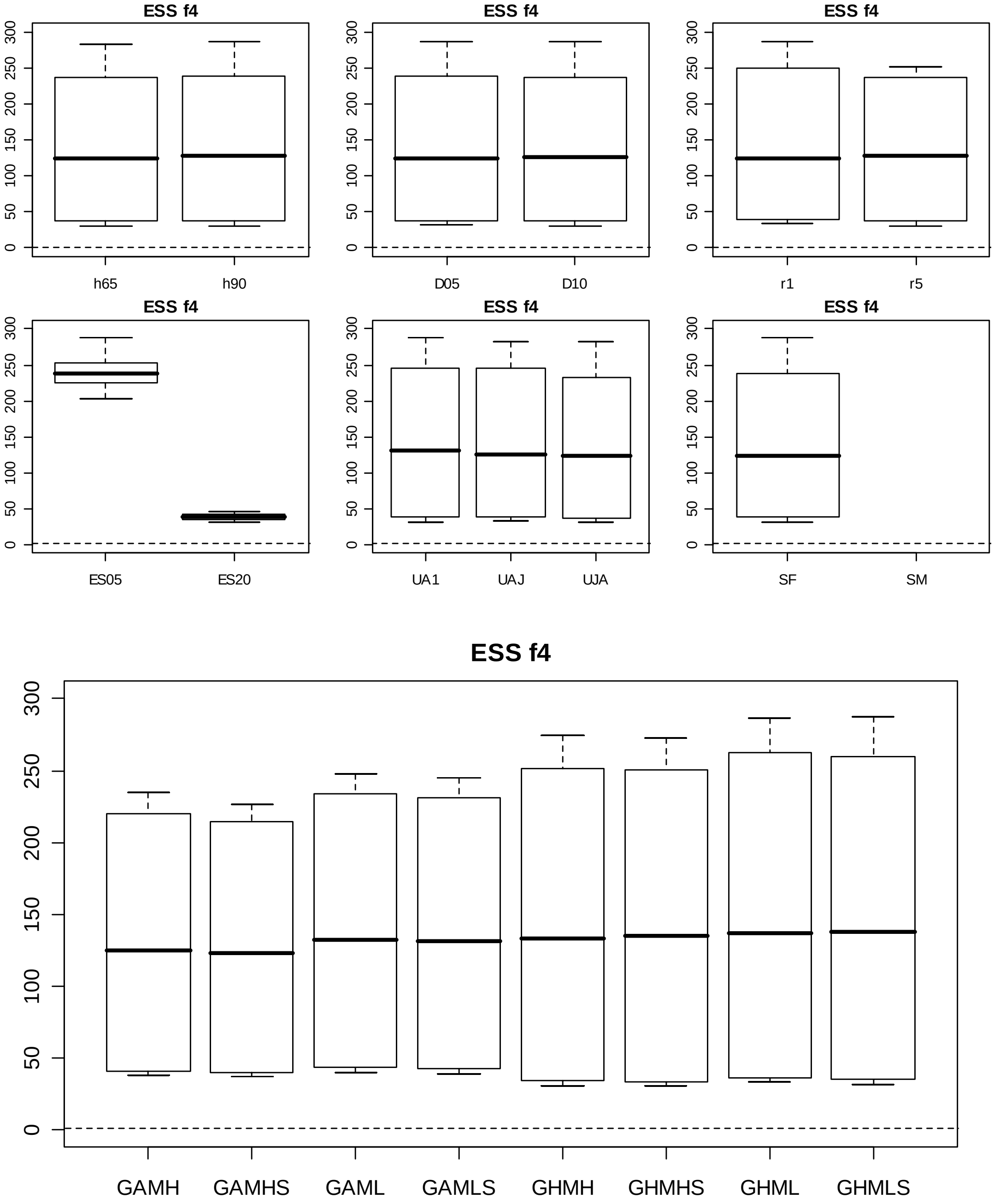


Figure 16. Illustration of how the various assumptions in the uncertainty grid (Table 2) affect the quality of fit to the Australian (fishery 4) size composition data. Y-axis is the mean ESS (see text). Each panel contains results from 384 models, partitioned according to individual model factors from the uncertainty grid (boxplots indicate 0, 25, 50, 75 and 100 percentiles).

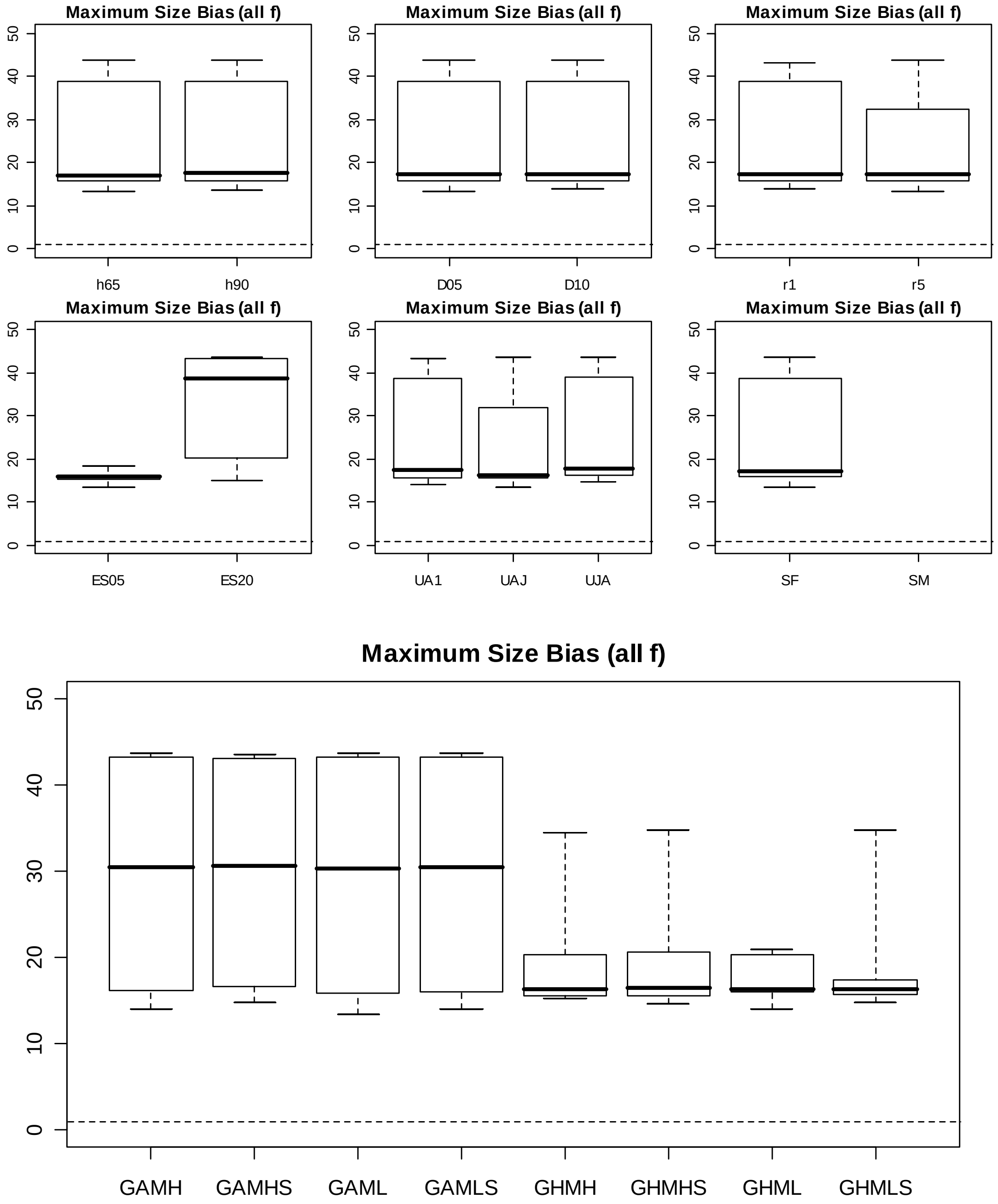


Figure 17. Illustration of how the various assumptions in the uncertainty grid (Table 2) affect the MPD model fit to the size composition data. Y-axis is the maximum of the mean size bias among fleets in cm (excluding the Australian fleet). Each panel contains results from all 384 models, partitioned according to individual model factors from the uncertainty grid (boxplots indicate 0, 25, 50, 75 and 100 percentiles).

Table 4. Summary of model plausibility diagnostics (terms defined in text). The highlighted values indicate major discrepancies between the accepted (ES05) and discarded (ES20) elements of the model assumption grid.

	Uncertainty Grid Specification 192 models **without** ES20 assumption (Most Plausible Ensemble)		192 models **with** ES20 assumption (Rejected)	
Model fit Diagnostic	min	max	min	max
output ESS f=1	18	21	13	14
output ESS f=2	50	58	27	32
output ESS f=3	8	17	3	5
output ESS f=4	203	287	31	46
output ESS f=5	30	35	23	27
output ESS f=6	5	5	4	4
output ESS f=7	41	55	19	25
output ESS f=8	15	37	5	17
output ESS f=9	20	23	10	13
output ESS f=10	15	16	10	12
output ESS f=11	52	67	24	41
maximum size bias f=all	13	19	15	44
cpueRMSE f=2	0.44	0.65	0.39	0.62
cpueRMSE f=4	0.13	0.32	0.12	0.43
cpueRMSE f=7	0.58	0.69	0.55	0.69
cpueRMSE f=11	0.22	0.38	0.22	0.45

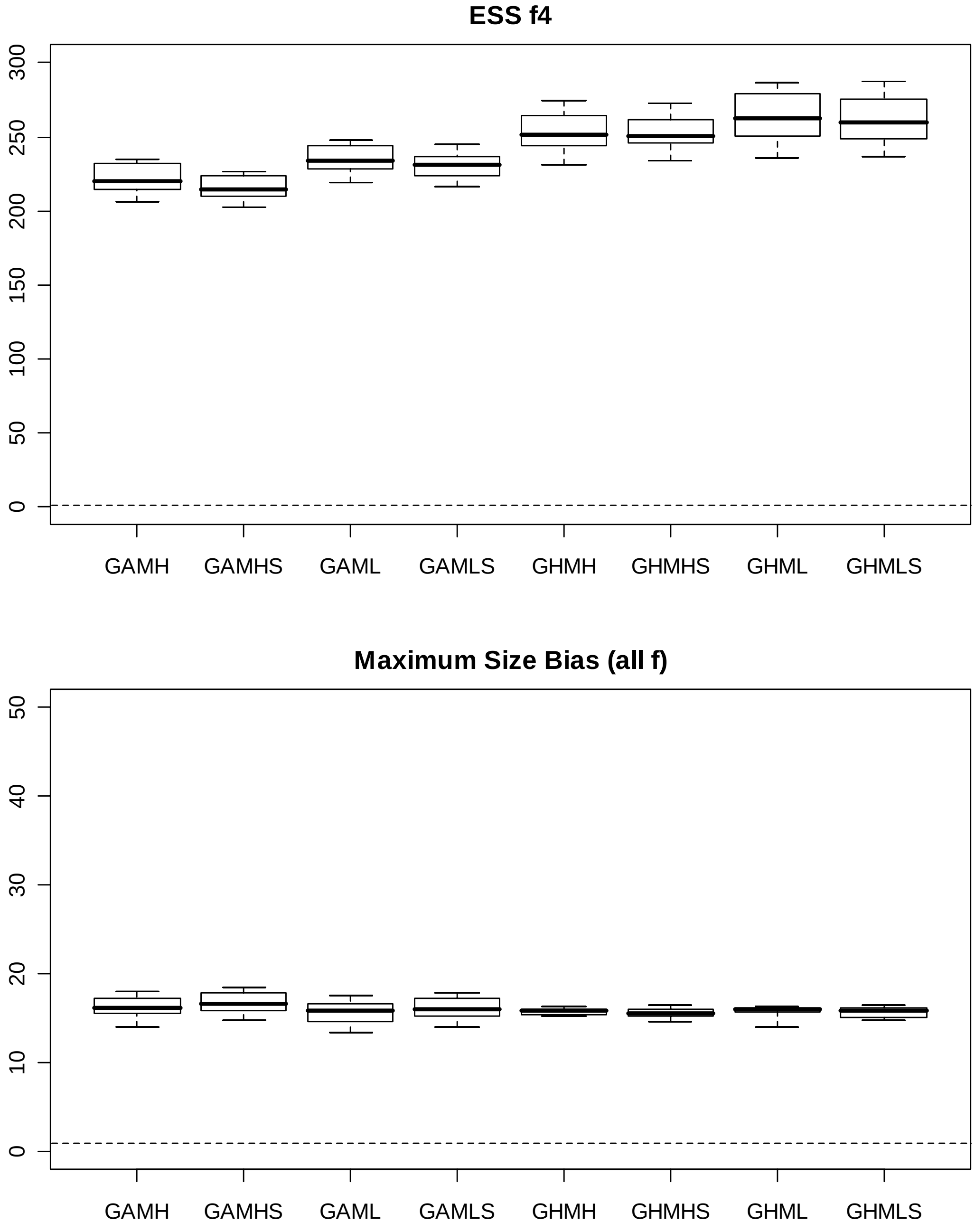


Figure 18. Quality of fit diagnostics for the size composition data, illustrating that the growth/maturity/mortality assumptions did not have a major impact. Each panel contains results from all 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions (Table 2) from the uncertainty grid (boxplots indicate 0, 25, 50, 75 and 100 percentiles).

4.1.2 Detailed results from two example models

In this section, the MPD results from two example models from the SWP MPE are described in detail. The two models represent the most pessimistic and optimistic results in terms of estimated MSY. The models with the highest and lowest MSY estimates have few overlapping structural assumptions and in many respects we would expect the other model combinations to be intermediate in character between these two.

The MPD fits for the CPUE data are shown over time in Figure 19 and Figure 21. Figure 20 and Figure 22 are scatterplots of the predicted and observed CPUE. Both models seem to describe the general downward CPUE trend since 1998 very effectively for all fleets, and the recent upward trend in the Australian and New Zealand fleets. The Japanese CPUE series are not fit as well as the Australian and New Zealand series, although to some extent this appears to be related to noise in the seasonal variability rather than the inter-annual variability which we are most interested in. For the Japanese fleet in area 2 (fishery 7), there is evidence for a systematic lack of fit for both models (predictions exceed observations in the early 1970s and 2000s; observations exceed predictions in the late 1990s). These results are qualitatively consistent with our relative levels of confidence in the CPUE series from the different fleets, and there does not seem to be a compelling argument to prefer one model over the other on the basis of the CPUE fits.

Figure 23 and Figure 24 illustrate predicted and observed catch size frequency distributions for the two models by fishery, aggregated over time. These plots suggest that the general characteristics of the size composition are reasonably well predicted by both models. The polymodal observed size frequency distributions of some fleets indicate the influence of very small sample sizes (i.e. in the time-averaged plots, frequency distributions were weighted equally among years even though sample sizes differed). The fit appears to be the worst for fisheries 3 and 8, which to some extent reflects the fact that these fisheries are poorly sampled, and might reflect combined characteristics of northern and southern (SBT-targeting) fleets. Qualitatively, it would be difficult to conclude that either the pessimistic or optimistic model was preferable on the basis of these results.

Figure 25 and Figure 26 compare the time series of predicted and observed mean catch-at-size for all fleets. The highly sampled Australian fleet shows a clear declining size trend over time, which is reasonably well described by both models. The other fleets show an erratic pattern of observed mean sizes which again is presumably attributable to poor sampling. Given the poor size composition data, it is not obvious that there are major biases in predicted mean catch sizes for either model.

Fishery selectivities for the pessimistic and optimistic models are shown in Figure 27. The selectivity for the bulk of the fleets (fisheries 1,2,4-7,9 and 10) are strongly dome-shaped. The SBT-targeting fishery (8) shows an increasing logistic shape in both cases (though the optimistic model is slightly domed). Selectivity of fishery 3 in both cases shows a strong mode around age 3-4, but also a second mode on older ages. This might reflect the mixed character of this southern fishery (i.e. sometimes SBT-targeting). It would be preferable if the northern and southern fleets could be more reliably separated, but given the small magnitude of catches in this fishery, it probably does not have much influence on the assessment overall. Of more concern is the selectivity of the NZ domestic fishery (11), which was consistently estimated to be (at least somewhat) bimodal, with modes around age 2-3 and 6-10. We are not aware of any biological justification for the bimodal New Zealand selectivity, though it might be worth investigating the evidence for seasonally variable selectivity and sexual dimorphism. In the current assessment, recognizing the bimodality does not help to distinguish between plausible and implausible models because it was present to a greater or lesser degree in most (or all) models. The variability in selectivity between models would be expected to allow different growth rate and M assumptions to result in similar predicted size composition.

Figure 28 illustrates the fit to the stock recruitment curve for the pessimistic and optimistic models, and suggests that these data do not provide strong evidence to distinguish between the two steepness options examined.

Figure 29 illustrates total and spawning biomass time series estimated from the two example models, in relation to the biomass estimated to have resulted if there had not been any fishing. These plots are useful for examining fishery impacts over time when biomass is believed to be changing substantially for reasons other than fishery exploitation (e.g. recruitment regime shifts). Both of these models attribute part of the biomass decline since 1999 to recruitment declines (but this is clearly more of a concern for the optimistic model). The majority (but not all) of the models attributed at least some portion of the 1997-2004 biomass decline to declining recruitment. This may represent a real effect of recruitment variability, but in some models, at least part of the apparent recruitment shift is an artefact of the model assumptions (e.g. incorrect M specification).

Quality of fit diagnostics and stock status reference points associated with these individual models are listed in Table 5.

Note that predicted and observed total catch in numbers showed no substantial deviations (not shown).

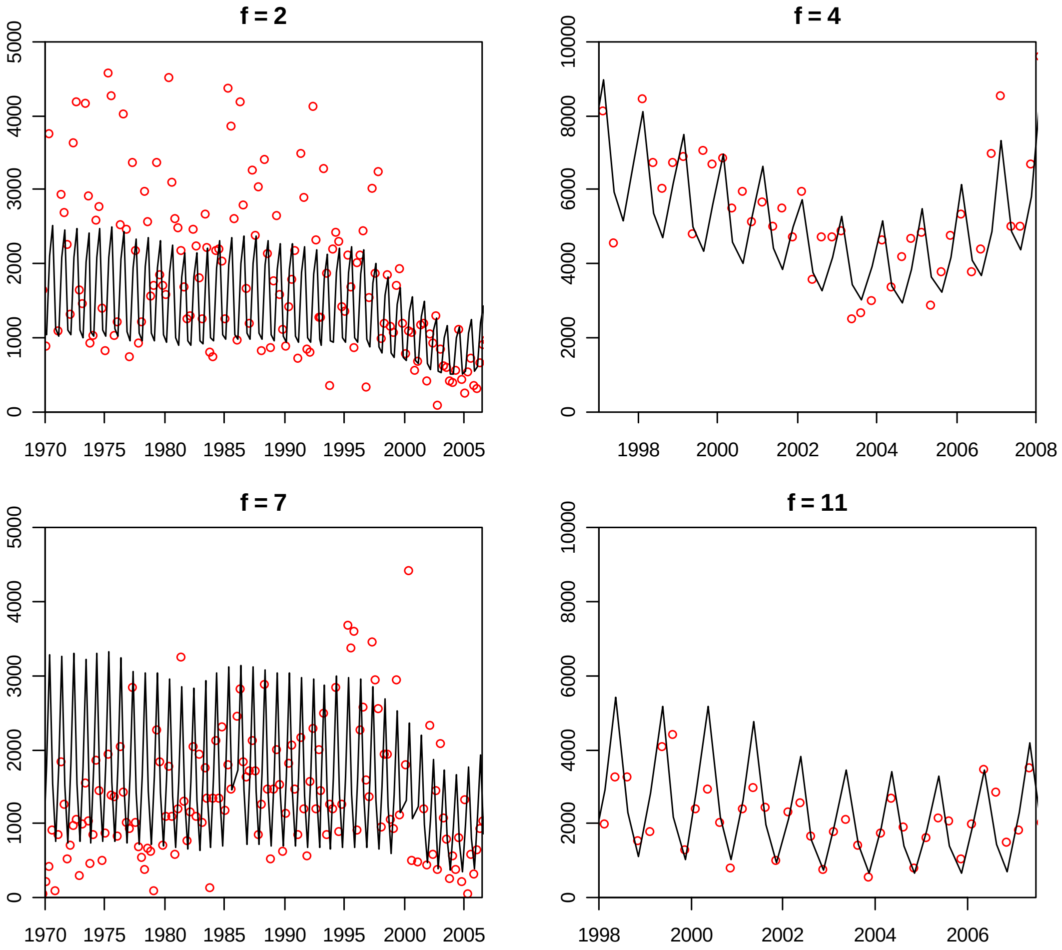


Figure 19. Predicted (lines) and observed (circles) CPUE for the most pessimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Only the 4 fisheries that are assumed to have informative CPUE series are shown.

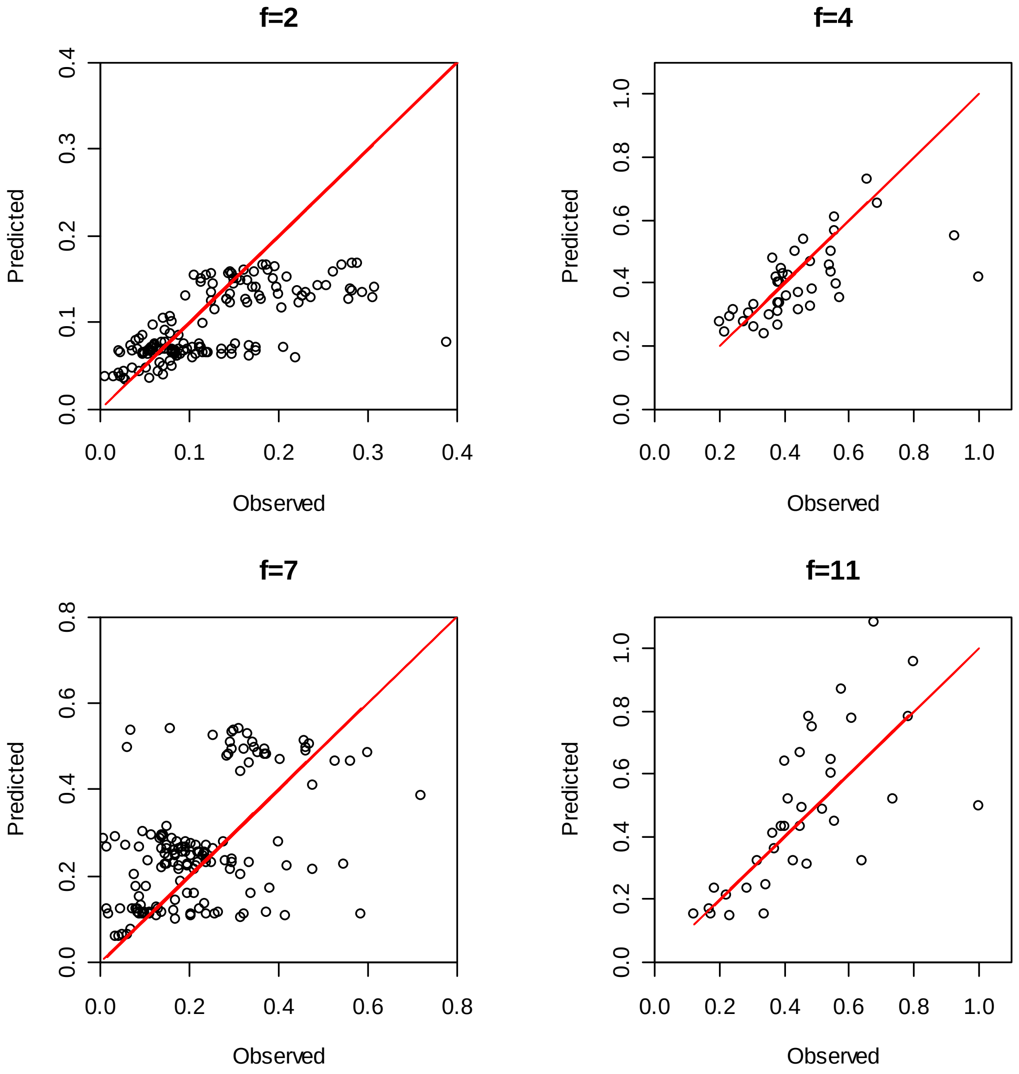


Figure 20. Scatterplot of predicted and observed CPUE for the most pessimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Only the 4 fisheries that are assumed to have informative CPUE series are shown. Scale is relative to observed. Lines indicate the 1:1 line). One outlier is off the scale for fishery 2, and two for fishery 7.

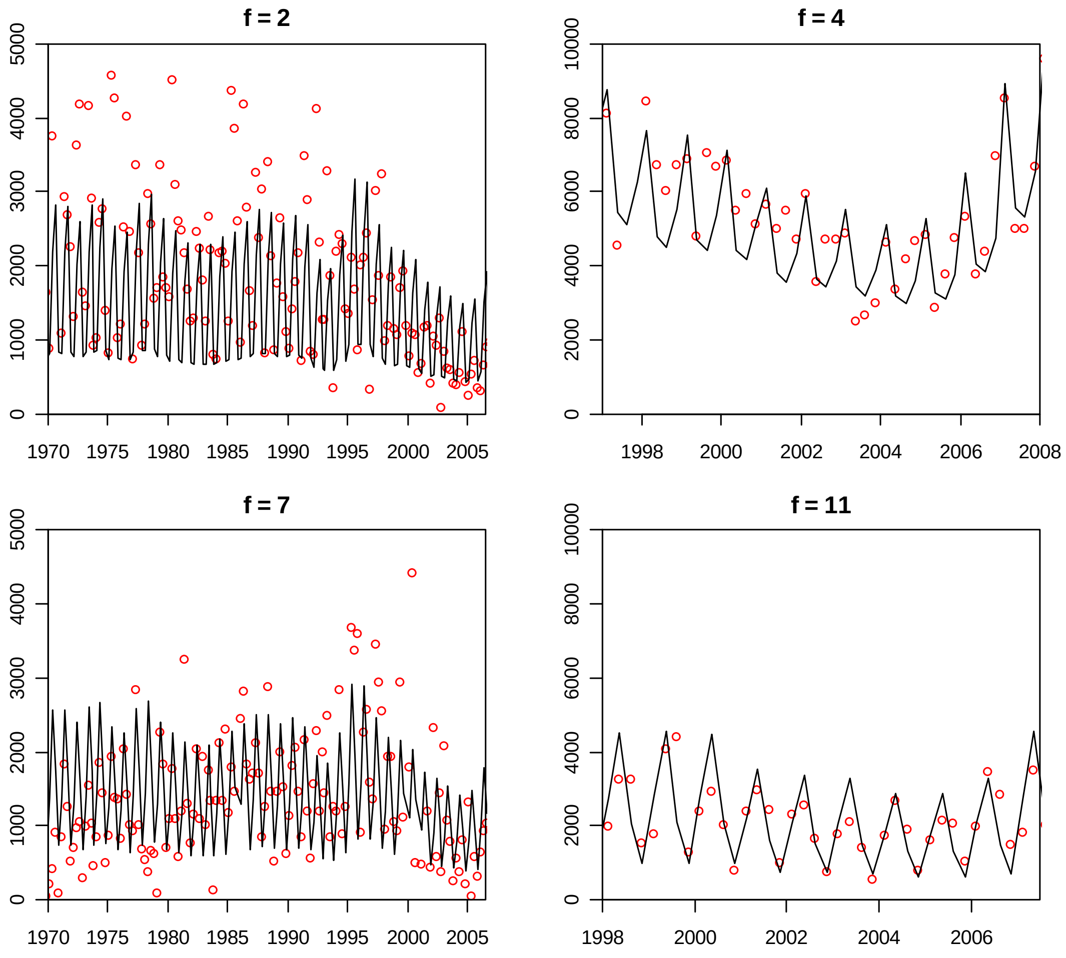


Figure 21. Predicted (lines) and observed (circles) CPUE for the most optimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Only the 4 fisheries that are assumed to have informative CPUE series are shown.

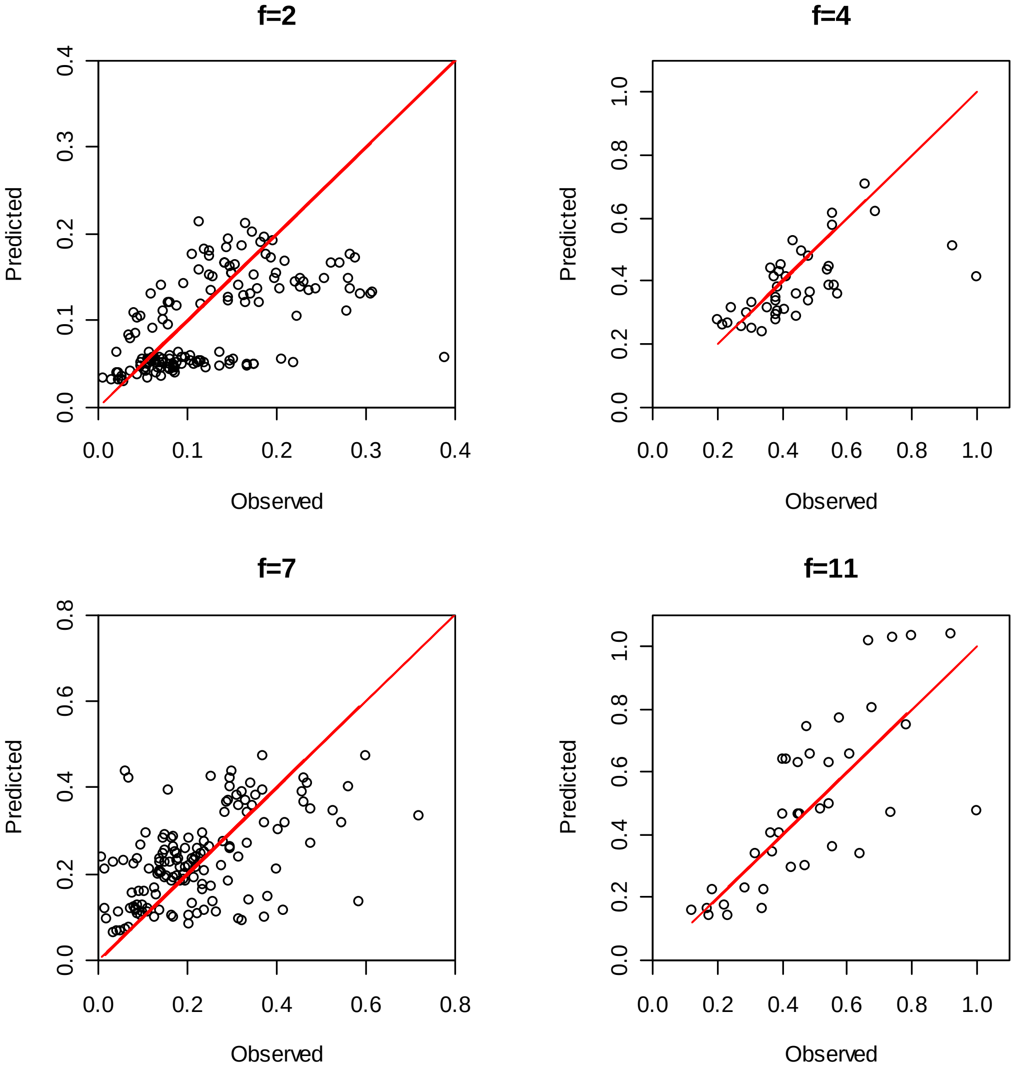


Figure 22. Scatterplot of predicted and observed CPUE for the most optimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Only the 4 fisheries that are assumed to have informative CPUE series are shown. Scale is relative to observed. Lines indicate the 1:1 line). One outlier is off the scale for fishery 2, and two for fishery 7.

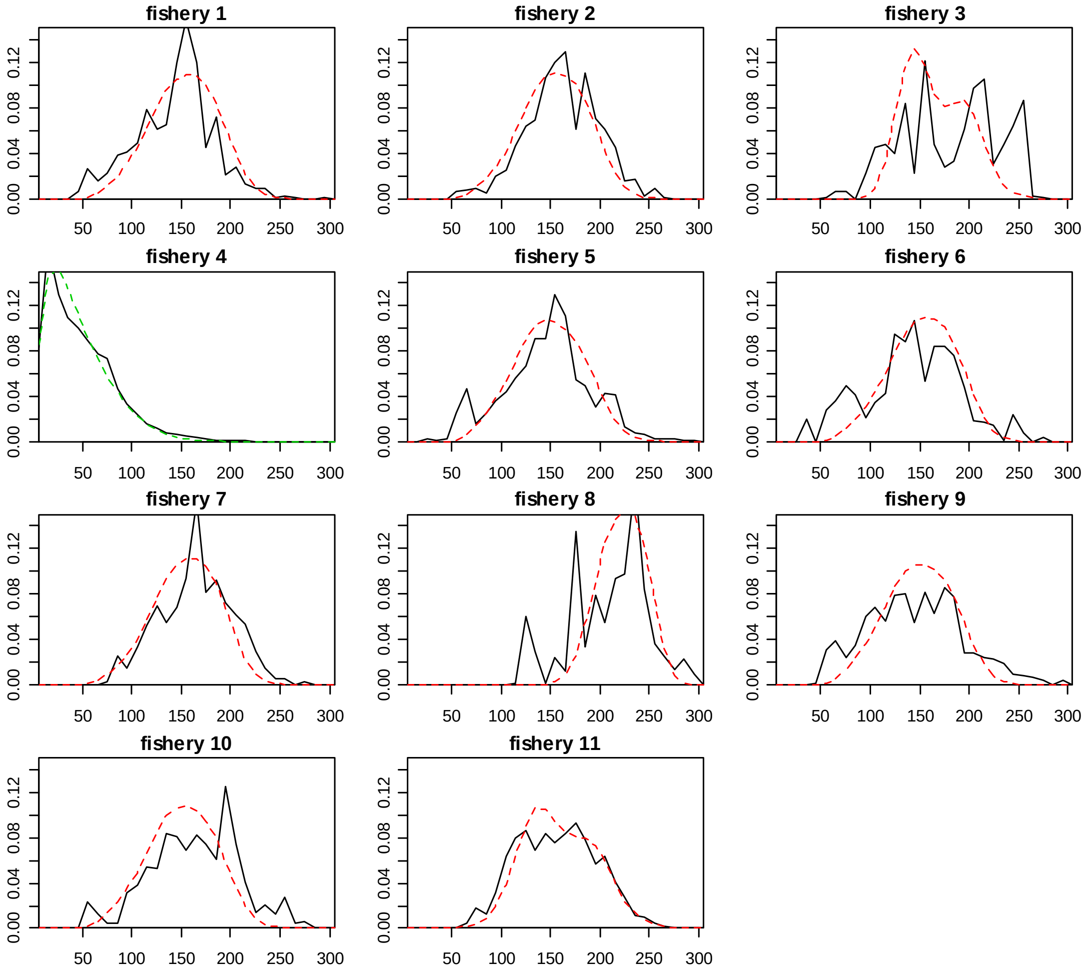


Figure 23. Predicted (broken lines) and observed (solid lines) size frequency distributions aggregated over time for the most pessimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Fishery 4 (Australian) is in units of trunked mass (kg), all others are lower jaw fork length (cm).

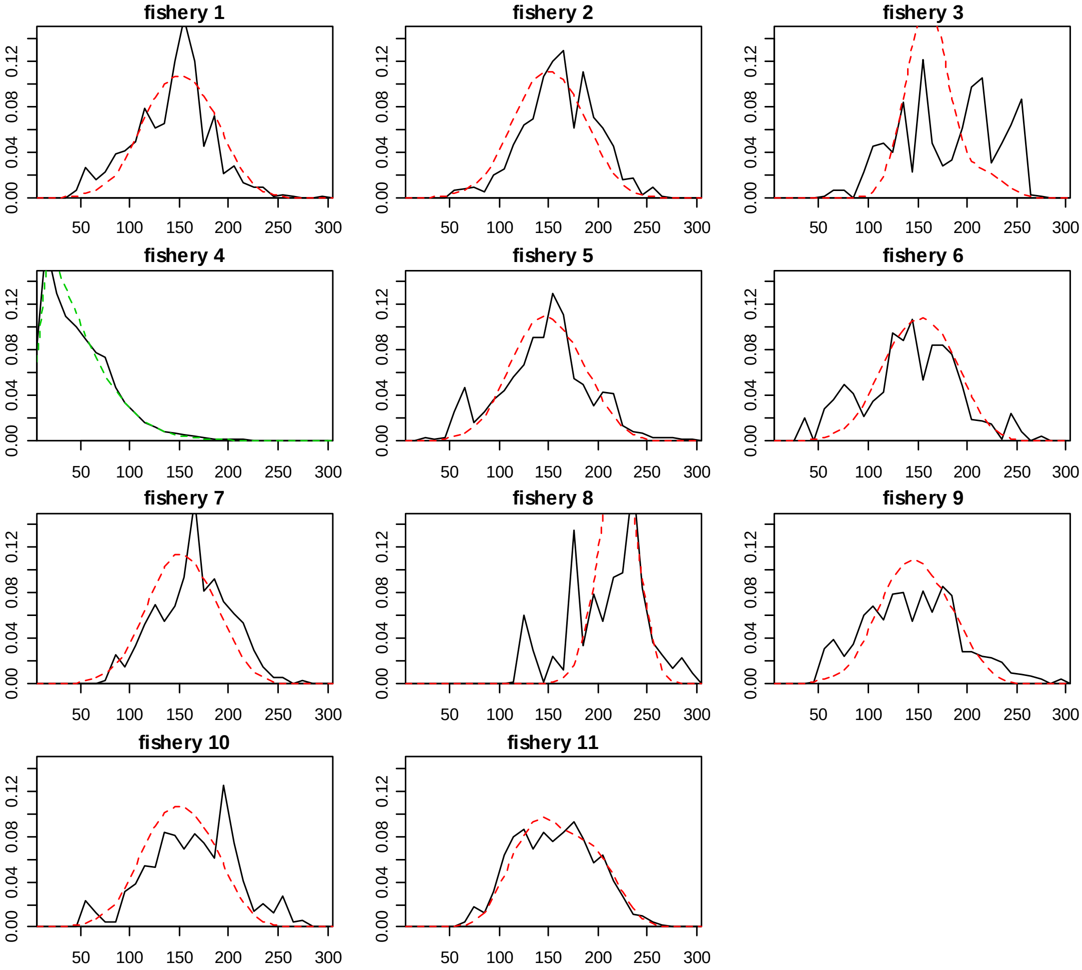


Figure 24. Predicted (broken lines) and observed (solid lines) size frequency distributions aggregated over time for the most optimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Fishery 4 (Australian) is in units of trunked mass (kg), all others are lower jaw fork length (cm).

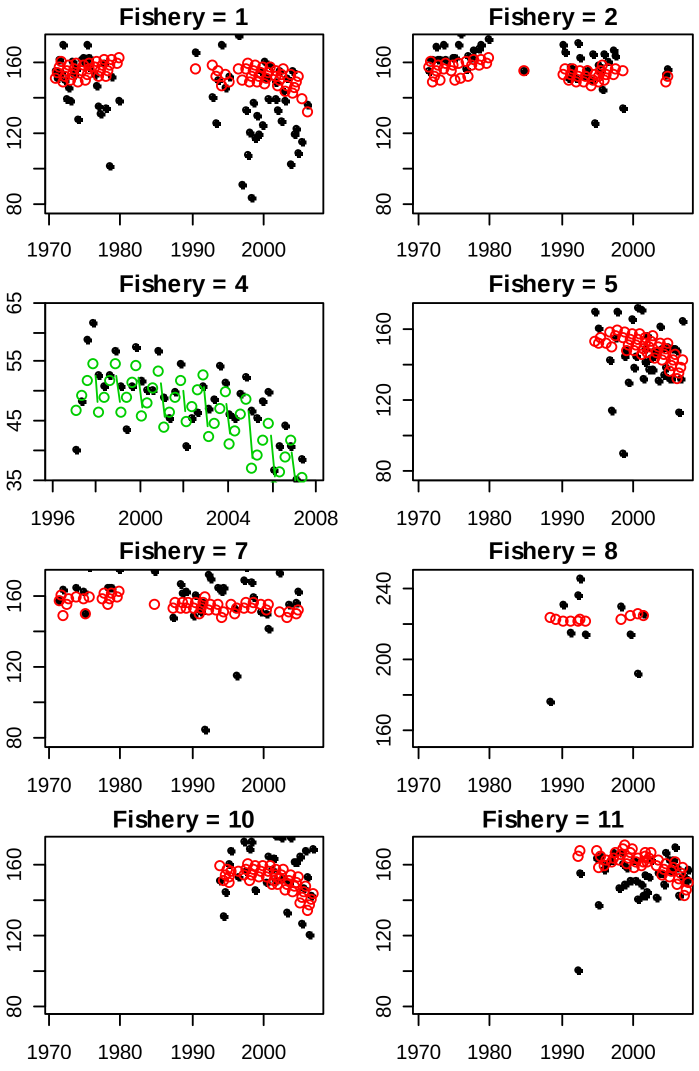


Figure 25. Predicted (coloured circles) and observed (black dots) mean size over time for the most pessimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Fishery 4 (Australian) is in units of trunked mass (kg), all others are lower jaw fork length (cm).

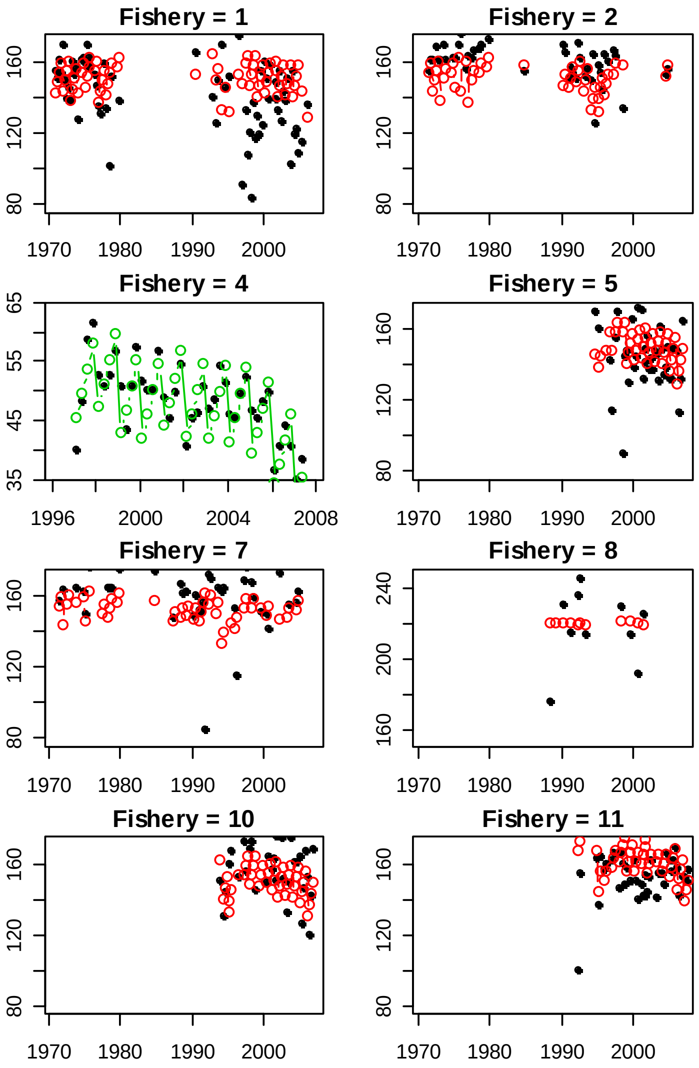


Figure 26. Predicted (coloured circles) and observed (black dots) mean size over time for the most optimistic (in terms of MSY) of the Most Plausible Ensemble of 192 SWP models. Fishery 4 (Australian) is in units of trunked mass (kg), all others are lower jaw fork length (cm).

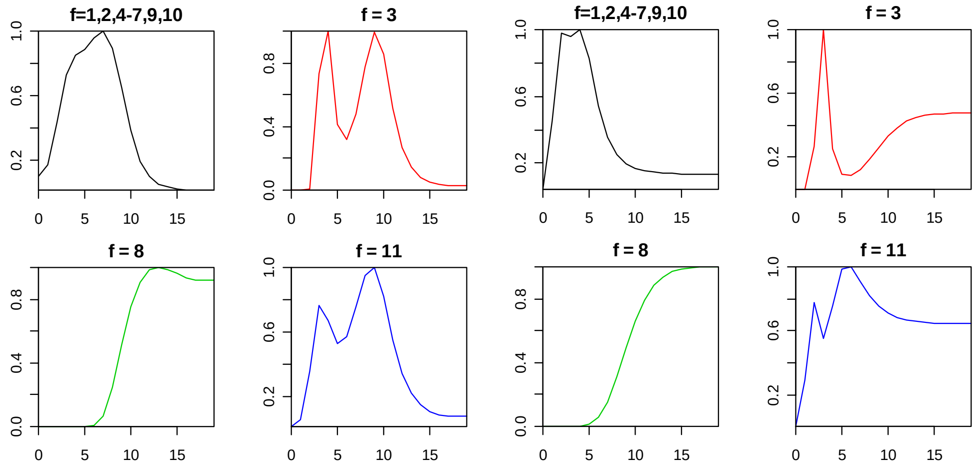


Figure 27. Fishery selectivity estimates from the pessimistic (left 4 panels) and optimistic (right 4 panels) example models. Fisheries are defined in

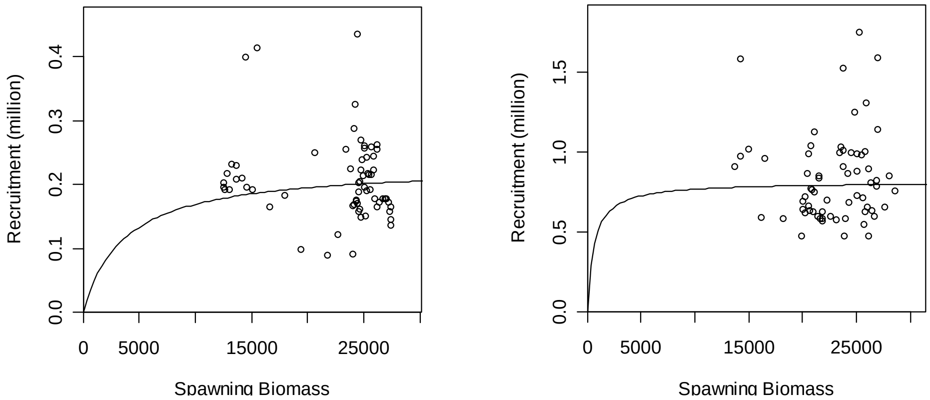


Figure 28. Estimated stock-recruitment relationships for the pessimistic (left panel) and optimistic (right panel) example models.

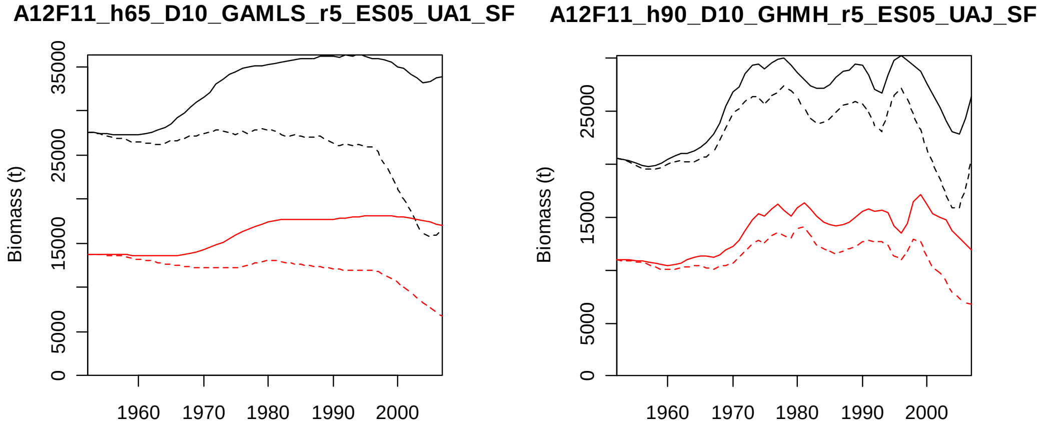


Figure 29. Estimated total (upper black) and spawning stock (lower red) biomass trends estimated for the SWP swordfish population (broken lines) compared to what was estimated would have been observed without fishing (solid lines) for the pessimistic (left panel) and optimistic (right panel) example models.

4.1.3 SW Pacific Stock Status Summary

The preceding section illustrates that even the most extreme models (in terms of MSY) seem to be plausibly consistent with the data and our prior expectations. There may be individual models that are identifiable as slightly more or less agreeable, but the differences do not seem to be as important as in 2006 because the stock status estimates are much more consistent than in 2006. range of results is much more consistent among models than was observed in 2006. If the extremes of the model range are plausible, then it is likely that plausible specifications exist that span the range, and we consider all of the models in the 192 model set to be worth including in the stock status summary.

Table 5 summarizes the MPE goodness of fit diagnostics and MPD estimates for the set of reference points identified at the April workshop (Anon. 2008). Figure 30-Figure 41 partition the reference points according to the individual assumptions from the uncertainty grid. These figures potentially allow one to identify the most important model sensitivities and the highest priorities for research to reduce uncertainties. However, they are not very effective for partitioning effects due to interactions. On the basis of these plots, we note:

- The steepness assumptions had predictable outcomes for MSY-related quantities, i.e. on average, higher steepness corresponds to higher MSY, higher B(2007)/B(MSY) and lower F(2007)/FMSY). However lower steepness was associated with slightly higher estimates of B(2007)/B(1997) and B(2007)/B(unfished) (where B is total or spawning).
- The different diffusion assumptions did not have a noticeable impact on any of the stock status reference points.
- The different assumptions about recruitment variability had little effect on current stock status estimates, but a noticeable effect on projections. The R5 assumption (SD of log recruitment = 0.5) was more optimistic than the R1 assumption, which probably reflects the model tendency to estimate large recent recruitment when unconstrained.
- The UA1 CPUE weighting assumption (Japan, Australia and New Zealand series all weighted equally) was more pessimistic in terms of current stock status than the UJA and UAJ assumptions. While there is considerable overlap among the model results corresponding to these sets of assumptions, we would have predicted that UJA (higher weighting on the Japanese CPUE series relative to Australia/New Zealand) would have had the more pessimistic outcome.
- The alternative growth/maturity/mortality assumptions had less of an impact on the current stock status estimates than expected, with a large degree of overlap among sets of model results for B(2007)/B(1997), and B(2007)/B(MSY).
- The alternative growth/maturity/mortality assumptions had important implications for the 5 and 10 year spawning stock projections. All of the fast growth curve models predicted substantial SSB increases by 2012 (assuming constant 2007 catches), while SSB remained stable near 2007 levels for the slow growth curve models.

The SWP stock status summary represents a synthesis of the results from all 192 models, from which we reach the following conclusions (estimates represent the median and range of the Maximum Posterior Density estimates; in the following section we illustrate that the model selection uncertainty is considerably broader than the statistical uncertainty estimated conditional on any individual model structure, so we consider the MPD estimates to provide a preferable reflection of the real uncertainty):

We consider relative biomass estimates for recent years to be the most reliable reference points, because they are the most closely linked to the highest quality data, and are reasonably robust to the alternative model assumptions explored. In 2006, Total Stock Biomass (TSB) was considered to be more reliable than Spawning Stock Biomass (SSB) reference points. However, given the recognition of additional uncertainty in growth rates in 2008, it is not clear that the TSB estimates are more robust than SSB. The MPD results from the plausible model ensemble indicate:

- median TSB(2007)/TSB(1997) = 0.69, range = (0.55 – 0.83).
- SSB(2007)/SSB(1997) = 0.58 (0.42 – 0.71).

The ratio of TSB relative to the biomass estimated to have occurred in the absence of fishing (TSBNF) provides a measure of the fishery impact on the population that might be more meaningful than the biomass ratio at two points in time if the population experiences non-stationary production dynamics (which these assessments tend to suggest to some degree).

- TSB(2007) / TSBNF(2007) = 0.58 (0.45 – 0.79)
- SSB(2007) / SSBNF(2007) = 0.43 (0.31 – 0.63).

The data are not sufficient to estimate a stock recruitment relationship reliably, and most or all models explored suggest some form of non-stationary (or at least highly variable) recruitment dynamics. This undermines the usefulness of the MSY-related reference points. However, in so far as these reference points have been calculated, the majority of MPD estimates from the plausible model ensemble suggest that biomass (total and spawning) are above levels that would sustain MSY and fishing mortality is probably below F(MSY).

- TSB(2007)/TSB(MSY) = 1.57 (1.22 – 2.06)
- SSB(2007)/SSB(MSY) = 1.98 (1.20 – 3.46)
- F(2007)/F(MSY) = 0.44 (0.18 – 0.67)

The stock projections (assuming deterministic future recruitment from the stock recruitment relationship, and constant catches relative to 2007 levels), suggest:

- TSB(2012) / TSB(2007) = 1.19 (1.03 – 1.54)
- SSB(2012) / SSB(2007) = 1.21 (0.91 – 2.07)
- TSB(2017) / TSB(2007) = 1.24 (1.05 – 1.64)
- SSB(2017) / SSB(2007) = 1.41 (0.94 – 2.30)
- TSB(2012) / TSB(MSY) = 1.89 (1.38 – 2.94)
- TSB(2017) / TSB(MSY) = 1.97 (1.43 – 2.99)

Overall the 2008 assessment suggests that current stock status and fishing mortality is in a less risky state than in 2006. This is not surprising given the recent drops in catch and effort. However, it is important to note that the recent increasing CPUE trends may be the combined result of reduced fishing effort and higher than average recent recruitment (see Figure 45 in the following section). There is no reason to expect that recruitment will be sustained at above average levels.

Table 5. Summary of model plausibility diagnostics and MPD stock status summaries (terms defined in text) for the Most Plausible Ensemble.

	Model Specification				
	Grid ES05 (192 models)			**Individual models at extreme range of MSY**	
Model fit Diagnostic	**median**	**min**	**max**	**pessimistic**	**optimistic**
ESS f=1	20	18	21	18	21
ESS f=2	54	50	58	55	54
ESS f=3	12	8	17	15	9
ESS f=4	238	203	287	236	246
ESS f=5	34	30	35	34	30
ESS f=6	5	5	5	5	5
ESS f=7	45	41	55	43	49
ESS f=8	23	15	37	23	15
ESS f=9	21	20	23	22	20
ESS f=10	15	15	16	15	16
ESS f=11	56	52	67	53	56
size bias f=all	16	13	19	16	17
cpueRMSE f=2	0.53	0.44	0.65	0.48	0.56
cpueRMSE f=4	0.18	0.13	0.32	0.16	0.18
cpueRMSE f=7	0.63	0.58	0.69	0.63	0.64
cpueRMSE f=11	0.29	0.22	0.38	0.30	0.29
Reference Point					
TSB2007 / TSB1997	0.69	0.55	0.83	0.64	0.77
SSB2007 / SSB1997	0.58	0.42	0.71	0.57	0.57
TSB2007 / TSBunfished	0.58	0.45	0.79	0.49	0.78
SSB2007 / SSBunfished	0.43	0.31	0.63	0.40	0.58
TSB2007 / TSBMSY	1.57	1.22	2.06	1.32	2.06
SSB2007 / SSBMSY	1.98	1.20	3.46	1.50	3.30
TSB2012 / TSB2007	1.19	1.03	1.54	1.14	1.30
SSB2012 / SSB2007	1.21	0.91	2.07	0.94	1.79
TSB2017 / TSB2007	1.24	1.05	1.64	1.21	1.32
SSB2017 / SSB2007	1.41	0.94	2.30	1.11	1.92
TSB2012 / TSBMSY	1.89	1.38	2.94	1.50	2.68
TSB2017 / TSBMSY	1.97	1.43	2.99	1.59	2.72
Aggregate F 2007	0.05	0.03	0.11	0.05	0.04
F2007 / FMSY	0.44	0.18	0.67	0.66	0.18
max(F / FMSY)	0.85	0.43	1.39	1.37	0.45
MSY (trunked mass *t*)	2381	1722	4119	1722	4119

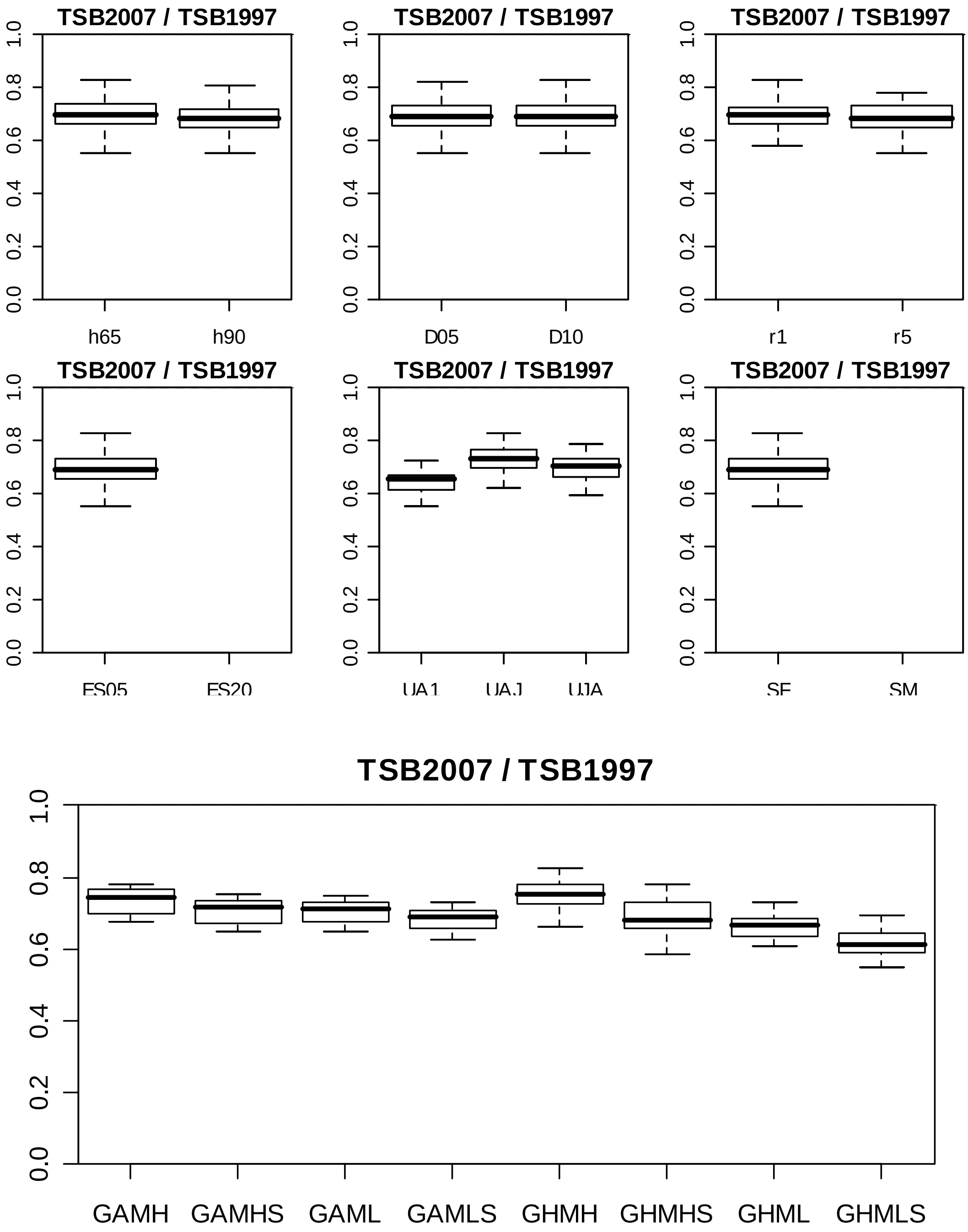


Figure 30. Summary of TSB(2007)/TSB(1997) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

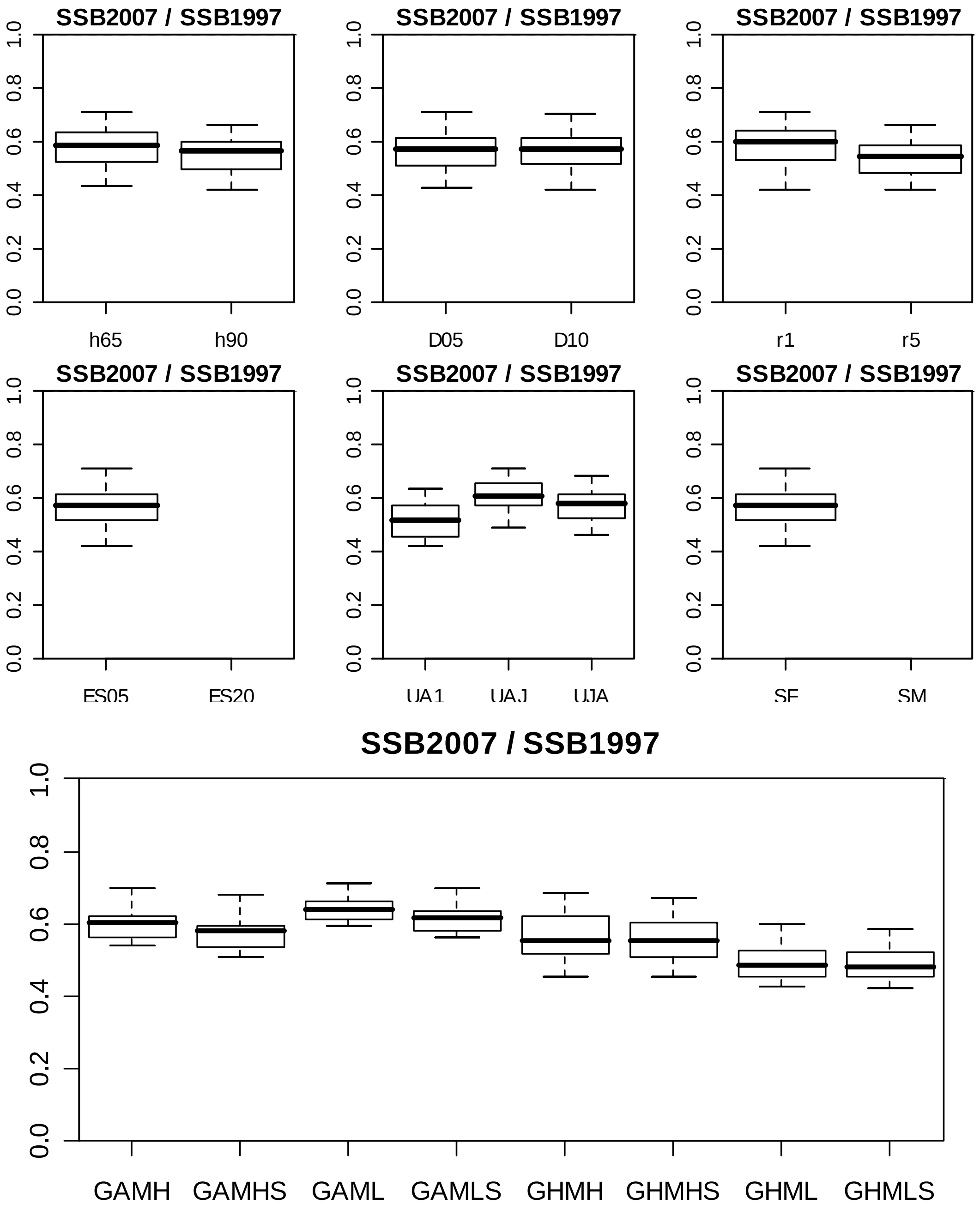


Figure 31. Summary of SSB(2007)/SSB(1997) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

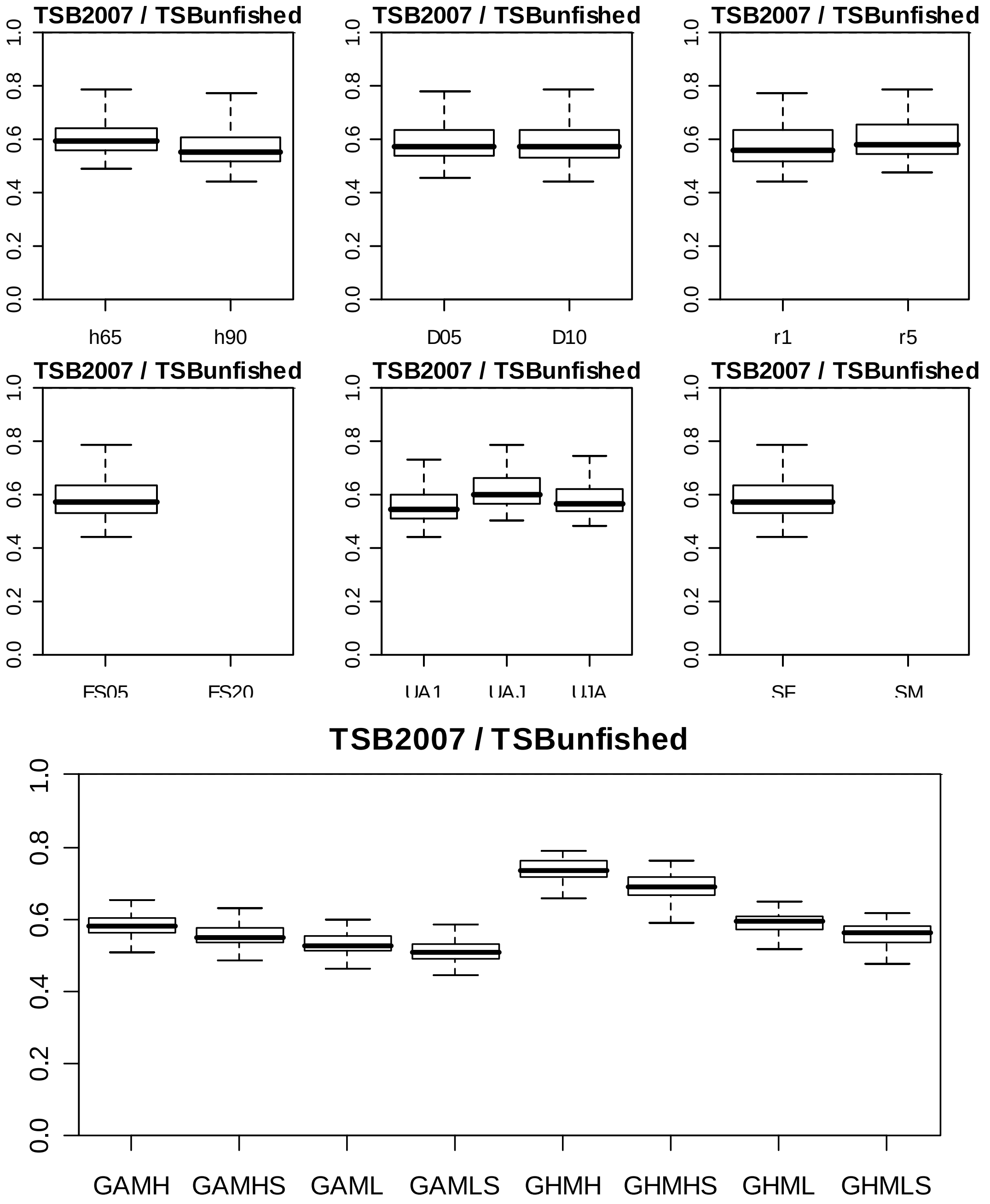


Figure 32. Summary of TSB(2007)/TSB(unfished) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

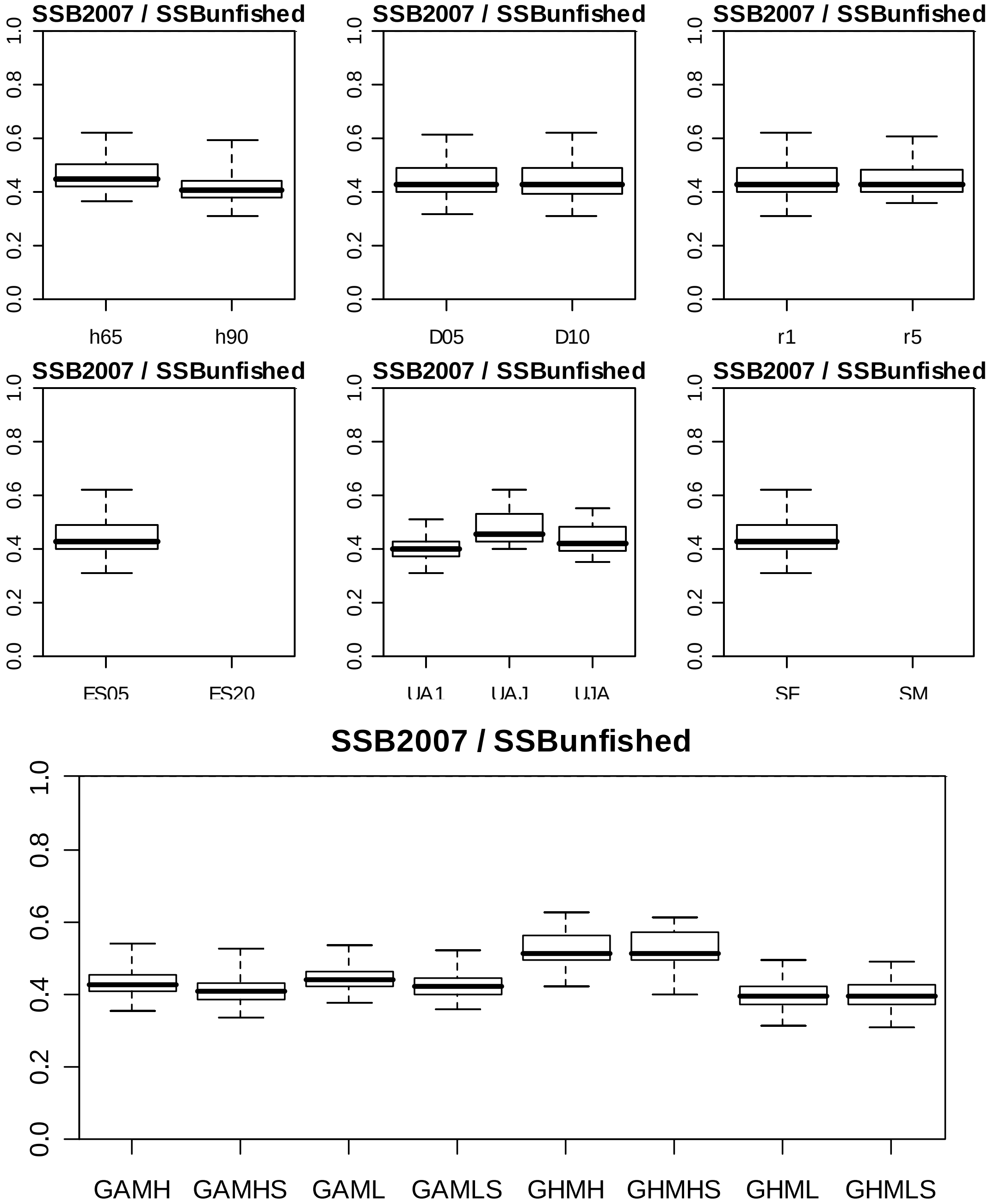


Figure 33. Summary of SSB(2007)/SSB(unfished) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

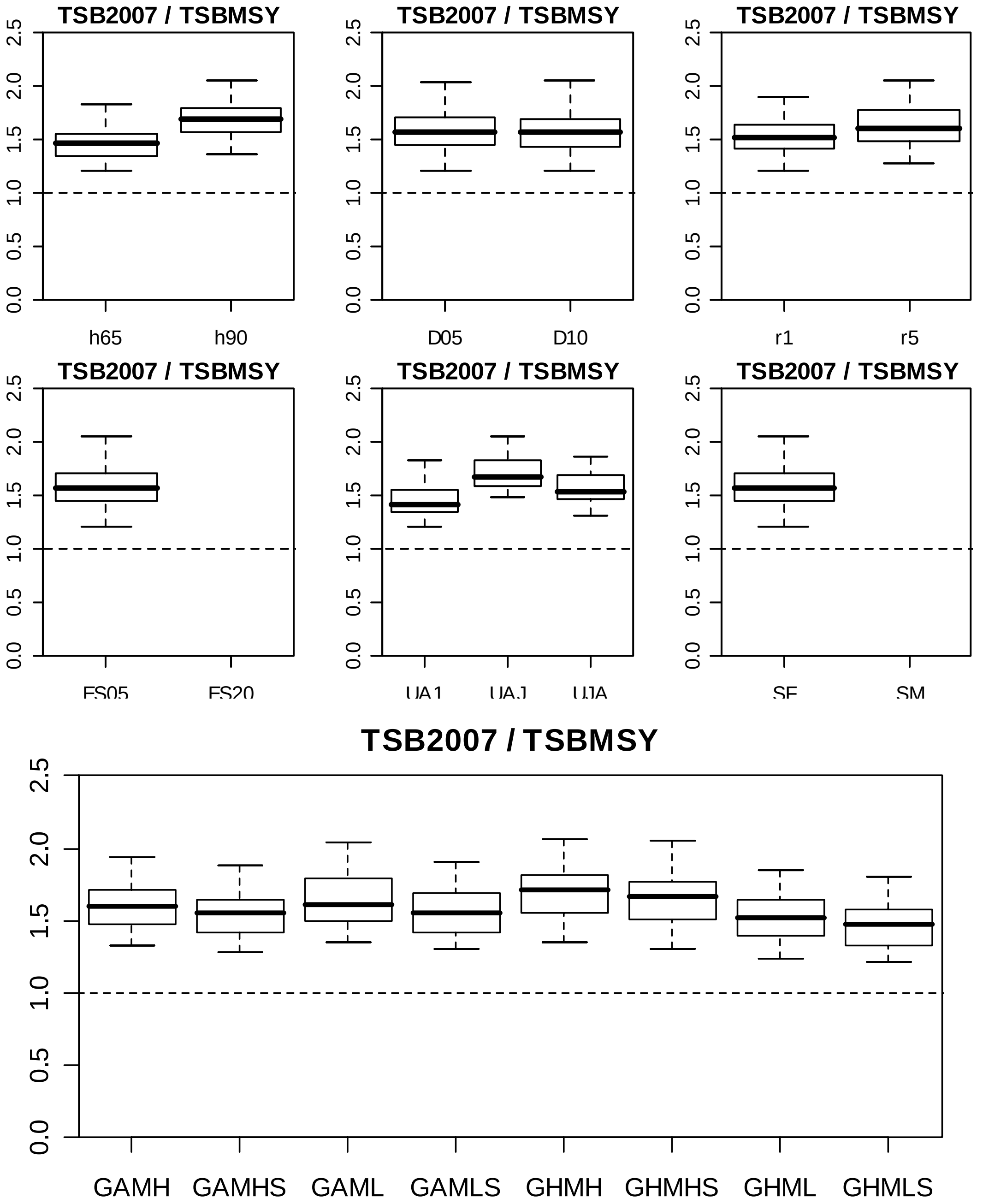


Figure 34. Summary of TSB(2007)/TSB(MSY) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

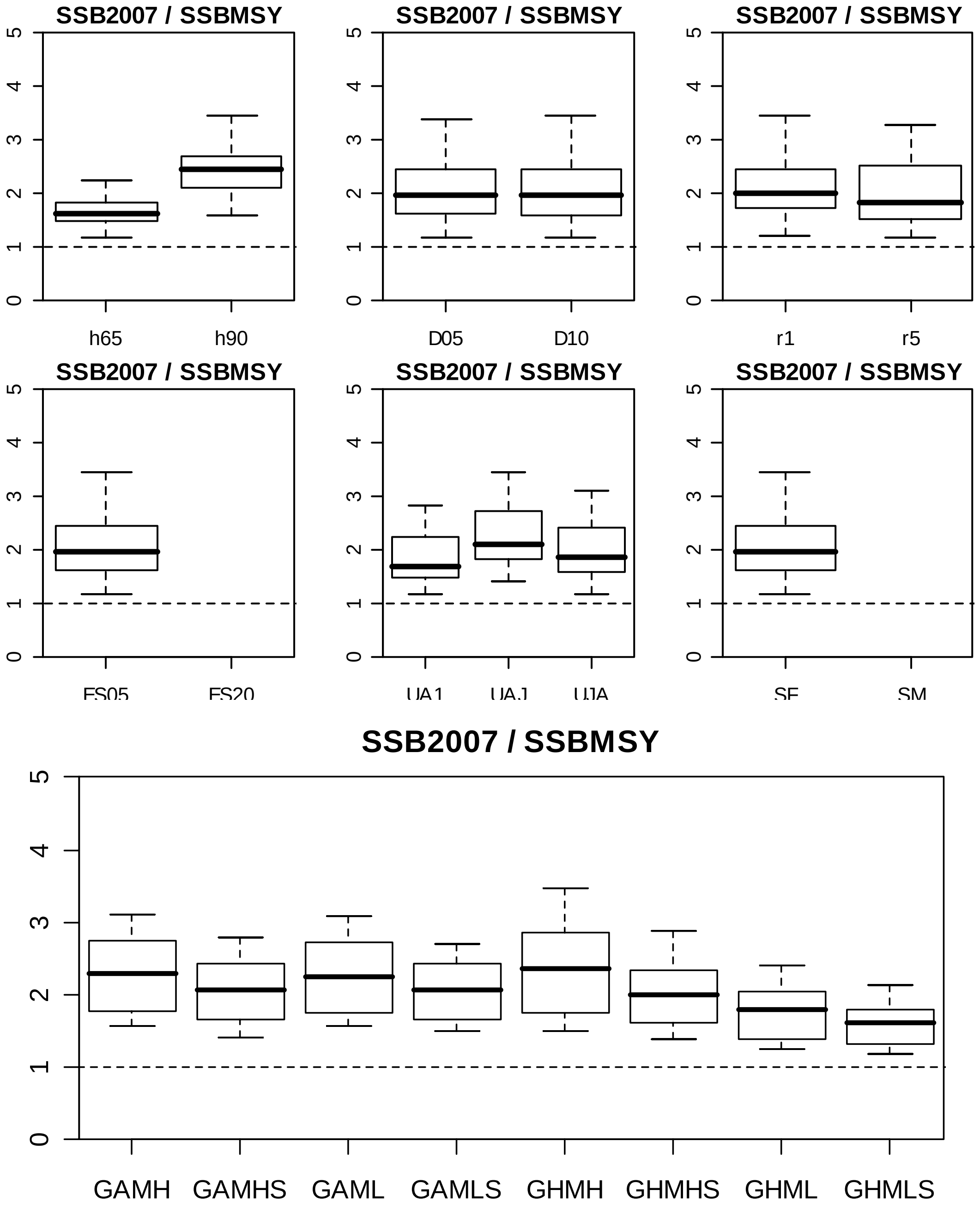


Figure 35. Summary of TSB(2007)/TSB(MSY) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

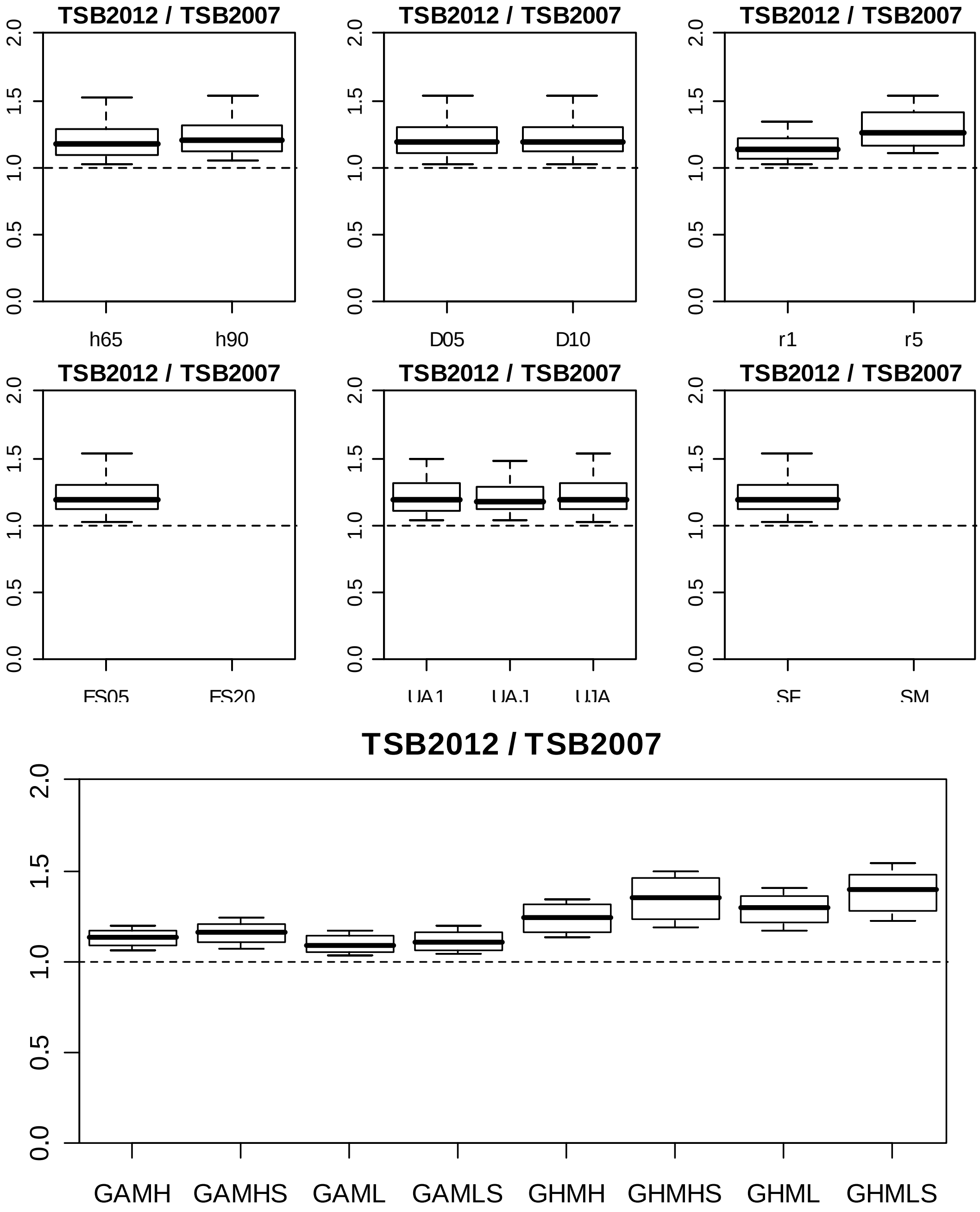


Figure 36. Summary of TSB(2012)/TSB(2007) MPD estimates from the South-West Pacific (assuming projected catch at 2007 levels and deterministic recruitment from the stock recruitment relationship). Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

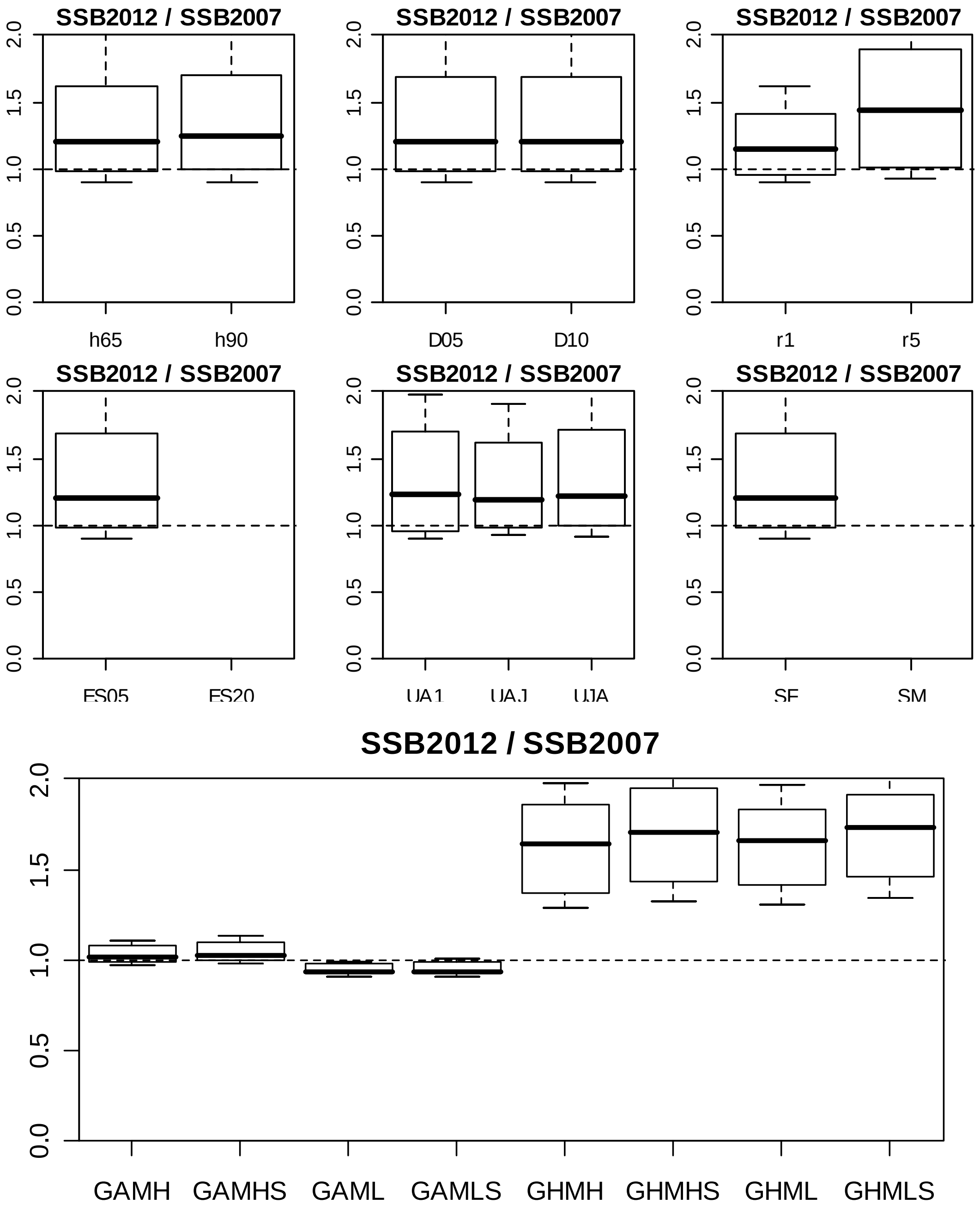


Figure 37. Summary of SSB(2012)/SSB(2007) MPD estimates from the South-West Pacific (assuming projected catch at 2007 levels and deterministic recruitment from the stock recruitment relationship). Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

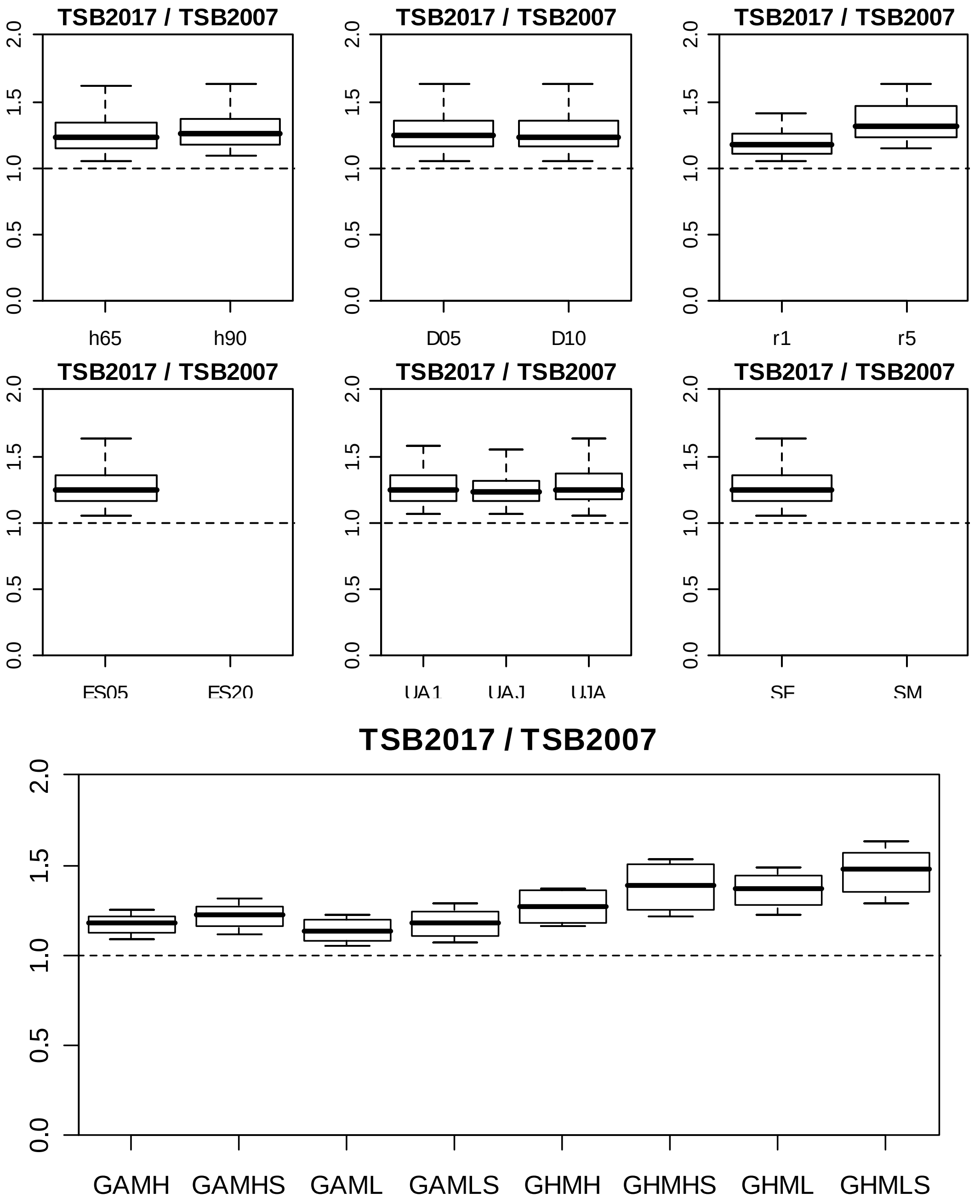


Figure 38. Summary of TSB(2017)/TSB(2007) MPD estimates from the South-West Pacific (assuming projected catch at 2007 levels and deterministic recruitment from the stock recruitment relationship). Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

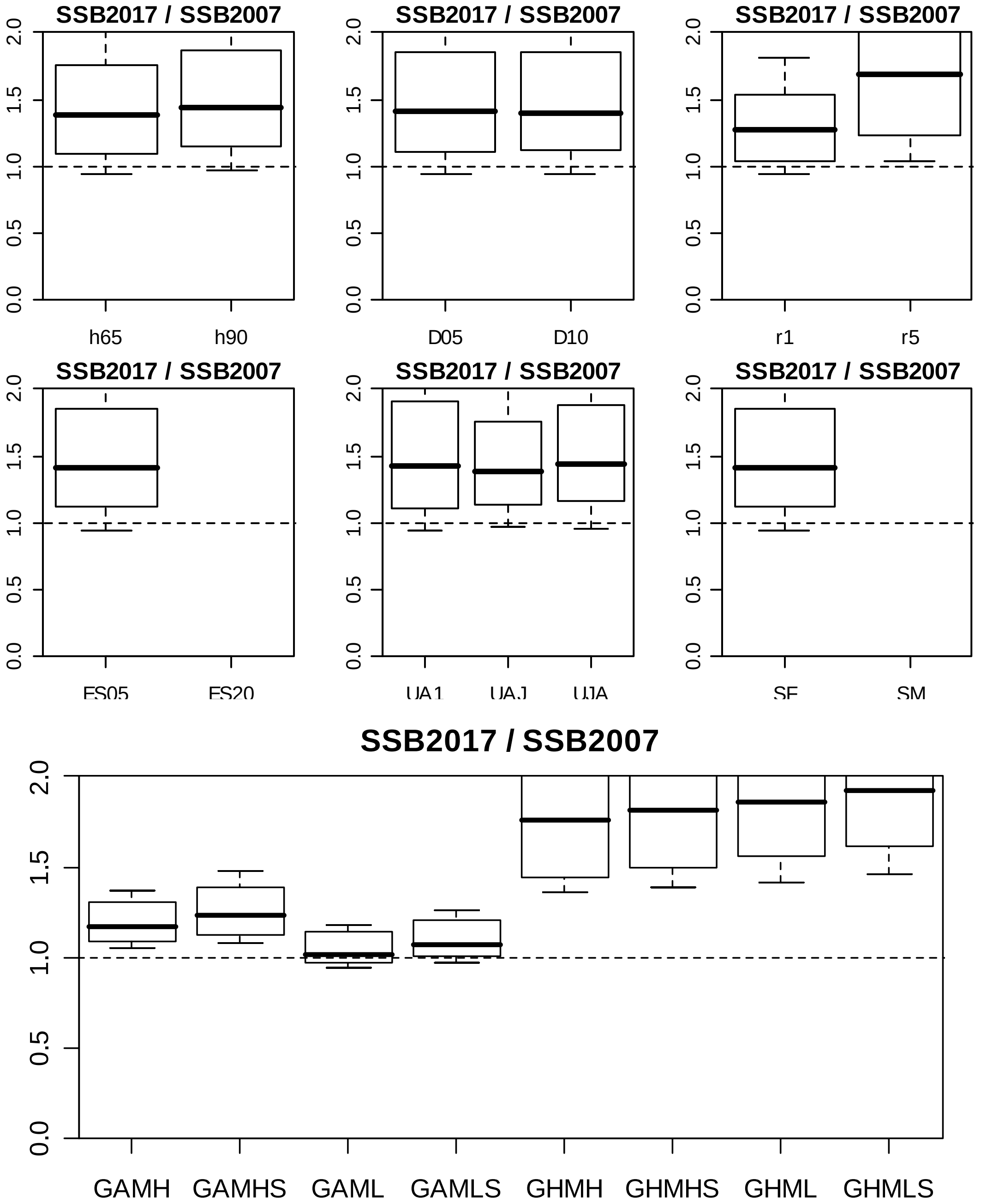


Figure 39. Summary of SSB(2017)/SSB(2007) MPD estimates from the South-West Pacific (assuming projected catch at 2007 levels and deterministic recruitment from the stock recruitment relationship). Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

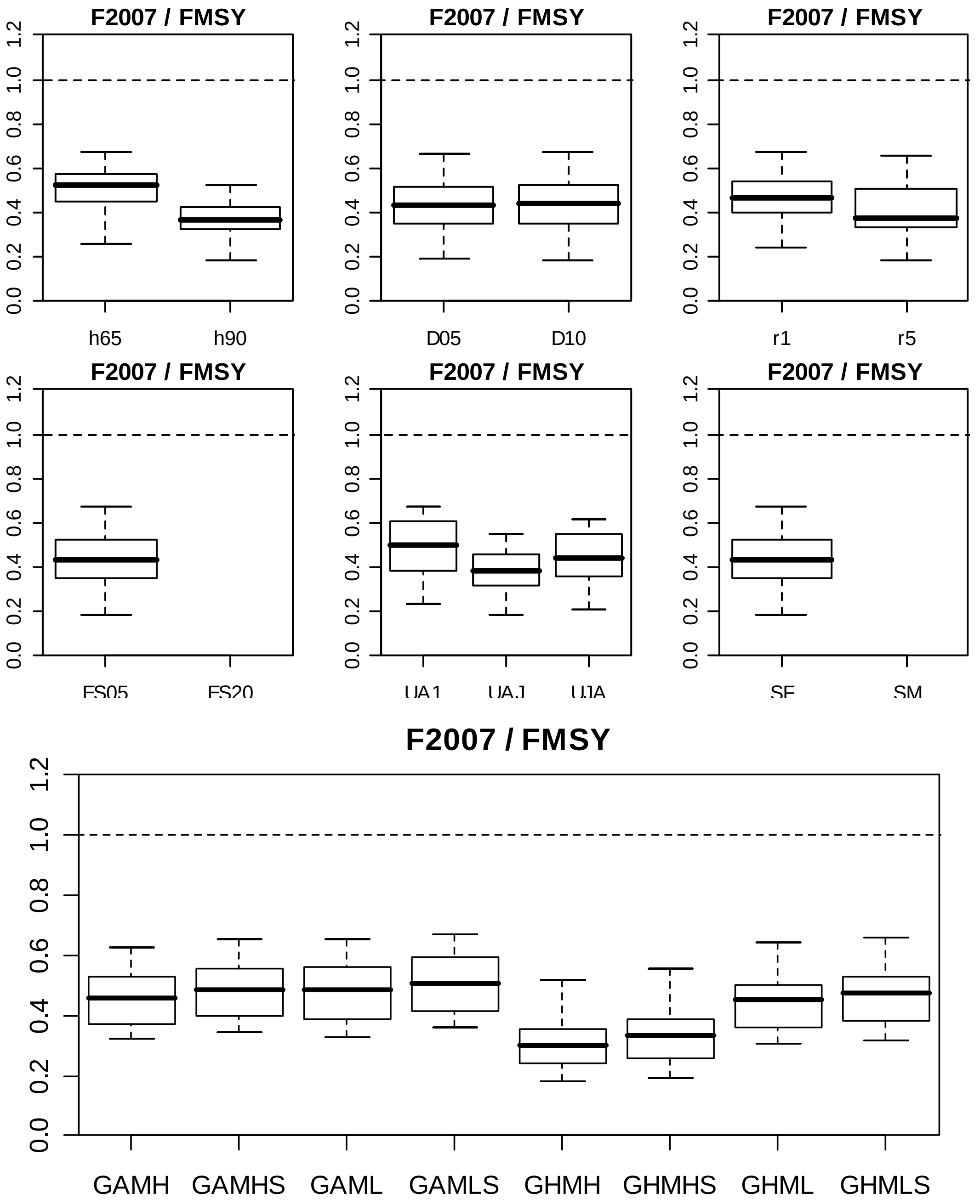


Figure 40. Summary of F(2007)/F(MSY) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

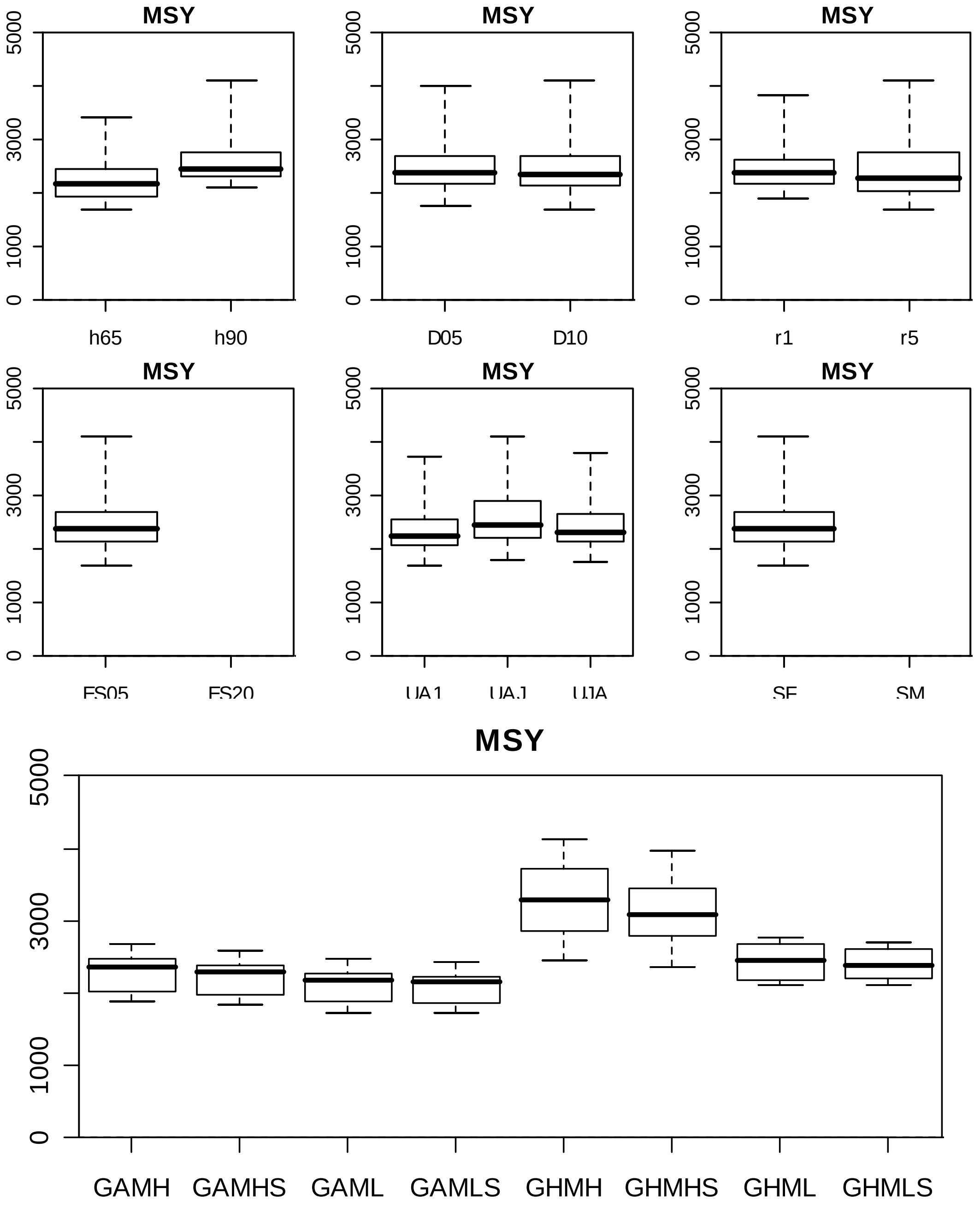


Figure 41. Summary of MSY (trunked mass in tonnes) MPD estimates from the South-West Pacific. Each panel summarizes 0, 25, 50, 75 and 100 percentiles from the distribution of 192 models in the Most Plausible Ensemble, partitioned according to individual model assumptions from the uncertainty grid (**Table 2**).

4.1.4 Comparison of model selection uncertainty and parameter estimation uncertainty

Mathematical theory provides rigorous methods for quantifying the uncertainty associated with statistical models, and provided that the model is correct, these uncertainty estimates should be very reliable. Unfortunately, in fisheries systems the models are never entirely correct, and methods for admitting uncertainty associated with alternative plausible models are not well developed. The following figures illustrate the uncertainty associated with the SWP model selection (or specification) uncertainty in relation to the confidence intervals generated by the statistical parameter estimation uncertainty. For clarity, only a subset of models from the Most Plausible Ensemble is discussed. This subset, hereafter referred to as the “Range-Set”, corresponds to the 7 models with the most extreme MPD estimates for the following reference points:

- TSB(2007)/TSBNF(2007)
- TSB(2007)/TSB(MSY)
- F(2007)/F(MSY)
- MSY

Figure 42 illustrates the time series of Total Stock Biomass for the Range-Set of models. In this figure it is clear that the statistical confidence intervals do not provide a very good indication of the uncertainty that is observed among plausible model specifications. This general result is also clearly evident for F(t)/F(MSY) in Figure 43, absolute SSB(t) in Figure 44, absolute recruitment in Figure 45, and the sustainable yield curves in Figure 46. Figure 47 illustrates the relationship between TSB(2007)/TSB(MSY) and F(2007)/F(MSY).

We recognize that the narrow confidence limits for some of these models are related to our restrictive assumptions about variances (i.e. we do not believe that any of the CPUE series realistically should have an observation error CV of 0.1).

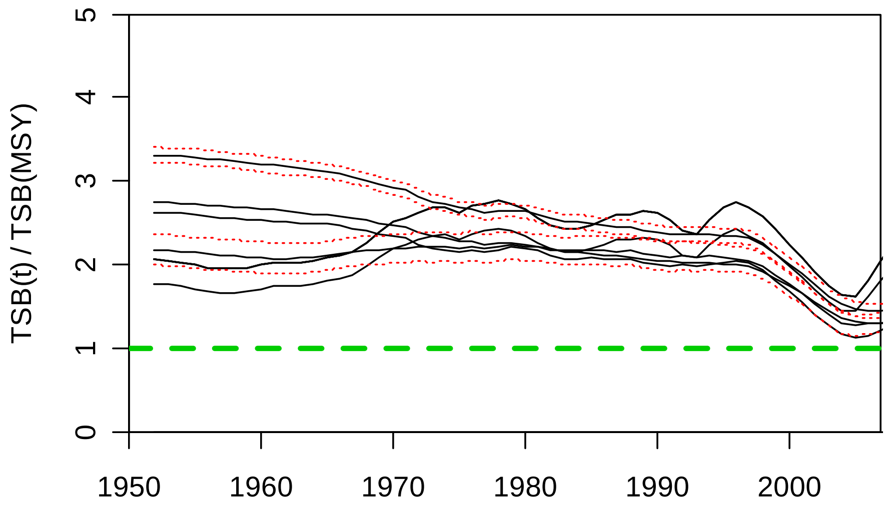


Figure 42. TSB(t) / TSB(MSY), for the "range-set" of models (the most extreme of the 192 ES05 model set on the basis of TSB(2007)/TSB(MSY), F(2007)/F(MSY), TSB(2007)/TSB(unfished) and MSY). Black lines indicate the MPD estimates for the individual models, while the dotted (red) lines indicate the upper and lower 95% confidence limits for two example models.

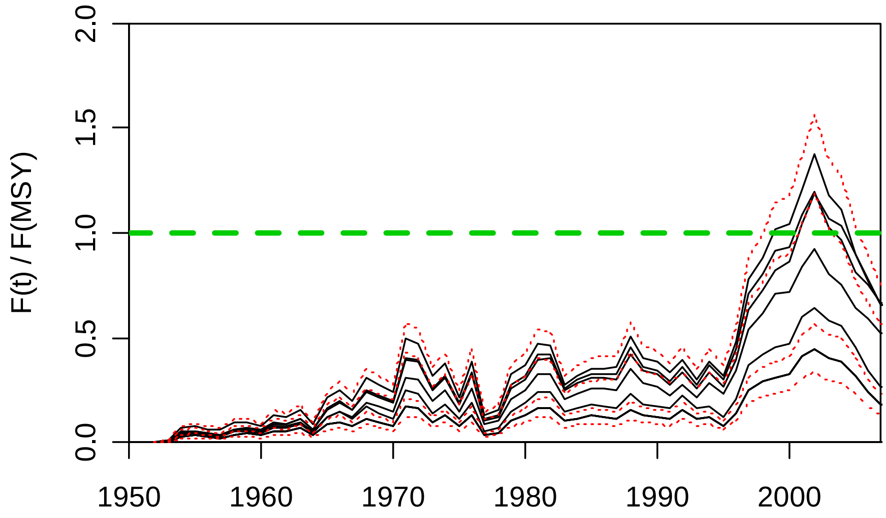


Figure 43. Fishing mortality relative to F(MSY) over time, for the "range-set" of models (the most extreme of the 192 ES05 model set on the basis of TSB(2007)/TSB(MSY), F(2007)/F(MSY), TSB(2007)/TSB(unfished) and MSY). Black lines indicate the MPD estimates for the individual models, while the dotted (red) lines indicate the upper and lower 95% confidence limits for two example models.

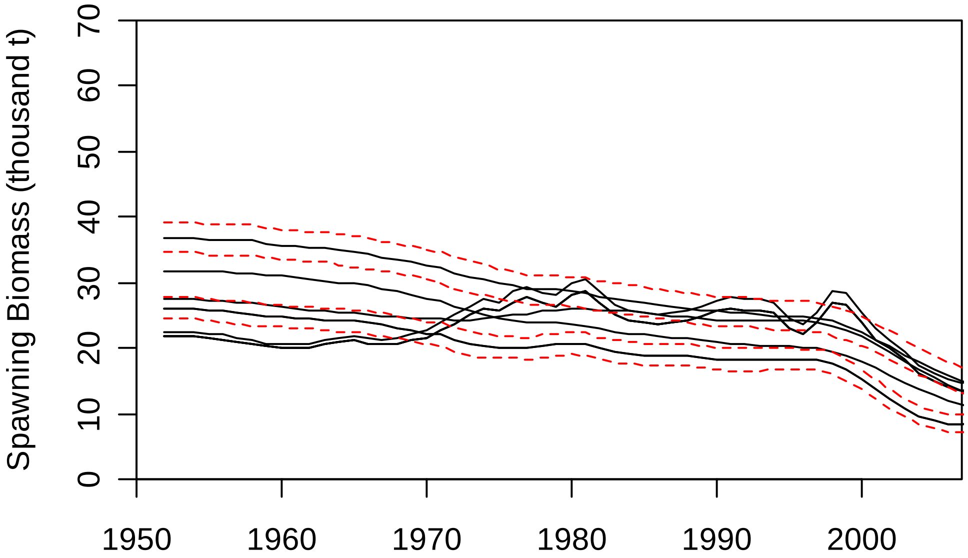


Figure 44. SSB(t) (thousand tonnes) for the "range-set" of models (the most extreme of the 192 ES05 model set on the basis of TSB(2007)/TSB(MSY), F(2007)/F(MSY), TSB(2007)/TSB(unfished) and MSY). Black lines indicate the MPD estimates for the individual models, while the dotted (red) lines indicate the upper and lower 95% confidence limits for two example models.

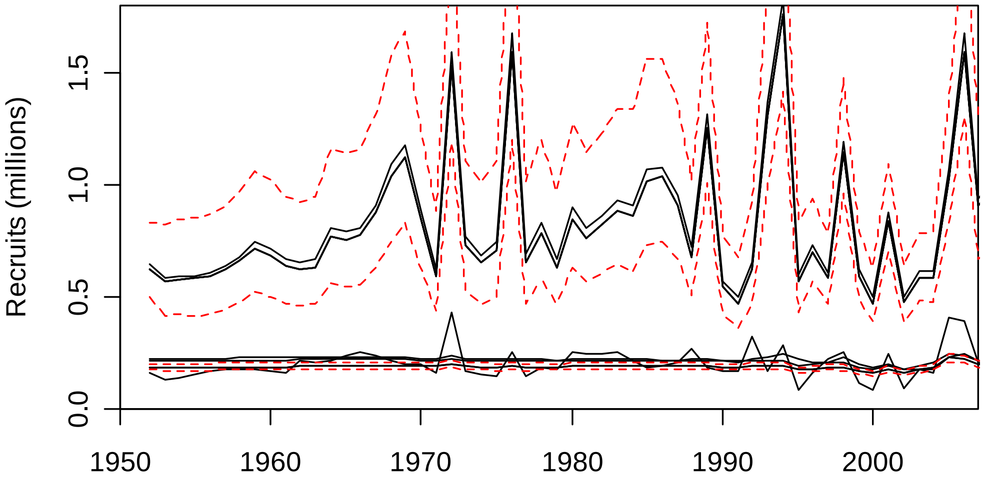


Figure 45. Recruitment time series for the "range-set" of models (the most extreme of the 192 ES05 model set on the basis of TSB(2007)/TSB(MSY), F(2007)/F(MSY), TSB(2007)/TSB(unfished) and MSY). Black lines indicate the MPD estimates for the individual models, while the dotted (red) lines indicate the upper and lower 95% confidence limits for two example models.

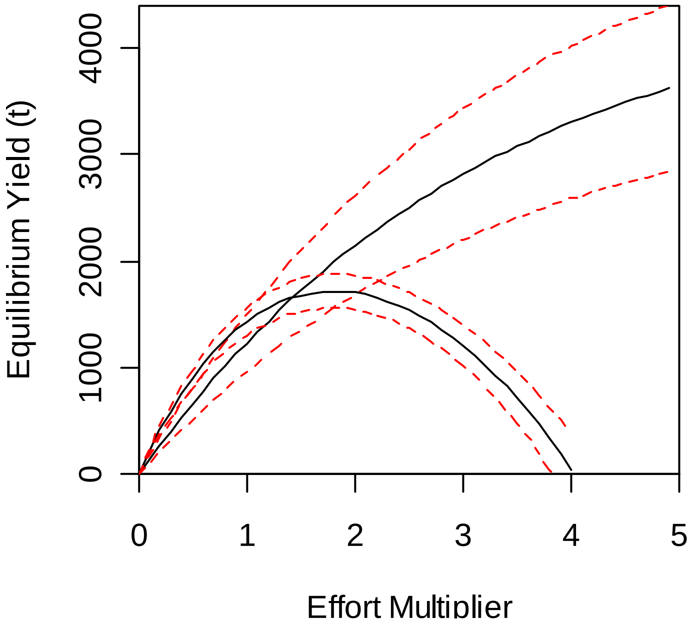


Figure 46. Sustainable yield curves for the most extreme of the models on the basis of MSY. Black lines indicate the MPD estimates for the individual models, while the dotted (red) lines indicate the upper and lower 95% confidence limits.

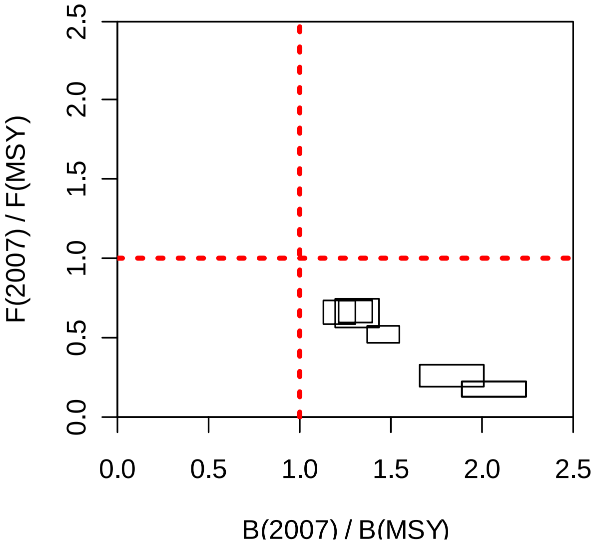


Figure 47. Summary plot comparing current fishing mortality, F(2007)/F(MSY), and total stock biomass, TSB(2007)/TSB(MSY), from the "range-set" of models extracted from the Most Plausible Ensemble. Boxes indicate the upper and lower 95% confidence limits (but not the covariance) for each individual model.

4.1.5 SWP Stock status summary relative to 2006 assessment

Figure 48 illustrates the summary relationship between estimated total biomass and fishing mortality in 2004 relative to MSY-related reference points extracted from the 2006 assessment. Superimposed on the 2006 figure are the (approximate) equivalent stock status estimates (again for 2004) derived from the Most Plausible Ensemble from the 2008 assessment. The 2008 estimates appear to be much more certain than 2006, and near the center of the distribution of estimates provided in 2006. This reduction in uncertainty is what might have been predicted given that the recent reduction in fishing effort seems to have been sufficient to break the "one-way-trip" nature of the fishery (e.g. Hilborn and Walters 1992) that was observed up to 2003-4, and hence might have provided informative contrast with which to improve the estimation of stock productivity. However, it is also likely that the revised spatial structure and constrained migration estimates have limited the number of ways that the models can fit the data (i.e. combining the northern and southern areas of the fishery removes one possible source of flexibility for the models to maintain large "cryptic biomass" reserves).

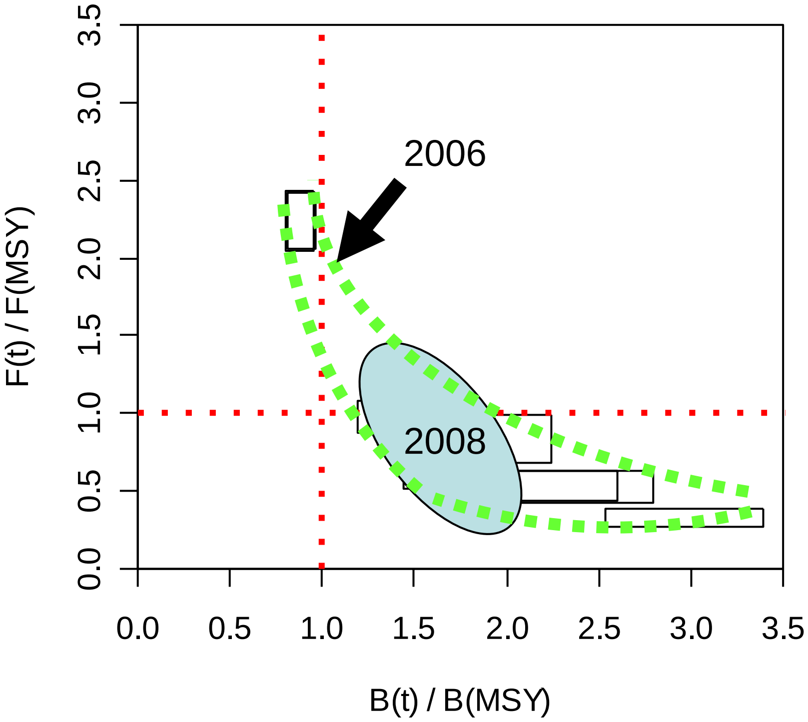


Figure 48. Summary plot comparing 2004 biomass and fishing mortality relative to MSY levels for the Most Plausbile Ensemble of models from the 2006 assesment (Kolody et al. 2006), and the range of models resulting from the 2008 assessment. Each black box indicates the 95% confidence intervals (though not the correlation) associated with an individual model from the 2006 assessment. The dashed (green) banana shape roughly outlines the space that was considered plausible in 2006. The blue oval roughly corresponds to the uncertainty space resulting from the 192 plausible models (with confidence limits) from the 2008 assessment.

4.1.6 Combined SWP-SCP Assessment

An assessment on the combined SWP-SCP was attempted, with an uncertainty grid of 144 models fit (**Table 3**). However, none of the results were satisfying, for reasons that were anticipated during the 2006 assessment and discussed at the swordfish assessment workshop (Anon. 2008). The nominal and standardized CPUE series that we were able to calculate from all the major fishing fleets in the SCP show a stable or continuous upward trend for the last several years (up to 20 or more depending on the series) despite the rapid increase in catches over the last decade (e.g. Figure 4, Figure 6, Figure 7). There is also a paucity of size composition data in the SCP (Figure 8). Thus there are no informative signals in either the CPUE or size composition data with which to estimate the impact of the fishery on the SCP stock.

An example of how the combined SWP-SCP models typically fit the observed CPUE series is illustrated in Figure 49. In general, the models produce an averaging effect in which the predicted CPUE is relatively flat, but with a general upswing over time. The observed declining trend in the SWP is not captured well by the models, and neither is the increasing trend in area 4 of the SCP (fishery 16). The SCP fisheries generally exhibit persistent biases in mean CPUE, with CPUE over-estimated in area 3, and under-estimated in area 4, particularly in the most recent 10-20 years. The bias arises (presumably) because the catchability of the Japanese fleet is shared across regions, and the model estimates some inconsistency in the estimated densities across regions. The bias effect is not as strong in the models that have greater flexibility in movement among regions. However, the divergence in the quality of fit trends among areas is always evident.

Most of the models estimate a trend in increasing recruitment for much of the duration of the fishery. In many cases, the models estimate very low stock recruitment curve steepness (i.e. a linear relationship between spawning biomass and abundance despite the restrictive priors, Figure 50). This is associated with the paradoxical implication that both biomass and recruitment are increasing over time, despite 3-4 decades of overfishing relative to F(MSY). In a few cases, the models suggest that, biomass is very large, and the fishery catch is negligible relative to the biomass (Figure 51). If the SCP is actually experiencing a gradual long-term change in recruitment productivity, then none of these models are very helpful for predicting what will happen in the future.

If we assume that all of the CPUE trends are reasonably accurate, then the models are not describing the conflicting signals among areas very well. To resolve the conflicting trends, presumably recruitment processes would need to be more localized, and migration among areas either needs to be very restricted, or subject to interannual variability of a form that MULTIFAN-CL cannot describe (i.e. random effects, as opposed to mean advection/diffusion).

However, another plausible explanation for the conflicting CPUE trends in the SCP might be found in the temporal trends in gear deployment and targeting practices. Without independent confirmation, one can rarely be confident that commercial effort standardization is effectively creating an unbiased relative abundance index, and this is particularly true in the SCP, where little operational data on setting procedures is available for the standardization analysis. It seems clear that the Taiwanese fleet has undergone a substantial operational shift toward targeting swordfish. Perhaps something similar, but more gradual, is occurring among the other DWF fleets.

We did not feel that it would be productive to pursue the combined SWP-SCP models further at this time. At present, there is no compelling evidence to indicate that the SCP swordfish fishery is over-exploiting the SCP population, but we do not consider the available data to be very convincing.

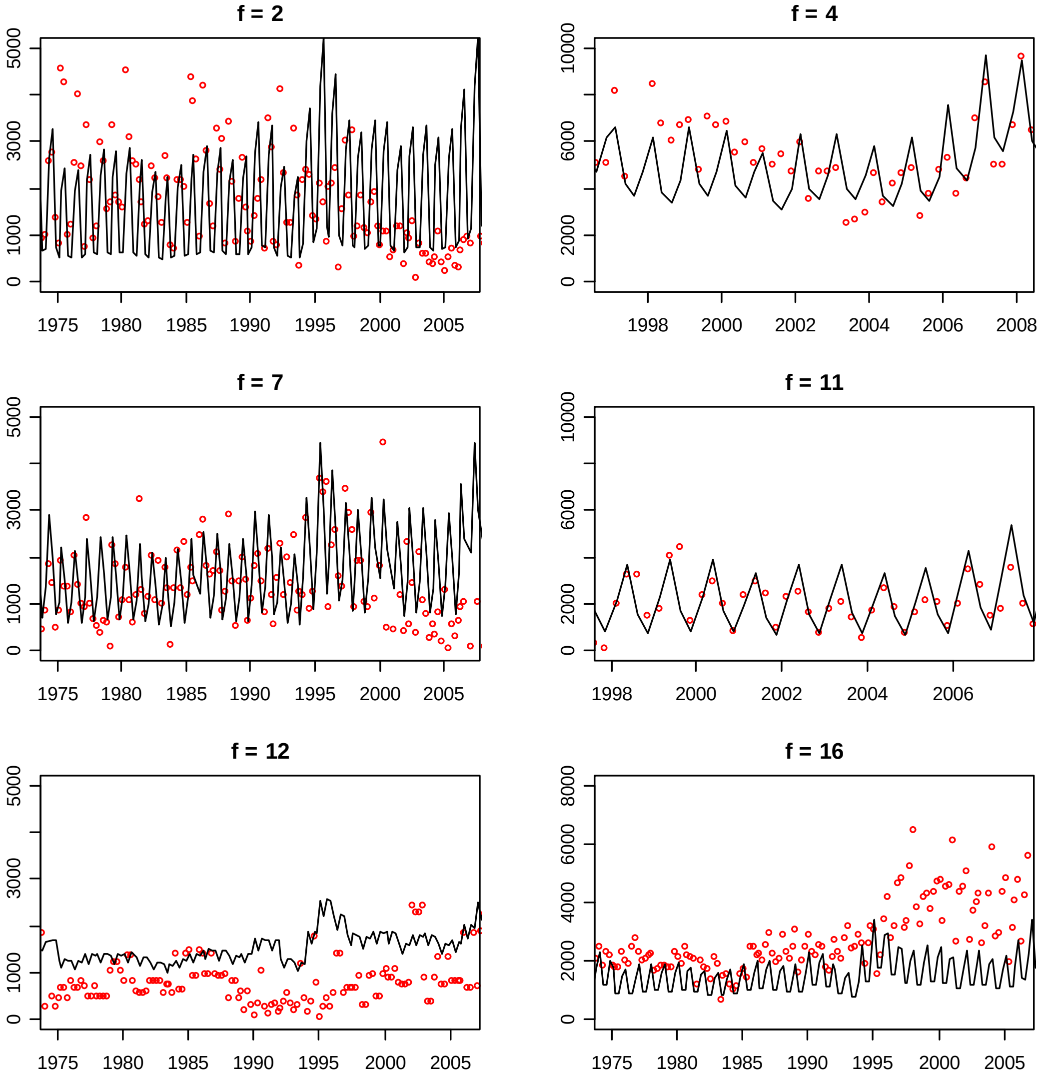


Figure 49. Typical illustration of the fits between predicted (solid lines) and observed (points) CPUE series for the combined SWP and SCP assessment. Fisheries 2 (Japan) and 4 (Australia) operate in SWP area 1, fisheries 7 (Japan) and 11 (New Zealand) operate in SWP area 2, fishery 12 (Japan) operates in SCP area 3, and fishery 16 operates in SCP area 4.

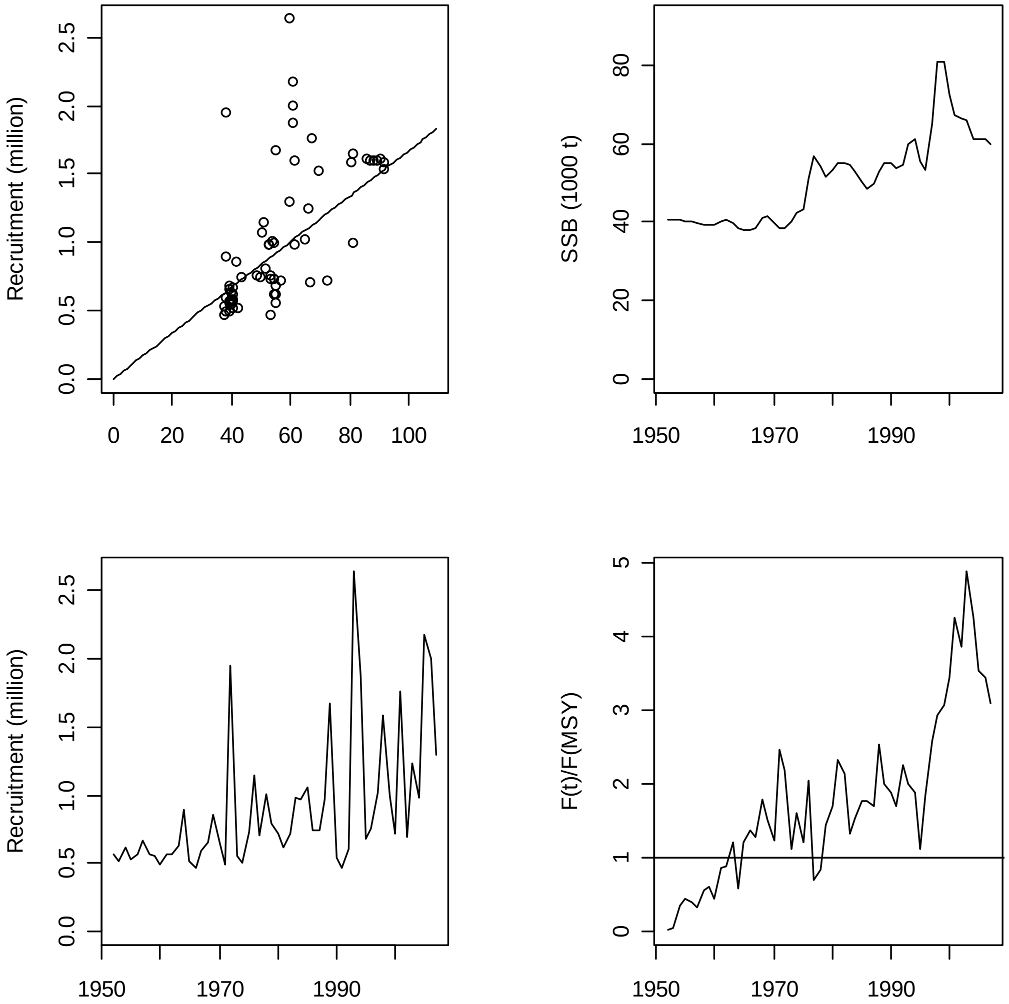


Figure 50. Representative dynamics estimated for the combined SWP and SCP assessment.

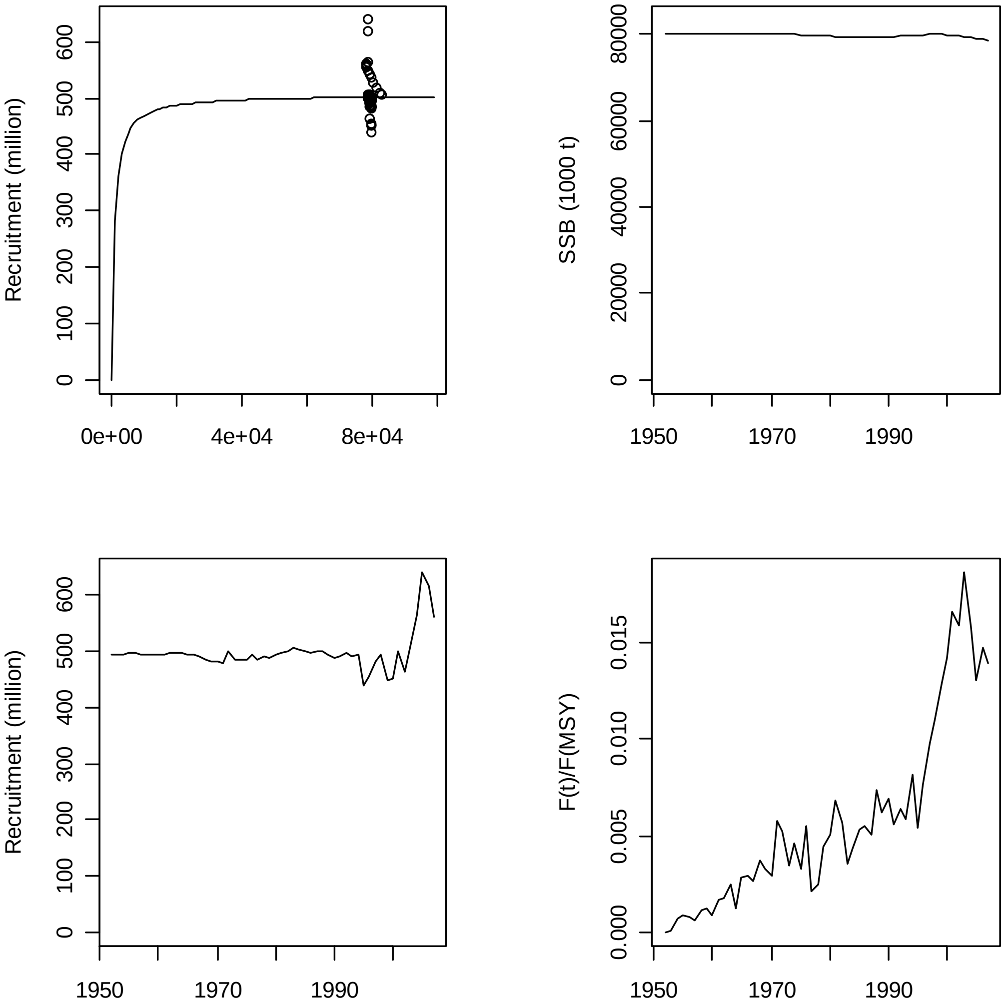


Figure 51. Representative dynamics estimated for the combined SWP and SCP assessment.

4.2 Future Assessment Considerations

Major assessment uncertainties and potential means for resolving the uncertainties are discussed below.

The appropriate spatial structure for use in the south Pacific swordfish assessment remains unclear. There seem to be reasonable arguments for assuming that the SW Pacific forms at least a semi-independent population. The SCP might form another semi-independent population, or it might be more closely linked with populations from the Eastern or Northern Pacific. On the basis of maturity studies, Mejuto et al. (2008) suggest that there is a major spawning ground in the central equatorial Pacific, which would presumably contribute to the SCP population as defined here. Kolody et al. 2006 and Davies et al. 2006 explored alternative spatial assumptions related to homogenous mixing vs site-fidelity with seasonal migration. However, the 2006 modelling studies, combined with genetic, demographic and tagging studies since 2006 have prompted these migration ideas to be revisited in the context of a broader spatial scale (Figure 52). Improved assessment of the SCP might need to involve a further expansion of the assessment domain.

Genetic connectivity studies might help to inform this debate further, if appropriate genetic markers can be identified, and reasonable sample coverage can be obtained. However, given that relatively small numbers of long distance migrations can blur genetic boundaries, we might not gain much understanding of the mixing with adjacent Pacific (and Indian) Ocean populations unless substantial numbers of tags can be deployed. This could include conventional, electronic and/or genetic tags. While PSAT tags can provide high resolution detail of seasonal movements, the value of conventional tags for revealing long term mixing patterns should not be under-estimated.

Irrespective of the population connectivity studies, it seems unlikely that the SC Pacific assessment will be substantively improved without better data from the region. Any additional information that can be gathered to help quantify the impact of the fishery in the SCP would be worthwhile. We note that operational level data exist for a number of fleets, and we would encourage collaborative research with other nations in the analysis of these data. In particular it was noted that operational level data from the Taiwanese fleet exists (and perhaps may be obtainable from the USA records from Pago Pago). The Spanish longline fleet represents a new and attractive data opportunity, given their comprehensive biological sampling programs, and a time series that is starting to be long enough to discern trends.

All fleets should conduct adequate biological sampling. There is very little historical size sampling for most fleets (particularly in the SCP), and the best data that are available suggest that the catch size composition has declined dramatically since the late 1990s (in the SWP). Stratified random sampling by sex, area, and time is encouraged for all fleets. From an assessment point of view, collection of hard parts for direct age estimation would actually be more informative than size, as size is primarily used as an indirect approximation for age.

Studies that improve our understanding of the relationship between catch rates and abundance are encouraged. This includes collection of additional data about fishing practices from all fleets (e.g. fishing master decisions about where and when to fish, species targeting and gear configuration), and ecological studies of fish distributions (e.g. using electronic tags and oceanographic data to understand swordfish habitat preferences). Application of standard survey techniques using commercial gear might be a powerful tool for quantifying relative abundance. Comparisons between standardized gear and current fishing practices would be valuable for understanding the implications of changing fishing methods on commercial catchability and selectivity.

Young et al. (2008) have illustrated that there remains substantial uncertainty about the methods of estimating ages for swordfish. Different labs use different methods, and we are not aware of any convincing age validation studies for swordfish. We would strongly encourage attempts to directly validate fin ray annulus counts. It would be cost effective to add oxy-tetracycline injection along with tagging studies. It is also worth reducing the uncertainty in maturity estimates, but most of this uncertainty seems to be dependent on the age estimation problem.

These types of stock assessment models are critically dependent on the quantification of total fishery removals, and these data are generally assumed to be known with very little error. For swordfish, we are not aware of any evidence to suggest that there are major errors in the catch data, but observations of recent discarding and historical information from the various fleets (and markets) might help to validate this assumption.

There is strong evidence for sex-specific growth and migration characteristics in swordfish. Wang *et al*. (2005) use swordfish assessment simulations to illustrate that model biases can be reduced through the inclusion of sex-dimorphism. This may be important at some point, however, in the short-term, it seems likely that other sources of assessment uncertainty are more important for this species (e.g. age validation is likely required before sex disaggregation can be meaningful).

Very little is known about natural mortality of swordfish. Given the divergent growth and migration characteristics between the sexes, it would not be surprising if mortality also differed. Concerted tagging studies, and direct age estimation from routine hard parts sampling (by sex) would be expected to help to reduce these uncertainties.

The unfortunate fact that stock assessments cannot produce accurate estimates about many of the key quantities of interest to managers has been recognized in many fisheries (often with much better data than this one), and has been a part of the growing popularity of formal methods for Management Strategy Evaluation (MSE, or equivalently, Management Procedures or Harvest Strategies). In 2005, the Australian Department of Agriculture, Fisheries and Forestry initiated a program to have domestic harvest strategies in place for target species of all commonwealth managed fisheries (e.g. Campbell et al. 2007). MSE is perceived to have a number of advantages over other methods of fisheries management, and foremost among these advantages is the use of pre-agreed feedback decision rules that are simulation tested to provide long term management performance that is robust to the stock assessment uncertainty. We consider it to be a positive move for the effective management of the Australian ETBF fishery, and encourage a similar, multilateral approach for the straddling and migratory stocks of the WCPO, including swordfish.

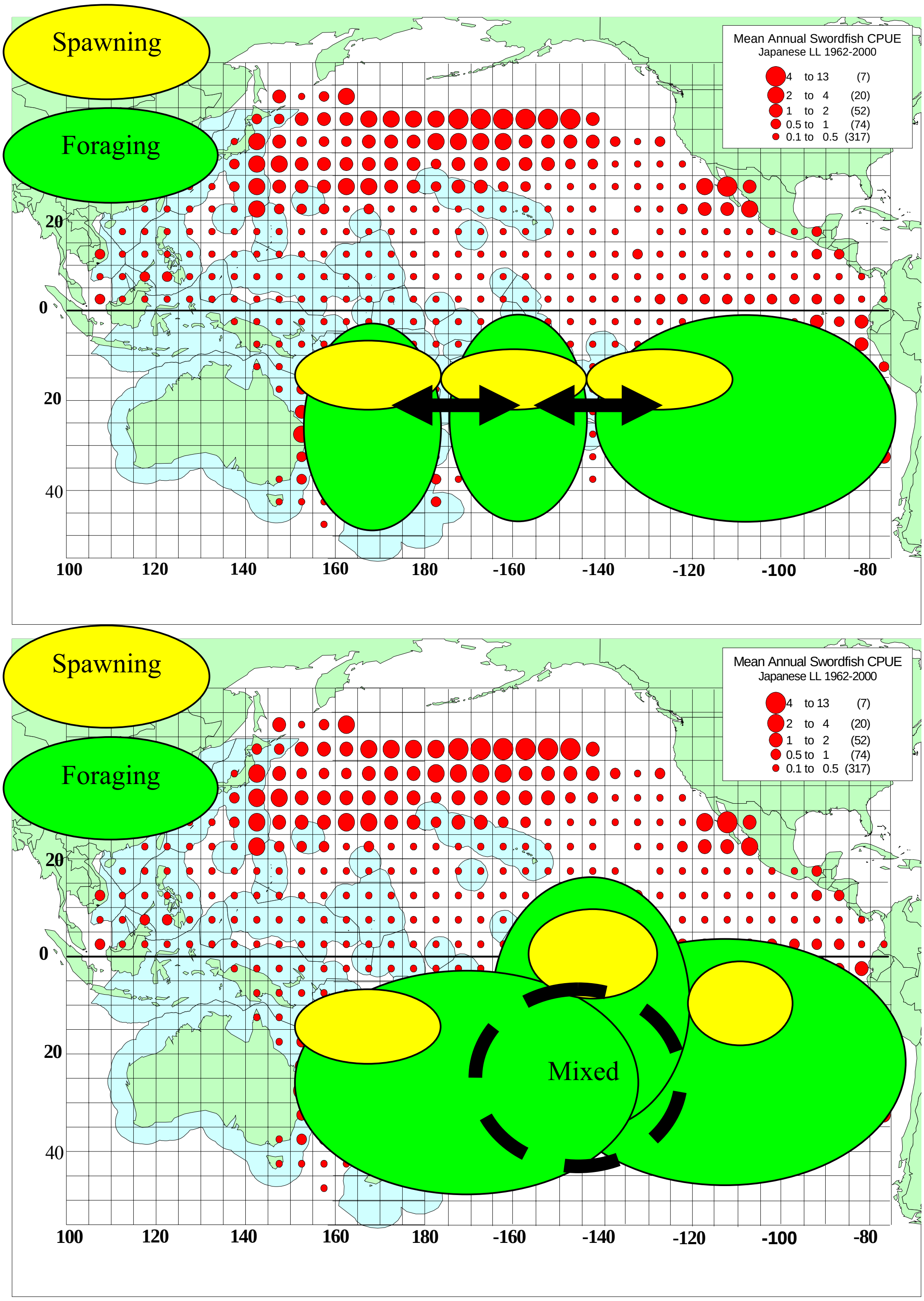


Figure 52. (Figure 10 from Kolody and Davies 2008) Schematic representation of two possible stock structure represensions for South Pacific swordfish: top panel = homogenous mixing, bottom panel = foraging site fidelity.

5 Conclusions

- This paper describes an attempt to assess the status of the South-West and South-Central Pacific swordfish population(s) using MULTIFAN-CL software to integrate the available fisheries data (total catch in numbers, standardized catch rates, and catch size composition) with biological studies (on age, growth, maturity, stock structure and migration dynamics). The main differences from the 2006 assessment included:
    - an explicit attempt to include the South-Central Pacific region in addition to the South-West Pacific
    - 2-3 additional years of data were added, including a period of recent catch and effort declines in the SWP that potentially provides informative contrast to the time series
    - A revision of the spatial structure and movement rate assumptions in relation to recent tagging studies in the SWP.
    - Recognition that swordfish growth rate and maturity estimates are more uncertain than previously recognized due to a lack of independent validation studies.

- Assessment results for the SWP are based on a synthesis of 192 model specifications that appear to be plausibly consistent with the data and our prior expectations of the fishery dynamics. The results are more consistent among models than observed in 2006. This is thought to represent the combined effect of i) recent informative contrast in the catch/effort series breaks the “one-way trip” history of the fishery, and ii) the revised spatial structure and movement assumptions constrain the model capacity for estimating “cryptic biomass”. SWP Stock status reference points based on Maximum Posterior Density estimates include:
    - TSB(2007)/TSB(1997) median = 0.69, range = (0.55 – 0.83)
    - TSB2007 / TSB1997 = 0.69 (0.55-0.83)
    - SSB2007 / SSB1997 = 0.58 (0.42-0.71)
    - TSB2007 / TSBunfished = 0.58 (0.45-0.79)
    - SSB2007 / SSBunfished = 0.43 (0.31- 0.63)
    - TSB2007 / TSBMSY = 1.57 (1.22 - 2.06)
    - SSB2007 / SSBMSY = 1.98 (1.20 - 3.46)
    - TSB2012 / TSB2007 = 1.19 (1.03 - 1.54)
    - SSB2012 / SSB2007 = 1.21 (0.91 – 2.07)
    - TSB2017 / TSB2007 = 1.24 (1.05 -1.64)
    - SSB2017 / SSB2007 = 1.41 (0.94 - 2.30)
    - SSB2012 / TSBMSY = 1.89 (1.38 - 2.94)
    - TSB2017 / TSBMSY = 1.97 (1.43 - 2.99)
    - Aggregate F 2007 = 0.05 (0.03 - 0.11)
    - F2007 / FMSY = 0.44 (0.18 - 0.67)
    - max(F / FMSY) = 0.85 (0.43 -1.39)
    - MSY (trunked mass tonnes) = 2381 (1722 – 4119)

  Confidence intervals based on the statistical estimation uncertainty have been calculated and illustrated for some of these reference points, however, the model selection uncertainty represented in the MPD estimates is broader, and considered to be a more realistic reflection of uncertainty.

- An attempt was made to model the combined SWP-SCP. However, none of the results were satisfying, due to problems with the SCP data that were anticipated during the 2006 assessment and discussed at the swordfish assessment workshop in April 2008 (Anon. 2008). The nominal and standardized CPUE series from all the major fishing fleets in the SCP are either stable or increasing over the last 20 years, despite a rapid increase in catches. There is also a paucity of size composition data in the SCP. Thus there are no informative signals in either the CPUE or size composition data with which to quantify the fishery impact on the SCP stock. If it is assumed that the SCP CPUE indices provide a true reflection of abundance trends then:
    - The SCP probably is experiencing a gradual long-term change in recruitment productivity and historical data provide little indication of what is going to happen in the future, and
    - The SCP swordfish population is not rapidly mixing with the SWP population, as the general CPUE trends in the two areas are in opposite directions despite a similar magnitude of catch removals.

  If so, it follows that the SWP population should be assessed independently of the SCP population (and the SCP population might be more appropriately assessed with the North-Central or Eastern Pacific populations).

  However, it remains possible that the increasing CPUE trends are the result of changes in gear deployment (targeting) practices in the SCP. Overall we did not find any compelling evidence to suggest that the swordfish fishery is over-exploiting the SCP population, but we do not consider the available data to be very convincing. Collection and exchange of operational level logbook data and improved catch composition sampling is encouraged. We recognize that the extensive observer programs in the Spanish fleet might prove very informative in future assessments and encourage more collaboration in future assessments.

- Major assessment uncertainties include:
    - Stock-recruitment relationship cannot be reliably estimated, and there is some evidence for shifting recruitment regimes in both the SWP and SCP.
    - Commercial catch rates are used as relative abundance indices, and we do not know how effective the standardization methods are. Recent conflicting trends between the Australia/New Zealand vs: Japanese series is a concern. Data for standardization analyses in the SCP are poor
    - The migratory link between the SWP, SCP and broader Pacific (and possibly Indian Ocean) populations remains poorly quantified.
    - Growth rates, maturity schedules and natural mortality for this species remains poorly quantified.

- Recommendations to improve future assessments are provided, including:
    - Comparison of methods for estimating age and maturity of swordfish are encouraged.
    - Direct validation of ageing methods should be undertaken (e.g. oxy-tetracycline marking in conjunction with tagging).
    - Collection of additional gear deployment (targeting) data to improve understanding of commercial catch rate interpretation (logbook data for the Taiwanese fleet are known to exist). Ideally, this might include some portion of the commercial fleet setting standardized gear with consistent survey methodology.
    - Research into the relationship between fish distributions and movement in relation to oceanographic variability should assist in interpreting catch rates.

  - Collection and exchange of better catch composition data for all fleets, ideally including length, mass, and sex, plus hard parts for direct age estimation. Existing data (e.g. Spanish size composition data for 2005-7 should be included next time)
  - Electronic, conventional and genetic tagging programs are encouraged to help quantify migration characteristics within the SW-SC Pacific and between adjacent waters.

- We expect that improvements to the assessment will continue to be made. However, we suggest that the most productive use of the assessment advice in the short term might be to use Management Strategy Evaluation to develop harvest strategies that are robust to the major uncertainties identified.

6 Acknowledgements

Thanks to David Fournier, and the MULTIFAN-CL development team for providing the assessment software. John Hampton, Simon Hoyle and Adam Langley provided useful suggestions to the assessment and critical insight required to navigate undocumented features in MULTIFAN-CL. Thanks to all who participated in person or by sending working papers to the swordfish assessment workshop. Andre Punt and Campbell Davies provided useful suggestions for the MS. We are indebted to the countless people that have collected the fisheries data over the years, and especially grateful to Naozumi Miyabe, Peter Williams, and Martin Unwin for providing much of the data and supporting analyses for CPUE standardization. Thanks to Chris Wilcox, Karen Evans, John Holdsworth and Tim Sippel for sharing the swordfish PSAT data. This project was jointly funded by DAFF, AFMA and CSIRO (Australia) and through collaborative arrangements, NIWA and the Ministry of Fisheries (New Zealand).

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8 Appendix 1 – Batch file indicating South-West Pacific swordfish assessment Multifan-CL switches and phased parameter estimation

The assessment was run using the windows version of mfclopt.exe executable compiled May 2006. In the following, “#switch” indicates options that were tested as part of the model uncertainty grid. Other elements in the model uncertainty grid (e.g. growth, maturity and natural mortality) were controlled through the .ini input files.

```
#doitall grid entry
# generic shell for batch processing of MFCL model fitting across a balanced grid of factors
# 1) remove existing files that might confuse process if errors encountered
# 2) conventional doitall with switches flagging parts to replace
# 3) rename results to grid identification
rm *.par
rm 01.*
rm plot.rep
rm length.fit
rm weight.fit
rm *.hes
rm *.var
#! over bin over sh
#
#rm *.par
#------------------------
#  PHASE 0 - create initial par file
#  ------------------------
#
#if [ ! -f 00.par ]; then
#  mfclo32May2808 switch_frqA SWO5P001.ini 00.par -makepar
#fi
#  ------------------------
#  PHASE 1 - initial par
#  ------------------------
#
if [ ! -f 01.par ]; then
  #mfclo32May2808 switch_frqA 00.par 01.par -file - <<PHASE1
  #mfclo32May2808  swo2007A12F11003.frq 002007A12F11001.inpar 01.par -file - <<PHASE1
#switch .inpar options (includes Growth, M, Mat, Migration rate, SR steepness)
#inpar switch ###: mfclo32May2808  swo2007A12F11003.frq  ###: 01.par -file - <<PHASE1
  2 113 1        # estimate initpop over 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 69 1         # sets generic movement option (now default)
  2 94 1 2 95 10  # initial age structure based on estimated 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 2
   -4 24 1
   -5 24 1
   -6 24 1
   -7 24 1
   -8 24 3
   -9 24 1
  -10 24 1
  -11 24 4
#  -1 29  1     #group catchabilities to prevent weirdness (deviations ?)
#  -2 29  2     #group catchabilities
```

```
#  -3 29  3      #group catchabilities
#  -4 29  4      #group catchabilities
#  -5 29  5      #group catchabilities
#  -6 29  6      #group catchabilities
#  -7 29  7      #group catchabilities
#  -8 29  8      #group catchabilities
#  -9 29  9      #group catchabilities
#  -10 29 10      #group catchabilities
#  -11 29 11      #group catchabilities
  -1  60 1      #group catchabilities to prevent weirdness (averages ?)
  -2  60 2      #group catchabilities
  -3  60 3      #group catchabilities
  -4  60 4      #group catchabilities
  -5  60 5      #group catchabilities
  -6  60 6      #group catchabilities
  -7  60 2      #group catchabilities
  -8  60 7      #group catchabilities
  -9  60 8      #group catchabilities
  -10 60 9      #group catchabilities
  -11 60 10      #group catchabilities
  2 107 100       # turn on exploitation rate target
  2 108 10        # set exploitation rate target as x% (Catch(numbers) over Rec(N)
PHASE1
fi
#  ---------
#   PHASE 2
#  ---------
if [ ! -f 02.par ]; then
mfclo32May2808  swo2007A12F11003.frq 01.par 02.par -file - <<PHASE2
  #-999 49 10         # LF ESS reweighting by factor of 1 over n
  #-999 50 10         # massF ESS reweighting
  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 over 10 (500 over 10 ~ cv of 0.1)
  1 1 400        # 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
  1 13 0        # attempt to shut off mean last length growth estimation
  1 14 0        # attempt to shut off k growth estimation
PHASE2
fi
#  ---------
#   PHASE 3
#  ---------
if [ ! -f 03.par ]; then
mfclo32May2808  swo2007A12F11003.frq 02.par 03.par -file - <<PHASE3
#  2 70 1         # activate parameters and turn on (recruitment time series variability among regions?)
#  2 71 1         # estimation of temporal changes in recruitment distribution (related to above)
  2 70 0         # dk attempt to turn off recruitment time series variability among regions?)
  2 71 0         # dk 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
mfclo32May2808  swo2007A12F11003.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
#  2 68 1         # estimate movement coefficients #manual says activates movement
#  2 69 1         # 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
mfclo32May2808  swo2007A12F11003.frq 04.par 05.par -file - <<PHASE5
  1 16 0          # estimate length dependent SD (I3=1)
  -999 27 1       # estimate seasonal catchability for all fisheries
PHASE5
fi
#  ---------
#   PHASE 6
#  ---------
if [ ! -f 06.par ]; then
mfclo32May2808  swo2007A12F11003.frq  05.par 06.par -file - <<PHASE6
###  1 14 1         # estimate K
  1 141 0        # sets likelihood function for LF data to mod chi2
  -1 13 -1       # effort dev weighting (neg = sqrt transformed)
#switch relative weighting of Aus/NZ vs Jpn CPUE
#UA1 ###:   -2 13 50       # effort dev weighting (neg = sqrt transformed)
#UAJ ###:   -2 13 8       # effort dev weighting (neg = sqrt transformed)
#UJA ###:   -2 13 50       # effort dev weighting (neg = sqrt transformed)
  -3 13 -1       # effort dev weighting (neg = sqrt transformed)
#UA1 ###:  -4 13 50       # effort dev weighting (neg = sqrt transformed)
#UAJ ###:  -4 13 50       # effort dev weighting (neg = sqrt transformed)
#UJA ###:  -4 13 8       # effort dev weighting (neg = sqrt transformed)
  -5 13 -1       # effort dev weighting (neg = sqrt transformed)
  -6 13 -1       # effort dev weighting (neg = sqrt transformed) 100 over 10 = CV 0.15
#UA1 ###:  -7 13 50       # effort dev weighting (neg = sqrt transformed)
#UAJ ###:  -7 13 8       # effort dev weighting (neg = sqrt transformed)
#UJA ###:  -7 13 50       # effort dev weighting (neg = sqrt transformed)
  -8 13  -1      # effort dev weighting (neg = sqrt transformed)
  -9 13  -1      # effort dev weighting (neg = sqrt transformed)
  -10 13 -1      # effort dev weighting (neg = sqrt transformed)
#UA1 ###:  -11 13 50       # effort dev weighting (neg = sqrt transformed)
#UAJ ###:  -11 13 50       # effort dev weighting (neg = sqrt transformed)
#UJA ###:  -11 13 8       # effort dev weighting (neg = sqrt transformed)
 -1 16 0  #selectivity flexible with age =0
 -2 16 0
 -3 16 0
 -4 16 0
 -5 16 0
 -6 16 0
 -7 16 0
#switch selectivity on southern area free or non-decreasing with age
#SF ###:   -8 16 0  #selectivity non-decreasing with age =1
#SM ###:   -8 16 1  #selectivity non-decreasing with age =1
 -9 16 0
 -10 16 0
 -11 16 0
#-999 16 0
PHASE6
fi
#  ---------
#   PHASE 7
#  ---------
if [ ! -f 07.par ]; then
mfclo32May2808  swo2007A12F11003.frq 06.par 07.par -file - <<PHASE7
# steepness should be fixed...
  2 145 1        # estimate Beverton Holt SRR with small penalty
  2 146 1        # SRR parameter active
  2 147 0        # recruitment lag is 0 quarters (this was 1 in 2006...confirm implications)
  2 148 4       # base F is average over last 24 quarters (MSY stuff) (was 24)
  2 155 0        # base F average does not include last 4 quarters  (MSY stuff) was 4)
#  2 153 9000      # parameters of beta distribution defining prior for
#  2 154 1000      # steepness - mode = (153 flag  over (153 flag + 154 flag), sd approaches 0 as flags get big
# beta priors ignored - fixed in .inpar
PHASE7
fi
```

```
# ---------
#   PHASE 8
# ---------
if [ ! -f 08.par ]; then
mfclo32May2808  swo2007A12F11003.frq 07.par 08.par -file - <<PHASE8
  2 107 0       # off- turn on exploitation rate target
  2 108 0        # off- set exploitation rate target as x% (Catch(numbers) over Rec(N)
#not sure which of 145/149 below takes precedence - set both
#switch SRDevs
#switch SRDevs
#r5 ###: 1 149 2       # set penalty on recruitment devs to n over 10 (500 over 10 ~ cv of 0.1; 14 over 10 ~ 0.6;
31~0.4)
#r5 ###: 2 145 20      # set penalty on SR devs to n (seemingly not n over 10) (500 over 10 ~ cv of 0.1; 14 over 10
~ 0.6; 31~0.4)
#r1 ###: 1 149 50      # set penalty on recruitment devs to n over 10 (500 over 10 ~ cv of 0.1; 14 over 10 ~ 0.6;
31~0.4)
#r1 ###: 2 145 500     # set penalty on SR devs to n (seemingly not n over 10) (500 over 10 ~ cv of 0.1; 14 over 10
~ 0.6; 31~0.4)
  2 113 0        # shut off estimate initpop over totpop scaling parameter
  1 1 750        # set no. function evaluations
  1 50 -3          # set convergence criterion to 1En
PHASE8
fi
# ---------
#   PHASE 9
# ---------
if [ ! -f 09.par ]; then
mfclo32May2808  swo2007A12F11003.frq 08.par 09.par -file - <<PHASE9
# estimation of negative binomial parameter a
### -999 43 1        # estimate a for all fisheries
#  1 183 20       # change recruitment CV for first I3 time intervals (or years - test)
#  -100001 1 1000  # constrain rec in all regions by I3 over 10 ???
#  -100001 2 1000  # constrain rec in all regions by I3 ???
#  -100001 3 1000  # constrain rec in all regions by I3 ???
#  -100001 4 1000  # constrain rec in all regions by I3 ???
#  -100001 5 1000  # constrain rec in all regions by I3 ???
#-999 49 5 -999 50 5
#-999 49 20 -999 50 20
#switch CLM Effective sample sizes
#ES05 ###: -999 49 5 -999 50 5
#ES20 ###: -999 49 20 -999 50 20
PHASE9
fi
# ---------
#   PHASE 10
# ---------
if [ ! -f 10.par ]; then
mfclo32May2808  swo2007A12F11003.frq 09.par 10.par -file - <<PHASE10
  1 1 3000        # set no. function evaluations
  1 50 -6          # set convergence criterion to 1En
  -999 55 1       # compute biomass with catchability for all fisheries set to 0
PHASE10
fi
# ---------
#   PHASE 11
# ---------
#if [ ! -f 11.par ]; then
#mfclo32May2808  swo2007A12F11003.frq 10.par 11.par -file - <<PHASE11
#  1 145 3        # set output level 3 for Hessian calc
#PHASE11
#fi
#scenario switch ###: cp 10.par ../crossB/ ###:.outpar
#scenario switch ###: cp plot-10.par.rep ../crossB/ ###:.rep
#scenario switch ###: cp plotq0-10.par.rep ../crossB/ ###:.q0.rep
#scenario switch ###: cp length.fit ../crossB/ ###:length.fit
#scenario switch ###: cp weight.fit ../crossB/ ###:mass.fit
#scenario switch ###: #cp *.hes ../crossB/ ###:.outHes
```

```
#scenario switch ###: #cp *.var ../crossB/ ###:.outVar
#
#scenario switch ###: mv 10.par  ###:.outpar
#scenario switch ###: mv plot-10.par.rep  ###:.rep
#scenario switch ###: mv plotq0-10.par.rep  ###:.q0.rep
#scenario switch ###: mv length.fit  ###:length.fit
#scenario switch ###: mv weight.fit  ###:mass.fit
#scenario switch ###: #mv *.hes  ###:.outHes
#scenario switch ###: #mv *.var  ###:.outVar
```

Attachment 2. Data summary pertaining to the catch of swordfish by longline fleets operating in the southern WCPO. WCPFC-SC4-2008/SA-IP-3. (35p.)

SCIENTIFIC COMMITTEE
FOURTH REGULAR SESSION

11-22 August 2008
Port Moresby, Papua New Guinea

DATA SUMMARY PERTAINING TO THE CATCH OF SWORDFISH BY LONGLINE FLEETS OPERATING IN THE SOUTHERN WCPO

WCPFC-SC4-2008/SA-IP-3

Robert Campbell[1]

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[1] CSIRO Marine and Atmospheric Research, Hobart, Australia

Data summary pertaining to the catch of swordfish by longline fleets operating in the southern WCPO.

Robert Campbel1
CSIRO Marine and Atmospheric Research, Australia

July 2008

1. Introduction

This document provides a summary of the data available for undertaking the 2008 stock assessment for swordfish in the southern Western Central Pacific Ocean (WCPO). This region is defined as the area bounded to the north by the equator and to the east by the eastern boundary of the WCPFC Area (130°W or 230°E). The southern boundary was placed at 50°S and the western boundary at 140°E. In particular, the data pertains to the catch of swordfish taken by longline fleets operating in this region between 1952 and 2007. A summary of the main data sets is provided in the next section while the remainder of the document consists of a number of summary Figures and Tables.

2. Available Data

The following data sets are available for the 2008 swordfish assessment:

1. Catch and Effort
   - Data held at SPC, Noumea on longline effort and associated catch of swordfish for all fleets operating in the southern WCPO.
   - Logbook data held by the Australian Fisheries Management Authority relating to the Australian domestic longline fleet operating in the Eastern Tuna and Billfish Fishery off eastern Australia.
   - Logbook data held by the Ministry of Fisheries, NZ relating to the New Zealand domestic longline fleet operating around New Zealand.

2. Commercial Size Data
   - Length (lower jaw to caudal fork) data held at SPC, Noumea pertaining to individual swordfish sampled from longline fleets operating across the southern WCPO.
   - Processor measured and recorded dressed weights (trunked) pertaining to swordfish landed at various ports within the Australian Eastern Tuna and Billfish Fishery operating off eastern Australia.
   - Port sampling lengths (lower jaw to caudal fork) pertaining to swordfish landed within the domestic New Zealand longline fishery.
   - Dressed weight and length (orbital-eye to caudal fork) data held at NRIFSF, Japan pertaining to individual swordfish sampled from longline fleets operating across the southern WCPO.
   - Length (lower jaw to caudal fork) provided by Spain pertaining to individual swordfish sampled from longline fleets operating across the Pacific Ocean.

3. Observer Data
   - Data collected by AFMA observers on Japanese longline vessels operating off eastern Australian between 1980 and 1997.
   - Data collected by AFMA observers on Australian longline vessels operating off eastern Australian between 2001 and 2007.
   - Data collected by NZ observers on Japanese longline vessels operating within the New Zealand EEZ.

4. Tagging Data
   - Data pertaining to the tagging of swordfish in the Tasman and Coral Seas using Pop-Up Satellite Tags undertaken by Australian and New Zealand scientists in recent years.

3. Catch and Effort Data

Listing of the longline fleets operating in the southern WCPO for which catch and effort data is available is provided in Table 1. The following summary statistics are also provided:

(a) Fleet Type used to categorise fleet, - Distant Water Fishing Nation (DFWN), Pacific Island Nation (PIN) and Other (OTH). Australian and New Zealand fleets were retained as separate fleets.
(b) The first and last years for which data was available,
(c) The spatial extent of the data as defined by the number of 5x5-degree squares of latitude and longitude fished,
(d) Total effort over all years (Hundreds of Hooks), and
(e) Total Catch over all years in i) number of fish caught and ii) tonnes, estimated whole weight

The stock assessment model used to undertake the stock assessment is spatially dis-aggregated with the southern WCPO divided in the four main Areas shown in Figure 1. These four Areas are defined as follows:

Area 1: 140-165°E, 0-50°S
Area 2: 165-185°E, 0-50°S
Area 3: 185-205°E, 0-50°S
Area 4: 205-230°E, 0-50°S

Each Area was further stratified into a Northern (0-20°S), Central (20-40°S) and Southern (40-50°S) regions giving a total of 12 zones across the southern WCPO. Each of these zones is shown in Figure 1.

In the following data summaries the Southwest Pacific is defined as the combination of Areas 1 and 2 (i.e. between longitudes 140-185°E).

Furthermore, for some data summaries a single Distant Water Fishing Nation (DWFN) fleet and a single Pacific Island Nation (PIN) fleet are defined and consist of the combination of the corresponding data from all fleets having Fleet-Type equal to DWFN and PIN respectively in Table 2.

The following data summaries are provided in Table 3 and Figures 2-10:

Table 3a. Annual total catch (tonnes) of swordfish taken by all longline fleets operating in each of the four assessment areas of the southern WCPO.
Table 3b. Annual total catch (numbers) of swordfish taken by all longline fleets operating in each of the four assessment areas of the southern WCPO.

Figure 2. Annual catch, (a) tonnes, (b) numbers, of swordfish taken by longline fleets operating in each of the four assessment areas of the southern WCPO.

Figure 3a. Annual longline effort (hundred of hooks) for the major longline fleets within the four assessment regions of the southern WCPO.
Figure 3b. Annual longline swordfish catch (number of fish) for the major longline fleets within the four assessment regions of the southern WCPO.

Figure 4a. Annual longline effort (hundred of hooks) for the major longline fleets within the southern WCPO and south west Pacific.
Figure 4b. Annual longline swordfish catch (number of fish) for the major longline fleets within the southern WCPO and south west Pacific.

Figure 5a. Annual longline effort (hundred of hooks) for the main Pacific Island Nation longline fleets in the four assessment regions of the southern WCPO.
Figure 5b. Annual longline swordfish catch (number of fish) for the main Pacific Island Nation longline fleets in the four assessment regions of the southern WCPO.

Figure 6a. Annual effort (hundred of hooks) for the main Pacific Island Nation longline fleets within the southern WCPO and SW Pacific.

Figure 6a. Annual swordfish catch (number of fish) for the main Pacific Island Nation longline fleets within the southern WCPO and SW Pacific.

Figure 7. Proportion of (a) effort and (b) catch of swordfish taken by each fleet within each of the 12 zones used in the 2008 assessment.

Figure 8. Annual nominal swordfish CPUE (number of fish per 10,000 hooks), by area, for the major longline fleets operating in the south WCPO.

Figure 9. Annual nominal swordfish CPUE (number of fish per 10,000 hooks), by area, for the main Pacific Island Nation fleets operating in the south WCPO.

Figure 10a. Annual nominal swordfish CPUE (number of fish per 10,000 hooks) for the major longline fleets in the south WCPO and the SW Pacific.
Figure 10b. Annual nominal swordfish CPUE (number of fish per 10,000 hooks) for the main Pacific Island Nation longline fleets in the south WCPO and the SW Pacific.

4. Size Data

The listing of size data available (cf. Section 2) indicates that both dressed weight and length data was available. However, as the majority of the data was Lower-jaw to caudal-fork (LJFL) length data it was decided to use this size measurement as the standard. The Australian weight data and Japanese Orbital-eye to caudal-fork (OFL) data were converted to LJFL using the following conversion routines:

a) Weight to Length:
Measurements collected at sea of length (LJFL) and processed weight available from the New Zealand MFish observer programme (n = 3,128) were used to derive the following relationship.

LJFL = 56.544*(DWT^0.2865)

b) OFL to LJL:
Measurements collected at sea of both OFL and LJFL lengths available from the Australian AFMA observer programme on Japanese vessels (n = 2,215) were used to derive the following relationship.

OFL = 1.0753*(LJFL+6.898)

A summary of the number of swordfish size samples by fleet is given in Table 3. A large majority of the data pertains to the processor measured weight data collected from the Australian longline fleet. The most spatially extensive data pertains to the two sets of data collected from the Japanese longline fleet (13,298 fish in total) with samples across all four assessment areas. The third largest set of data pertains to the data collected from the Spain longline operations in the Pacific during 2004.

The following data summaries are provided in Figures 11a-d:

Figure 11a.	Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 1.
Figure 11b.	Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 2.
Figure 11c.	Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 3.
Figure 11d.	Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 4.

5. Spatial Distributions

The following maps displaying the following spatial distributions:

Map 1a.	Spatial distribution of the total catch of swordfish (number of fish) taken by longline vessels in the southern WCPO between 2000 and 2006.
Map 1b.	Spatial distribution of the total catch of swordfish (number of fish) taken by DWFN fleets in the southern WCPO between 2000 and 2006.
Map 1c.	Spatial distribution of the total catch of swordfish (number of fish) taken by PIN fleets in the southern WCPO between 2000 and 2006.

Map 2a.	Distribution of Australian swordfish catch: 2000-06.
Map 2b.	Distribution of New Zealand swordfish catch: 2000-06.
Map 2c.	Distribution of Japanese swordfish catch: 2000-06.
Map 2d.	Distribution of Taiwanese swordfish catch: 2000-06.
Map 2e.	Distribution of Korean swordfish catch: 2000-06.
Map 2f.	Distribution of Chinese swordfish catch: 2000-06.
Map 2g.	Distribution of Spanish swordfish catch: 2000-06.
Map 2h.	Distribution of Fijian swordfish catch: 2000-06.

Map 3.	Spatial distribution of Japanese nominal swordfish CPUE, by quarter, within the southern WCPO aggregated over the years 1971-2005. (Note, the same scale is used in each quarter and the size of the dots is scaled to represent the average CPUE within each level indicated in the legend for that quarter).

6. Observer data

A summary of this data will be provided in a separate working paper.

Table 1. Listing of the longline fleets operating in the southern WCPO for which catch and effort data are available. The following summary statistics are also provided: (a) Fleet Type used to categorise fleet, (b) The first and last years for which data was available, (c) The spatial extent of the data as defined by the number of 5x5-degree squares of latitude and longitude, (d) Total effort over all years (Hundreds of Hooks), and (e) Total Catch over all years in i) number of fish caught and ii) tonnes, estimated whole weight.

Nation	Abbrev.	Fleet	Data Years		Spatial	Effort	Catch	
	Flag	Type	First	Last	Extent	Hhooks	Number	Tonnes
Japan	JP	DWFN	1952	2006	166	29,479,144	1,134,717	77,091
Australia	AU	AU	1985	2007	34	1,279,098	346,953	18,692
Korea	KR	DWFN	1962	2006	151	25,793,328	375,143	16,384
Taiwan	TW	DWFN	1964	2006	146	15,861,012	180,979	11,552
New Zealand	NZ	NZ	1989	2007*	32	1,137,305	128,742	6,653
Spain	ES	DWFN	2004	2006	41	51,280	70,943	5,034
China	CN	DWFN	1996	2006	95	1,279,637	32,379	1,311
Fiji	FJ	PIN	1989	2006	38	3,221,827	25,458	1,222
French Polynesia	PF	PIN	1992	2006	39	1,652,488	16,555	965
Cook Islands	CK	PIN	1994	2006	41	299,627	10,809	587
Vanuatu	VU	DWFN	1996	2007	119	732,683	8,015	385
Tonga	TO	PIN	1982	2006	28	445,592	6,298	294
New Caledonia	NC	PIN	1983	2006	24	691,675	5,331	290
American Somoa	AS	PIN	1996	2006	27	705,029	2,147	255
Papua NewGuinea	PG	PIN	1993	2006	19	533,055	5,281	236
Western Samoa	WS	PIN	1993	2006	4	637,193	3,121	202
Vanuatu	VU	PIN	1995	2007	92	313,159	2,250	111
Solomon Lslands	SB	PIN	1981	2005	14	381,116	1,418	72
United States	US	DWFN	1997	2004	7	11,935	104	6
Philippines	PH	OTH	2002	2003	4	1,818	99	5
Indonesia	ID	OTH	2004	2005	13	8,906	64	3
Nuie	NU	PIN	2005	2006	6	7,665	48	3
Kiribati	KI	PIN	2003	2003	5	1,985	31	1
Tuvulu	TV	PIN	2005	2005	2	65	1	0
Fed. States Micronesia	FM	PIN	1995	1998	2	565	5	0

* Third quarter of 2007 only

Table 2. Listing of the longline fleets operating in the southern WCPO for which size sampling data for swordfish are available. The following summary statistics are also provided: (a) Fleet Type used to categorise fleet, (b) Source of the data, (c) Data type (DWT=dressed weight, OFL=Orbital-fork length, LJL=Lower jaw-fork length) (d) The first and last years for which data was available, (e) The spatial extent of the data as defined by the number of 5x5-degree squares of latitude and longitude, (f) Total number of individual swordfish sampled.

Nation	Abbrev. Flag	Fleet Type	Data Source	Size Type	Data Years First	Data Years Last	Spatial Extent	Number Fish
Australia *	AU		AFMA	DWT	1997	2007	32	244775
Spain	SP	DW	Spain	LJL	2004	2004	24	9548
Japan **	JP	DW	NRIFSF	OFL	1971	2002		8607
Japan	JP	DW	SPC	LJL	1987	2004	44	5291
Fiji	FJ	PN	SPC	LJL	1994	2006	24	1600
Papua New Guinea	PG	PN	SPC	LJL	1996	2006	11	1397
New Zealand	NZ		SPC	LJL	1992	2005	16	1387
Tonga	TO	PN	SPC	LJL	1995	2006	8	1235
New Caledonia	NC	PN	SPC	LJL	1993	2006	8	798
Taiwan	TW	DW	SPC	LJL	1997	2006	19	703
Cool Island	CK	PN	SPC	LJL	1995	2005	8	432
Solomon Island	SB	PN	SPC	LJL	1996	2004	7	258
French Polynesia	PF	PN	SPC	LJL	1996	2006	13	253
Korea	KR	DW	SPC	LJL	1992	2006	16	231
Western Somoa	WS	PN	SPC	LJL	1998	2005	4	206
Vanuatu	VU	PN	SPC	LJL	2003	2005	14	158
Philippines	PH	OT	SPC	LJL	2003	2003	2	116
China	CN	DW	SPC	LJL	1996	2005	11	33
United Stats	US	OT	SPC	LJL	2004	2004	1	11
American Somoa	AS	PN	SPC	LJL	2002	2004	4	7
Marshall Islands	MH	PN	SPC	LJL	1993	1993	1	3
Fed. State Micronesia	FM	PN	SPC	LJL	2002	2002	1	1

* Trunked weights, ** Data aggregated by 10x20-degrees of latitude and longitude

Figure 1. Map of the southern Western Central Pacific Ocean indicating the Areas and Zones used to stratify the catch and effort data.

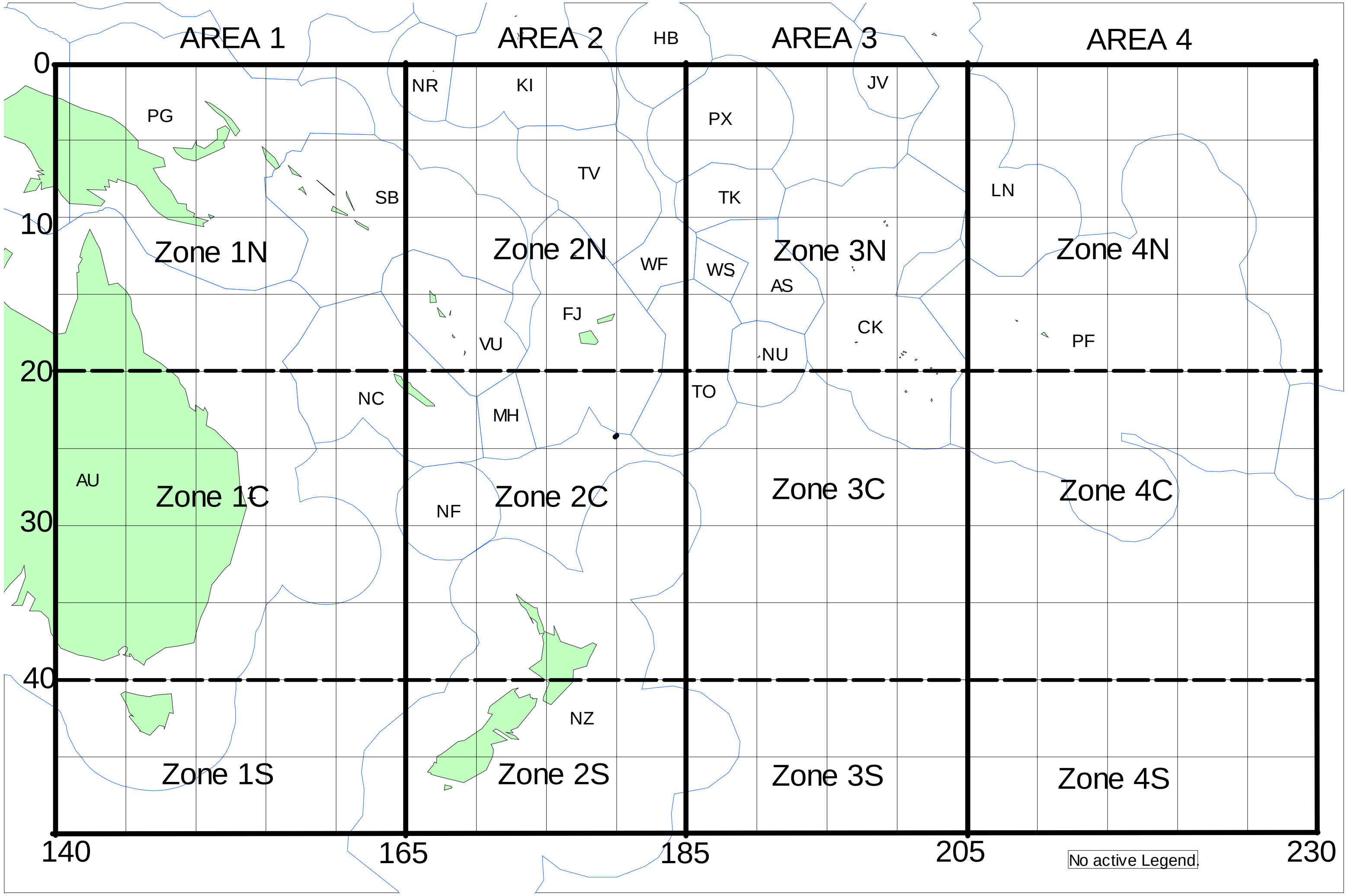


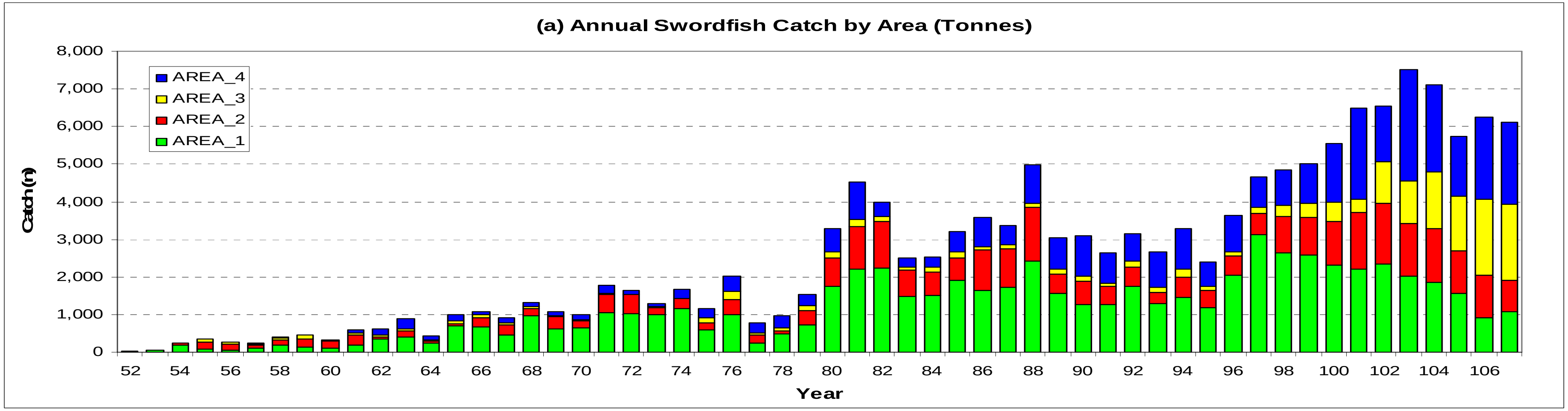
Table 3a. Annual total catch (tonnes) of swordfish taken by all longline fleets operating in each of the four assessment areas of the southern WCPO.

YEAR	AREA_1	AREA_2	AREA_3	AREA_4	TOTAL
1952	17	0	0	0	17
1953	41	1	1	0	42
1954	185	59	4	0	248
1955	93	177	84	1	355
1956	62	159	50	3	274
1957	104	86	19	20	230
1958	200	119	70	22	412
1959	130	218	102	10	461
1960	117	169	19	16	321
1961	184	282	41	96	604
1962	354	63	29	164	611
1963	394	163	68	253	879
1964	244	64	24	102	433
1965	703	60	62	185	1010
1966	678	244	81	84	1087
1967	452	263	76	122	913
1968	964	187	50	127	1328
1969	607	335	36	89	1067
1970	655	178	25	125	983
1971	1042	496	31	210	1780
1972	1033	492	22	96	1644
1973	992	206	25	79	1302
1974	1163	260	13	242	1678
1975	580	213	113	243	1150
1976	999	415	195	408	2017
1977	246	215	46	264	771
1978	497	78	58	330	964
1979	723	390	119	309	1542
1980	1757	737	160	628	3282
1981	2199	1138	190	996	4523
1982	2234	1231	135	399	3998
1983	1472	722	82	223	2498
1984	1511	606	153	267	2537
1985	1922	573	160	545	3200
1986	1654	1070	85	762	3572
1987	1717	1032	104	506	3359
1988	2419	1422	118	1020	4980
1989	1564	506	149	831	3050
1990	1259	638	134	1068	3099
1991	1274	488	78	790	2630
1992	1762	509	163	728	3162
1993	1286	291	148	944	2669
1994	1447	533	238	1081	3300
1995	1177	460	102	656	2395
1996	2047	522	107	949	3625
1997	3112	590	161	784	4647
1998	2629	980	309	935	4853
1999	2594	991	363	1074	5022
2000	2310	1168	503	1570	5550
2001	2206	1511	355	2429	6501
2002	2335	1615	1112	1485	6546
2003	2033	1380	1126	2971	7511
2004	1856	1443	1492	2320	7110
2005	1555	1143	1448	1590	5736
2006	910	1144	2013	2188	6255
2007	1089	830	2013	2188	6120

Table 3b. Annual total catch (numbers) of swordfish taken by all longline fleets operating in each of the four assessment areas of the southern WCPO.

YEAR	AREA_1	AREA_2	AREA_3	AREA_4	TOTAL
1952	350	6	0	0	356
1953	856	18	12	0	886
1954	3902	1251	95	0	5248
1955	1956	3746	1771	30	7503
1956	1300	3359	1059	68	5786
1957	2205	1825	395	424	4849
1958	4223	2523	1488	458	8692
1959	2744	4610	2161	219	9734
1960	2470	3560	405	340	6775
1961	3889	5963	875	2035	12762
1962	7474	1329	623	3472	12898
1963	8311	3452	1446	5352	18561
1964	5149	1357	499	2144	9149
1965	14845	1269	1303	3911	21328
1966	14309	5163	1707	1772	22951
1967	9555	5548	1695	2579	19377
1968	20238	3927	990	2599	27754
1969	12878	7052	751	1851	22532
1970	13708	3768	543	2643	20662
1971	21924	10441	649	4400	37414
1972	21597	10294	458	1896	34245
1973	20868	4293	442	1578	27181
1974	24536	5447	334	4853	35170
1975	12136	4363	2210	5066	23775
1976	21105	8383	3013	7827	40328
1977	5253	4344	809	5319	15725
1978	10499	1589	1172	5651	18911
1979	15129	8186	2460	6487	32262
1980	18531	8249	2441	7782	37003
1981	21506	11792	3110	11345	47753
1982	22212	13150	2102	4648	42112
1983	14713	7635	1473	2802	26623
1984	17146	7055	3161	3913	31275
1985	21823	7264	3199	8536	40822
1986	17440	11771	1593	11466	42270
1987	17066	10990	2345	8072	38473
1988	23901	14799	2809	14501	56010
1989	21616	7679	3530	13066	45891
1990	18082	9509	3569	18699	49859
1991	18254	6842	2167	14668	41931
1992	23436	7430	3795	13446	48107
1993	18429	4707	4355	16825	44316
1994	22742	8906	6910	22662	61220
1995	16834	7820	2425	12618	39697
1996	27959	7980	2910	19548	58397
1997	48490	8682	4083	14337	75592
1998	46091	15200	6640	16084	84015
1999	49924	16220	8276	22414	96834
2000	44587	19828	11418	32647	108480
2001	38404	31386	8289	47734	125813
2002	41995	32055	18520	26094	118664
2003	33807	26112	20572	56403	136894
2004	30221	25759	23753	37351	117084
2005	28070	20285	21801	28163	98319
2006	21169	24179	30150	37649	113147
2007	24868	17315	30150	37649	109982

Figure 2. Annual catch, (a) tonnes, (b) numbers, of swordfish taken by longline fleets operating in each of the four assessment areas of the southern WCPO



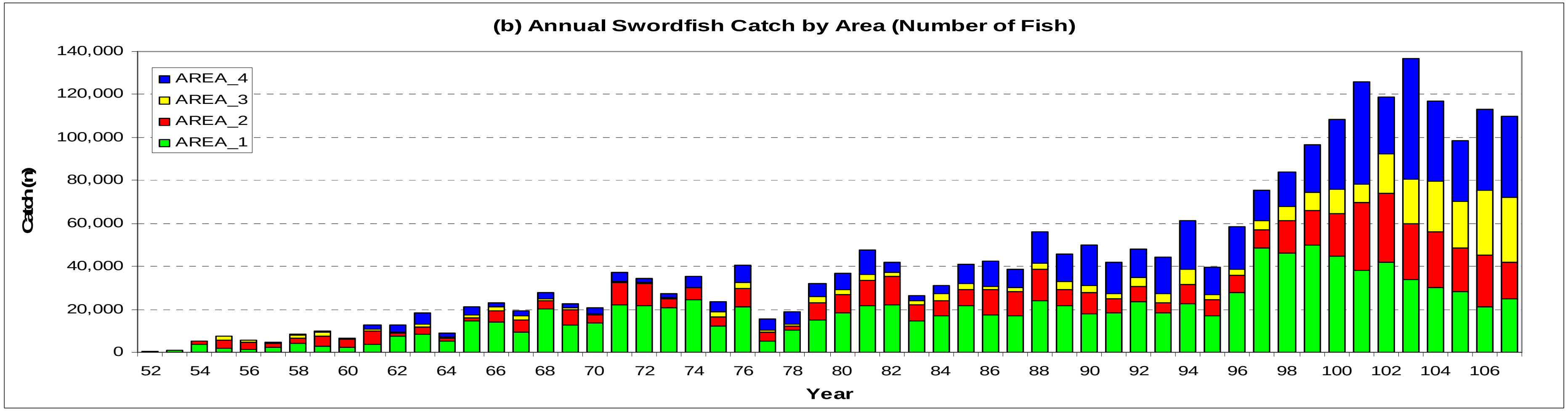
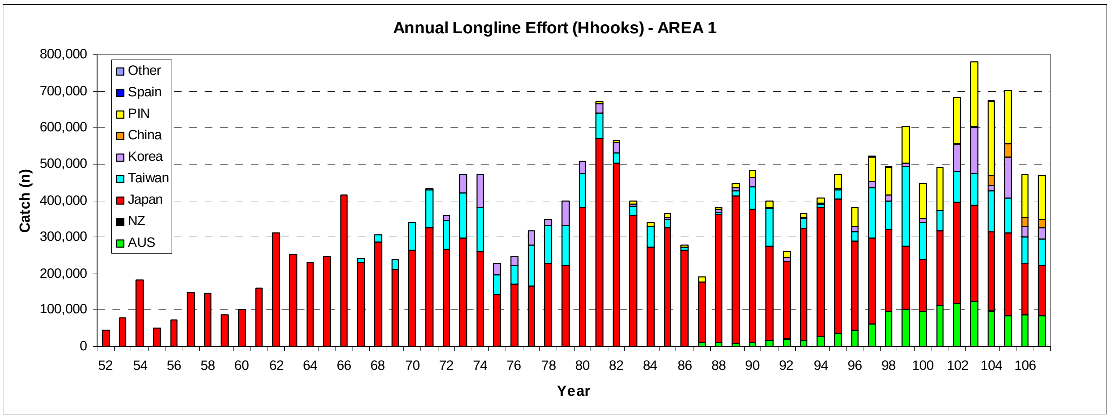
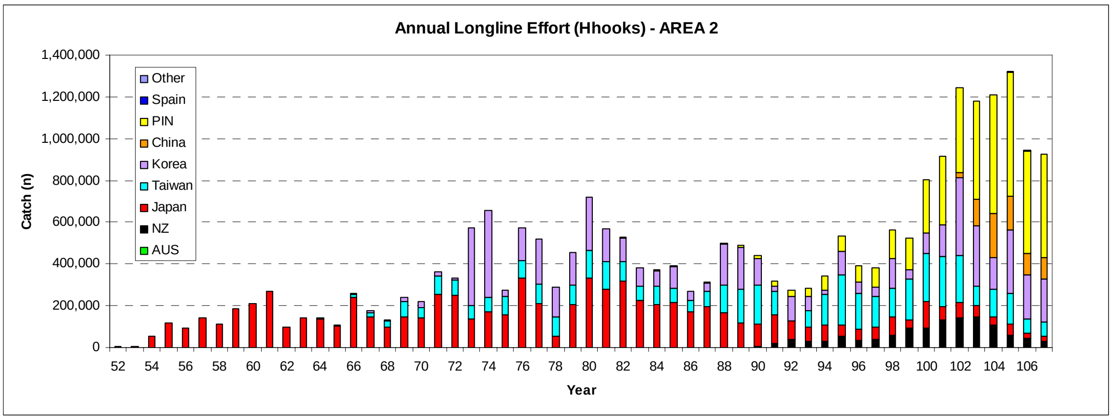
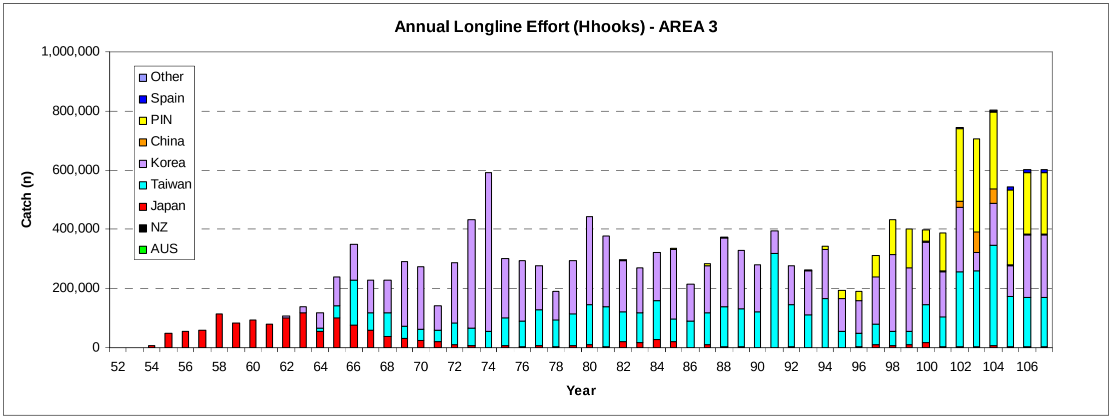


Figure 3a Annual longline effort (hundred of hooks) for the major longline fleets within the four assessment regions of the southern WCPO.







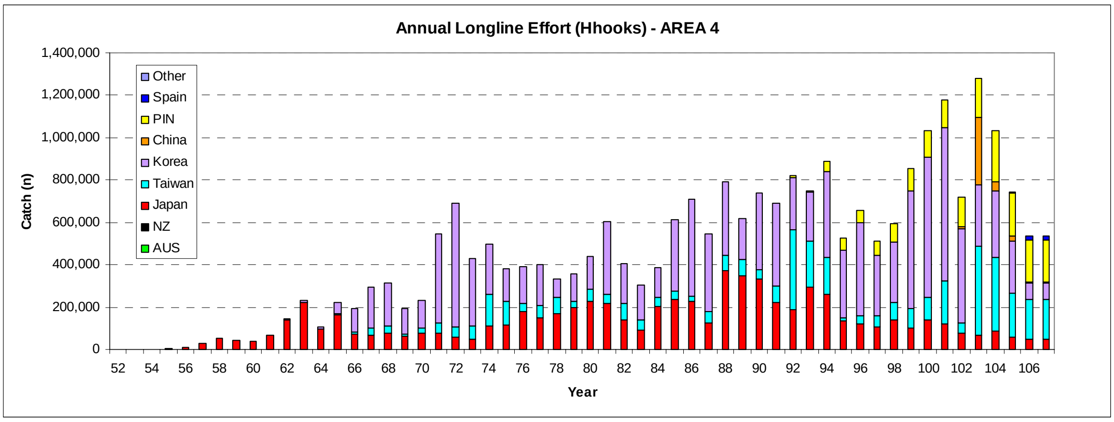


Figure 3b Annual longline swordfish catch (number of fish) for the major longline fleets within the four assessment regions of the southern WCPO.

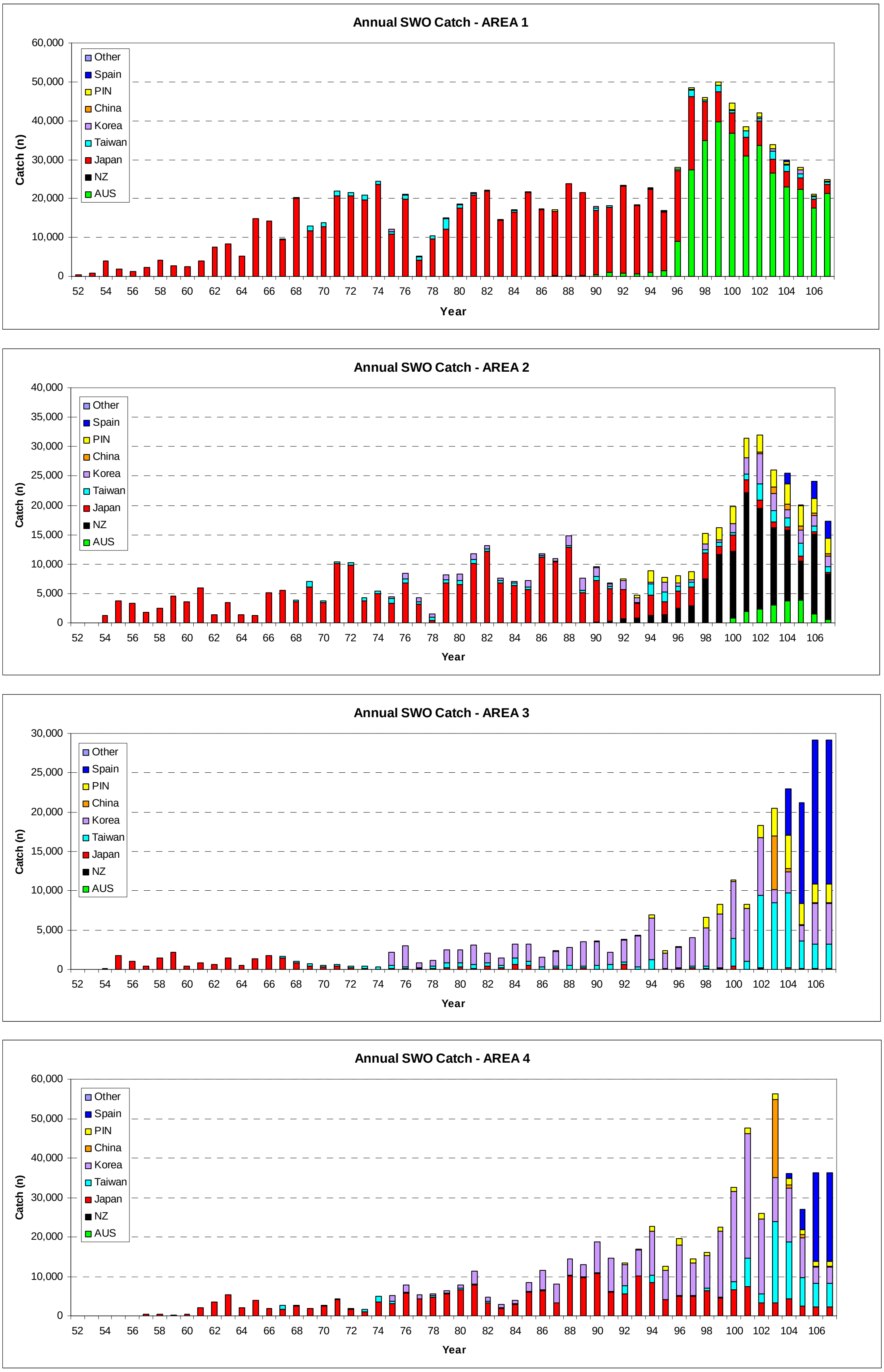
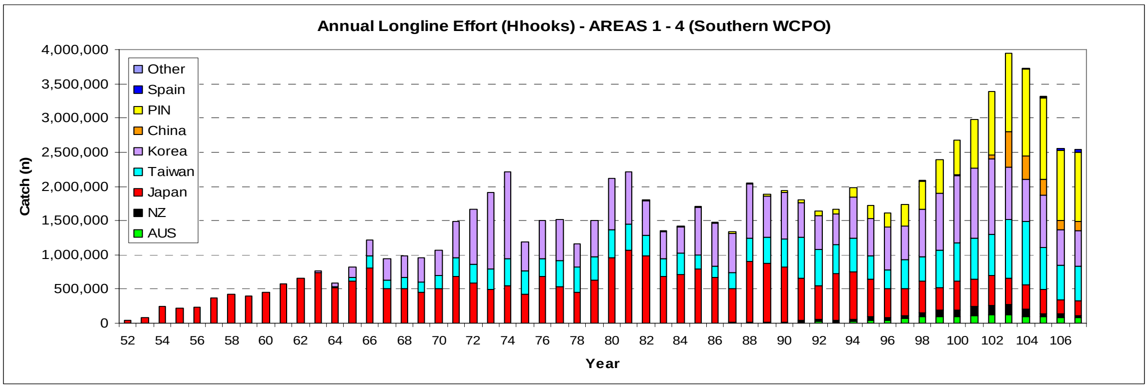


Figure 4a. Annual longline effort (hundred of hooks) for the major longline fleets within the southern WCPO and south west Pacific.



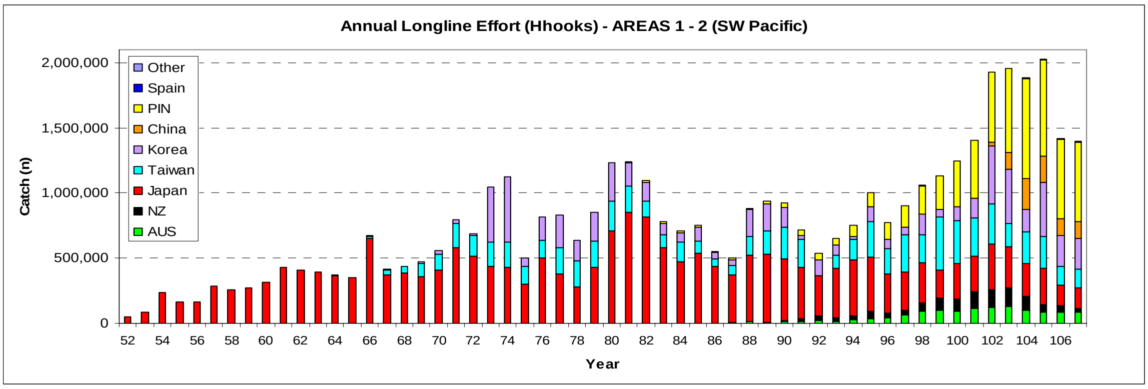
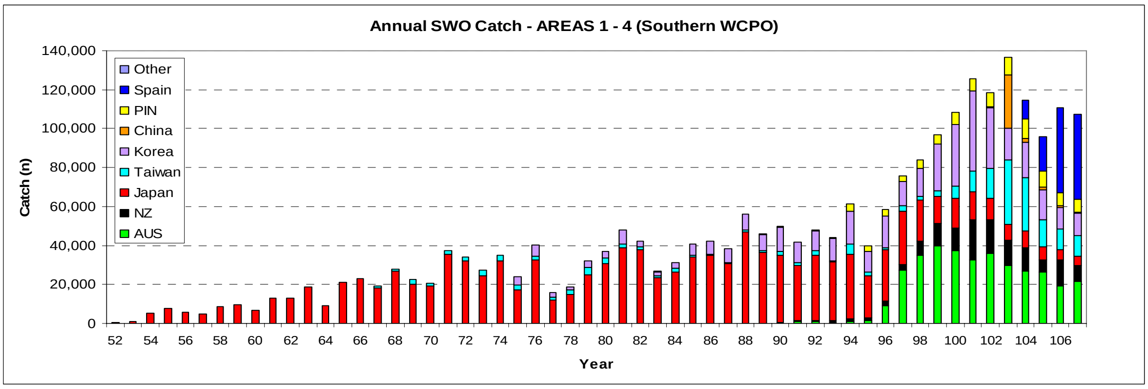


Figure 4b. Annual longline swordfish catch (number of fish) for the major longline fleets within the southern WCPO and south west Pacific.



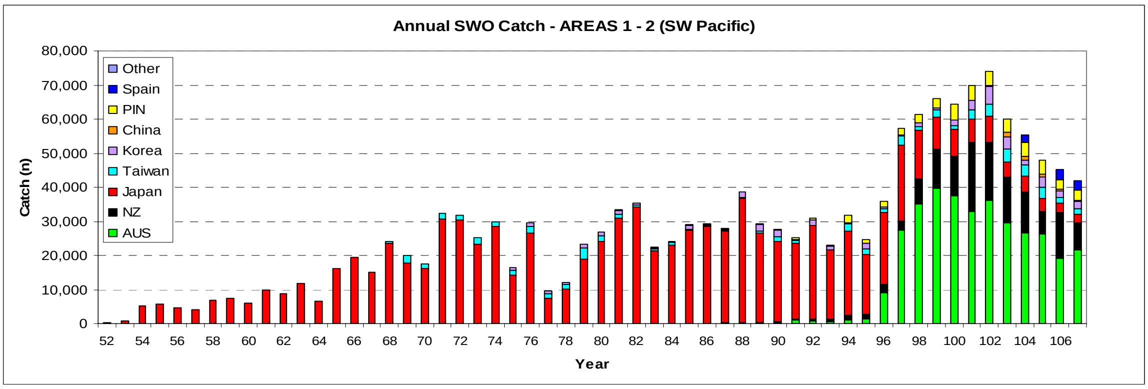
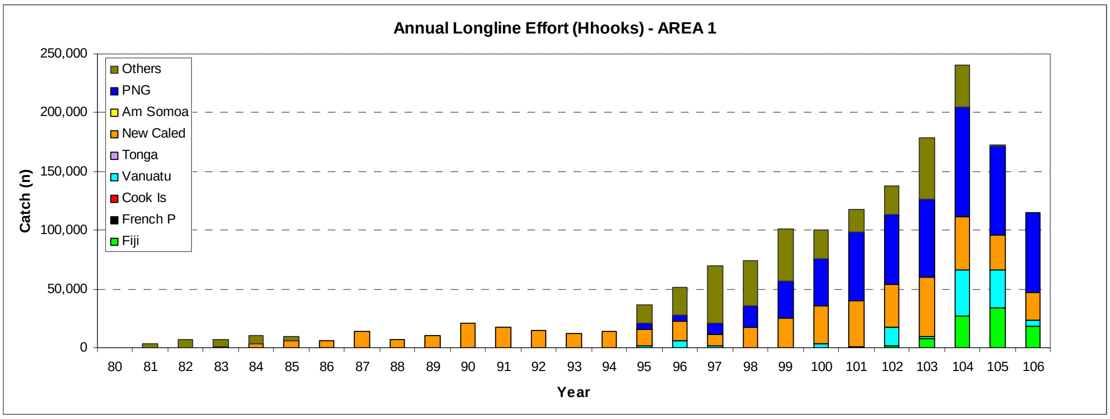
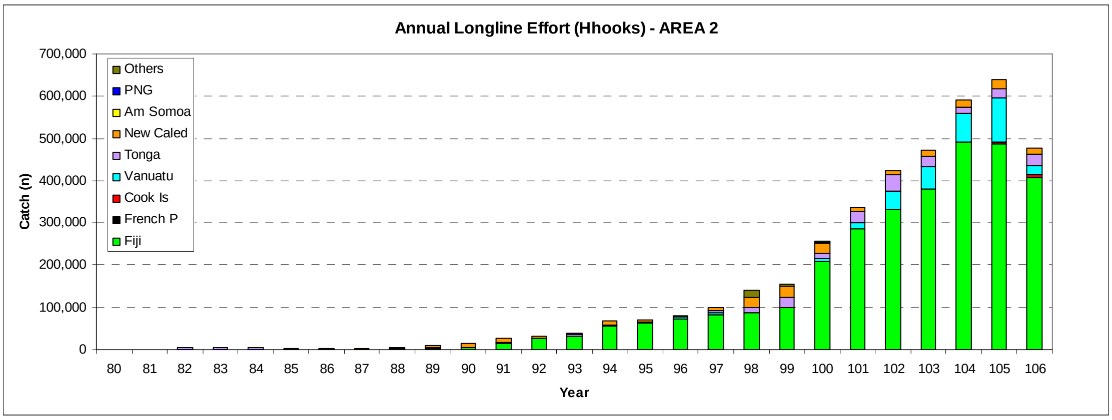
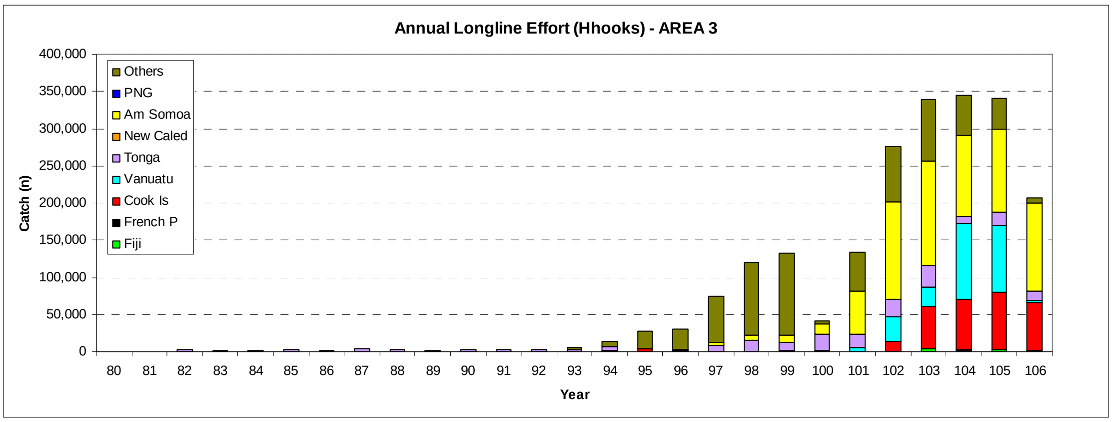


Figure 5a. Annual longline effort (hundred of hooks) for the main Pacific Island Nation longline fleets in the four assessment regions of the southern WCPO.







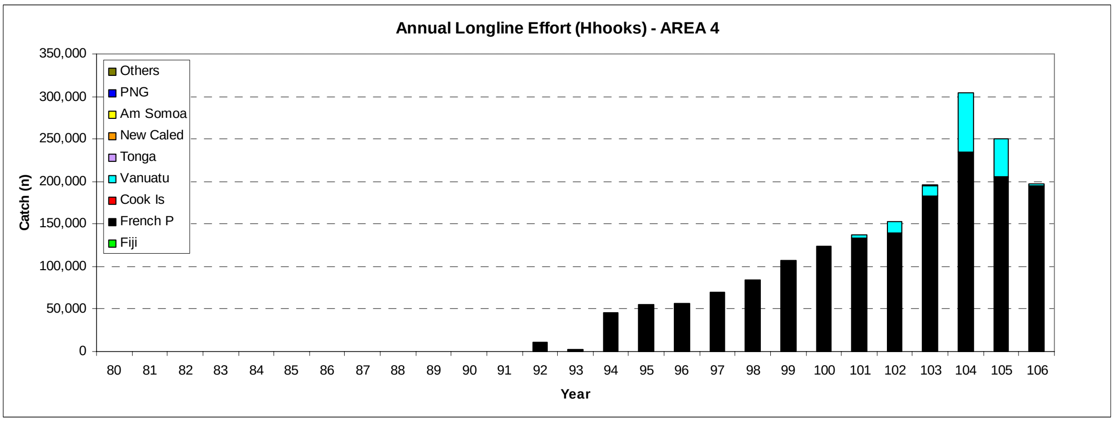


Figure 5b. Annual longline swordfish catch (number of fish) for the main Pacific Island Nation longline fleets in the four assessment regions of the south WCPO.

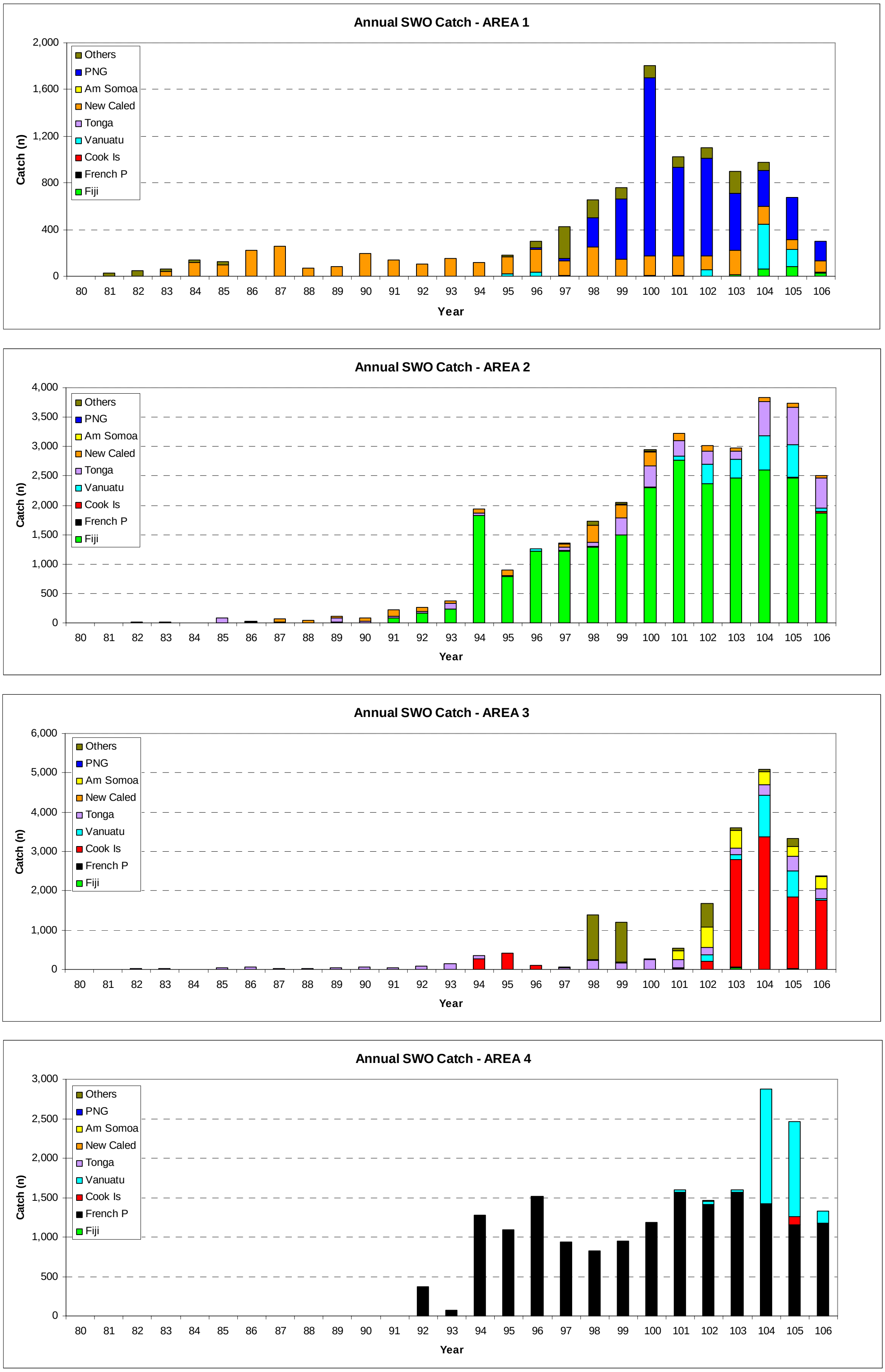
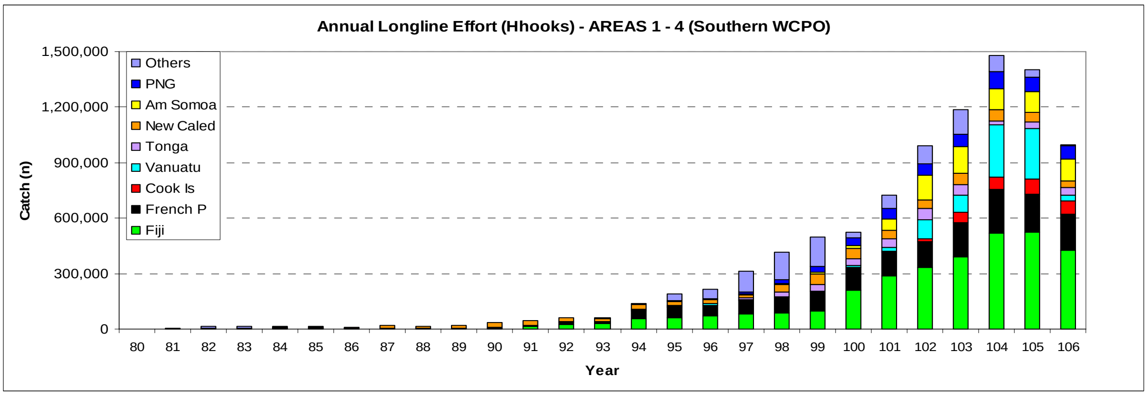


Figure 6a. Annual effort (hundred of hooks) for the main Pacific Island Nation longline fleets within the southern WCPO and SW Pacific.



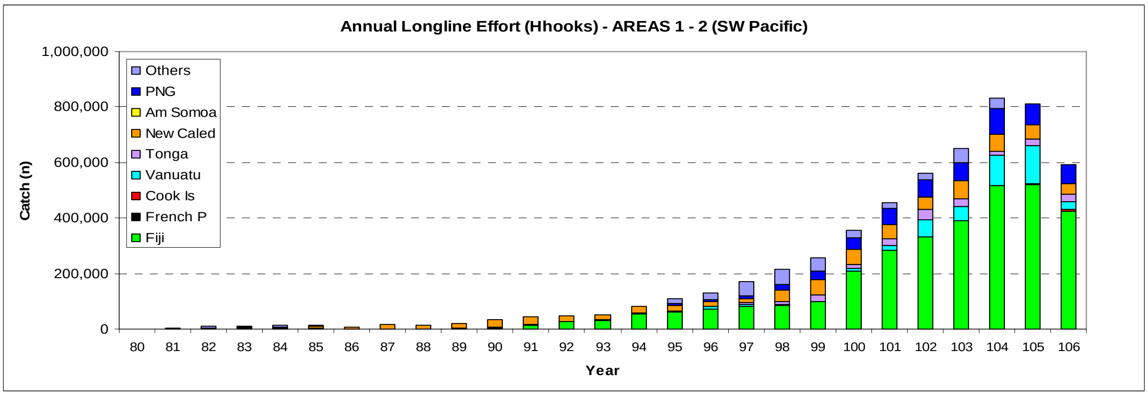
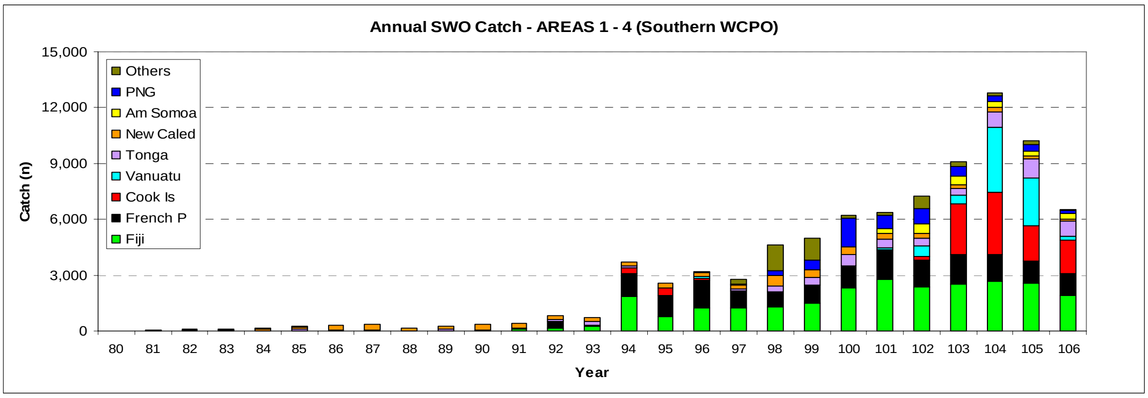


Figure 6a. Annual swordfish catch (number of fish) for the main Pacific Island Nation longline fleets within the southern WCPO and SW Pacific.



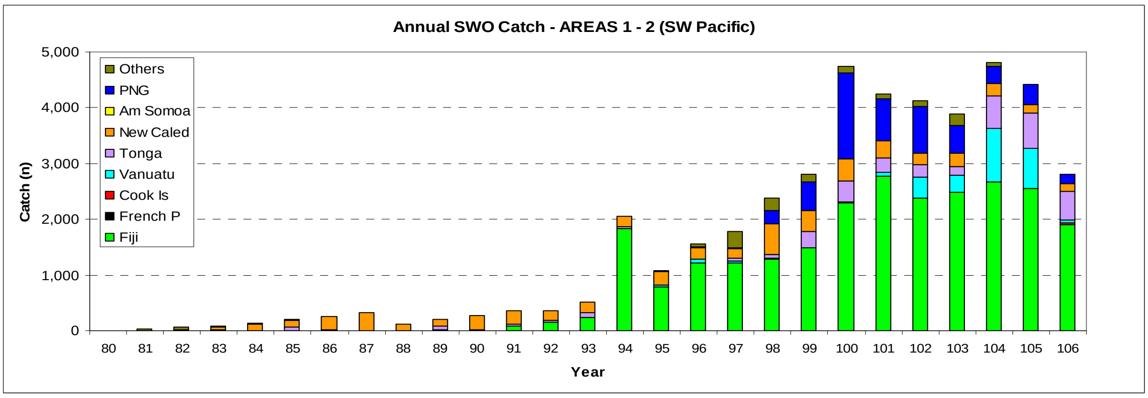
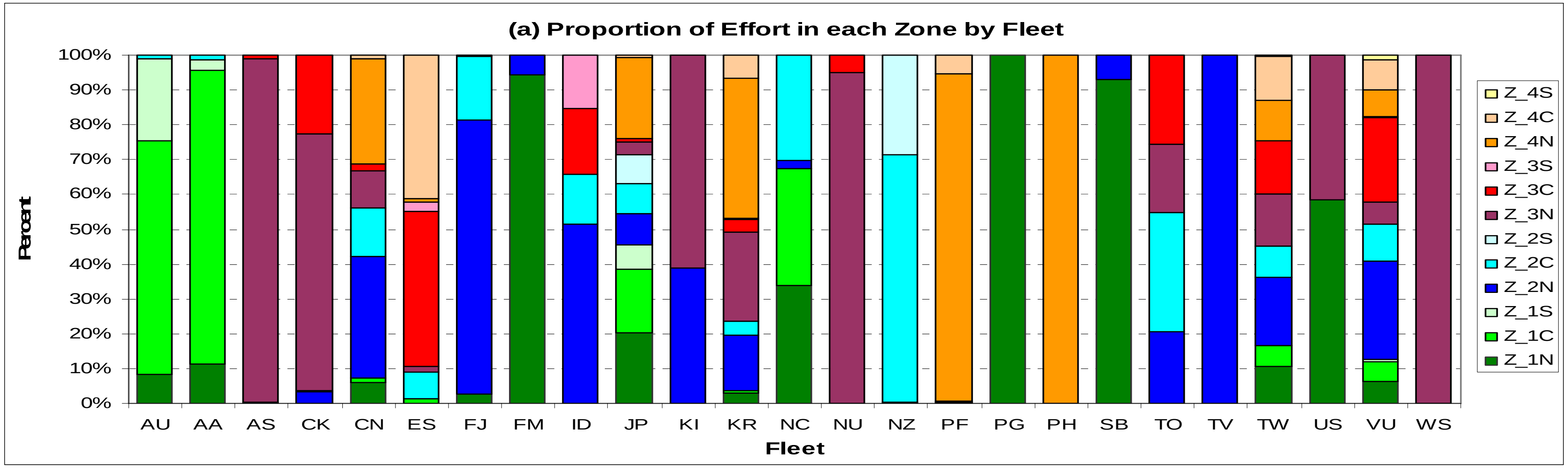


Figure 7. Proportion of (a) effort and (b) catch of swordfish taken by each fleet within each of the 12 zones used in the 2008 assessment.



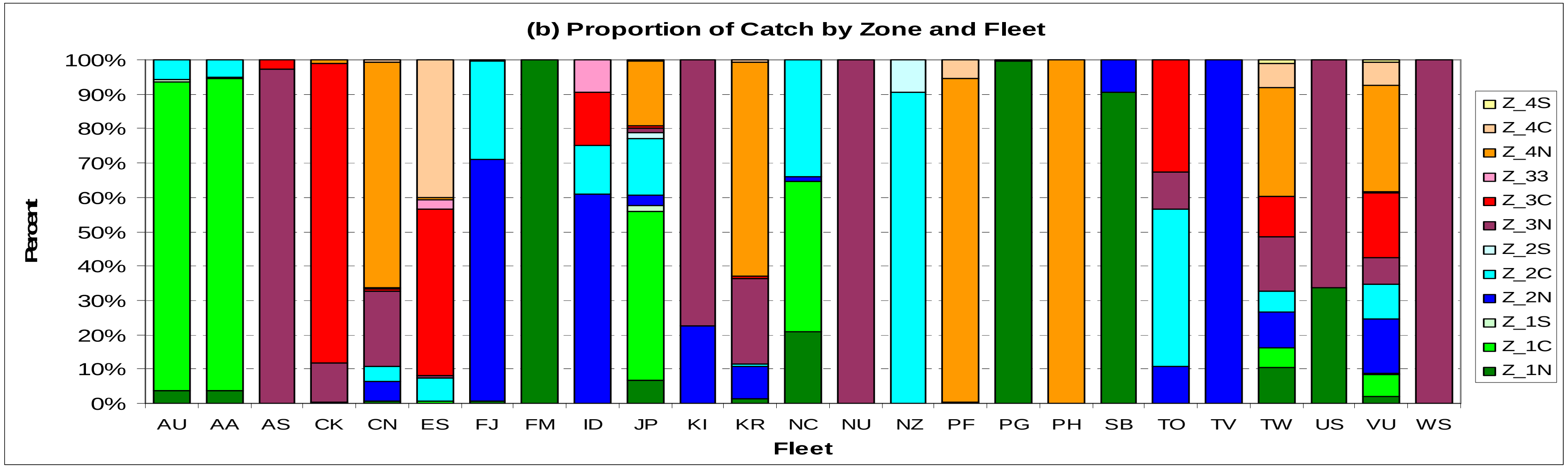
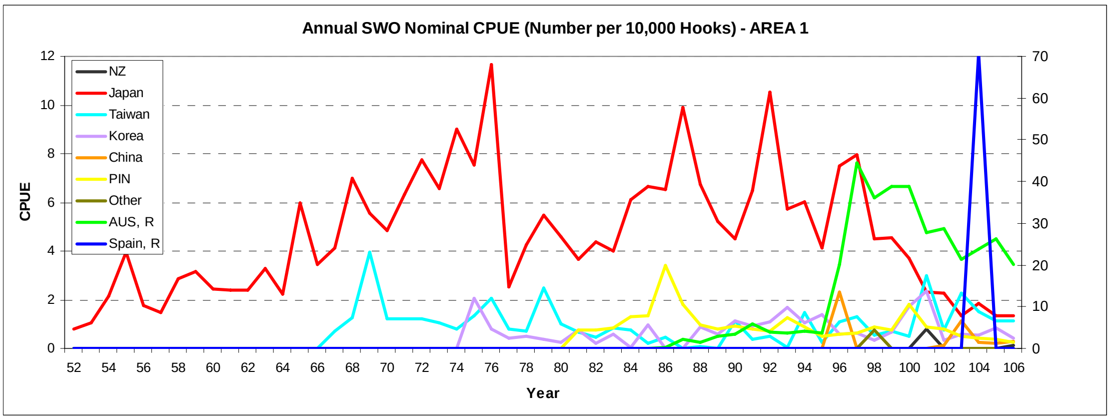
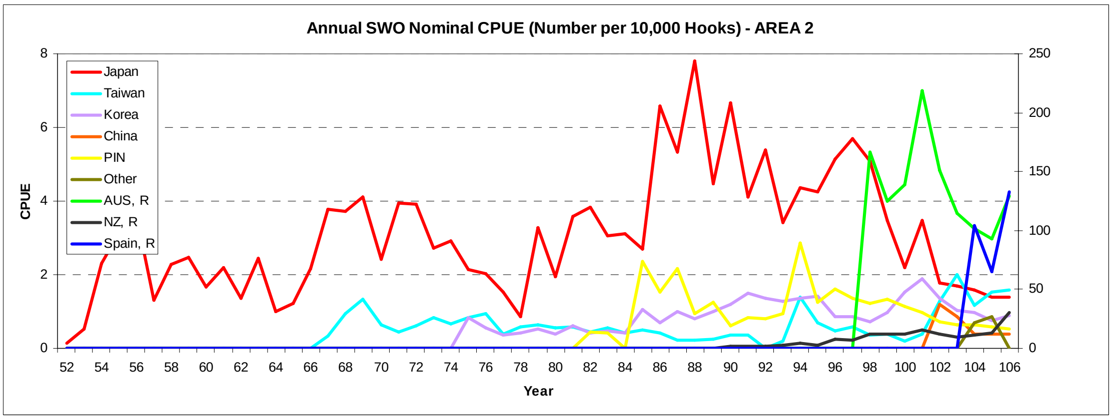
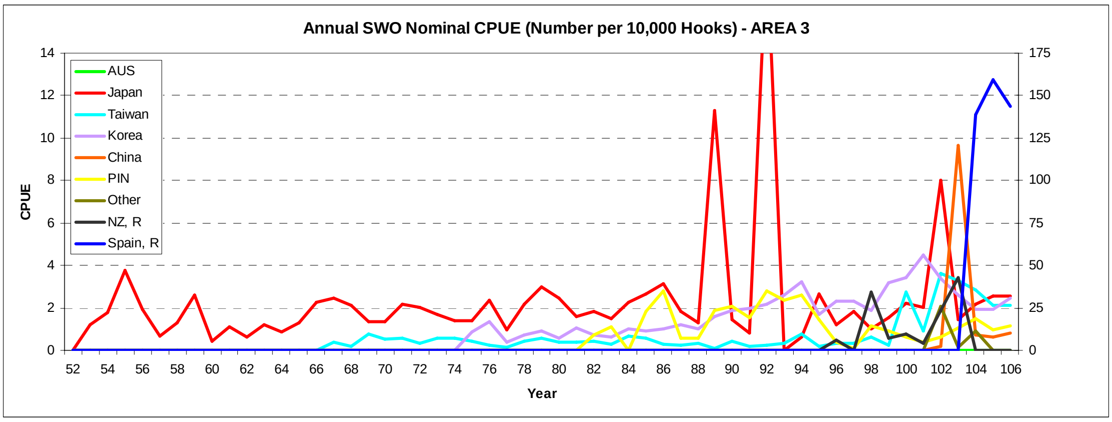


Figure 8. Annual nominal swordfish CPUE (number of fish per 10,000 hooks), by area, for the major longline fleets operating in the south WCPO. (Note: Fleets with CPUE referenced by the right-hand scale are annotated with the letter R.)







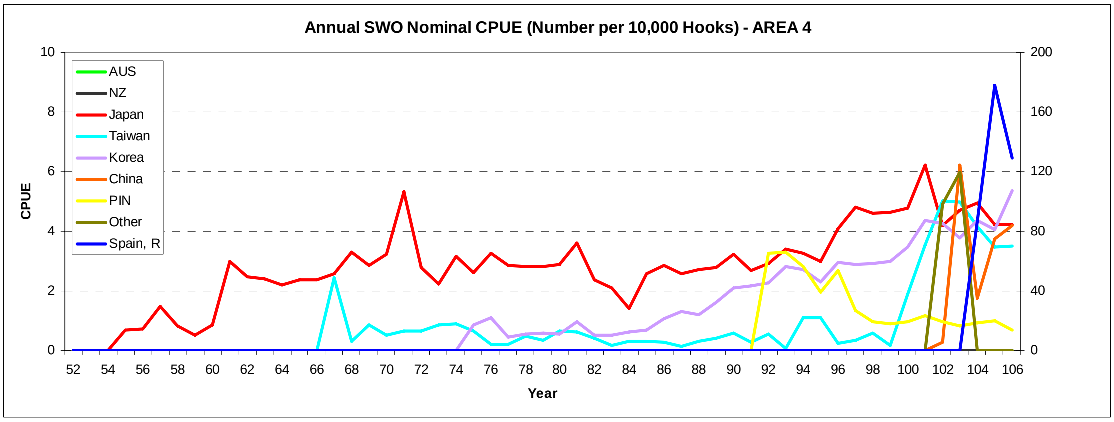
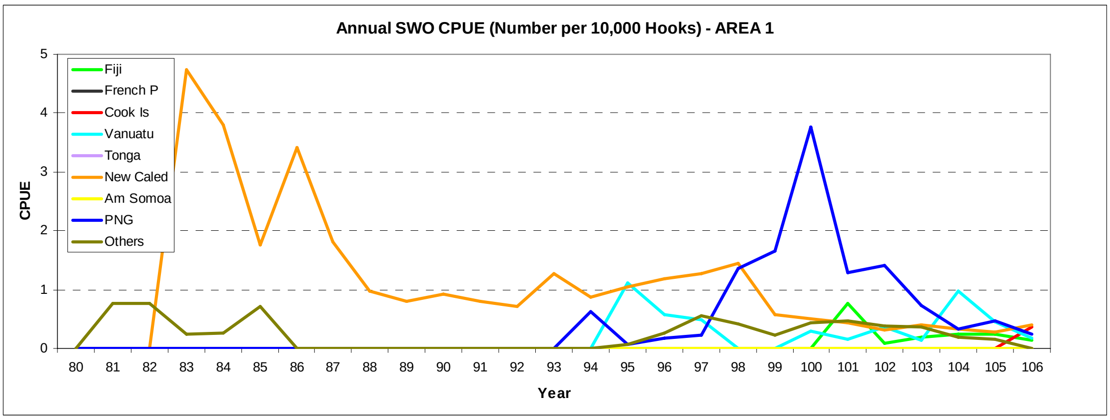
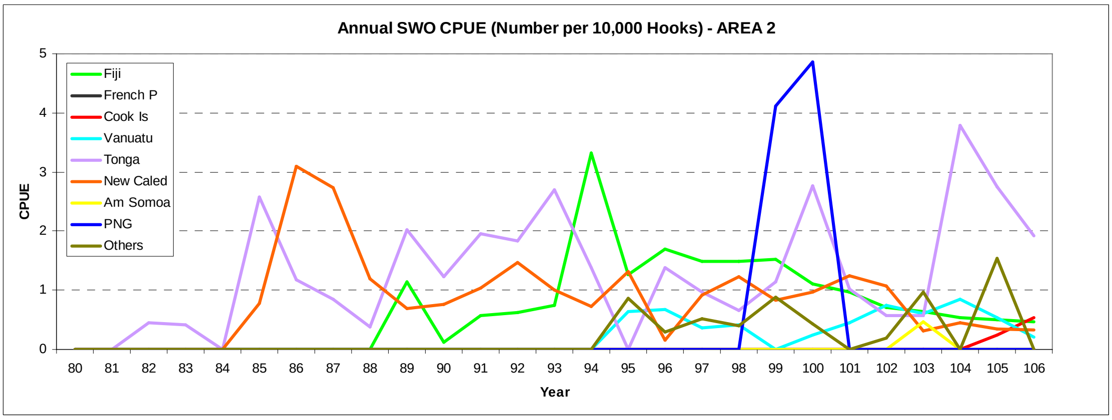
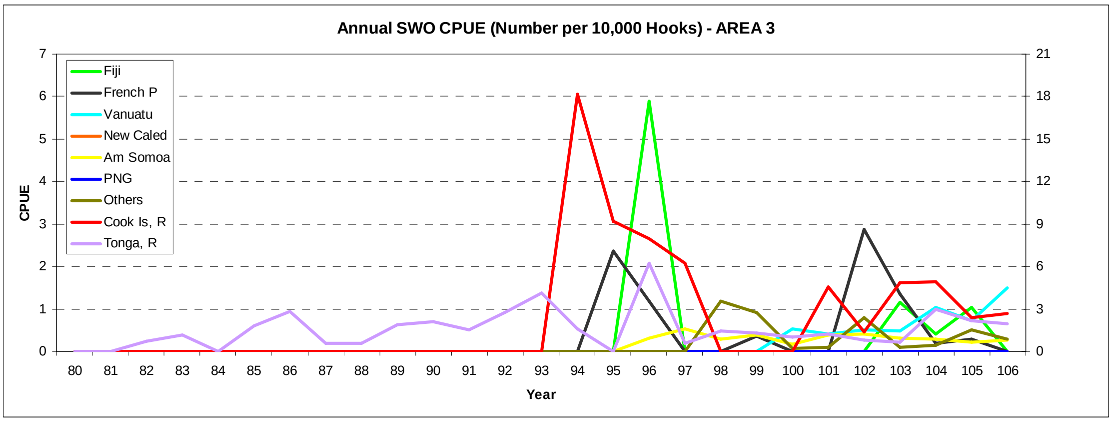


Figure 9. Annual nominal swordfish CPUE (number of fish per 10,000 hooks), by area, for the main Pacific Island Nation fleets operating in the south WCPO. (NB: Fleets with CPUE referenced by the right-hand scale are annotated with the letter R.)


Annual SWO CPUE (Number per 10,000 Hooks) - AREA 1


Annual SWO CPUE (Number per 10,000 Hooks) - AREA 2


Annual SWO CPUE (Number per 10,000 Hooks) - AREA 3

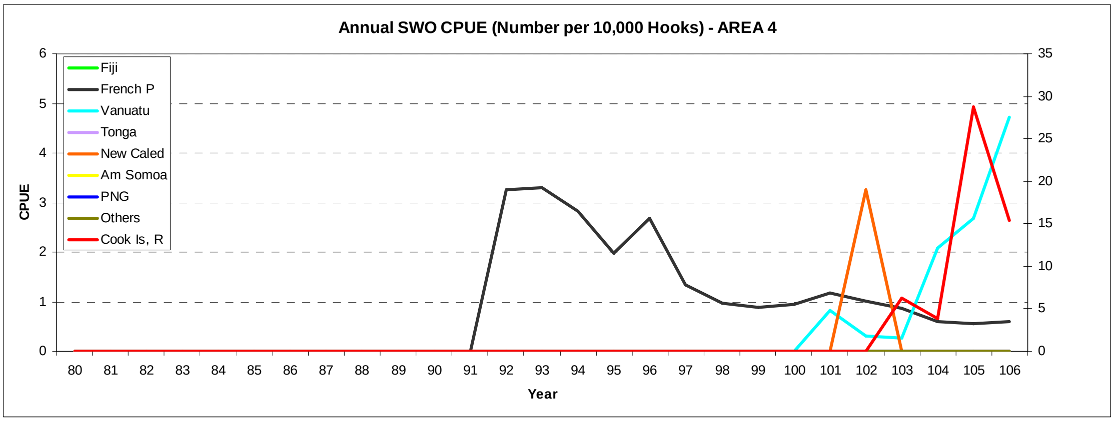

Annual SWO CPUE (Number per 10,000 Hooks) - AREA 4

Figure 10a. Annual nominal swordfish CPUE (number of fish per 10,000 hooks) for the major longline fleets in the south WCPO and the SW Pacific. (Note: Fleets wiht CPUE referenced by the right-hand scale are annotated with the letter R.)

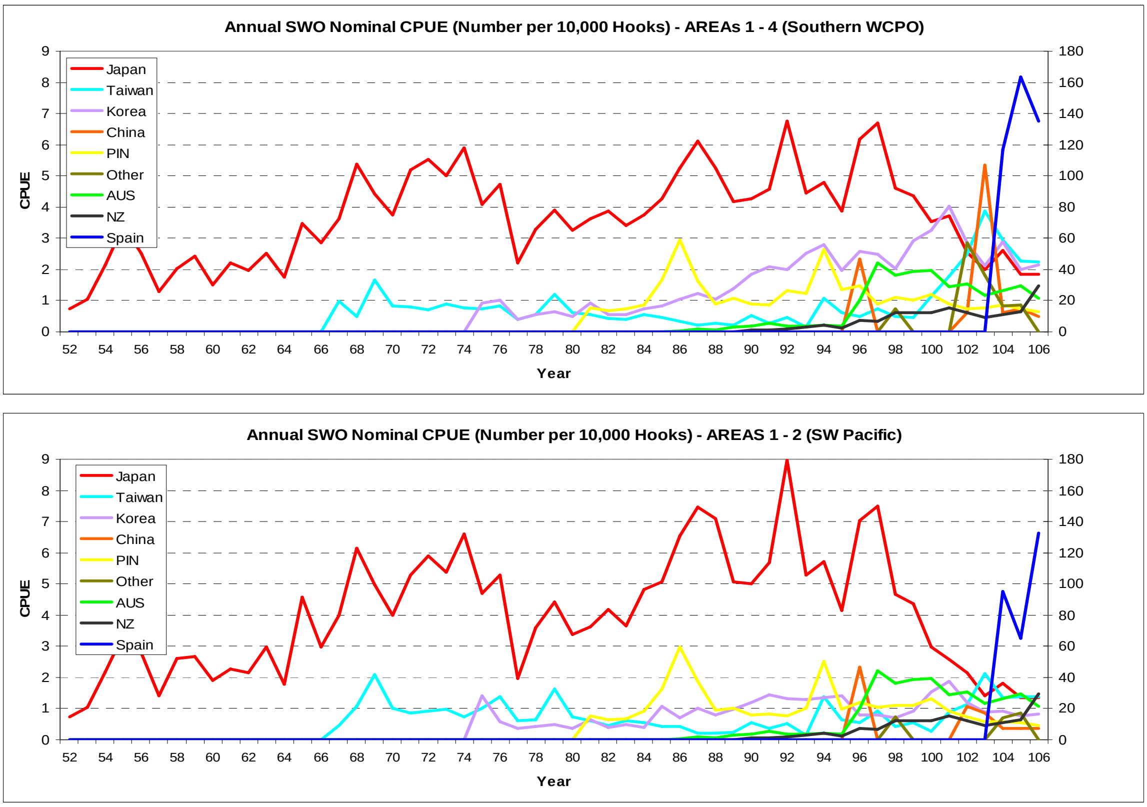


Figure 10b. Annual nominal swordfish CPUE (number of fish per 10,000 hooks) for the main Pacific Island Nation longline fleets in the south WCPO and the SW Pacific.

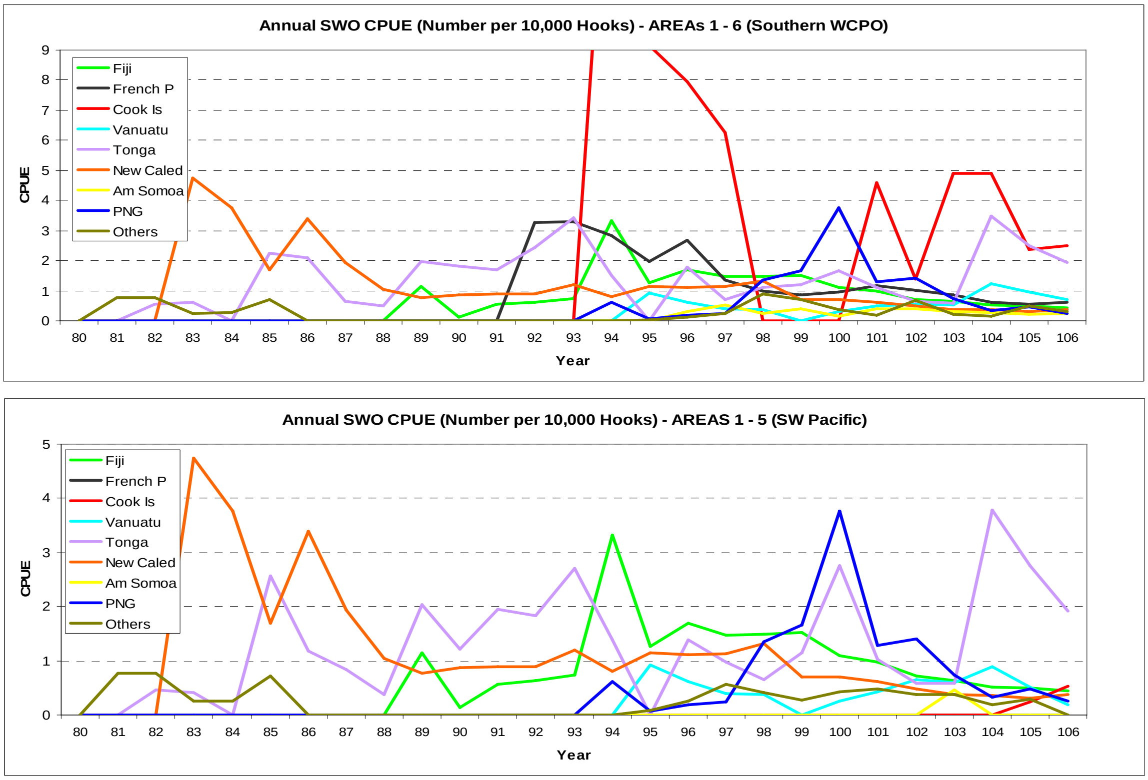


Figure 11a. Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 1.

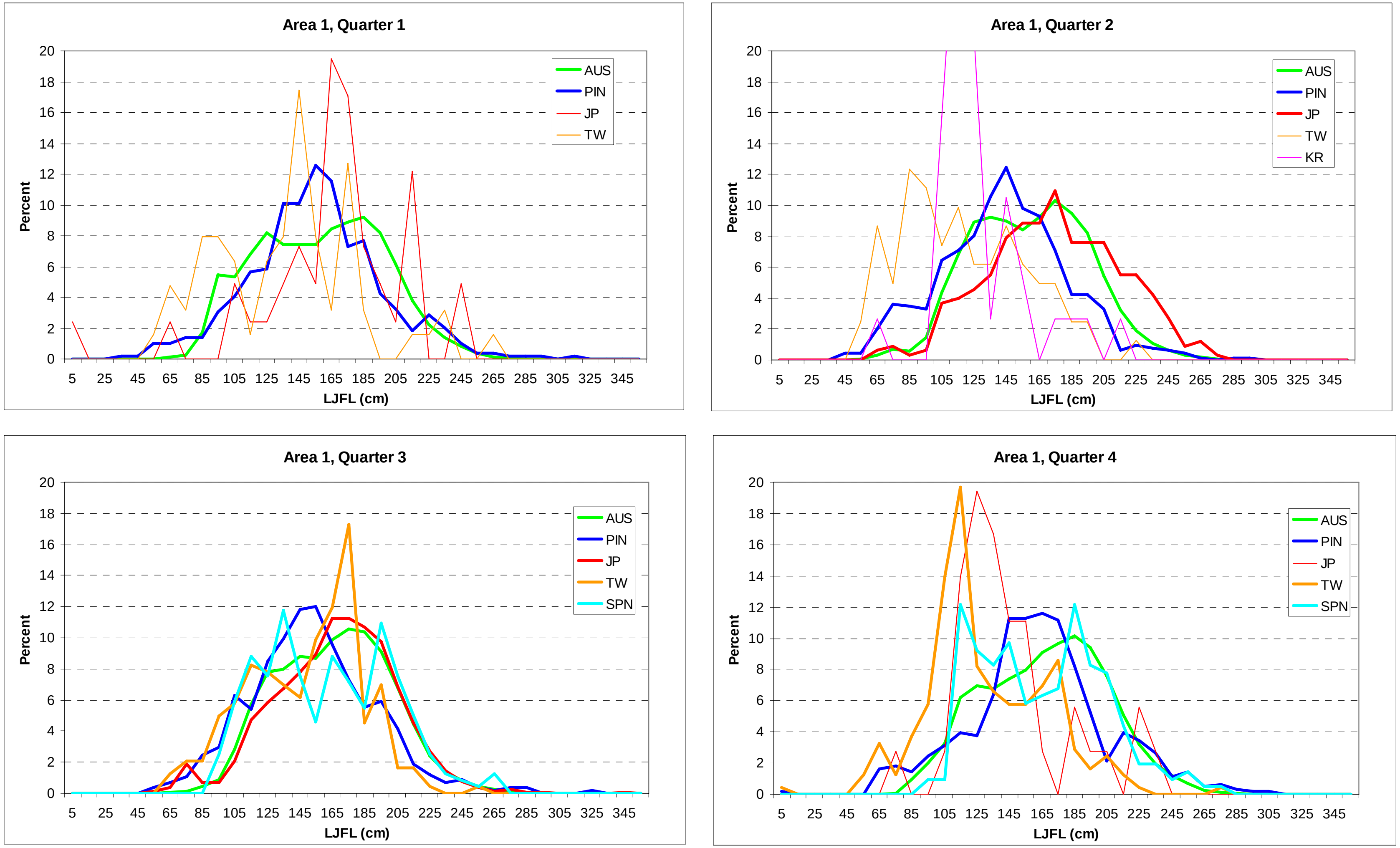


Figure 11b. Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 2.

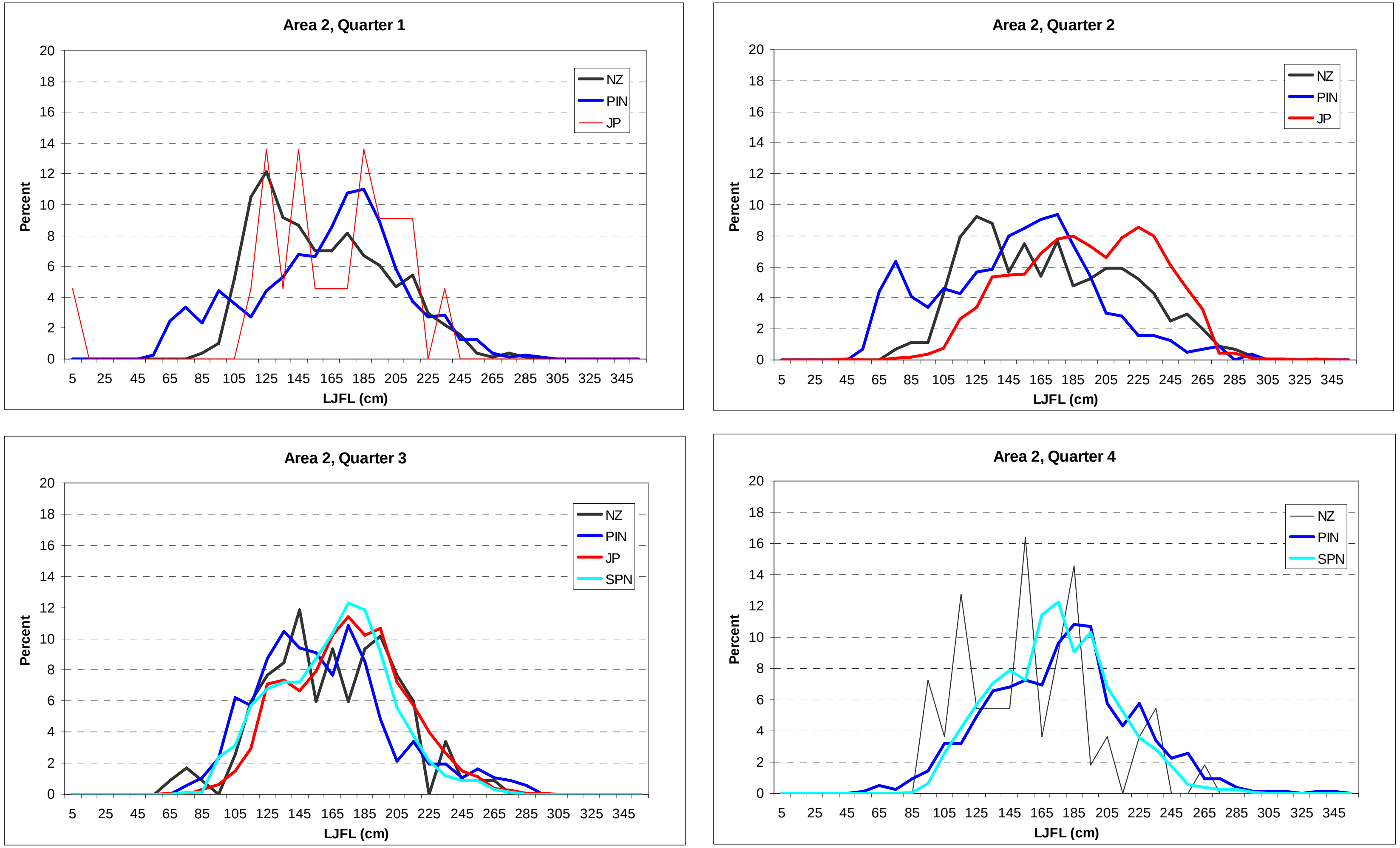


Figure 11c. Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 3.

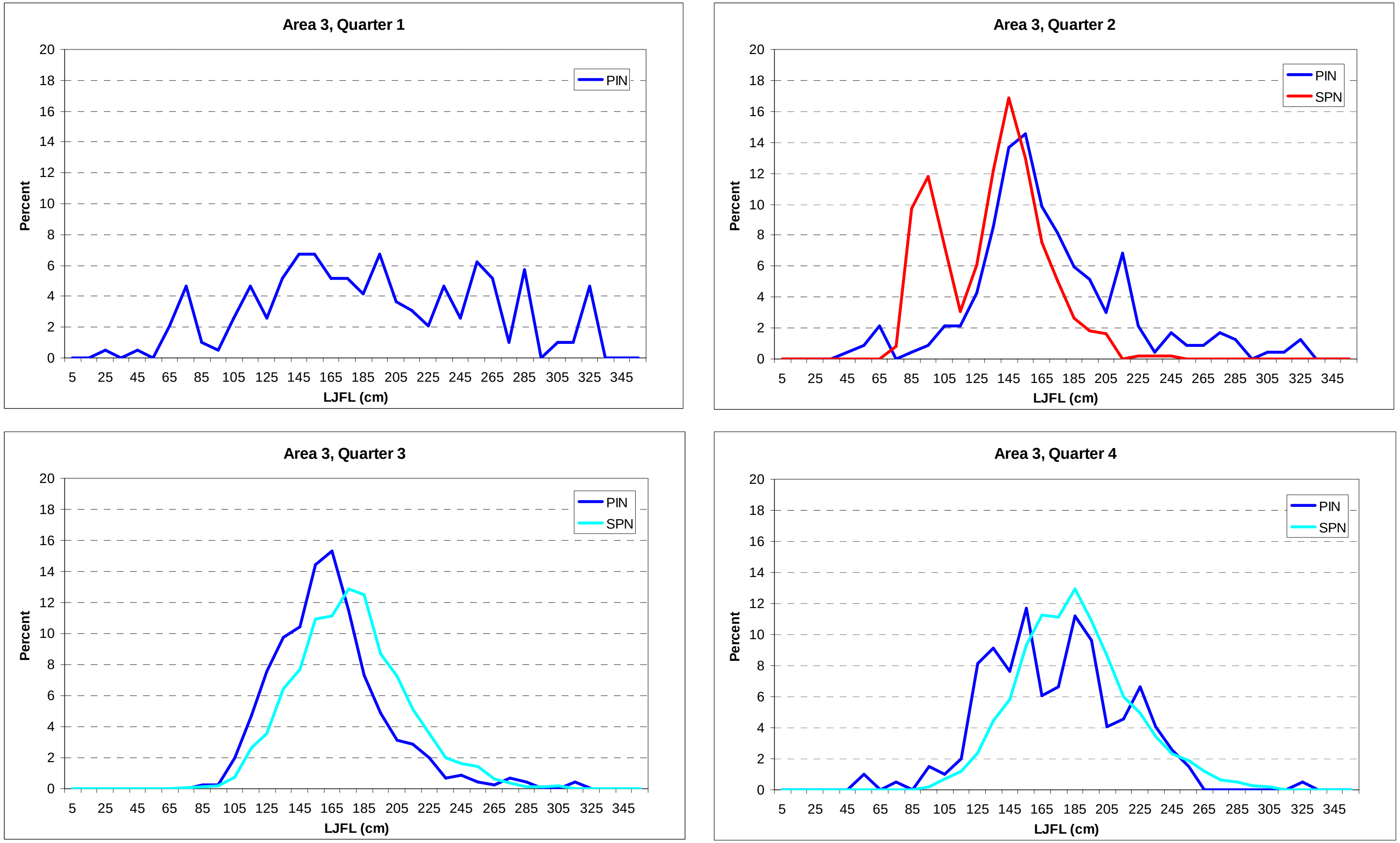
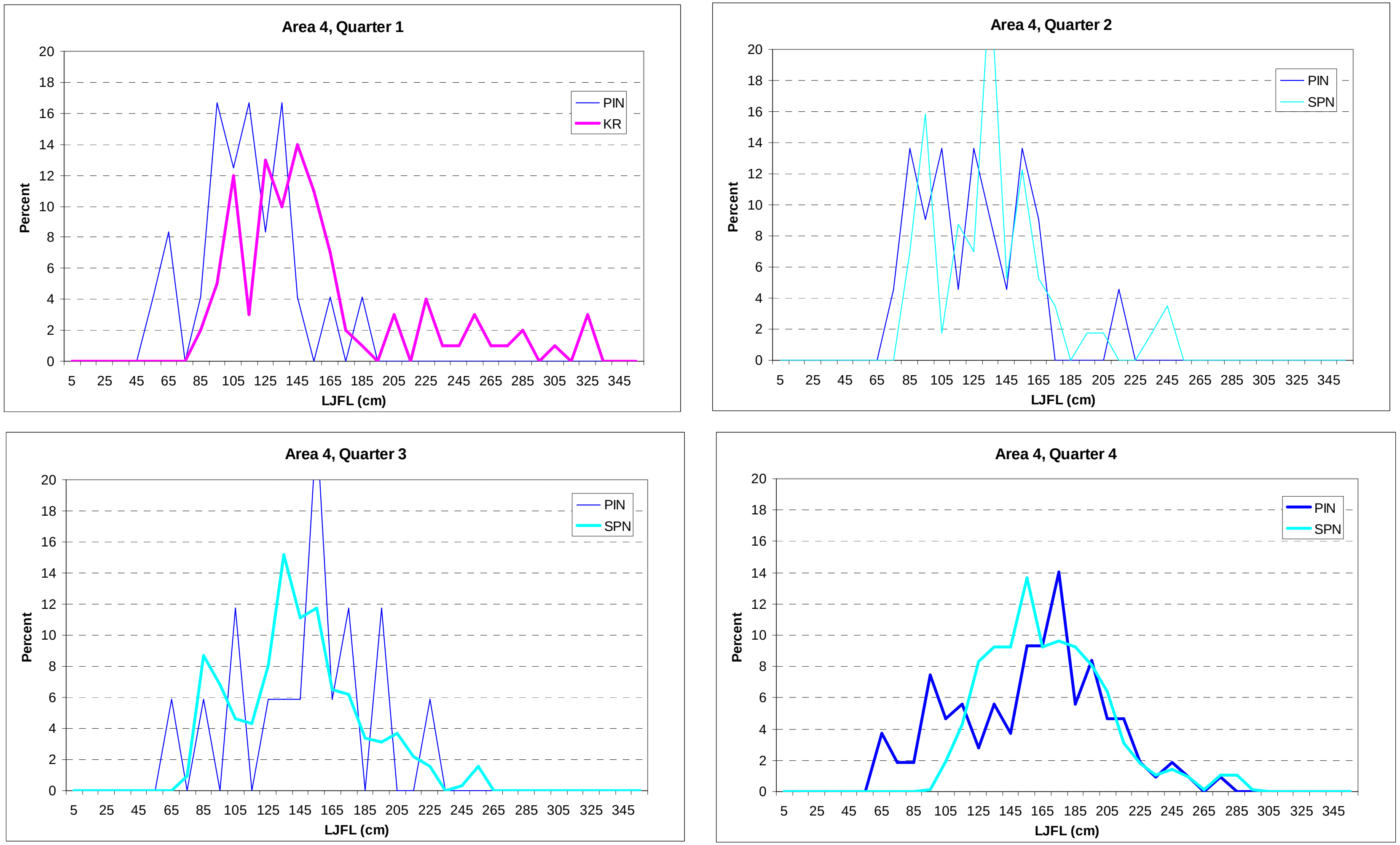
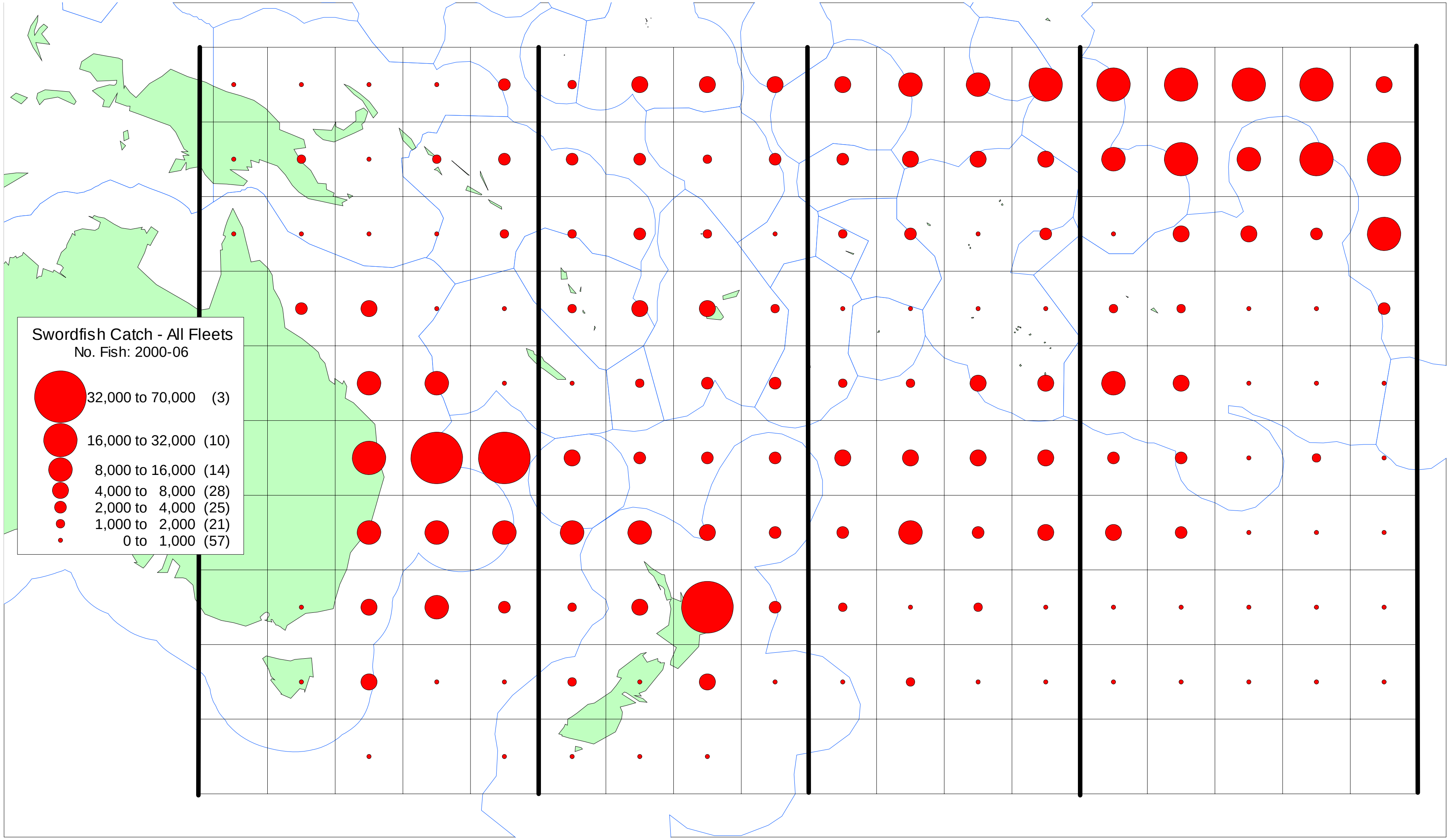


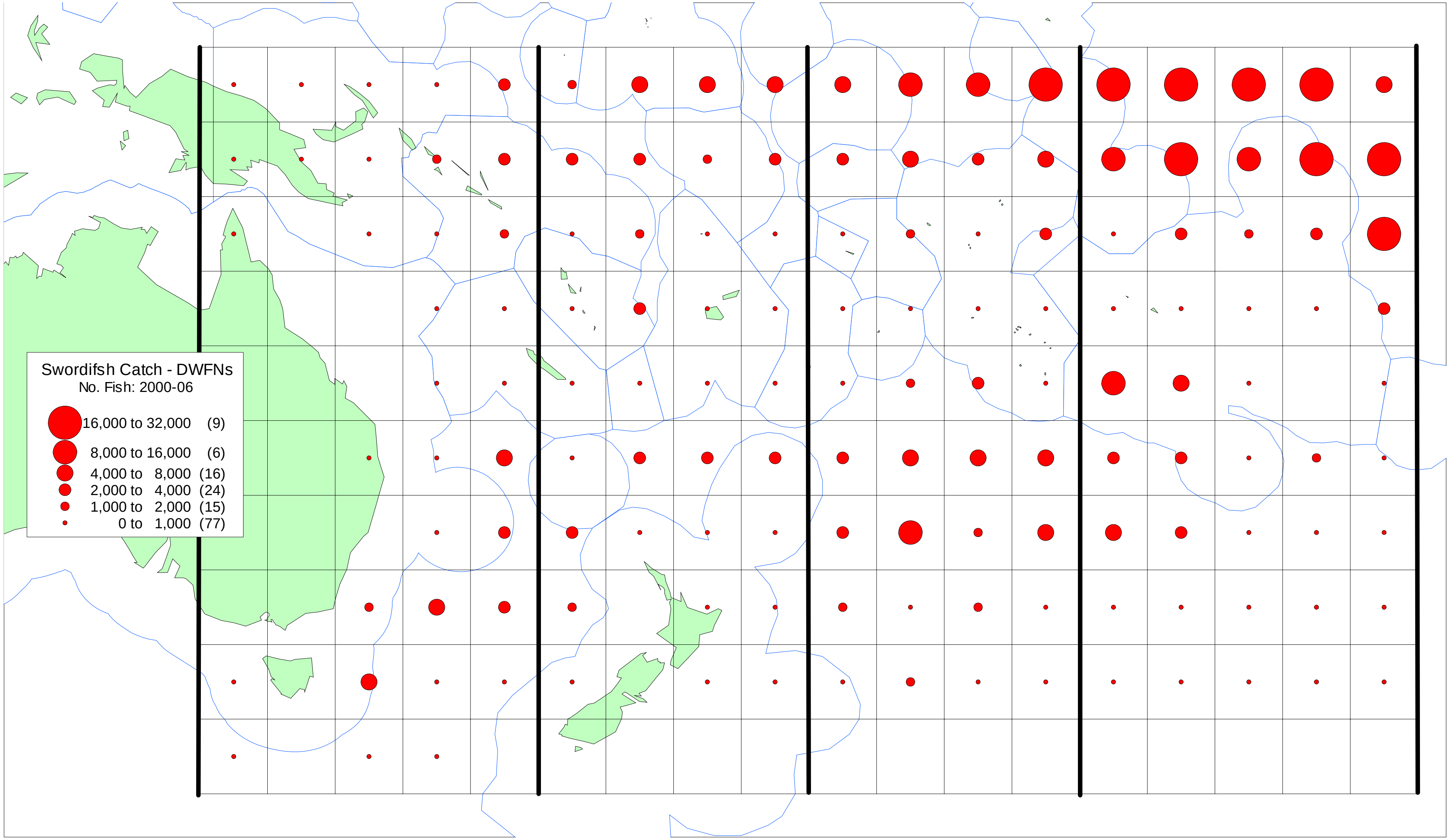
Figure 11d. Histograms of lower-jam to caudal length measurements, by quarter, for swordfish caught by various fleets operating in assessment Areas 4.



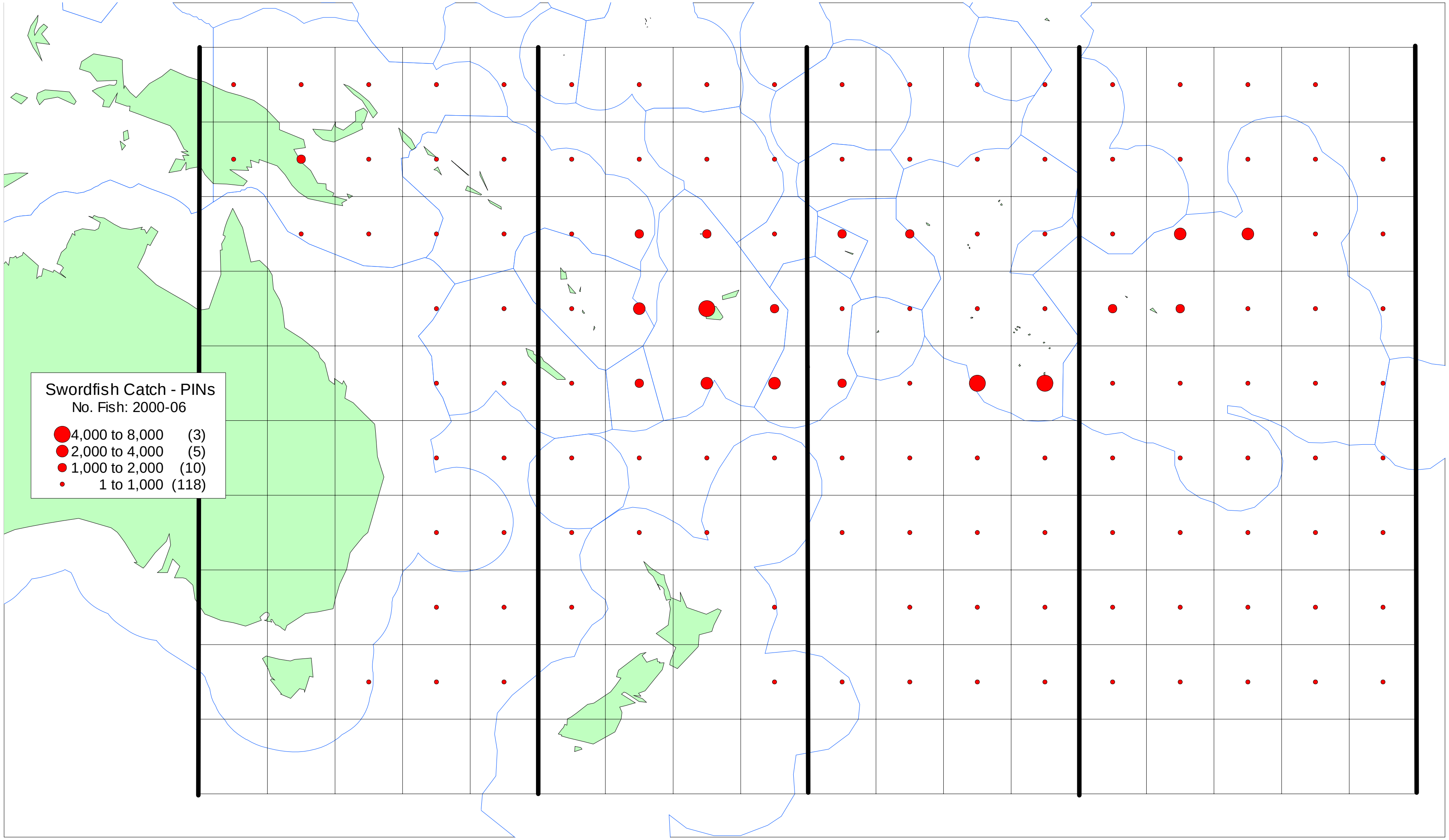
Map 1a. Spatial distribution of the total catch of swordfish (number of fish) taken by longline fleets in the southern WCPO: 2000 and 2006.



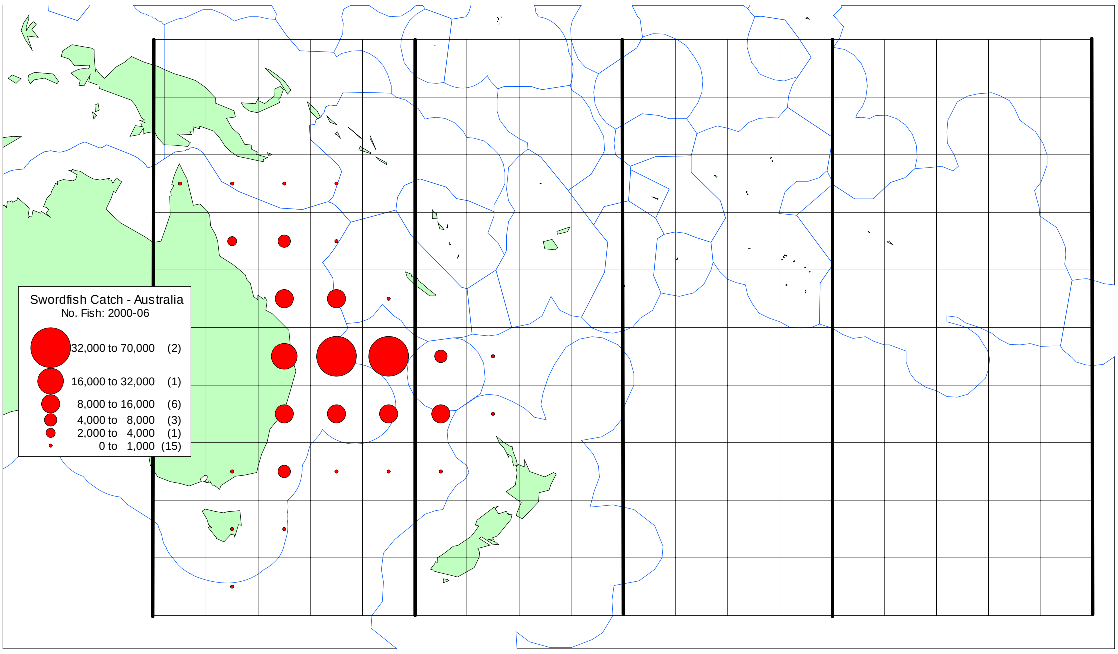
Map 1b. Spatial distribution of the total catch of swordfish (number of fish) taken by DFWN fleets in the southern WCPO: 2000 and 2006.



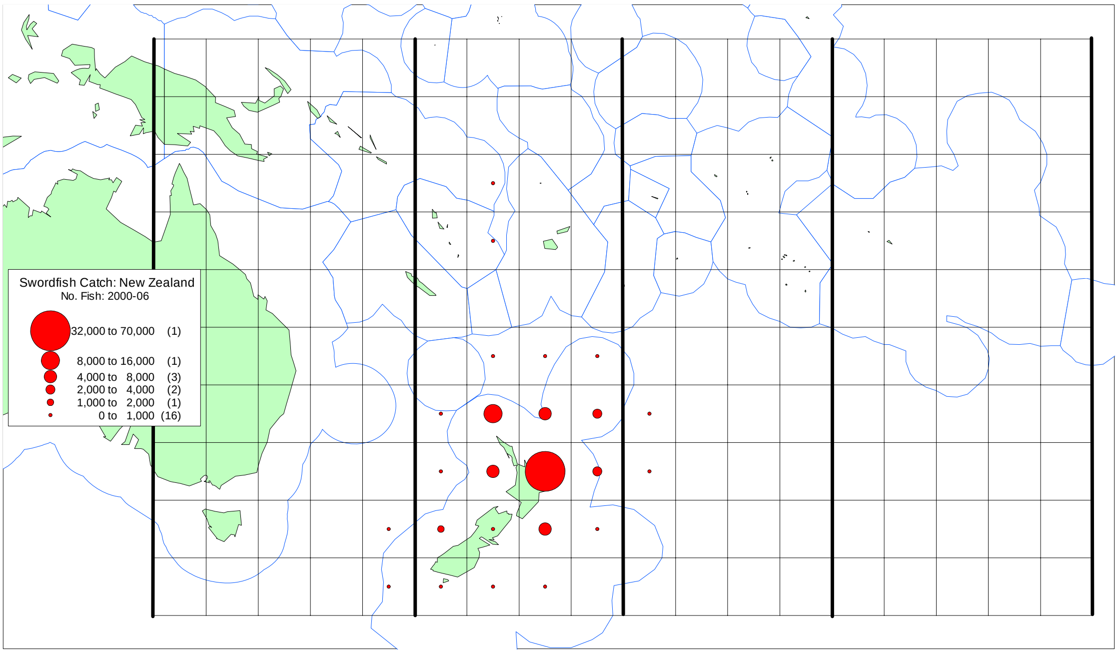
Map 1c. Spatial distribution of the total catch of swordfish (number of fish) taken by PIN fleets in the southern WCPO: 2000 and 2006.



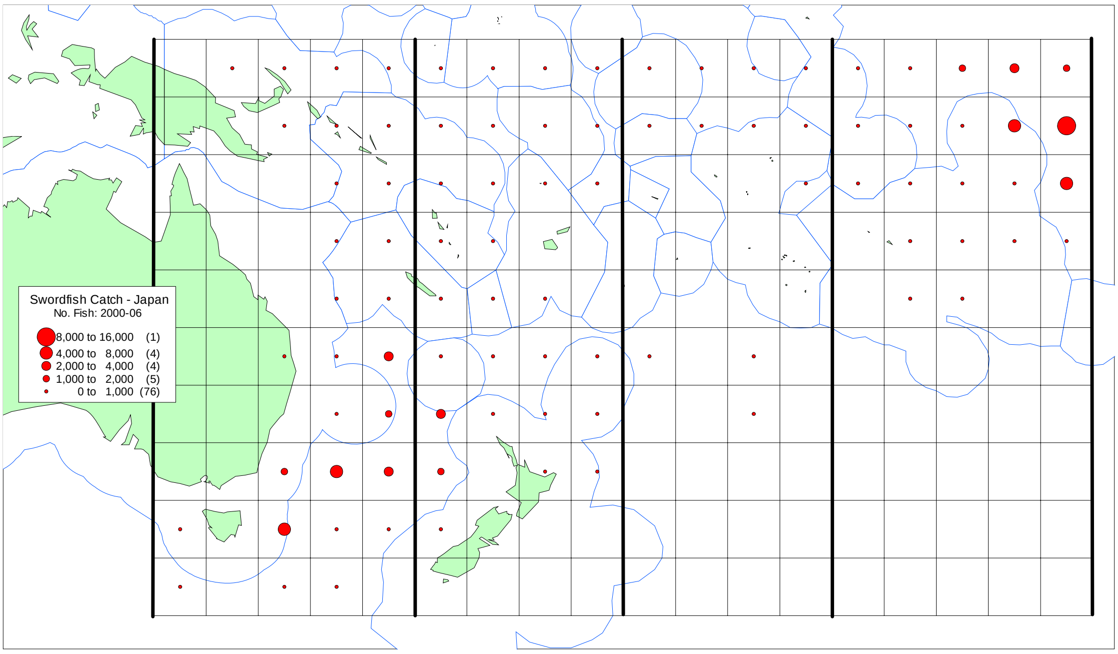
Map 2a. Distribution of Australian swordfish catch: 2000-06.



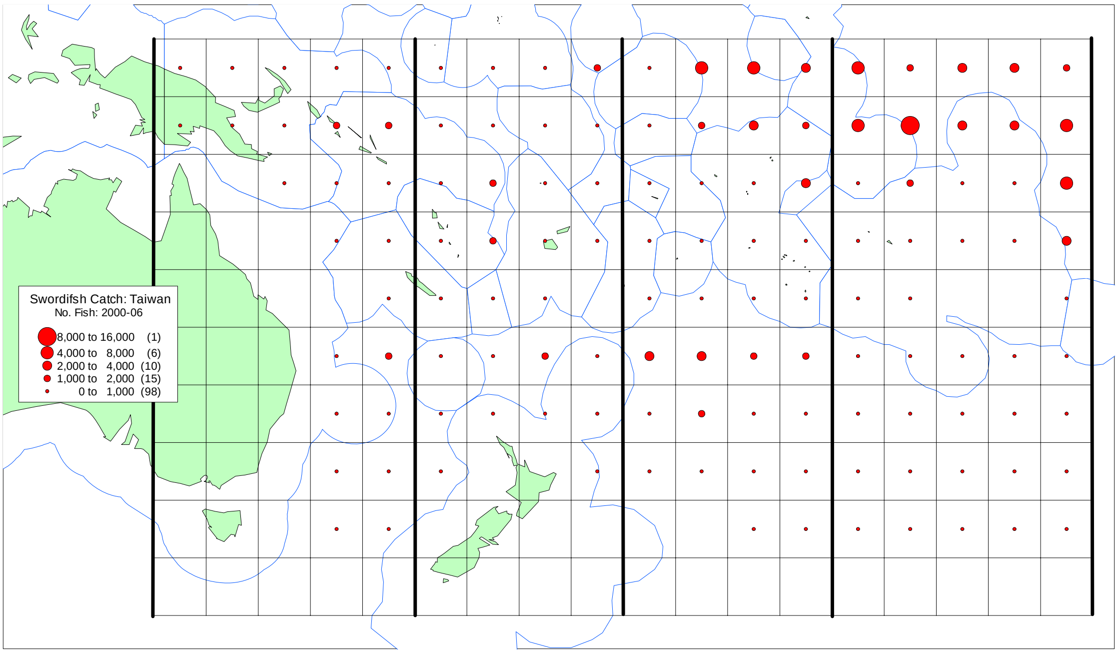
Map 2b. Distribution of New Zealand swordfish catch: 2000-06.



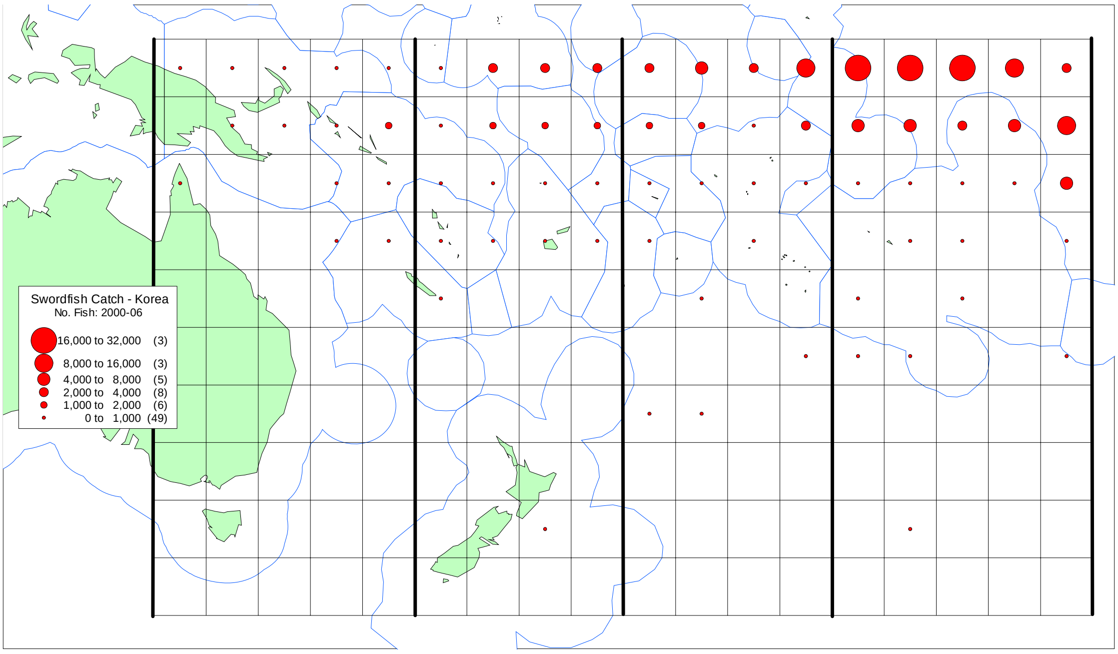
Map 2c. Distribution of Japanese swordfish catch: 2000-06.



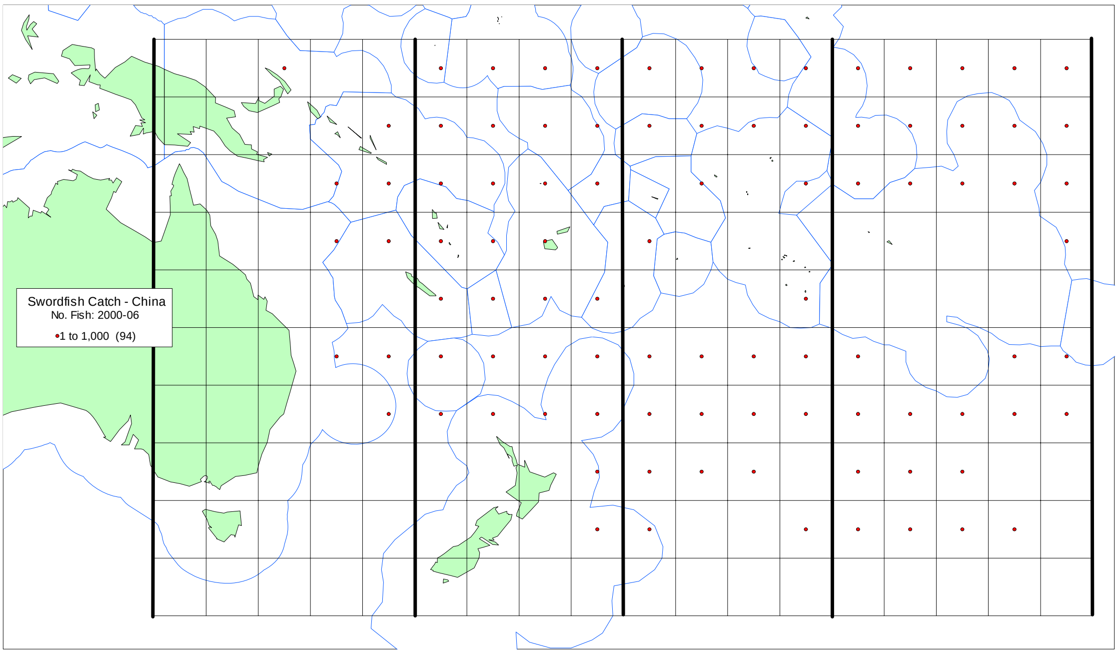
Map 2d. Distribution of Taiwanese swordfish catch: 2000-06.



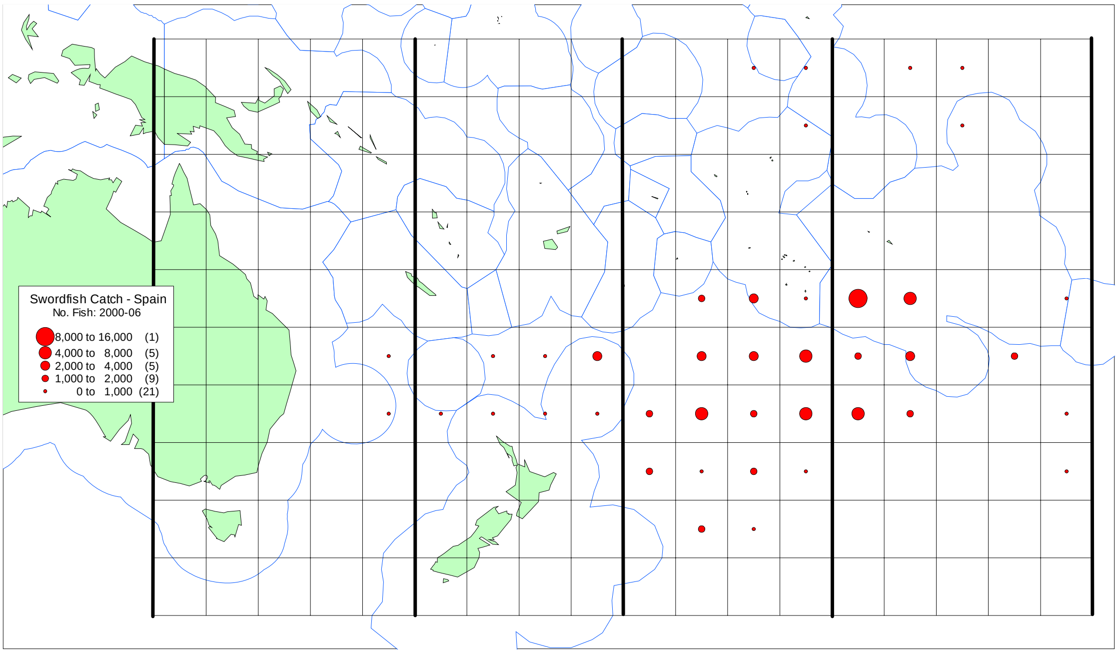
Map 2e. Distribution of Korean swordfish catch: 2000-06.



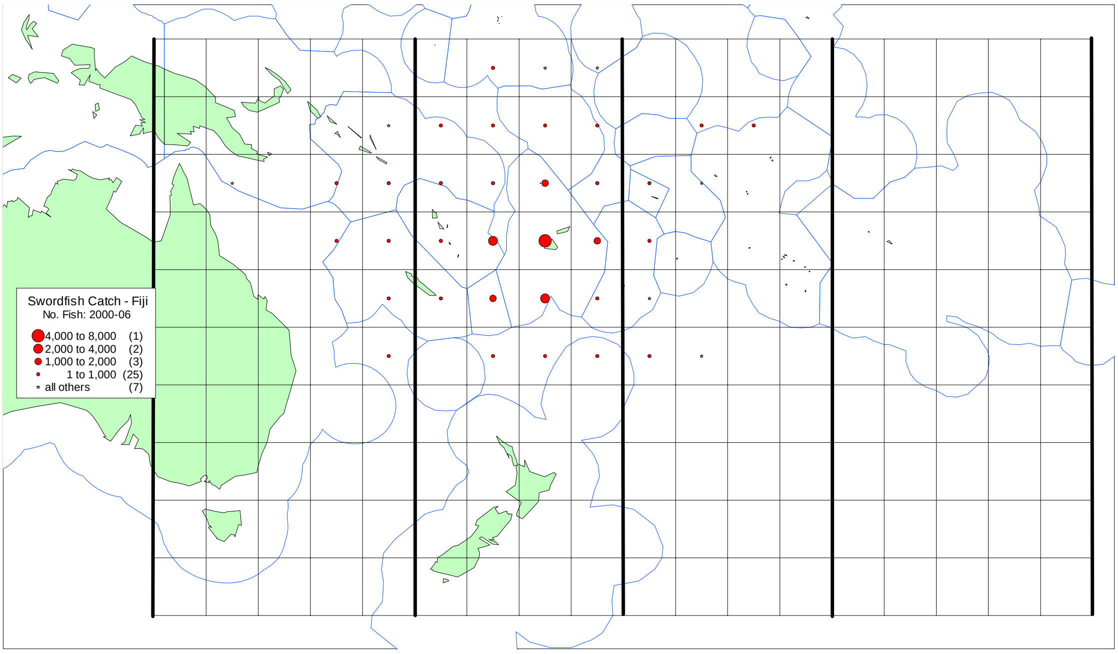
Map 2f. Distribution of Chinese swordfish catch: 2000-06.



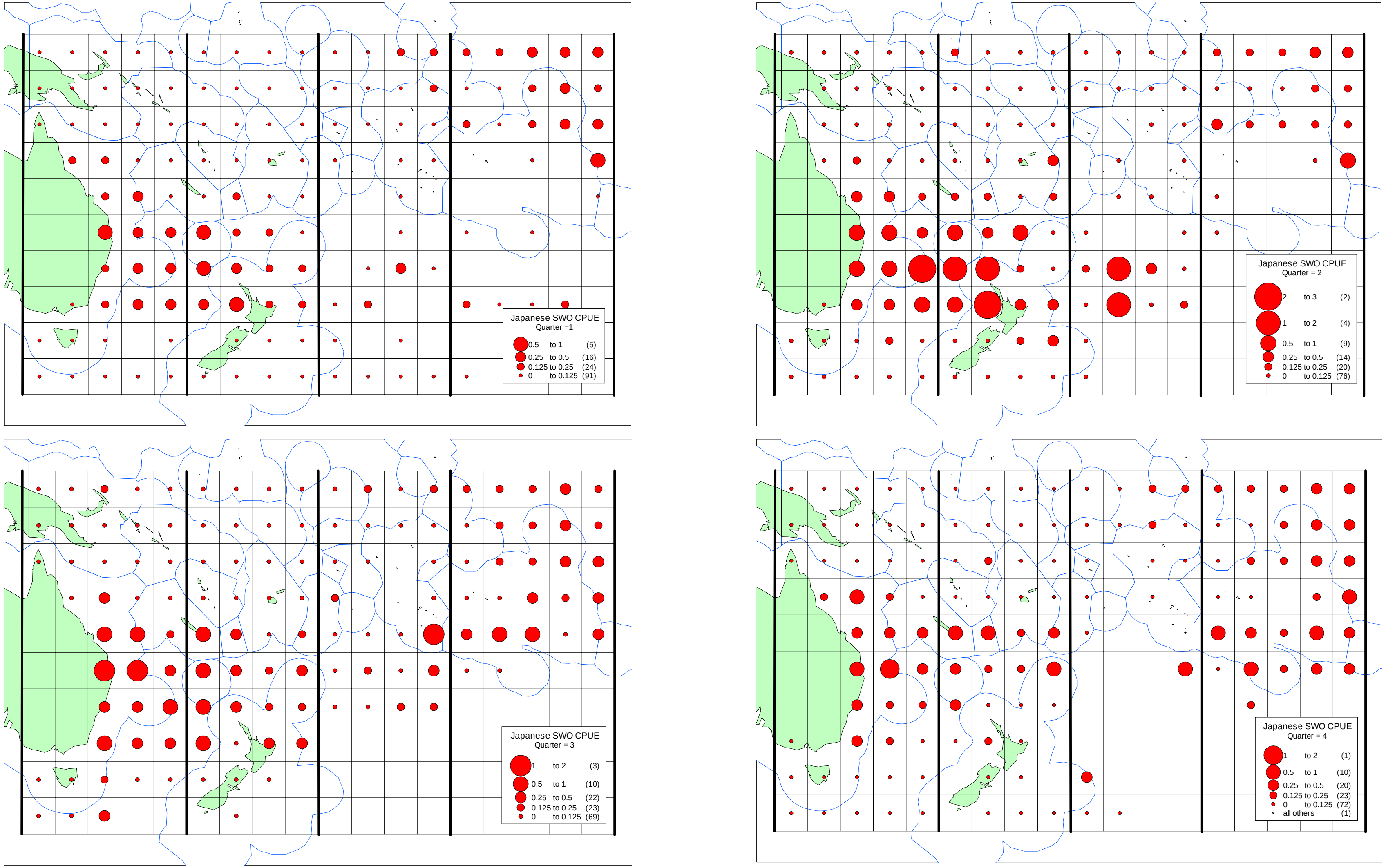
Map 2g. Distribution of Spain swordfish catch: 2000-06.



Map 2h. Distribution of Fijian swordfish catch: 2000-06.



Map 3. Spatial distribution of Japanese nominal swordfish CPUE, by quarter, aggregated over the years 1971-2005.



Attachment 3. Swordfish CPUE trends across the southern WCPO. WCPFC-SC4-2008/SA-IP-4.(33p.)

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SWORDFISH CPUE TRENDS ACROSS THE SOUTHERN WCPO

WCPFC-SC4-2008/SA-IP-4

Robert Campbell[1], Martin Unwin[2], Nick Davies[2], Naozumi Miyabe[3],

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[1] CSIRO Marine and Atmospheric Research, Hobart, Australia
[2] NIWA, New Zealand
[3] NRIFSF, Shimizu, Japan

Swordfish CPUE Trends across the Southern WCPO

Robert Campbell[1], Martin Unwin[2] and Nick Davies[2], Naozumi Miyabe[3]
1. *CSIRO Marine and Atmospheric Research, Australia*
2. *NIWA, New Zealand*
3. *NRIFSF, Japan*

July 2008

1. Introduction

Indices of stock abundance (or more correctly, resource availability) are an important input into most stock assessments. While fishery independent indices are preferred, in most assessments relating to high migratory species such as tunas and billfish such indices are usually not available due to practical issues of scale in undertaking the required surveys. As such, indices based on the catch and effort data obtained from the fleets catching these species are most commonly used. In particular, indices based on standardised catch–per-unit-effort (CPUE) are the most common indices used. In this paper a number of CPUE based indices relating to swordfish availability across the southern western-central Pacific Ocean (WCPO) are presented.

2. Standardised catch-rates - Australia

We use the data recorded in logbooks on catch and effort for the Australian Eastern Tuna and Billfish Fishery (ETBF) to calculate annual and quarterly time-series indexing swordfish availability to this fleet.

The ETBF has undergone several periods of development and associated changes in targeting practices since the advent of the logbook program in 1987. As a result, the consequence temporal and spatial heterogeneity of the fishery, and associated data limitations, influence the ability to formulate meaningful abundance indices.

2.1 *Temporal Limitations*

Since the inception of the logbook program in the ETBF in 1987, four different logbooks have been utilised – AL02, AL03, AL04 and AL05 (NB. AL = Australian Longline). The percentage of sets deployed in the ETBF each year covered by each of these logbooks is shown in Figure 3.1.

A range of different information on the nature of the fishing gears, baits and targeting practices associated with any single longline set has also been collected by these logbooks over the years. However, due to the fact that the types of information recorded in logbooks has changed over time, the amount and types of data available for standardizing catch rates has also changed over time. A listing of the main variables is shown in Table 3.1.

As most of the important standardising variables were not collected in the AL02 logbook, and several were missing from the AL03 logbook (which was only used for

Figure 3.1. Annual logbook coverage (as a percentage of sets) in the ETBF.

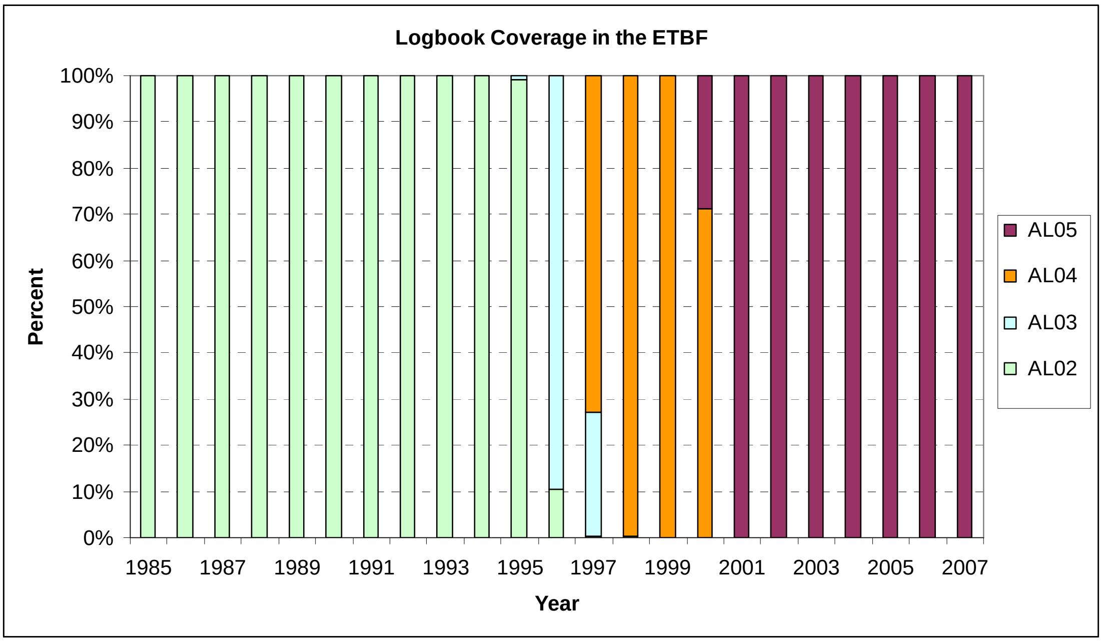


Table 3.1. List of information collected in each of the AL0x Logbooks useful for standardising CPUE.

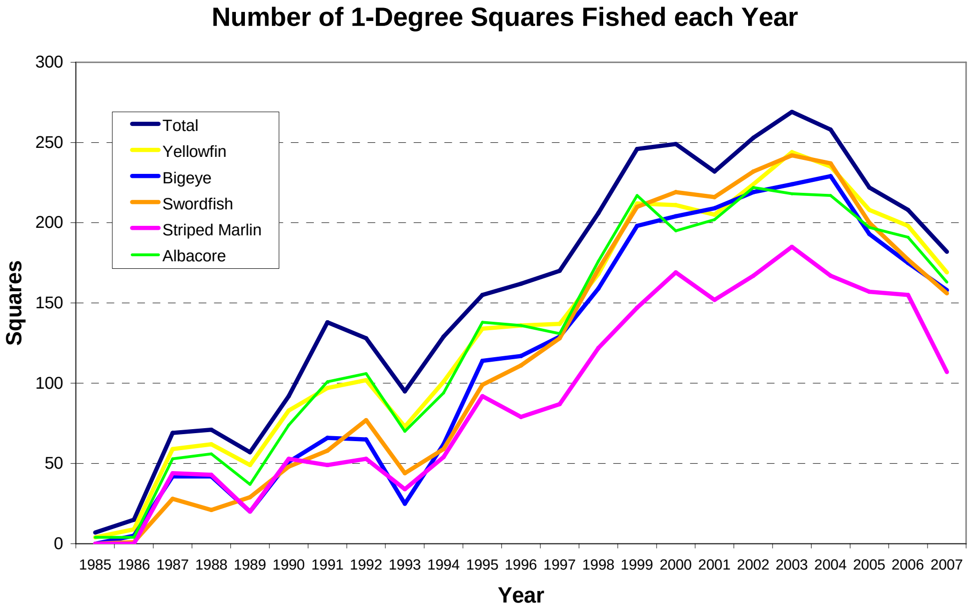
	AL02	AL03	AL04	AL05
Year	√	√	√	√
Quarter	√	√	√	√
Vessel	√	√	√	√
Hooks-per-basket	√	√	√	√
Start-time of set		√	√	√
Target Species		√	√	√
Bait-type			√	√
Number of hooks with light-sticks			√	√

a short period), all analyses outlined in this paper begin in 1997 and only makes use of the data collected in the AL04 and AL05 logbooks. (Note, as the year effect used in the standardisation corresponds to the financial year (1-July to 30 June) it is useful to note that 98.4% of sets during the second half of 1997 were covered by the AL04 logbook.)

2.2 *Spatial Limitations.*

The spatial extent of the ETBF can be usefully expressed by the number of 1x1-degreee squares of latitude and longitude fished each year and is shown in Figure 3.2. This clearly shows the spatial expansion of the fishery during the 1990s and early 2000s followed by a slight contraction in more recent years. The fishery reached its maximum extent in 2003 when 269 1x1-degree squares were fished. However, aggregated over all years, longline sets have been deployed in a total of 399 squares though many of these squares have been fished infrequently. Indeed, less than half (156) have been fished for at least 5 of the ten years between 1997 and 2006 and also have at least 5 sets deployed in any single year.

Figure 3.2. Number of 1-degree squares fished by longline vessels each year in the ETBF and the number of squares in which the five main target species were caught.



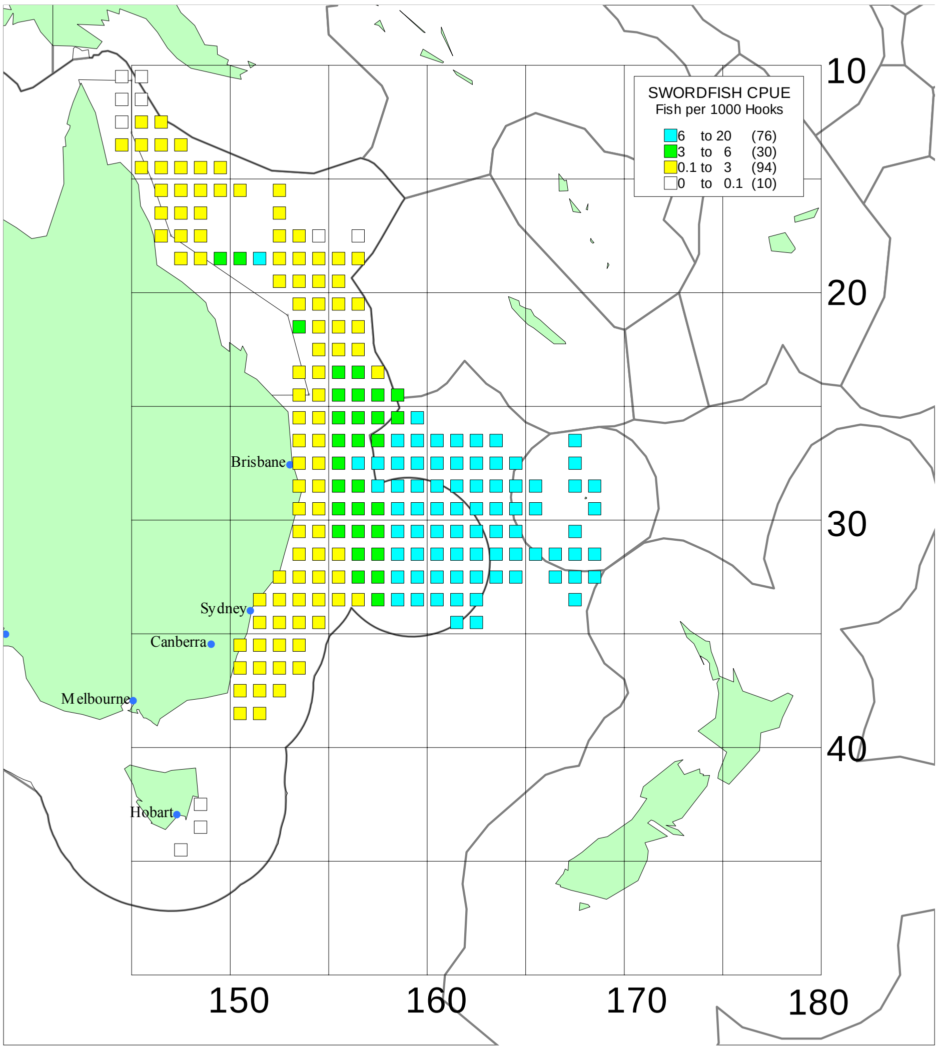
Due to the expansion of the fishery after 1997 the data coverage of many outer regions of the fishery is limited to a smaller number of years than the ten years between 1997 and 2006. This makes it difficult to estimate abundance indices at the beginning of the time series when these areas were not fished. In a similar manner, it is also difficult to estimate abundance indices in those areas which are no longer fished.

In deciding on the spatial limits to place on the data for use in the standardisations the spatial areas used in the GLM analysis were selected to match the spatial distribution of the catch rates for swordfish. In particular, the spatial distribution of nominal catch rates of swordfish within each 1-degree square (taken over the years 1997-2006 and only within 1-degree squares having greater than 4 sets over this period) is shown in Figure 3.3. Based on this distribution, three areas were identified based on combining adjacent squares with similar catch rates and only selecting consistently fished squares (each 1x1-square had to contain a least 30 fishing operations (fops) to be included). Each area for use in the GLM was defined as follows:

Area=1	Nfops>30 and cpe_swo>0.1 and cpe_swo<=3.0 latitude between -35 and -23 and longitude<157
Area =2	Nfops>30 and cpe_swo>3.0 and cpe_swo<=6.0 latitude between -35 and -23 and longitude>155
Area =3	Nfops>30 and cpe_swo>6.0 latitude between -35 and -23, longitude between 155 and 165

Of the 399 squares fishing across the entire ETBF, each area contains the following number of squares: Area 1 (33), Area 2 (27) and Area 3 (59).

Figure 3.3. Distribution of nominal swordfish CPUE (aggregated over the years 1997-2007) within 1x1-degree squares in the ETBF.



2.3 General Linear Models (GLMs)

A range of variables were available to standardize the CPUE. These variables, together with the model parameter names and category definitions, are listed in Table 3.2. The percentage of all fishing operations each year deploying various gear settings is displayed in Figures 3.4a-d. Most variables were fitted as categorical variables with a given range of values for each variable being associated with a discrete category (eg. the start times were categorized into six 4-hourly intervals of time). Only moon-phase was fitted as a continuous variable. The southern-oscillation-index variable was normalized based on the mean and standard deviation of the values across all sets included in the analysis, then categorized into one of the five categories depending on whether |z| was less than or greater than 0.3 or 1.0.

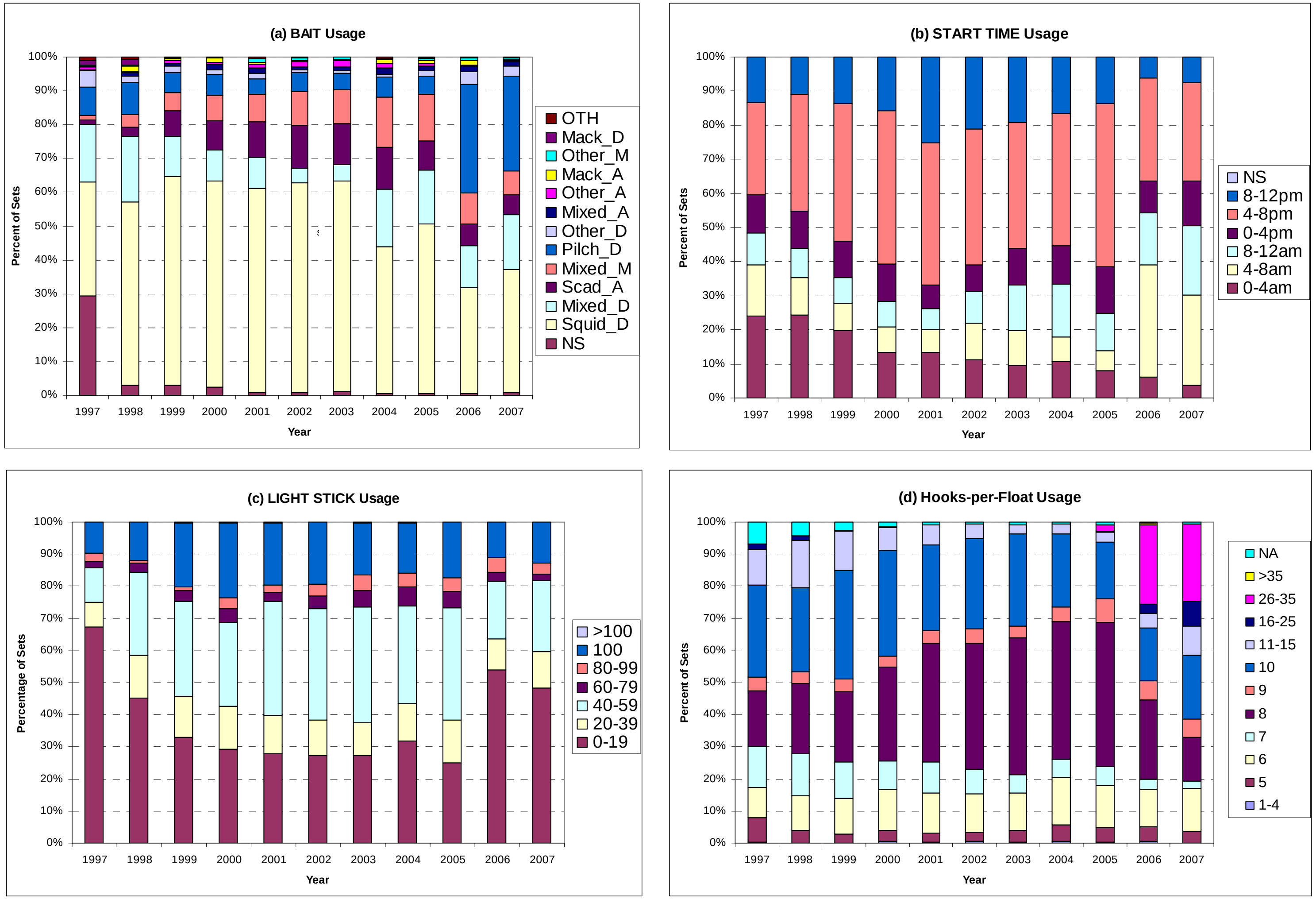
Several additional factors were also included in the analysis to help account for the influence of competitive factors between vessels on a daily and a monthly basis. These were defined as follows:

- The number of other vessels which fished in the same 1x1-degree / day strata. This was taken as a measure of the competition that day.

Table 3.2. Listing of variables, together with the model parameter names and category definitions, used to standardize CPUE.

Factor	Level	Category	Number of Sets
Year	1	1997	5147
	2	1998	6009
	3	1999	7513
	4	2000	7688
	5	2001	9294
	6	2002	9900
	7	2003	8553
	8	2004	7339
	9	2005	5772
	10	2006	4421
	11	2007	2435
Quarter	1	Jan-Mar	15908
	2	Apr-Jun	17393
	3	Jul-Sep	22381
	4	Oct-Dec	18389
Area Fished	1	Inshore	40390
	2	Middle	17490
	3	Offshore	16191
Start Time	1	before 4am	8455
	2	4am to 8am	6026
	3	8am to noon	5638
	4	noon to 4pm	6975
	5	4pm to 8pm	34488
	6	8pm to midnight	12489
Bait	1	squid, dead	47929
	2	yellowftail scad, alive	5252
	3	pilchard, dead	2676
	4	other, dead	1285
	5	other, alive	874
	6	mixed species, dead	498
	7		6853
	8		614
	9		7455
	10	mixed species, alive & dead	635
Hooks-per-Basket	1	HPB = 5 and below	2984
	2	6	9142
	3	7	6517
	4	8	29211
	5	9	3248
	6	10	14041
	7	HPB between 11 and 19	6449
	8	HPB between 20 and 40	2479
Hooks with Lights	1	0%	10940
	2	1 to 19 %	4212
	3	20 to 39 %	7556
	4	40 to 59 %	27996
	5	60 to 79 %	3797
	6	80 to 99 %	3259
	7	100%	16311
Southern Oscillation Index (standardised)	1	soi<-1sd	11108
	2	:-1sd<soi<-0.3sd	16928
	3	soi<abs(0.3sd)	17491
	4	0.3sd<soi<1sd	13935
	5	soi>1sd	14609
Moon-phase (days since full moon)	covariate	abs(cos(moon*3.14152/29))	74071
Number of other vessels fishing same 1-degree square on same day	1	0	29049
	2	1	17255
	3	2	10302
	4	3	6577
	5	4	3998
	6	5	2662
	7	6	1513
	8	7 or more	2715
Number of other vessels fishing same 1-degree square during same month	1	0 to 2	14829
	2	3 to 5	10858
	3	6 to 8	9523
	4	9 to 11	6986
	5	12 to 14	5819
	6	15 to 17	9681
	7	18 to 20	7586
	8	21 or more	8789
Total Sets			74071

Figure 3.4 Percentage of all fishing operations each year in the ETBF deploying various gear settings.



- The total effort (as measured by the total number of hooks) deployed by other vessels in the same 1x1-degree that month. This was taken as a measure of the competition that month.

Each variable was apportioned into a number of levels and the resulting factors fitted as categorical variables in the GLM.

Due to the inflated number of zero catch observations (30% of the 74,071 fops included in the analysis) it was considered more appropriate to standardise the CPUE data as a two stage process: the first stage being concerned with the pattern of occurrence of positive catches, and the second stage with the mean size of the positive catch rates. For both stages the means were modelled as linear combinations of the available standardising variables and then combined to give an overall mean abundance index.

A small example helps illustrate this approach. Consider a season for which there are n catch rate observations, C_i. The average catch rate can be expressed as follows:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} C_i = \frac{1}{n_S + n_F}\sum_{i=1}^{n_s} C_i = \frac{n_S}{n_S + n_F}\frac{1}{n_S}\sum_{i=1}^{n_s} C_i = p_S \mu_S$$

where n_S is the number of positive or successful catch rates obtained (C_i>0), n_F is the number of zero or failed catches (C_i =0), p_S is the proportion of positive catches and μ_S is the average of the positive catch rates. This result shows that the overall mean catch rate can be expressed as the combination of the parameters from the distributions used to model the probability of a successful catch and that used to model the non-zero catch rates. A similar approach was used in the estimation of egg production based on plankton surveys (Pennington 1983, Pennington and Berrien 1984) and for estimating indices of fish abundance based on aerial spotter surveys (Lo et al 1992).

Stage 1: Prob(positive catch)

The Binominal distribution is used to model the probability of a non-zero catch where we model each observation as either a success (C_i >0) of a failure (C_i =0), with the probability of either expressed as follows:

$$\Pr(C_i > 0) = p_S \qquad \text{and} \qquad \Pr(C_i = 0) = 1 - p_S$$

Associated with each observation is a vector of covariates or explanatory variables X_j thought likely to influence the probability of a positive catch. Furthermore, we assume that the dependence of p_S occurs through a linear combination $\eta = \sum \beta_j X_j$ of the explanatory variables. In order to ensure that $0 \leq p_S \leq 1$ we use the logit link function which takes the following form:

$$\eta = \log\left(\frac{p_S}{1 - p_S}\right)$$

The inverse of this relation gives the probability of a positive sighting as a function of the explanatory variables:

$$p_S = \frac{e^{\eta}}{1 + e^{\eta}} = \frac{\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}{1 + \exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + ...)}$$

The following model was then fitted to the data using the SAS GENMOD procedure:

MODEL p_S = *year*qtr* region + hpb + clights + bait +start_time +*

moon_phase + soi region + dvescat + mveseff*

/ dist=binomial link=logit

The standardised probability for a positive catch, p_S, was then calculated for each spatio-temporal strata (year, quarter and area) against a standard set of model factors.

Stage 2: Mean Size of Positive Catch Rate

Having fitted the above model to the probability of obtaining a positive catch, a separate model was fitted to the distribution of positive catch rates, μ_S. For this purpose a log-Gamma model was adopted, such that the μ_S was assumed to have a gamma distribution with a log link to the vector of covariates or explanatory variables X_j. The data fitted to the model were limited to those observations having a positive catch.

As before, the following model was then fitted to the data using the SAS GENMOD procedure:

MODEL μ_S= *year*qtr*region + hpb + lights + bait +start_time +*

moon_phase + soi region + dvesn + mvesn*

/ dist=gamma link=log

A standardised mean positive catch rate, μ_S, was then calculated for each spatio-temporal strata (year, quarter and region) against a standard set of model factors.

d) Abundance Index

The above models were fitted to each of the two data-sets defined previously and the results used to calculate a relative index of abundance, *I(year)*, by taking the average across all *NQ* quarters and then taking the area-weighted sum across all *NR* regions as follows:

$$I(year) = \sum_{region=1}^{NR} \left[\frac{Area_{region}}{NQ} \sum_{qtr=1}^{NQ} p_S(\text{year, qtr, region}) * \mu_S(\text{year, qtr, region}) \right]$$

where $Area_{region}$ is the spatial size of the individual regions. Finally, for ease of comparison across all models the index was "normalized" by dividing through the average index across all years (resulting in the average of the "normalized" index being equal to 1).

2.4 Selection of Data

The data selected for analysis satisfied the following criteria:

- The location of all selected sets was within one of the three spatial regions defined previously (this area is referred to as the GLM Area),
- The date of all selected sets was between 1 July 1997 to 30 December 2007 (i.e. the data for 1997 only includes the data for the final two quarters)
- All variables used in the models were available (i.e, associated number or hooks, number of hook-per-float, bait-type, number of light-sticks, start-set-time all non-null)

- The following outliners were removed: number of hooks≤100, number of hooks-per-float>40 and CPUE>50 fish per 1000 hooks.

2.5 Results

The resulting standardised CPUE index calculated after fitting the above models is compared with the nominal CPUE (total catch/total effort) across both the entire ETBF and within the GLM Area in Figure 3.5a (annual indices) and Figure 3.5b (quarterly indices). The relative effects of each level of the variables fitted to the Binomial model in Figure 3.6a and for the Gamma model in Figure 3.6b. Finally, the Type 3 statistics for each GLM model are displayed in Table 3.3.

2.6 Comparison with 2006 Spatial Structure and 2006 Assessment

The above model was re-run using the same spatial structure used in the previous 2006 assessment. In order to compare the result with the results of the CPUE standardisation undertaken for this 2006 assessment, the analysis was confined to the data within Areas 2, 3 and 5 used in this assessment. As these three areas are larger than the three areas used in the 2008 CPUE standardisation, the total number of records fitted to the model increased to 104, 040. A comparison of the quarterly standardised index for each of the two spatial structures is given in Figure 3.7. The standardised index used in the 2006 assessment is also shown for comparison.

Figure 3.7. Comparison of the quarterly standardised index for each of the two spatial structure described in the text, together with the standardised index used in the 2006 assessment.

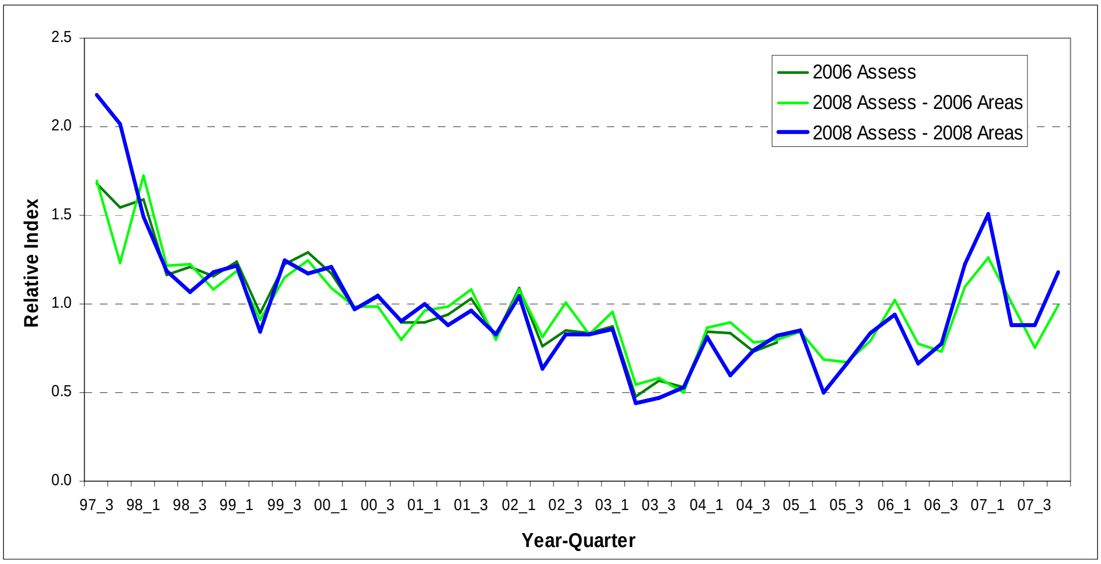


Figure 3.5a. Annual nominal and standardised CPUE indices.

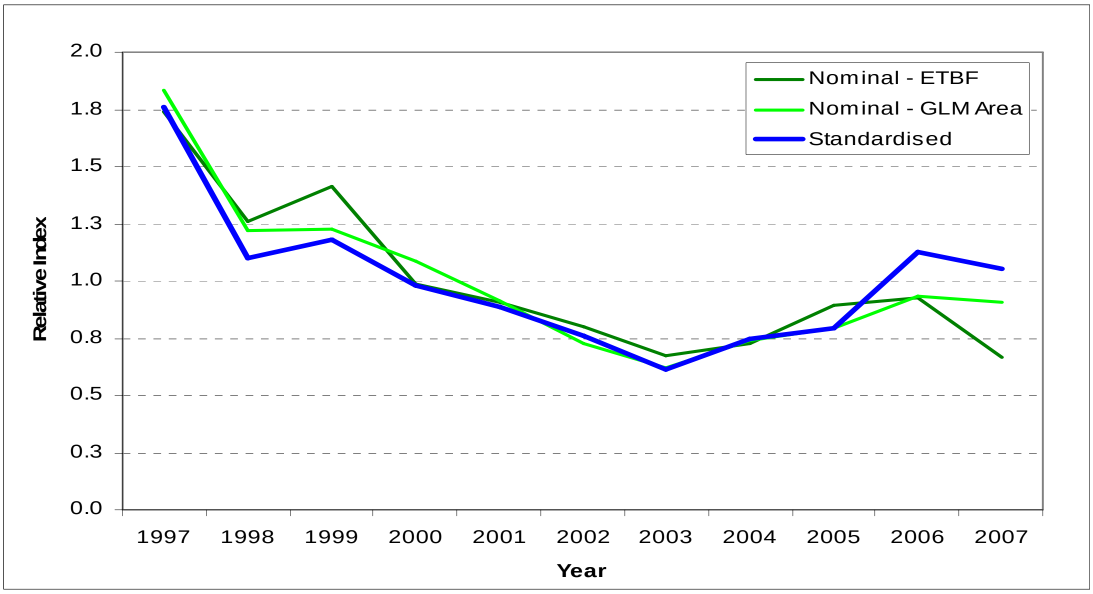


Figure 3.5b. Quarterly nominal and standardised CPUE indices.

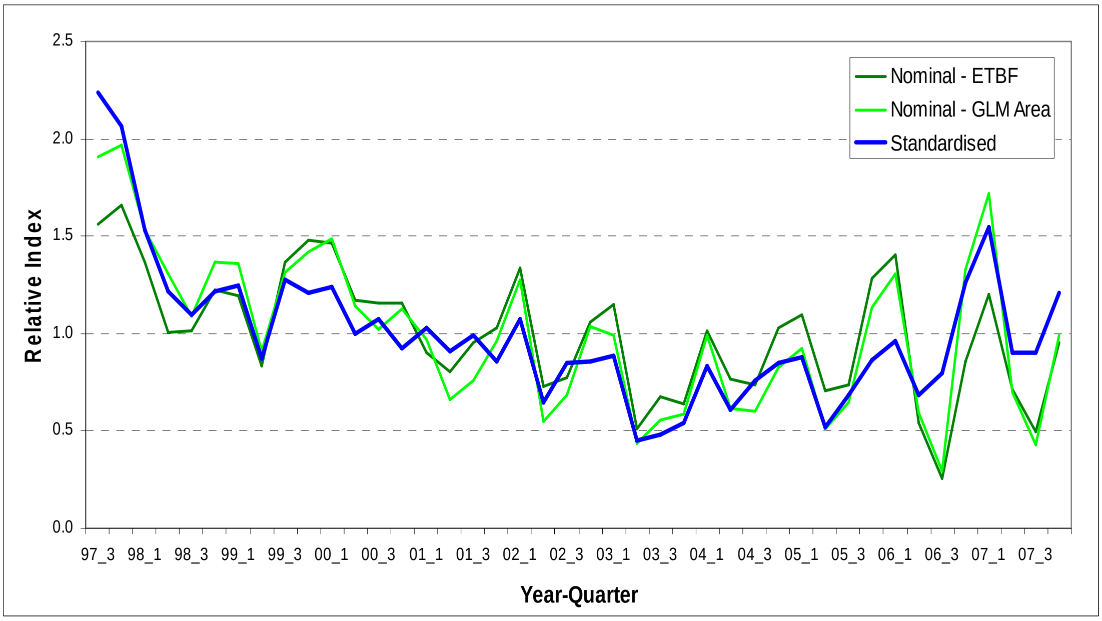


Table 3.3. Type 3 Statistics for each GLM model.

	Binominal Model			Gamma Model		
Fitted Variable	df	ChiSq	Pr>ChiSq	df	ChiSq	Pr>ChiSq
Year*Quarter*Region	123	2103.00	< 0.0001	123	7690.00	< 0.0001
Light-sticks	6	872.00	< 0.0001	6	1009.00	< 0.0001
Bait-type	9	259.00	< 0.0001	9	234.00	< 0.0001
Start Time	5	1838.00	< 0.0001	5	1263.00	< 0.0001
Hooks-per-basket	7	63.00	< 0.0001	7	775.00	< 0.0001
Daily vessel number	7	29.00	0.0001	7	30.00	< 0.0001
Monthly vessel effort	7	15.00	0.0268	7	76.00	< 0.0001
Area*SOI	12	36.00	0.0003	12	113.00	< 0.0001
MoonPhase	1	611.00	< 0.0001	1	1488.00	< 0.0001

Figure 3.6a. Relative effects of each variable fitted to the Binomial model of the probability of obtaining a swordfish catch. (Note: the standard level for each variable against which the effect of each other level is measured is that having no 95% confidence interval.)

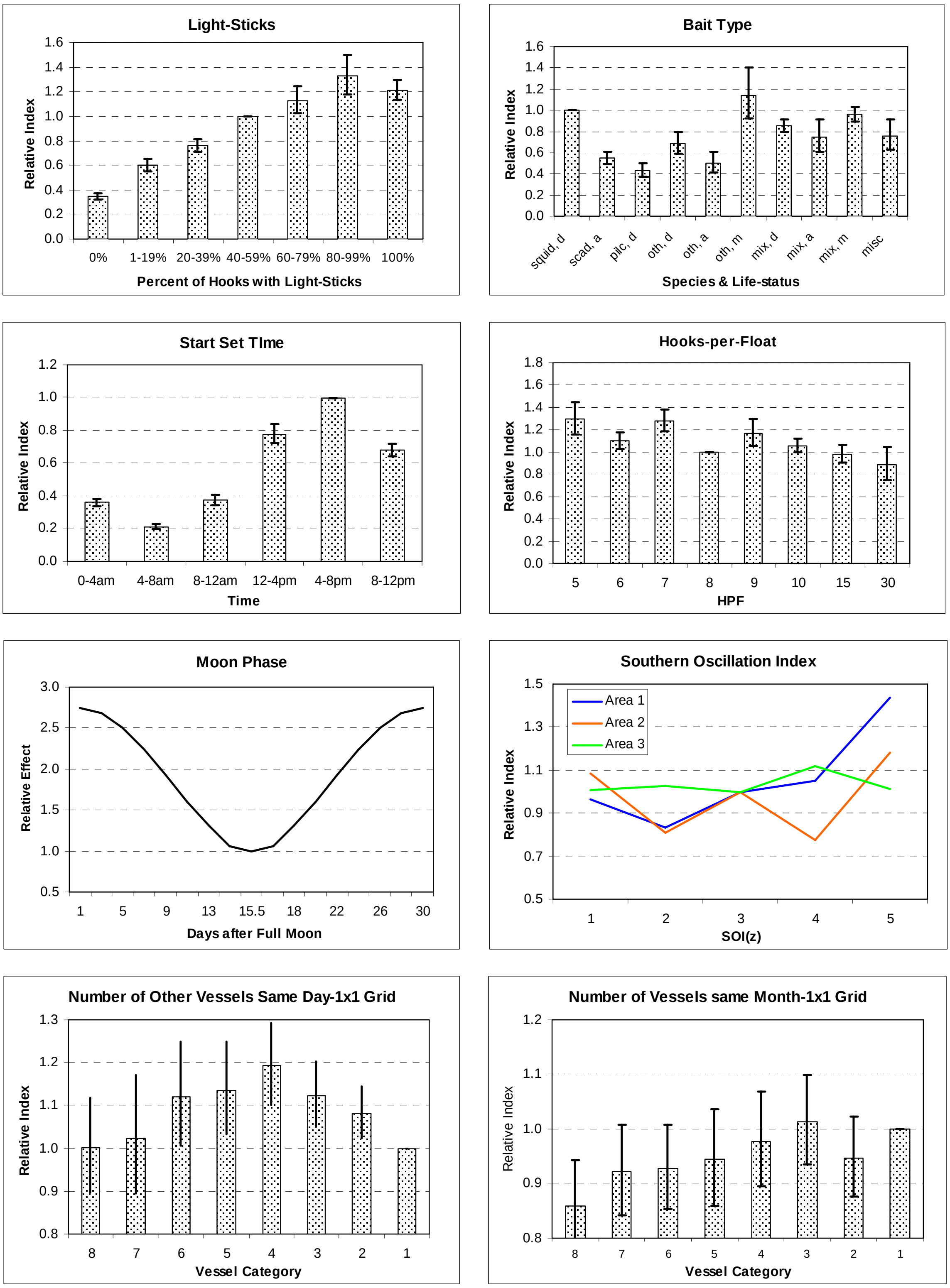
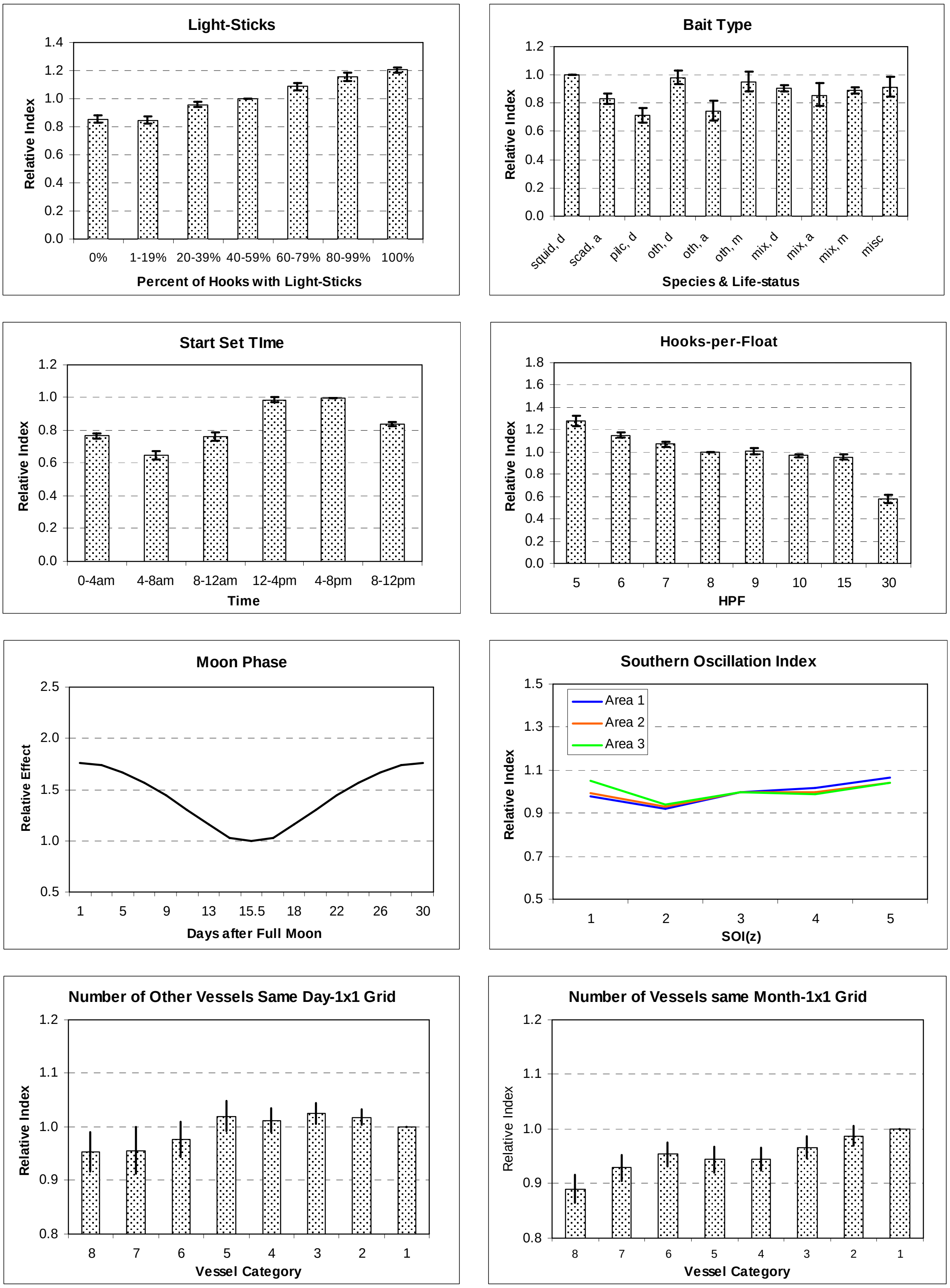


Figure 3.6b. Relative effects of each factor fitted to the Gamma model of the size of the swordfish catch given that a catch had been obtained. . (Note: the standard level for each variable against which the effect of each other level is measured is that having no 95% confidence interval.)



2.7 Standardised CPUE by Size Class

Individual weight data for swordfish caught and landed in the ETBF have been collected since mid-1997 and presently covers the ten financial years between 1997/98 and 2006/07. For this period information recorded in vessel logbooks indicates that a total of 311,888 swordfish were retained by longline vessels while during the same period 244,795 swordfish were sampled. This represents an average quarterly sampling proportion of 78.5%. Furthermore, the sampling proportion in all quarters over the period has been greater than 50 percent. As indicated by the high sampling rates, the data held are seen as being capable of representing the distributions of all size classes of swordfish caught in the fishery during this period. (For a comprehensive summary of these data, together with a number of time-series of indicators based on these data, see Campbell et al, 2007).

A histogram of the dressed weight of all swordfish measured is shown in Figure 3.8. Based on this distribution of weights three size categories were defined:

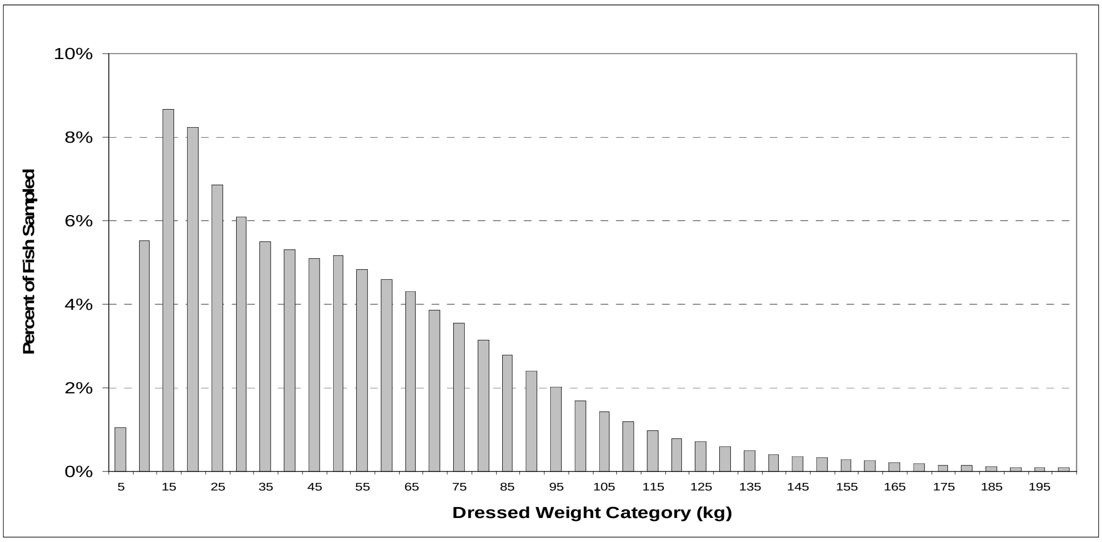
Small Fish	fish within the initial 25-percentile of the weight distribution
Large Fish	fish within the final 20-percentile of the weight distribution
Prime Fish	fish within the middle 50-55-percentile of the weight distribution

Cut-off weights were converted to whole weights using a dressed-to-whole conversion factor of 0.726 and these whole weights were rounded to the nearest five kilograms. The final selected cut-off weights, and the proportion of measured fish within each size category, are given in Table 3.4.

Table 3.4. Cut-off weights used to define three size-classes of swordfish.

Category	Dressed Weights	Whole Weights	Sample Proportion
Small Fish	< 21.78	< 30	26.2%
Prime Fish	21.78 < wt < 72.60	30.0 < wt < 100	50.9%
Large Fish	> 72.60	> 100	22.9%

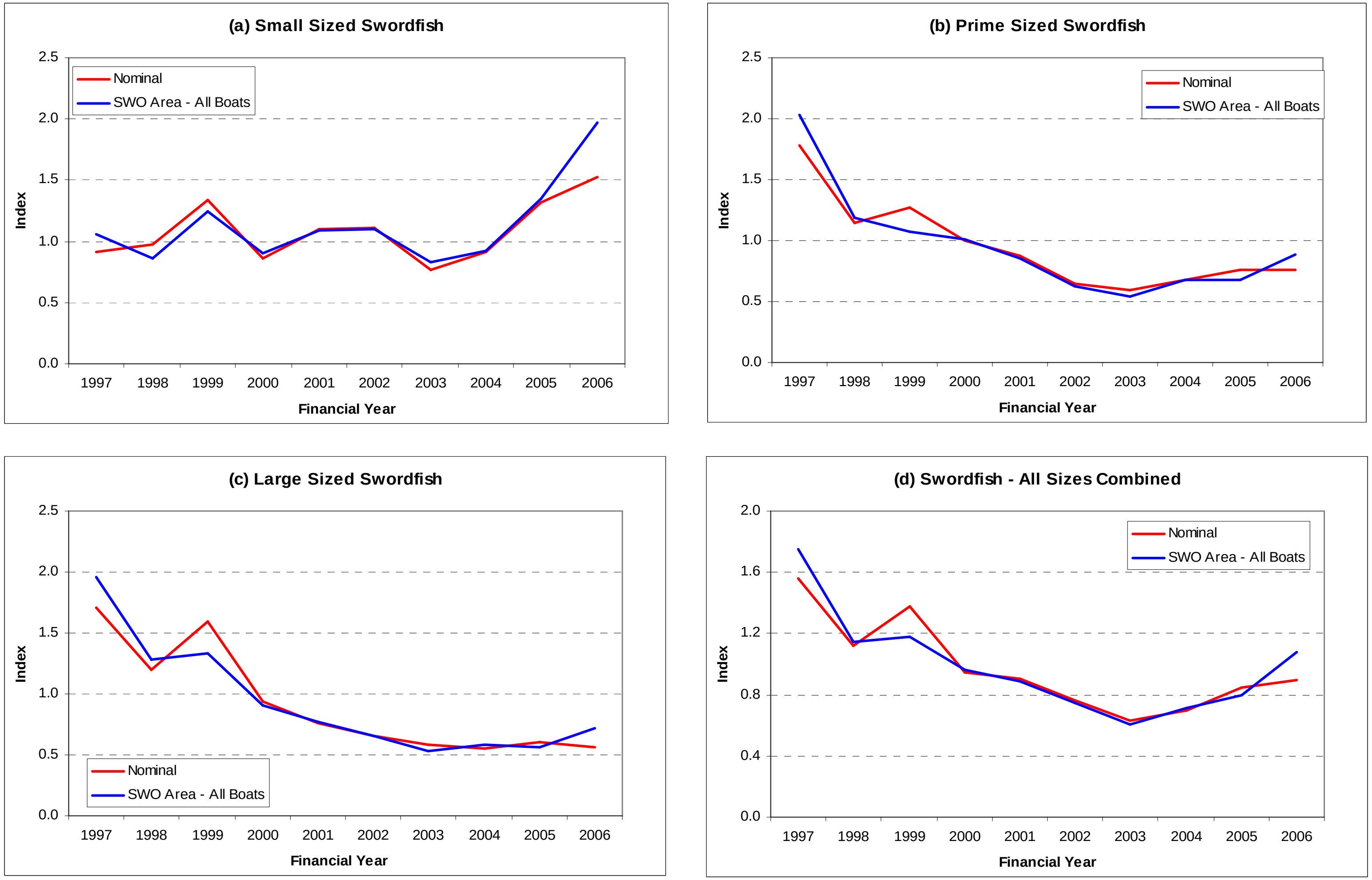
Figure 3.8. Histogram of dressed weights (to the nearest kilogram) of all swordfish sampled in the ETBF.



Using these cut-off weights the proportion of small, prime and large fish in each size sample was then calculated. As the sampling is undertaken at the processor upon unloading the fish at the end of a trip, each sample is related to the fish caught across all sets deployed during that trip. The catch associated with each individual longline fishing operation (held within a separate logbook data-set) was apportioned into each of the three size categories by matching the catch data for all sets within a trip with the associated processor data for the related trip. For those trips for which there were no processor data (or matching vessel identifier in the size data-set), the catches were apportioned using the average proportion of small, prime and large fish caught aggregated across all processor-related sets within an associated spatial-temporal strata. A hierarchical approach was used such that larger spatial-temporal strata were chosen to ensure that the number of sets in each stratum was at least 100.

Using the catch apportioned by size class, the standardised CPUE for each size class was determined by fitting the models described above. The resulting standardised indices for each size class (and the combined total) are shown in Figures 3.9a-d. (Note, these analyses include data between 1 July 1997 and 30 June 2007 only, covering the 1997 to 2006 financial years).

Figure 3.9a-d. Relative indices of (a) small, (b) prime, (c) large and (d) combined broadbill swordfish availability based on nominal and standardised CPUE.



3. Standardised catch-rates – New Zealand

Under the management system in place before 2004 the New Zealand tuna longline fleet was not allowed to target swordfish, though significant quantities (up to 1000 tonnes) of swordfish were still landed. Since the inclusion of swordfish in the Quota Management System (QMS) in October 2004, tuna longliners may target their operations for capturing swordfish. In this section, updated descriptive catch-effort analyses of the commercial fishery for swordfish within the New Zealand EEZ are summarised, and standardised CPUE indices are presented.

3.1 New Zealand catch-effort data

The New Zealand tuna longline fishery includes both chartered foreign vessels and domestically owned and operated vessels. Foreign vessels have fished in New Zealand waters since the late 1970s and were virtually the only longliners operating during the 1980s, but the domestic longline fishery has developed rapidly since 1990 and now accounts for about 90% of targeted longline effort (Griggs & Richardson 2005). Annual effort is currently about 10 million hooks (Ayers et al. 2004), having increased from about 5 million hooks in the mid 1990s with the entry of many new vessels into the fishery since 1998. The main target species are bigeye tuna (*Thunnus obesus*) and southern bluefin tuna (*T. maccoyii*), but about 10% of sets target albacore (*T. alalunga*) or other predominantly bycatch species such as yellowfin tuna (*T. albacares*) and (since October 2004) swordfish.

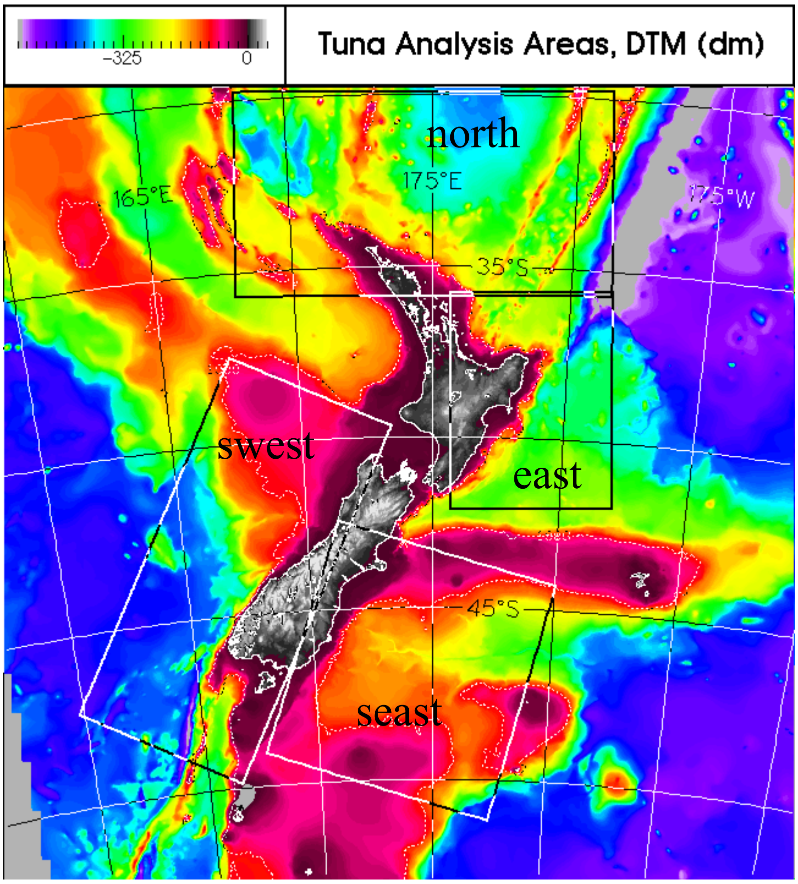
Catch and effort data for the longline fishery were derived from the Tuna Longline Catch Effort Return (TLCER) statistical forms provided by each fisher to MFish. Data recorded for each longline operation includes location and effort (e.g., date, position, set and haul times, number of hooks, line length), and catches of all QMS species. The data extracted for the analysis covered 1 January 1993 to 30 September 2007.

The descriptive analysis presented here mainly focuses on those longlining activities (operational variables) which potentially influence swordfish CPUE, including several which have become available only in the last 2-3 years. These include light stick usage and bait type, which were added to the standard statistical fishing forms used to record longline catches in 2003, and information on direct targeting of swordfish (as an alternative to the main target species, bigeye and southern bluefin), which became legal in October 2004. Thus, the updated datasets add considerably to our understanding of swordfish targeting practices, particularly with regard to trends (such as increased light stick usage).

3.2 Spatial disaggregation

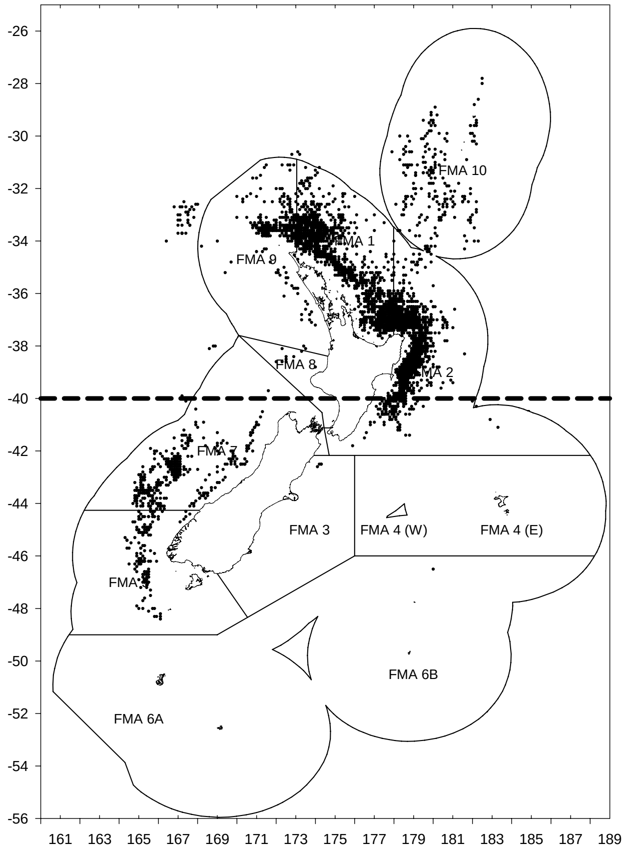
The data analysed were limited to longline sets for which the starting location lay within one of four areas which were the focus of the remote sensing programme (Figure 4.1). Conforming to these areas permitted linking each catch-effort record (each longline event) to environmental variables monitored at the event location. These four areas collectively include most of the three main longlining grounds in which significant swordfish bycatch occurs (North Cape, East Cape, and Fiordland/West Coast). For the purposes of this report, we partitioned the fishery into two disjoint areas, denoted as Area NE (the union of areas north and east), and Area SW (area swest), respectively. Sets occurring in Area seast, where swordfish are caught only rarely, were excluded from our analyses.

Figure 4.1: New Zealand and surrounding waters, showing areas used for analysis of longline CPUE within the New Zealand EEZ from 1993 to 2005. Areas used in this report are denoted Area NE (north + east), and Area SW (swest). Bathymetry ranges from 0 to 6000 m, with the 1000 m isobath shown by a dashed white line.



The Areas NE and SW correspond well with the areas defined for the spatial disaggregation of swordfish length frequency data in New Zealand, i.e., NORTH and SOUTH. These two areas also broadly correspond to the 40º S boundary that separates the CENTRAL and SOUTHERN zones under the fisheries definitions assumed in the 2008 regional swordfish assessment model (Figure 4.2). This boundary mostly subdivides the spatial distribution of the tuna longline operations in the NORTH and SOUTH areas as is evident from its position relative to the longline set locations in 2005–06 and 2006–07 (Figure 4.2).

Figure 4.2: Fisheries management areas (FMAs) making up the New Zealand EEZ, showing tuna longline set locations for 2005–06 and 2006-07 with the 40˚ S boundary used for fishery definitions in the 2008 regional swordfish assessment model.



3.3 Descriptive summaries

Total longlining effort in the NORTH Area fell steadily from 2005 to 2007, continuing a trend that has been apparent since 2002 (Table 4.1). This trend was evident in terms of number of sets, numbers of individual vessels, and total number of hooks. Average effort from 2005-2007 was only 37%-40% of the average over the three peak years of 2001-2003, and 55% - 63% of that in 2004. Despite this decline, swordfish landings were relatively high particularly in 2006 and 2007. These contrasting trends resulted in unusually high mean nominal CPUE for these two years (3.12 and 2.94 SWO per thousand hooks, respectively, in 2006 and 2007), with the 2006 figure representing an 82% increase over the highest previously recorded annual mean (1.71 in 1998; Table 4.1, Figure 4.3). Swordfish catches in the SOUTH Area totalled 313 fish over the three years from 2005 to 2007 (Table 4.2), representing 1.6% of the total landings reported in this study.

Catch and effort data were summarised with respect to tuna longline operational variables that are likely to influence swordfish catch rates. These included: target species, operation location (area), light stick usage and bait type.

Table 4.1: Summary statistics for swordfish taken by longliners in the New Zealand EEZ, 1993-2007, by analysis Area (NORTH and SOUTH). Figures shown for each Area are the total number of longline sets (Sets); number of vessels involved (Vessels); total effort (thousands of hooks); number of swordfish landed (SWO); and mean CPUE (SWO per thousand hooks).

	NORTH Area					SOUTH Area				
Year	**Sets**	**Vessels**	**Hooks (x 1000)**	**SWO**	**CPUE**	**Sets**	**Vessels**	**Hooks (x 1000)**	**SWO**	**CPUE**
1993	1 162	36	1 482	898	0.61	751	21	2 265	19	0.01
1994	1 326	44	1 115	862	0.78	363	17	909	5	0.01
1995	1 654	54	1 427	780	0.54	872	28	1 642	46	0.05
1996	1 390	54	1 177	1 207	1.07	224	15	265	49	0.22
1997	1 458	51	1 295	1 515	1.16	299	7	856	33	0.04
1998	2 406	67	2 393	3 799	1.71	210	7	625	57	0.08
1999	4 059	77	4 250	5 989	1.53	323	6	997	290	0.29
2000	4 924	98	5 422	8 955	1.69	301	8	901	207	0.25
2001	6 225	122	7 198	11 848	1.67	272	10	733	155	0.32
2002	6 683	139	7 881	10 613	1.36	491	27	1 004	178	0.27
2003	6 035	121	7 584	8 415	1.18	468	16	1 220	104	0.14
2004	3 989	91	4 630	6 962	1.52	750	35	1 620	218	0.24
2005	2 733	55	3 073	4 218	1.48	237	10	538	163	0.66
2006	2 671	52	2 911	8 847	3.12	274	7	663	117	0.40
2007	2 127	42	2 338	6 143	2.94	325	7	1 112	33	0.03

Figure 4.3: Annual longline effort (total hooks), annual catch of swordfish (SWO), and mean CPUE for swordfish in Area NE, 1993 to 2007.

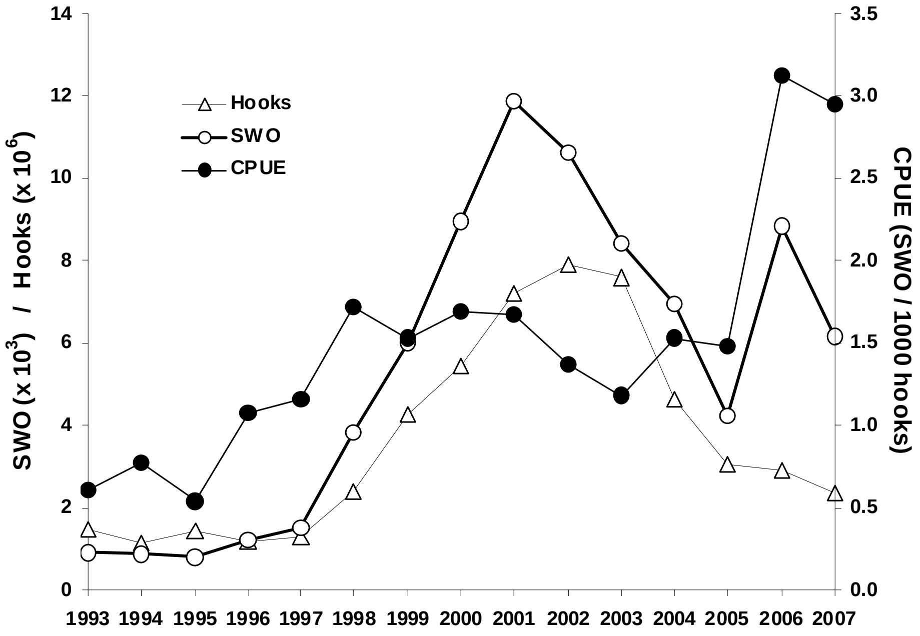


Table 4.2: Fishing effort in the NORTH Area (number of longline sets) by year and target species, 1993-2007. SWO targeting has been permissible since 2005.

Year	BIG	STN	ALB	OTH	SWO	Total
1993	790 (68.0%)	347 (29.9%)	9 (0.8%)	16 (1.4%)	-	1 162
1994	1 058 (79.8%)	163 (12.3%)	89 (6.7%)	16 (1.2%)	-	1 326
1995	1 275 (77.1%)	119 (7.2%)	209 (12.6%)	51 (3.1%)	-	1 654
1996	1 035 (74.5%)	197 (14.2%)	133 (9.6%)	25 (1.8%)	-	1 390
1997	1 111 (76.2%)	180 (12.3%)	127 (8.7%)	40 (2.7%)	-	1 458
1998	1 738 (72.2%)	225 (9.4%)	412 (17.1%)	31 (1.3%)	-	2 406
1999	3 148 (77.6%)	353 (8.7%)	492 (12.1%)	66 (1.6%)	-	4 059
2000	4 009 (81.4%)	484 (9.8%)	375 (7.6%)	56 (1.1%)	-	4 924
2001	4 905 (78.8%)	709 (11.4%)	434 (7.0%)	177 (2.8%)	-	6 225
2002	4 736 (70.9%)	1 169 (17.5%)	636 (9.5%)	142 (2.1%)	-	6 683
2003	3 431 (56.9%)	1 693 (28.1%)	793 (13.1%)	118 (2.0%)	-	6 035
2004	2 471 (61.9%)	1 064 (26.7%)	322 (8.1%)	132 (3.3%)	-	3 989
2005	1 594 (58.3%)	829 (30.3%)	120 (4.4%)	88 (3.2%)	102 (3.7%)	2 733
2006	1 637 (61.3%)	747 (28.0%)	60 (2.2%)	26 (1.0%)	201 (7.5%)	2 671
2007	1 268 (59.6%)	624 (29.3%)	16 (0.8%)	41 (1.9%)	178 (8.4%)	2 127

Table 4.3: Mean nominal catch per unit effort (swordfish per 1000 hooks) in NORTH Area by year and target species, 1993-2007. Swordfish targeting has been permissible since 2005.

Year	BIG	STN	ALB	OTH	SWO
1993	0.68	0.47	0.53	0.25	-
1994	0.89	0.33	0.30	0.54	-
1995	0.60	0.32	0.34	0.35	-
1996	1.11	0.82	0.80	2.71	-
1997	1.02	1.86	1.38	1.07	-
1998	1.61	2.31	1.88	0.94	-
1999	1.46	1.79	1.81	1.26	-
2000	1.50	2.26	2.86	2.15	-
2001	1.61	1.92	1.85	1.86	-
2002	1.32	1.33	1.68	1.71	-
2003	1.24	1.02	1.17	1.65	-
2004	1.56	1.29	1.95	1.82	-
2005	1.57	0.92	1.47	1.55	4.56
2006	3.10	1.81	1.82	5.46	8.21
2007	2.96	1.14	3.80	2.96	9.02

There has been increased targetting for swordfish since 2005 when this practice became legal following the introduction of swordfish to the NZ QMS (Table 4.2). Concurrent with this increase, there has been decreased targeting for albacore. Nominal CPUE is strongly related to target species, with operations targeting swordfish have around 100% higher catch rates than those targeting tunas (Table 4.3). Increases in CPUE are evident in 2007 over operations targeting swordfish, bigeye and albacore tuna, with the increase for swordfish target operations being substantial.

Swordfish catch rates were calculated for operations in the Fisheries Management Areas (FMAs) areas within the NORTH Area, shown in Figure 4.2. Catch rates differed between FMAs, with those in the Kermadec Islands area being up to 200% higher (Table 4.4). The number of operations in this area have increased markedly since 2004, from 4 to 80 longline sets. Although this is considerably lower effort in terms of sets the higher catch rates result in larger catches. It is evident from length frequency samples taken from trips in the Kermadecs Islands that catch size compositions differ from those in concurrent trips elsewhere in the NORTH area (Figure 4.4).

Table 4.4. Annual effort (number of longline sets) and mean swordfish CPUE in NORTH Area by year and Fisheries Management Area (FMA), 1993-2007.

	Number of longline sets				CPUE (SWO per 1000 hooks)			
Year	FMA1	FMA2	FMA9	FMA10	FMA1	FMA2	FMA9	FMA10
1993	705	381	18	25	0.65	0.54	0.52	0.66
1994	1 074	193	34	16	0.73	0.98	1.27	0.62
1995	1 320	278	19	28	0.50	0.70	0.56	0.59
1996	795	578	14	0	1.12	0.98	1.77	-
1997	1 027	396	33	0	0.99	1.54	1.82	-
1998	1 616	642	145	0	1.21	2.88	2.16	-
1999	2 854	1 012	149	39	1.00	2.79	1.65	6.66
2000	2 674	1 621	519	53	1.11	2.69	1.41	3.03
2001	3 189	2 075	799	109	1.34	2.42	0.97	1.72
2002	3 266	2 742	572	86	1.02	1.75	1.43	1.57
2003	1 658	3 685	642	40	1.14	1.24	0.78	3.18
2004	1 178	2 422	381	4	1.44	1.61	1.24	5.33
2005	1 147	1 188	382	13	1.37	1.28	2.32	3.28
2006	1 129	1 292	165	78	2.67	3.26	2.02	9.52
2007	725	1 158	164	80	2.62	2.78	3.35	7.34

Figure 4.4: Catch length compositions of landings of swordfish taken from the Kermadec Islands (Kerm) and other parts of the NORTH Area (non-Kerm) in the five quarters since 2006 quarter 3.

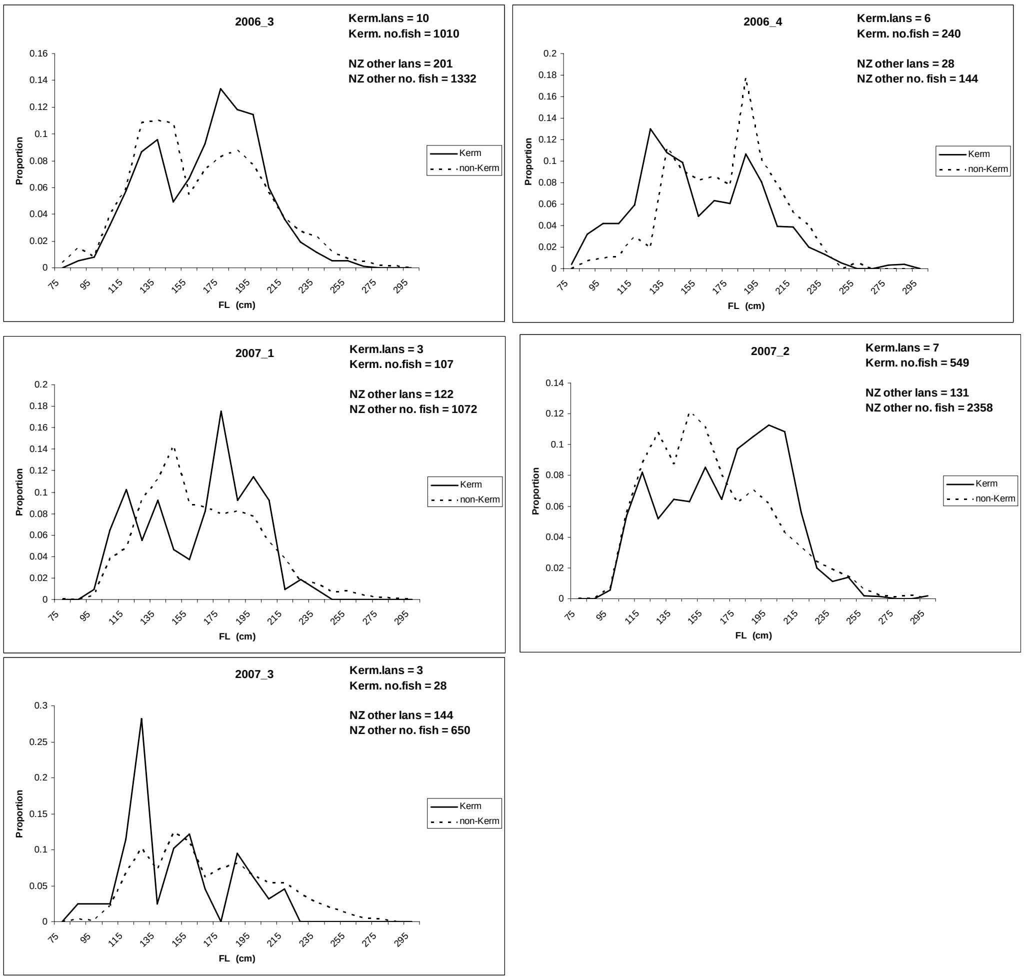


Table 4.5. Fishing effort in NORTH Area (number of longline sets) by light stick usage (light sticks per 1000 hooks) and year, 2003-2007, and by target species. Round and square brackets for light stick usage ranges denote open and closed intervals, respectively.

Light stick usage	2003	2004	2005	2006	2007
0	906 (22.0%)	427 (11.7%)	371 (14.2%)	156 (6.0%)	141 (6.8%)
(0-50]	634 (15.4%)	405 (11.1%)	115 (4.4%)	97 (3.8%)	57 (2.8%)
(50-100]	1 130 (27.4%)	1 121 (30.6%)	542 (20.7%)	407 (15.7%)	237 (11.5%)
(100-200]	1 008 (24.4%)	961 (26.2%)	657 (25.1%)	713 (27.6%)	527 (25.6%)
(200-500]	430 (10.4%)	714 (19.5%)	866 (33.1%)	1051 (40.6%)	904 (43.9%)
>500	16 (0.4%)	34 (0.9%)	63 (2.4%)	162 (6.3%)	193 (9.4%)
Total	4 124	3 662	2 614	2 586	2 059

Group	BIG	STN	ALB	OTH	SWO
0	1 014 (11.8%)	737 (15.9%)	213 (20.5%)	37 (11.7%)	0 (0.0%)
(0-50]	790 (9.2%)	374 (8.1%)	120 (11.6%)	24 (7.6%)	2 (0.4%)
(50-100]	2 127 (24.8%)	1 051 (22.7%)	198 (19.1%)	36 (11.4%)	25 (5.2%)
(100-200]	2 165 (25.2%)	1 301 (28.1%)	274 (26.4%)	74 (23.4%)	53 (11.1%)
(200-500]	2 333 (27.2%)	1 058 (22.9%)	227 (21.9%)	132 (41.8%)	215 (44.9%)
>500	163 (1.9%)	103 (2.2%)	5 (0.5%)	13 (4.1%)	184 (38.4%)
Total	8 592	4 624	1 037	316	479

Table 4.6 Fishing effort in NORTH Area (number of longline sets) by preferred bait type (% of hooks baited with squid) and year, 2003-2007, and by target species. Round and square brackets for % of squid bait ranges denote open and closed intervals, respectively.

% squid bait	2003	2004	2005	2006	2007
[0-25]	202 (4.6%)	86 (2.2%)	105 (3.9%)	41 (1.5%)	21 (1.0%)
(25-50]	2 517 (57.7%)	2 388 (60.5%)	1 421 (52.9%)	777 (29.3%)	459 (21.8%)
(50-75]	647 (14.8%)	459 (11.6%)	593 (22.1%)	711 (26.8%)	446 (21.2%)
(75-100]	996 (22.8%)	1 012 (25.7%)	569 (21.2%)	1 121 (42.3%)	1 182 (56.1%)
Total	4 362	3 945	2 688	2 650	2 108

% squid bait	BIG	STN	ALB	OTH	SWO
[0-25]	222 (2.4%)	78 (1.6%)	145 (13.6%)	5 (1.5%)	5 (1.1%)
(25-50]	4 940 (54.2%)	1 978 (41.4%)	482 (45.0%)	116 (35.4%)	48 (10.1%)
(50-75]	1 710 (18.8%)	891 (18.7%)	182 (17.0%)	33 (10.1%)	40 (8.4%)
(75-100]	2 234 (24.5%)	1 830 (38.3%)	261 (24.4%)	174 (53.0%)	383 (80.5%)
Total	9 106	4 777	1 070	328	476

The use of light sticks on tuna longlines has increased considerably since 2003 (Table 4.5), such that the percentage of operations using more than 200 light sticks per 1000 hooks has increased from less than 11% in 2003 to more than 53% in 2007. On average between 2003 and 2007, more than 83% of operations targeting swordfish employed more than 200 light sticks per 1000 hooks, compared to less than 30% for operations targeting bigeye, southern bluefin and albacore tunas. This indicates light stick usage as an important operational variable for swordfish catch rates.

Table 4.7 Number of sets and mean CPUE vs. light stick usage, hooks per basket, and usage of squid bait for longline sets targeting swordfish in Area NE, 2005-2007.

	Number of sets			Mean CPUE		
Light sticks	2005	2006	2007	2005	2006	2007
0	0 (0.0%)	0 (0.0%)	0 (0.0%)	-	-	-
(0-50]	0 (0.0%)	2 (1.0%)	0 (0.0%)	-	5.43	-
(50-100]	13 (12.9%)	3 (1.5%)	9 (5.1%)	4.18	1.61	5.40
(100-200]	15 (14.9%)	23 (11.4%)	15 (8.5%)	2.63	7.87	6.88
(200-500]	66 (65.3%)	101 (50.2%)	48 (27.1%)	4.30	8.93	8.23
>500	7 (6.9%)	72 (35.8%)	105 (59.3%)	12.23	7.66	10.08
Total	101	201	177			
Hooks per basket	2005	2006	2007	2005	2006	2007
[5-10]	28 (27.7%)	29 (14.4%)	26 (14.7%)	3.35	7.09	6.51
(10-15]	51 (50.5%)	74 (36.8%)	32 (18.1%)	3.68	7.33	8.23
(15-20]	17 (16.8%)	36 (17.9%)	16 (9%)	7.34	13.59	7.85
(20-25]	0 (0%)	5 (2.5%)	0 (0%)	NA	7.71	-
>25	5 (5%)	57 (28.4%)	103 (58.2%)	11.32	6.56	10.16
Total	101	201	177			
% squid bait	2005	2006	2007	2005	2006	2007
[0-25]	1 (1.0%)	0 (0.0%)	4 (2.2%)	8.90	-	5.80
(25-50]	28 (27.5%)	13 (6.5%)	7 (3.9%)	3.85	2.88	5.40
(50-75]	19 (18.6%)	14 (7.0%)	8 (4.5%)	3.17	3.72	6.20
(75-100]	54 (52.9%)	174 (86.6%)	159 (89.3%)	5.34	8.97	9.40
Total	102	201	178			

Similarly, the percentage of tuna longline operations using squid baits on more than 50% of hooks has increased from 37.6% in 2003 to 77.3% in 2007 (Table 4.6). Squid bait usage is an important operation variable influencing swordfish catch rates given that nearly 90% of operations targeting swordfish use squid more than 50% of the time.

A comparison of mean nominal CPUE by the operational variables: light stick usage, bait type and hooks per basket, over the period that these variables have been reported (2005 to 2007), indicates positive relationships (Table 4.7). In most years, generally higher catch rates are obtained with higher usage of light sticks and squid baits.

3.3 Standardised indices

A set of core vessels which accounted for the majority of the swordfish catch was selected for undertaking the CPUE analyses and the time series was limited to the first quarter of 1998 to the third quarter of 2007. Core vessels were identified on the basis of their fishing activity over the 10 years from 1998 to 2007, inclusive. For each individual vessel, counts were made of the number of years during they made at least one longline set within the study area during the period 1998-2007 (N9807) and the two years from 2006 to 2007 (N0607). Core vessels were those for which N9807 >= 6 and N0607 = 2.

All analyses were undertaken using a Generalised Additive Model (GAM) to which a large number of environmental variables in addition to the standard operational variables were fitted. The final predictor set consisted of the following five factors and thirteen covariates:

Factors:

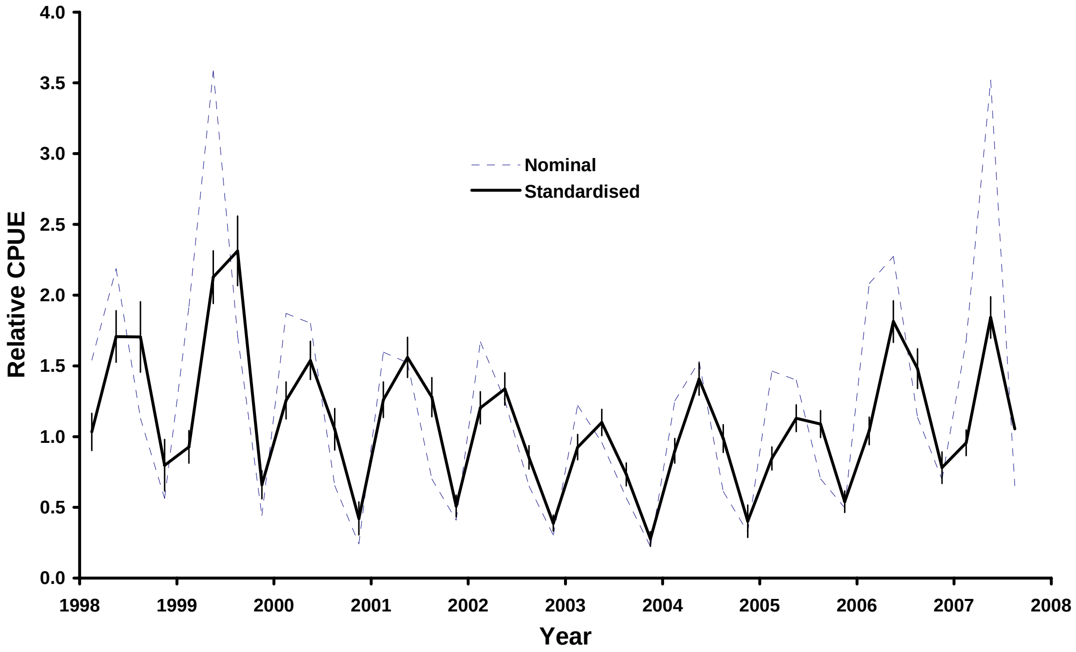
- Year × Quarter interaction (39 levels)
- Vessel size (small and large, based on mean longline length; 2 levels)
- Vessel experience (E = experienced, N = not experienced; 2 levels)
- Target species (albacore, bigeye, southern bluefin, other; 4 levels)

Covariates:

- Latitude
- Longitude
- Depth (metres)
- Depth standard deviation (metres)
- Number of sets within 50 km during previous 10 days
- Soak time measured from start of set to start of haul (hours)
- Moon phase
- Day length (hours)
- Hour at start of set
- Number of hooks per basket
- Night fraction
- Mean SST (°C)
- SST anomaly (°C)

A comparison of the resulting standardised CPUE index with the corresponding nominal CPUE is shown in Figure 4.5.

Figure 4.5 Comparison of the quarterly nominal and standardised CPUE indices for the New Zealand domestic longline fleet. Standard errors are shown for the standardised time-series.



3.4 Discussion

The main points evident from the descriptive analyses are:

1. High nominal CPUE in 2006 and 2007, largely irrespective of target species;
2. Increased targeting of SWO in 2006 and 2007

3. SWO targeting mainly along shelf, but also extends well out towards Kermadecs;
4. Clear signals re CPUE vs. light stick usage and bait type;

These features must be considered in combination with historical events in the management of the swordfish fishery. Notably, that prior to its introduction to the QMS in 2004, targeting for swordfish was not legal, and was therefore not reported. The operational variables – light stick usage and bait type – have been reported by fishers on logbooks since 2005. Consequently, the three operational variables influencing swordfish catch rates are available for only part of the catch effort time series (1993 to 2007).

Despite the declining effort, swordfish landings in the NORTH Area increased markedly in 2006 and 2007, with nominal CPUE (3.12 swordfish per thousand hooks) close to double the previous record. This appears to be partly related to an increase in the proportion of vessels targeting swordfish, for which nominal CPUE was up to three times higher than for other species, but swordfish CPUE was also relatively high for vessels targeting bigeye and southern bluefin tunas. Other factors clearly associated with increased swordfish CPUE are light stick usage and the percentage of hooks set with squid bait (rather than fish bait), both of which have increased markedly in recent years irrespective of target species. Two features suggest another factor potentially affecting swordfish CPUE - heterogeneity in the population in the NORTH Area. Firstly, the marked difference in the size composition of swordfish in catches from the Kermadec Islands, compared with elsewhere in the NORTH Area. Secondly, the higher CPUE observed in catches from the Kermadec Islands area (FMA10).

It has yet to be established whether the increase in swordfish CPUE since 2005 reflects increased availability, increased targeting efficiency, or a combination of both. Either way, the fishery appears to be changing significantly. Calculation of standardised CPUE indices for the fishery aims to describe the relationships between swordfish CPUE and operational variables, but is likely to be confounded by the lack of data for bait type and light stick usage prior to 2003, and the legalisation of swordfish targeting in 2005. Strategies must be developed for modelling CPUE over the full fifteen year time series despite the absence of complete data on these potentially highly significant predictors.

4. Standardised catch-rates – Japan

Unlike the Australian and New Zealand fleets, whose fishing operations are mainly confined to regions close to home ports, the spatial coverage of fishing operations for distant water fishing nations is much more extensive and, as such, provides the opportunity to generate indices of resource availability based on standardised CPUE across several areas of the southern WCPO. Japanese fleets have recorded the number of hook-per-baskets for their associated longline fishing operations since 1975 and for the previous assessment undertaken in 2006 this data was used to generate a standardised CPUE index for swordfish within the SW Pacific. A similar set of analyses was undertaken for this assessment within each of the four regions used in the 2008 assessment. The data used for these analyses consisted of the Japanese longline catch and effort data aggregated at a 1x1-degree level of latitude and longitude and stratified by the number of hook-per-basket (HPB). This data is located at the National Research Institute for Far Seas Fisheries in Shimizu, Japan.

Within each of the four assessment areas across the southern WCPO, the analysis was limited to those zones where (i) there was a sufficient time-series of catch and effort data , and (ii) the overall CPUE was sufficiently high (relative to other zones). This eliminated all but the following areas and zones:

1) Area 1, Central zone (Area 1C)
2) Area 2, Central zone (Area 2C)
3) Area 3, Northern zone (Area 3N)
4) Area 4, Northern zone (Area 4N)

The time-series of annual effort and catch of swordfish (number of fish) for each area is provided in Figure 3.1. It is evident that there has been a significant decline in Japanese fishing effort in most areas since the early-mid 1990s and this may have a bearing on the ability to maintain sufficient spatial coverage in order to obtain a meaningful index across each area. In particular, there was little or no fishing in Area 3N from the late 1980s to the mod-1990s and as such these years were excluded from the analysis. The analysis for this area was also limited to the second and third quarters.

Within each of the above four regions, the following GLM was fitted to the data:

MODEL Catch= Year*Quarter + Quarter*Area + HPBcat* Area

Distribution=negative-binominal

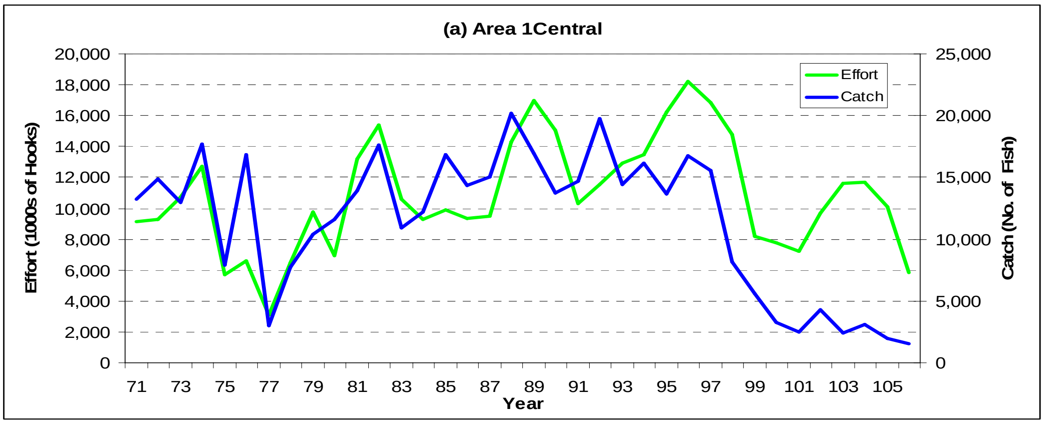
Link=*log*

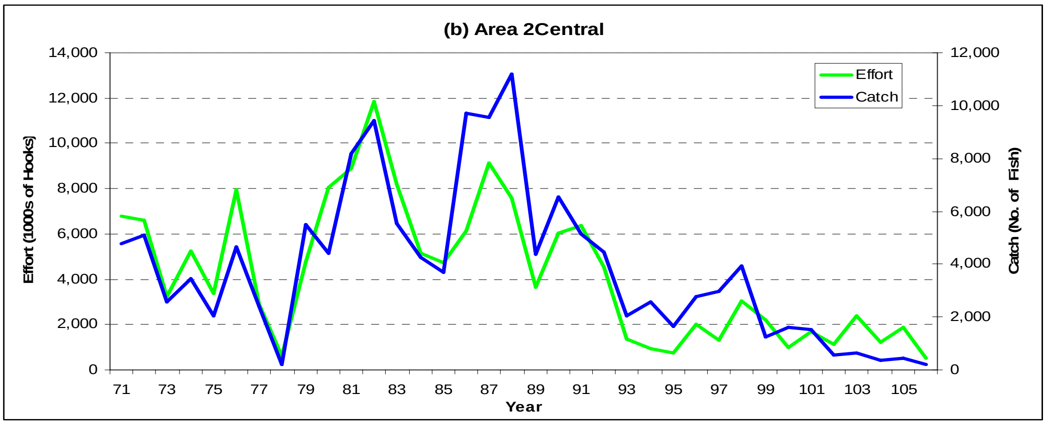
Offset=*log*(*Effort*)

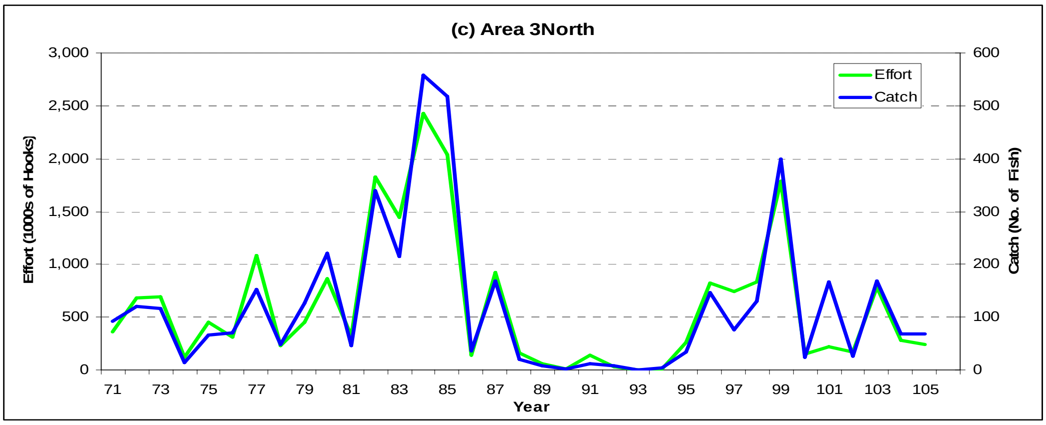
where the number of observations and the fitted values for each categorical variable in each region are as follows:

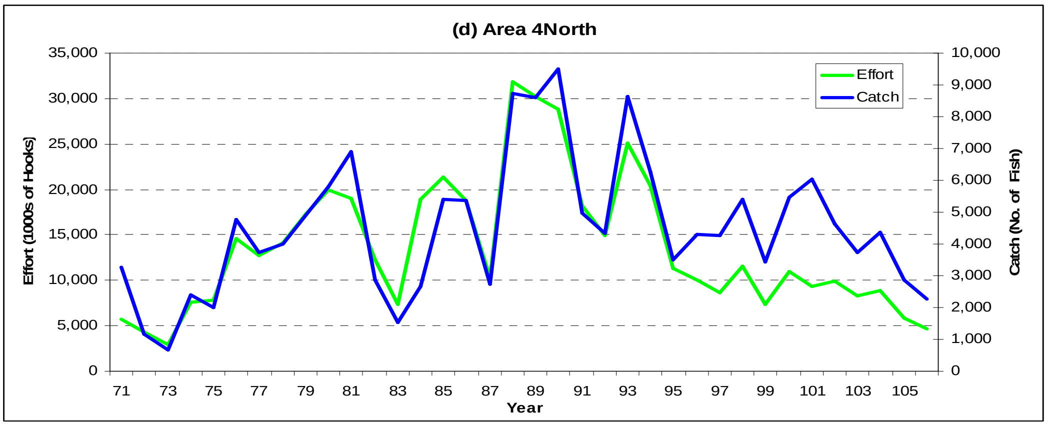
Area 1C	*Year*	36 levels	1971 – to 2006
(N=24,737)	*Quarter*	4 levels	1, 2, 3, 4
	Area	5 levels	refer to Figure 3.2
	HPBcat	6 levels	refer to Table 3.1
Area 2C	*Year*	36 levels	1971 – to 2006
(N=9,183)	Quarter	4 levels	1, 2, 3, 4
	Area	3 levels	refer to Figure 3.2
	HPBcat	6 levels	refer to Table 3.1
Area 3N	*Year*	29 levels	1971 – to 1988, 1996 - 2006
(N=3,349)	*Quarter*	2 levels	3, 4
	Area	4 levels	refer to Figure 3.2
	HPBcat	7 levels	refer to Table 3.1
Area 4N	*Year*	36 levels	1971 – to 2006
(N=61,318)	*Quarter*	4 levels	1, 2, 3, 4
	Area	5 levels	refer to Figure 3.2
	HPBcat	8 levels	refer to Table 3.1

Figure 3.1. Annual time-series of Japanese effort and catch of swordfish within the four main areas of the southern WCPO.


(a) Area 1Central


(b) Area 2Central


(c) Area 3North


(d) Area 4North

Within each area, the sub-area structure used in the GLM was based on combing 5x5-degree areas with similar nominal CPUE calculated over all years, while the HPB categories were chosen to ensure a reasonable number of observations within each category.

Table 3.1 Hook-per-Basket categories used in the GLM analyses for each region.

Areas 1C and Area 2C		Areas 3N and Area 4N	
HPB category	HPB values	HPB category	HPB values
5	≤ 5	6	≤ 6
6	6	8	7 – 8
7	7	10	9 – 10
8	8	12	11 – 12
10	9 - 10	14	13 – 14
15	> 10	16	15 – 16
		18	17 – 18
		20	>18

Figure 3.2 Schematic representation of each area indicating the sub-area structure used in the GLMs.

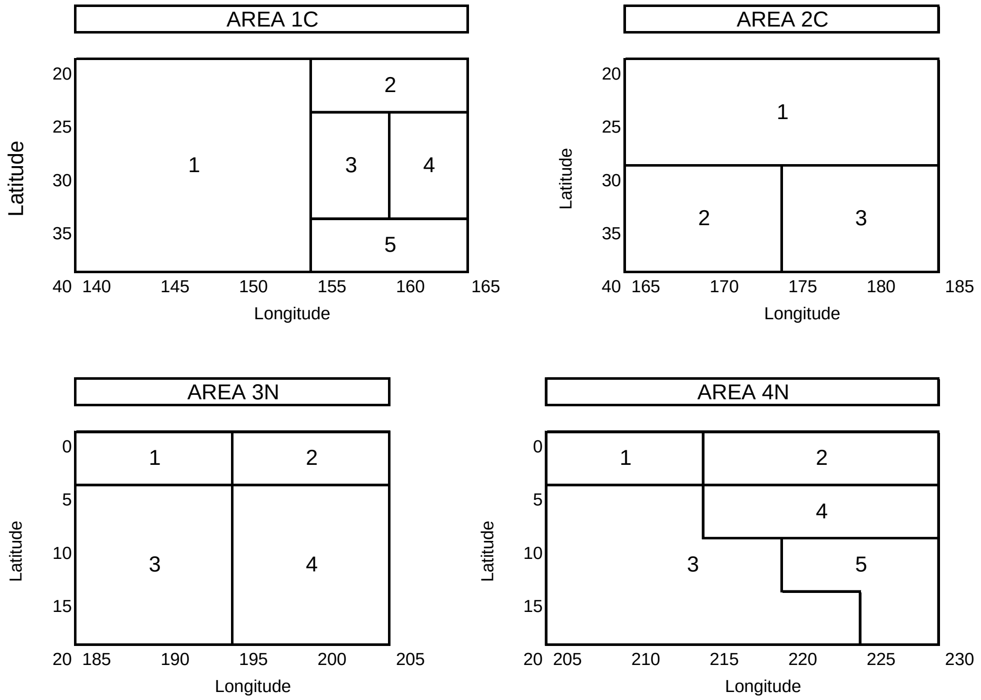
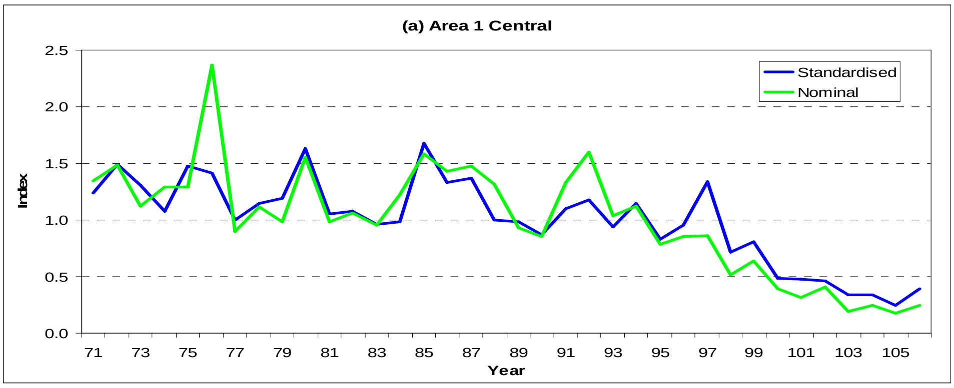


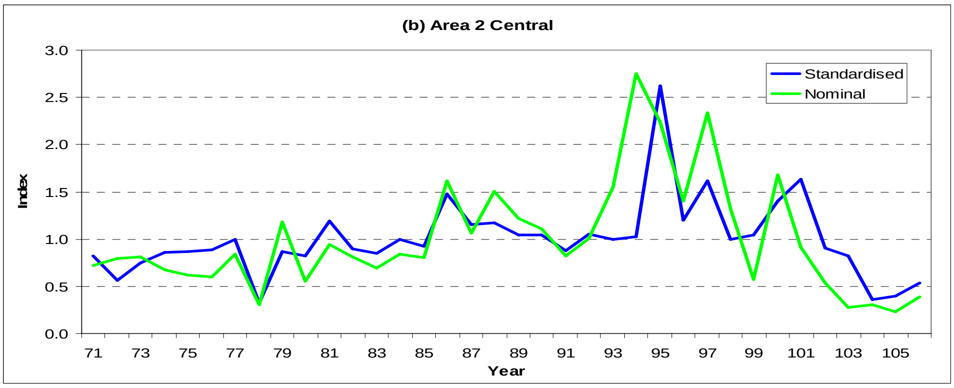
Table 3.2 Type 3 statistics associated with the GLM fitted to each area.

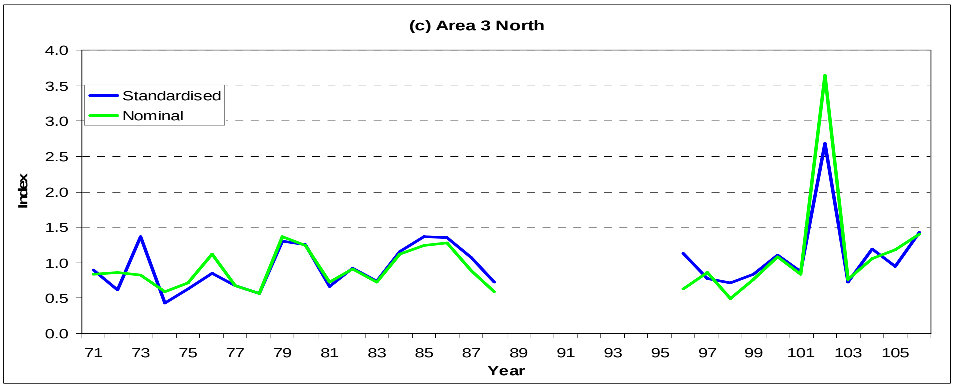
Area\Variable	*Year*Quarter*			*Quarter*Area*			*Area*HPBcat*		
	df	*Chi*	*Prob*	*df*	*Chi*	*Prob*	*df*	*Chi*	*Prob*
Area 1C	140	3069	<0.0001	12	443	<0.0001	25	447	<0.0001
Area 2C	130	769	<0.0001	6	135	<0.0001	15	223	<0.0001
Area 3N	56	204	<0.0001	3	7	0.0661	24	69	<0.0001
Area 4N	140	3125	<0.0001	12	1011	<0.0001	35	221	<0.0001

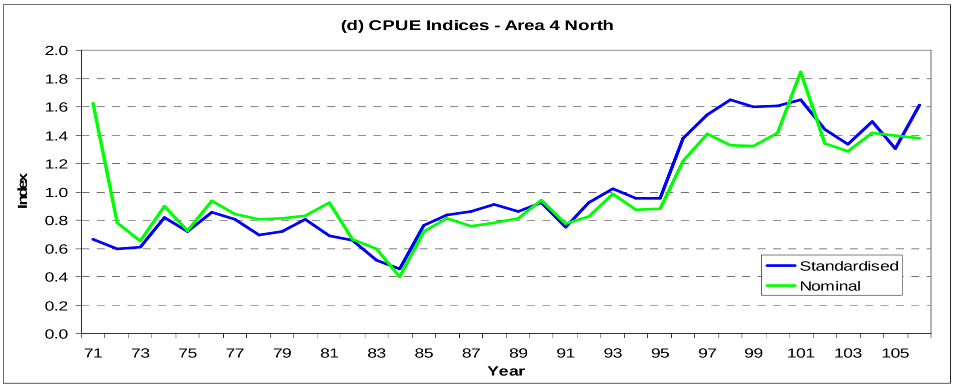
The resulting standardised CPUE index for each area, together with the nominal index for the data fitted, is shown in Figure 3.3. The Type 3 statistics associated with the GLM fitted to each area are also shown in Table 3.2.

Figure 3.3 The nominal and standardised swordfish CPUE indices for the Japanese fleet operating in four areas within the southern WCPO. Note, all indices are scaled such that the mean across the time-series is equal to 1.









4. Standardised catch-rates – Korea

A similar analysis to that undertaken for the Japanese fleet was also conducted using the catch and effort data for the Korean fleet in the northern zones of Areas 3 and 4. However, only aggregated 5x5-degree catch and effort data was available for this fleet and there was also no information on gear settings (i.e. hook-per-basket). Consequently, the following simplified model was fitted to the data:

MODEL *Catch= Year*Quarter + Quarter*Area*

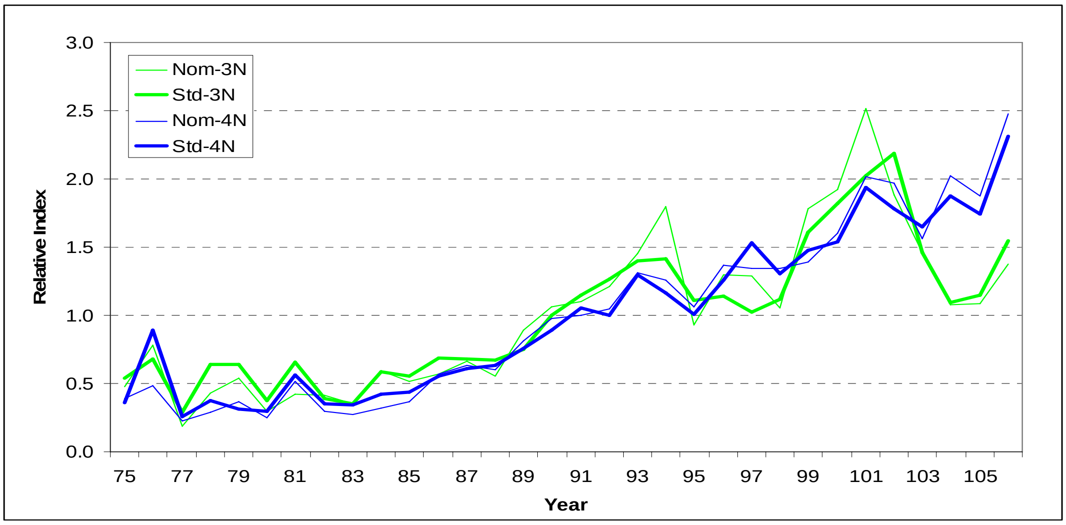
Distribution=negative-binominal

Link=*log*

Offset=*log*(*Effort*)

The results are shown in Figure 4.1.

Figure 4.1 The nominal and standardised swordfish CPUE indices for the Korean fleet operating in two areas within the southern WCPO. Note, all indices are scaled such that the mean across the time-series is equal to 1.

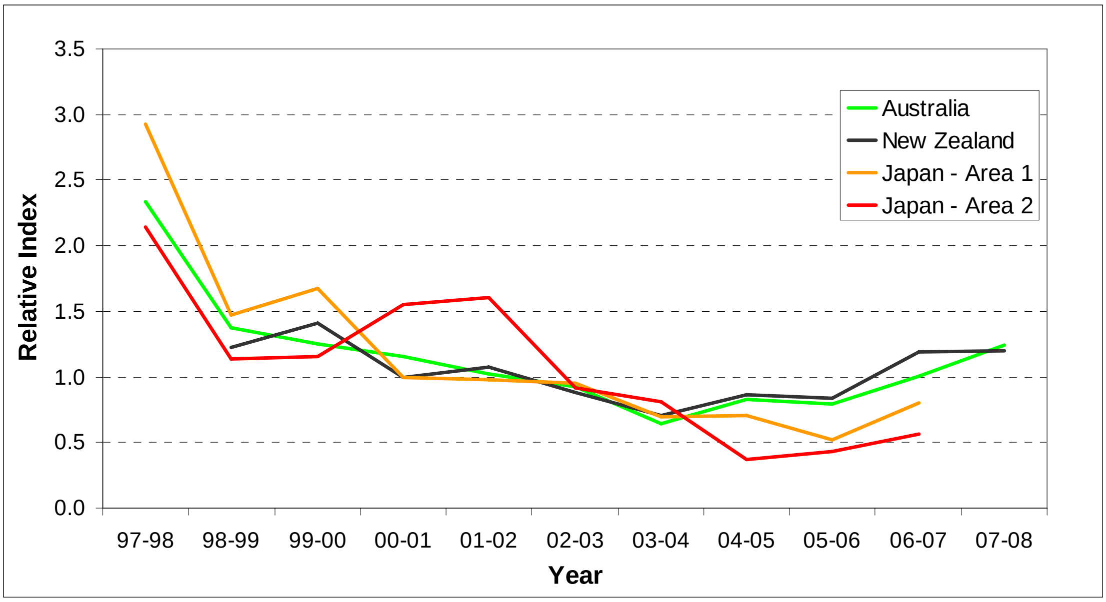


5. Comparison of Indices

5.1 Areas 1 and 2

If the swordfish resource within the Southwest Pacific (comprising Areas 1 and 2) comprises a single stock, and if the standardised CPUE indices based on the catch and effort data for different fleets fishing in this region are each considered to be approximately proportional to the size of the available swordfish population, then one would expect similar trends in the respective time-series of standardised CPUE. Such a comparison is shown in Figure 5.1 for the Australian, New Zealand and Japanese fleets. Note that the index for each annual period is based on the average of the quarterly index over the four quarters between 1-July to 30-June.

Figure 5.1 Comparison of the standardised swordfish CPUE indices for the Australian, New Zealand and Japanese fleets operating within assessment areas 1 and 2 the southern WCPO. Note, all indices are scaled such that the mean across the years 98-99 to 05-06 is equal to 1.

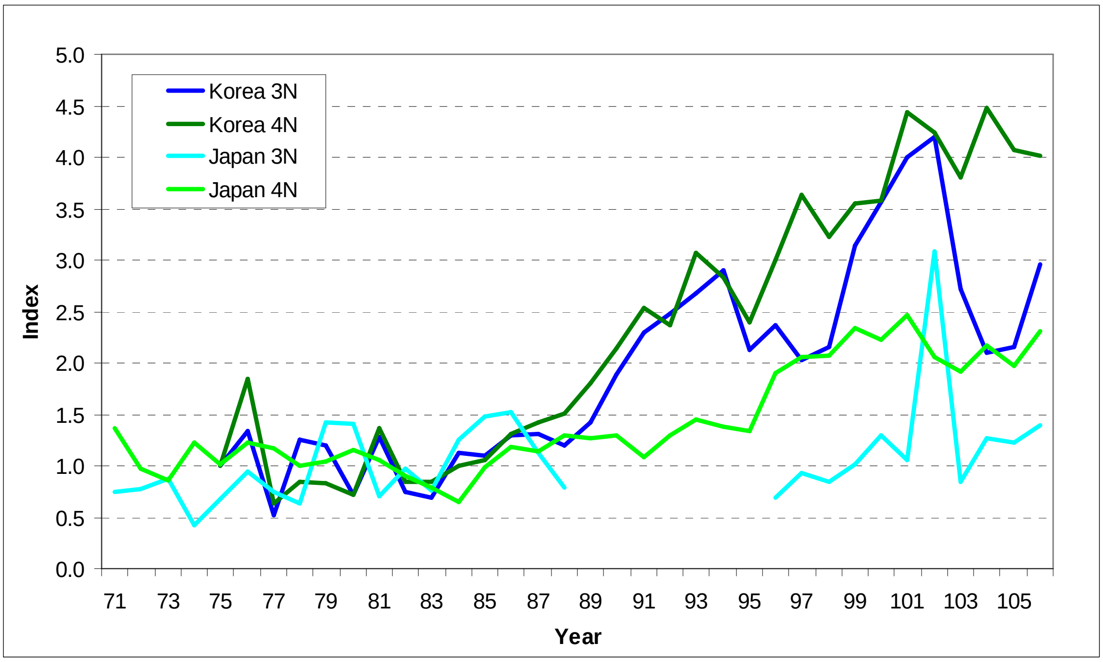


The trends for the Australian and New Zealand fleets are seen to be quite similar. This is an encouraging result as these two fleets catch the majority of the swordfish in the Southwest Pacific. Furthermore, it is for these two fleets that we have a most information on targeting and gear-setting practices required to standardise the effort. The trends for the Japanese fleet also show very similar trends to the Australian and New Zealand fleets for the first 7 years (i.e. up until 03-4) but remain below the other two indices for the remainder of the series. Nevertheless, there does appear to be an increased in the trend for the Japanese fleet at the end of the time series in line with the increasing trends since in the indices for the Australian and New Zealand fleets. Whether or not the utility of the Japanese indices in these latter years is being constrained (or at worst biased) due to the declines in overall effort in these areas remains uncertain, but the precision of the estimates will have decreased.

5.1 Areas 3 and 4

Within Areas 3 and 4 a comparison of the Japanese and Korean indices is shown in Figure 5.2. Within Area 4 both indices show a steady increase since the late 1980s, though the extent of this increase is different for the two fleets with the increase in the Korean index twice that of the Japanese index. The reason for this difference remains uncertain, though it may be due to a successive shift in targeting within the Korean fleet that has not been accounted for by the standardisation (due in part to the missing information on gear configuration). Within Area 3 the two indices are more divergent, with the Japanese index displaying little or no increase compared to a doubling in the Korean index over the past 20 years. As with the result for Area 4, this increase may be due to a shift in the targeting by the Korean fleet.

Figure 3.6 Comparison of the standardised swordfish CPUE indices for the Korean and Japanese fleets operating within assessment areas 3 and 4 the southern WCPO. Note, all indices are scaled such that the mean across the years 1975-85 is equal to 1.



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Attachment 4. Spatial structure in South Pacific Swordfish Stocks and Assessment Models. WCPFC-SC4-2008/SA-IP-2. (31p.)

SCIENTIFIC COMMITTEE
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SPATIAL STRUCTURE IN SOUTH PACIFIC SWORDFISH STOCKS AND ASSESSMENT MODELS

WCPFC-SC4-2008/SA-IP-2

Dale Kolody[1], Nick Davies [2]

[1]CSIRO Marine and Atmospheric Research, Hobart, Australia
[2]Secretariat of the Pacific Community, Noumea, New Caledonia

Spatial structure in South Pacific Swordfish Stocks and Assessment Models

Dale Kolody (CSIRO, Hobart, Australia; email: Dale.Kolody@csiro.au)
Nick Davies (NIWA, New Zealand and SPC, New Caledonia)

Abstract

This paper describes the evidence used to define the spatial structure of the South-West Pacific swordfish stock assessment in 2006, reviews the arguments used in other swordfish fisheries, and describes a new structure that was proposed to the April 2008 swordfish assessment workshop (**WCPFC-SC4-2008/SA-IP-1**) and adopted for the 2008 assessment (**WCPFC-SC4-2008/SA-WP-6, WCPFC-SC4-2008/SA-WP-7**). The 2006 spatial structure was based on observations from larval distributions, genetic connectivity studies, and fishery characteristics, including fleet distributions and seasonal patterns in catch, CPUE, and size composition. Since the 2006 assessment, additional studies have been published on swordfish genetics, and several Pop-up Satellite Archival Tags (PSATs) have been deployed in Australia and New Zealand. The new spatial structure is revised in relation to 1) the qualitative description of movements from individual tagged fish (including a handful of conventional tags), 2) the WCPFC request to encompass the broader South Pacific convention area in the assessment, and 3) simplification of the latitudinal structure that was problematic in 2006. Quantitative methods of using the tagging data are discussed, diffusion rates are estimated, and bulk transfer coefficients are calculated for the new spatial structure.

Introduction

Broadbill swordfish (*Xiphias gladius*) is a highly migratory and broadly distributed pelagic species found throughout most of the tropical and temperate regions of the oceans. Because of the potential for large-scale dispersive migration and/or seasonal spawning/foraging migrations, it is difficult to identify the stock structure that is most appropriate for the purposes of population assessment and fishery management. This paper i) provides a review of the relevant data used in defining the SW Pacific spatial structure used in the 2006 assessment (Kolody et al. 2006, Davies et al. 2006), ii) examines the arguments applied in other swordfish fisheries, and describes a revised spatial structure for the 2008 assessment. This paper was initially prepared for the *Southern WCPO Swordfish Assessment Workshop*, held at the Secretariat of the Pacific Community 16-18 Apr 2008 (Anon. 2008), and has been updated to reflect some new information obtained at the workshop.

The model domain adopted in the 2006 assessment was defined in relation to the need for Australian and New Zealand domestic management advice. The spatial boundary was delineated in consideration of the data available at the time (e.g. qualitatively described in Kolody et al. 2006), but it was recognized that most of these data provide only indirect evidence for movement and stock structure. That assessment included only the South-West Pacific, whereas the Conservation and Management Measure (CMM2006-3) based on the assessment covered the whole WCPFC convention area, South of 20°S (see Figure 1). This represents a substantial mismatch in area between the scientific advice and management measure (and we cannot find documentation that explains the reasoning).

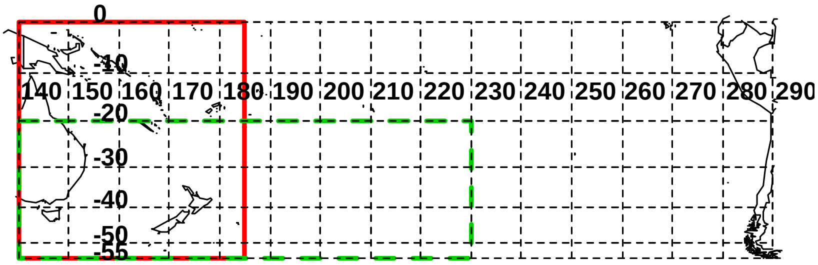

Figure 1. South Pacific map illustrating 2006 swordfish assessment domain (solid red box), and area of application of WCPFC Conservation and Management Measure 2006-3 (broken green box).

The Commission explicitly requested assessment advice in 2008 in relation to the broader South Pacific region. This potentially includes the south-eastern Pacific (outside of the WCPFC convention area) if the request is interpreted literally.

The internal structure of the assessment assumed in 2006 is illustrated in Figure 2 (areas 1-5 only). There is an ongoing debate about how much spatial structure to include in an assessment, and the preference for regional swordfish assessments (eastern Pacific, north Pacific, north Atlantic, and Indian Ocean) has generally been to use a spatially aggregated structure. The motivation for a disaggregated structure in the SW Pacific was largely driven by the perception of serial local depletion, particularly in the Australian Eastern Tuna and Billfish Fishery (ETBF) (e.g. Figure 3), which suggests heterogeneous structure within what is assumed to be a single population. It seems reasonably clear that the fishery has had an effect on the population in this area, but it remains unclear how quickly the stocks mix, and what the appropriate spatial considerations are for effectively managing the stock.

There were a number of problems noted in relation to the internal structure of the 2006 assessment (Kolody et al. 2006), including:

- The spatial split adopted between the southern (SBT-targeting) and northern (all other) longline fisheries did not result in an entirely satisfactory delineation of fleets. i.e. Notably the Australian fleet seemed to show a mix of northern and southern fishery size composition characteristics (the SBT-targeting fleet tends to catch predominantly very large female swordfish). Furthermore, partitioning the southern region as a fundamentally different fleet did not allow the effective sharing of fishery catchability and selectivity parameters across regions, such that the model had the potential to estimate very high or low southern sub-population abundance that was inconsistent with expectations.

- With only indirect evidence of movement, the migration rates estimated in the model were not expected to be very reliable, and some of the results seemed counter-intuitive.
- The CPUE estimates from different fleets (Japan and Australia) operating in the same area suggested very similar annual trends, but differing patterns of seasonal abundance. This suggests that seasonal fluctuations in CPUE represent a confounding of movement and catchability effects for one or both fleets. As such it is clear that the seasonal CPUE patterns cannot be interpreted directly as movement.

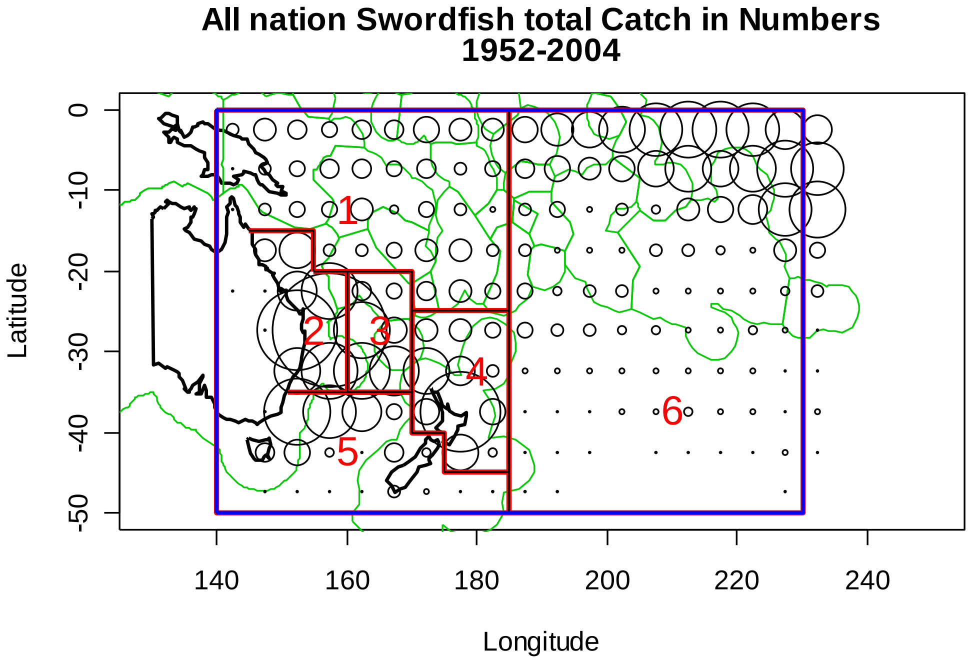

Figure 2. Spatial structure of the SW Pacific swordfish assessment in 2006 (Kolody et al. 2006). Area 6 was initially defined for sensitivity trials but this was not pursued. The area of the black circles represents the relative catch in each 5x5° region summed over the period 1952-2004.

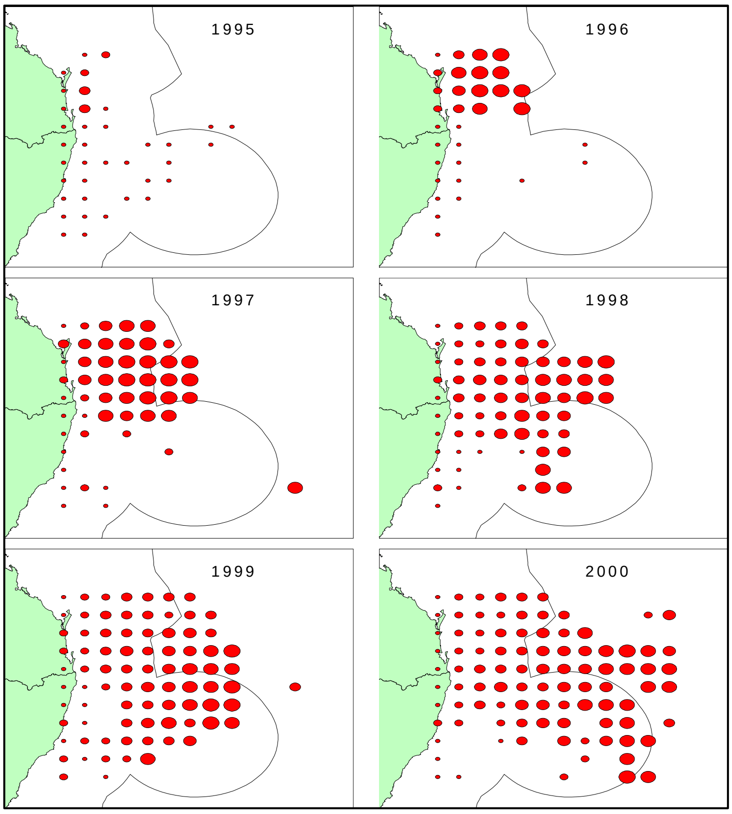

Figure 3. Potential evidence for sequential depletion and spatial heterogeneity observed during the development of the Australian Eastern Tuna and Billfish longline fishery. Circles are proportional to the catch rates. Figure from Campbell and Hobday (2003).

In redefining the spatial boundaries to be applied in the 2008 assessment, we review evidence from the following:

- Population genetics
- Spawning distributions inferred from larval distribution surveys and maturity studies
- Catch demographics (catch rates and size composition)
- PSAT tag tracks and conventional tag release/recoveries

We note that similar lines of evidence were used by Hinton and Alvarado Bremer (2006) to examine spatial structure, particularly in relation to the Eastern Pacific. The tags provide the most substantive new evidence, in that the movements of (a small number of) individual fish have been observed directly.

There are also additional considerations in the formulation of assessment boundaries that are not driven by swordfish biology, including:

- Fishery structure
- Data quality, quantity and accessibility
- Tractable limits of assessment model representation and parameter estimation
- Commission convention boundaries

After a largely qualitative discussion and synthesis of these factors, some new boundaries were proposed as a basis for discussion at the *Southern WCPO swordfish assessment workshop* (Anon. 2008). A quantitative analysis of the tagging data is described in which diffusion parameters were estimated, and these parameters were translated into bulk transfer coefficients that were used directly in the stock assessment (Kolody et al. 2008, Davies et al. 2008).

Population Genetics

Genetic differences among regions can provide strong evidence for distinct populations, however, the absence of genetic differences does not provide sufficient evidence to conclude that there is a single spawning stock, or a justification for assuming a homogenous population structure in an assessment model. In some cases, the genetic markers examined might not be sufficiently informative, or sample sizes too small, for population differences to be detected. Relatively few dispersers (of any age), could result in substantive genetic mixing. However, whether or not there are genetically identifiable sub-populations, the mixing rates might be relatively slow, and there may be important implications for fishery management.

Reeb et al. (2000), suggests a broad "⊃"-shaped genetic connectivity pattern for swordfish in the Pacific Ocean, such that the SW and NW Pacific populations seem to be the most distinct from each other (Figure 4), with central and eastern populations intermediate between the two (and the SW Pacific indistinguishable from the eastern Indian Ocean). Alvarado Bremer et al. (2006) were able to conclude that the South-East Pacific stock was genetically distinct from the North-East and South-West. They collected additional evidence to suggest that the South-Central Pacific might represent a population intermediate between the SW and SE, (and North-Central and NE), but it was recognized that sample sizes in the South-Central region were not sufficient to be conclusive (Michael Hinton, IATTC, pers. comm.).

There is currently not much evidence to indicate that swordfish stocks from the Eastern Indian Ocean and SW Pacific are separate, (e.g. Reeb et al. 2000 pooled samples from these regions because sample sizes were small from both regions). However, the potential migration corridors around the north and south of Australia are thought to have relatively low swordfish densities. Given the distances involved, it seems unlikely that the Indo-Pacific mixing would be substantive (though larval drift through the northern route might not be trivial).

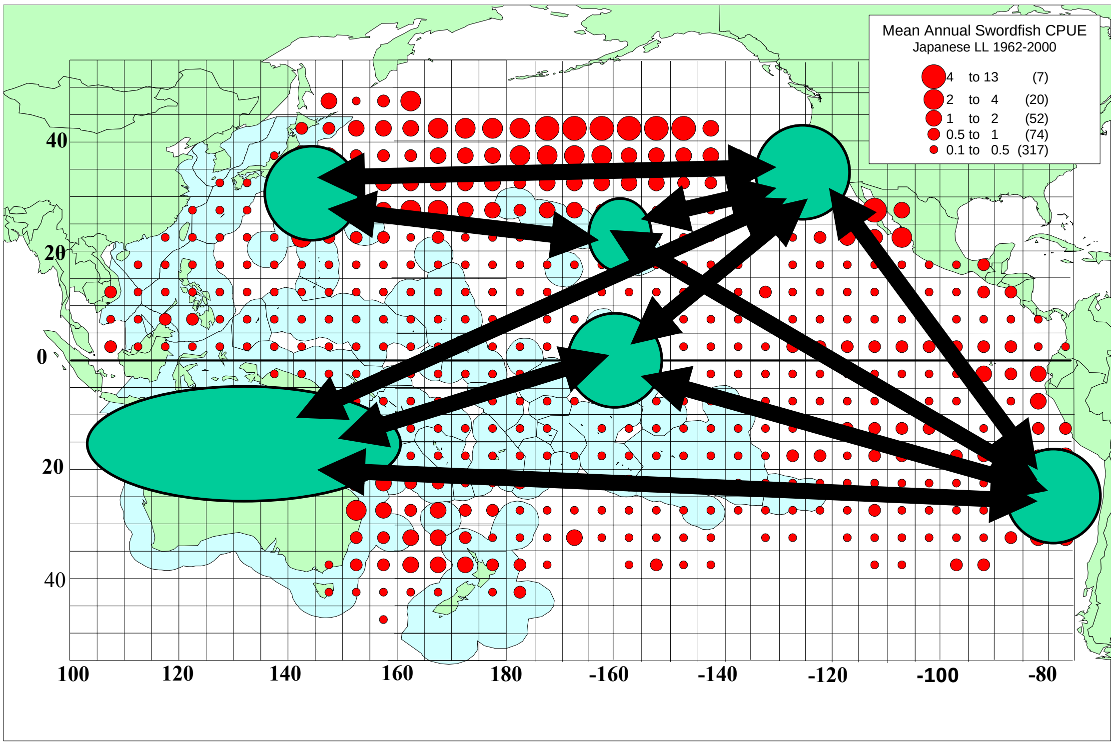

Figure 4. Schematic representation of swordfish genetic connectivity in the Pacific Ocean (after Reeb et al. 2000). Green circles indicate sample locations. Samples linked by arrows are more closely related than those that are not linked. Red circles indicate mean annual swordfish catch rates from the Japanese longline fleet (1962-2000), as an approximation of swordfish density.

Larval Distribution Surveys and Maturity Studies

Japanese studies of larval distributions from the 1950s-80s (Nishikawa et al. 1985) provide some indication of likely spawning locations in the Pacific, although spatial and temporal coverage in the South Pacific is patchy. In the South Pacific, substantive larvae concentrations were identified in the tropical/subtropical waters near the North-east coast of Australia, and lesser concentrations are found in more Eastern regions of the South Pacific (Figure 5). These data suggest a major spawning ground off NE Australia, and a maximal latitudinal bound for spawning activity. In the 2006 assessment, it was assumed that the area off NE Australia was the main spawning area in the SW Pacific (however, this assumption was only relevant for the site-fidelity models, and did not affect the final assessment results which were based on a homogenous mixing assumption that assumed that all spawners contributed to recruitment irrespective of location). The PSAT tag tracks (see below) suggest that SW Pacific swordfish might be migrating from southern foraging grounds toward Northern spawning grounds (which meet warm temperature characteristics typical of billfish spawning), without any obvious longitudinal preference. If the NE coast of Australia actually is a particularly dense spawning region, it might reflect a larger population in the Western-most region of the South Pacific, rather than any substantive longitudinal spawning migration. However, it is equally plausible that the aggregate larval survey results might reflect spatial and temporal sampling biases.

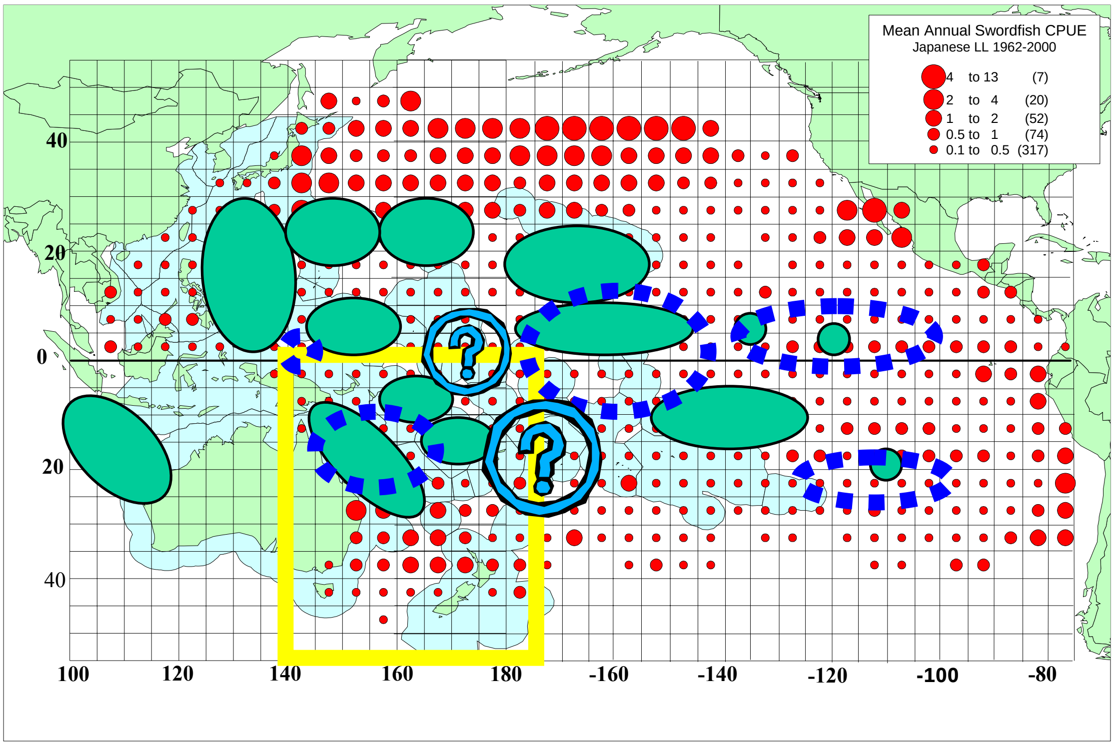

Figure 5. Cartoon of likely swordfish spawning regions in the Pacific. Larval distributions observed in Japanese surveys are approximated by (solid) green ovals. Areas with substantial numbers of mature females estimated from Spanish and Australian catch sampling are approximated by (broken) blue ovals. Yellow box indicates SW Pacific region defined for stock assessment in 2006. Question marks indicate regions in the South-West/South-Central Pacific that are particularly poorly sampled by maturity studies.

Anecdotal evidence presented at the swordfish workshop (Anon. 2008) revealed that substantial numbers of very small swordfish were observed recently in the Cook Islands, and this was considered unusual.

Regions with likely active spawning as inferred from maturity studies suggest broad areas of overlap with the larval distributions (Figure 5). Young and Drake (2002) describe the spatial distribution of mature spawners observed in the Australian Eastern Tuna and Billfish Fishery (ETBF). They estimate that spawning occurs in waters warmer than 24°C, with higher proportions of active spawners observed north of 27°N in the SW Pacific spawning season. This study did not include any samples from the region East of 168°E and north of 35°S. Mejuto et al. (2008) describe spawning activity from collections made by the Spanish longline fleet operating throughout the Pacific. They observed relatively few mature (active) female spawners south of 10°S in the SW Pacific, but very few samples were taken from the region 10-25°S. However, they did find a high proportion of active spawners in the equatorial region 10°N-10°S east of 180°. It is unclear to what extent the central equatorial spawners contribute to northern or southern hemisphere populations. This study had very little equatorial sampling west of 180°. If there are substantial numbers of spawners in this region, then they presumably contribute to the populations of either the northern or southern hemisphere (i.e. because Reeb et al. 2000 suggest that the northern and southern populations in the western Pacific are genetically distinct).

Catch Demographics

Commercial fisheries data in the South Pacific are described in more detail in Campbell et al. (2008), and Campbell (2008). We only mention summary points below in reference to figures in those documents.

Catch and CPUE Distributions

Figure 2 illustrates the distribution of total swordfish catches in the South Pacific WCPFC convention area (summed over time). There are two major concentrations of catch: the northern Tasman Sea to southern Coral Sea area (~20-40° S), and the South-Central equatorial region. In contrast, the mean CPUE estimates from the Japanese fleet suggest only one major concentration (the Tasman-Coral Sea region, Figure 4). The difference between the catch and CPUE distributions reflects the enormous amount of longline effort targeted at the tropical tunas in the equatorial region. CPUE is generally considered to be the more appropriate measure of fish density, and on this basis alone, it is easy to recognize 3-4 large-scale swordfish concentrations in the Pacific: North-West, South-West, and Eastern. Further scrutiny, and other lines of evidence suggest a northern and southern delineation in the Eastern Pacific (e.g. Hinton and Bremer 2006).

Size Composition

Unfortunately, size composition sampling in the South-West Pacific has been limited for most fleets. However, a couple important size trends are evident:

- In the SW Pacific, there seems to be a seasonal cycle of larger fish tending to be relatively more abundant in the tropical spawning regions (off Central-Northern Australia) in quarters 1 and 4, and conversely more abundant in the southern waters (e.g. New Zealand) during quarters 2 and 3. This is strongly suggestive of spawning migrations.
- The southern SBT-targeting fisheries in the SW Pacific tend to catch predominantly very large, (mostly female) swordfish (though in relatively small numbers) as by-catch.
- Declining size trends have been observed in the western part of the Australian fishery for the last few years, which is suggestive of a depletion effect. However, due to the poor size sampling, it is unclear whether these trends are occurring in the other fisheries.

Spatial inferences from tagging studies

At the time of this analysis, we were aware of 21 successful swordfish PSAT tags that had reported positions from the SW Pacific (14 Australian and 7 New Zealand). The tags we consider here were at liberty for at least 60 days, and have position fixes for release and pop-off (Argos positioning), plus several intermediate point estimates for positions from SST- and light-based geo-positioning.

Only six conventional swordfish tags have been recovered in the South Pacific that we know of, four with release durations longer than 60 days. These tags are less informative than the PSAT tags in that only release and recovery positions are available, and recoveries are restricted to commercial fishing operations (and the associated non-random effort distributions). However, the conventional tags are more informative than the PSAT tags in terms of the long release durations (3 of 1-2 years, and one of 6 years). There is also one unconfirmed tag that suggests a movement across the Tasman Sea (from New Zealand to the Australian inshore fishery) (Clive Stanley, CSIRO, pers. comm.).

South Pacific-Indian Ocean tagging studies are ongoing, with several more releases expected over the next year. As such, there has not yet been a concerted effort to analyse the existing tag tracks to form a general synthesis, and this is expected to occur over the next 1-2 years (Chris Wilcox, CSIRO, pers. comm.). This descriptive work undertaken in support of the assessment represents a first attempt to make some qualitative and quantitative inferences. Three possible approaches for using PSAT tagging tracks (and conventional tag recapture data) in the swordfish assessment context were considered:

1. Qualitative summary. Given the small number of tags, it is not clear that anything conclusive will come out of a quantitative analysis at this time, while a visual depiction of movements can be interpreted in the context of the other qualitative work described in this paper.

2. PSAT tag tracks can be modelled in a spatially-disaggregated assessment model in a fashion analogous to conventional tags. This approach involves simply breaking up a continuous track into a series of consecutive release/recapture events according to the spatial structure and time-step of the assessment model, and defining special fisheries that catch 100% of PSAT tagged fish and 0% of untagged fish. While there are caveats associated with this approach, it may be feasible to attempt with the data available.

3. One can attempt to formulate and estimate parameters for advection-diffusion models (e.g., Sibert et al. 1999). Quantitative estimates from these models can be translated into bulk transfer coefficients (or priors) that are compatible with spatially-disaggregated assessment models. We did attempt to estimate the parameters for a diffusion model and discuss the appropriateness of this model in the context of the swordfish assessment.

Each of these is discussed under separate headings below. We note the following caveats in relation to our description and interpretation of the tagging data:

- Tag releases are not seasonally representative, as they tend to be released during the peak of the swordfish fishing season. Tag release durations have typically been short, with only 3 PSAT tags out for longer than 6 months, so evidence regarding cyclic migrations and site fidelity would be expected to be weak. Conventional tag releases are longer (up to 6 years), but recoveries are dependent on fishery operations, and potentially biased by non-reporting.
- Size and sex of the released fish are uncertain (though visual size approximations are recorded)
- All swordfish tag tracks to date are based on the limited data that are available from Argos satellite transmissions (as opposed to the full archival data that would be available if a tag was returned). The algorithms used to select which data are transmitted to the satellite are not well described, and there may be issues with data transmission reliability.

- In general, the light-based geo-positioning estimates are expected to be more accurate and precise for longitude than latitude (and this is especially true near the equinoxes, when day length is constant with latitude).
- The PSAT track descriptions feeding into these analyses were not estimated using identical methods:
    - The Australian tag tracks use the Wildlife Computer longitude estimates, which are proprietary and poorly described. Latitude estimates were based on an SST matching algorithm (Toby Patterson, CSIRO, pers. comm.). Position errors are sometimes sufficiently large that they can be recognized as implausible on the basis of physiological limits to migration rates. In this presentation, an arbitrary limit was adopted to reject all points with estimated migration rates faster than 400km/d (this removed two conspicuous back and forth longitudinal movements).
    - The NZ tag position estimates are based on light (longitude) and SST-based (latitude) position estimates using the SST-Kalman filtering algorithm (Nielsen et al. 2006). Statistical constraints on position estimates link consecutive position estimates in such a way that the few large and questionable movements estimated for the Australian tags are presumably less likely to be estimated with this algorithm. However, there are suspicious characteristics in the NZ latitude estimates, in that all of the positions from all tags were estimated to be north (often substantially) from the release and pop-off points.
- SST-based estimates of latitude are generally considered to be better than the light-based latitude estimates, however, it is unclear that the errors in the SST position estimates are properly understood, given the low level of ground-truthing for the SST fields in relation to PSAT near-surface temperature measurements. e.g. In using the Kalman filter – SST algorithm, on the New Zealand PSAT tags, latitude estimates were very sensitive to the smoothing assumptions assumed for the SST fields (Tim Sippel, Auckland University, pers. comm.).

Qualitative summary of tag tracks

Australian and New Zealand PSAT tag tracks are shown in Figure 6. Figure 7 illustrates a rectangle for each of these tag tracks, which encapsulates the maximum NS and WE region of the point estimates. The rectangular box exaggerates the perception of spatial movement of each tagged fish, but facilitates a useful visualization of multiple overlapping tracks. One New Zealand tag exhibits unique behaviour in that there is a large East-West displacement (~3000km), that seems to be reliably supported on the basis of multiple proximal position fixes. There appears to be a 20°S northern boundary for the Aus and NZ tags, and it would be interesting to know if this is a real bound (i.e. perhaps spawners need only migrate to a region of sufficiently high SST, and have no reason to go further). But this may be a coincidence of a small number of tags, or an artefact of the SST-based latitude position estimation algorithms used. Two of the NZ PSAT tagged fish overlapped with the Australian tagged fish. Figure 8 illustrates only the release and pop-off locations of the PSAT tags, along with conventional tag recoveries.

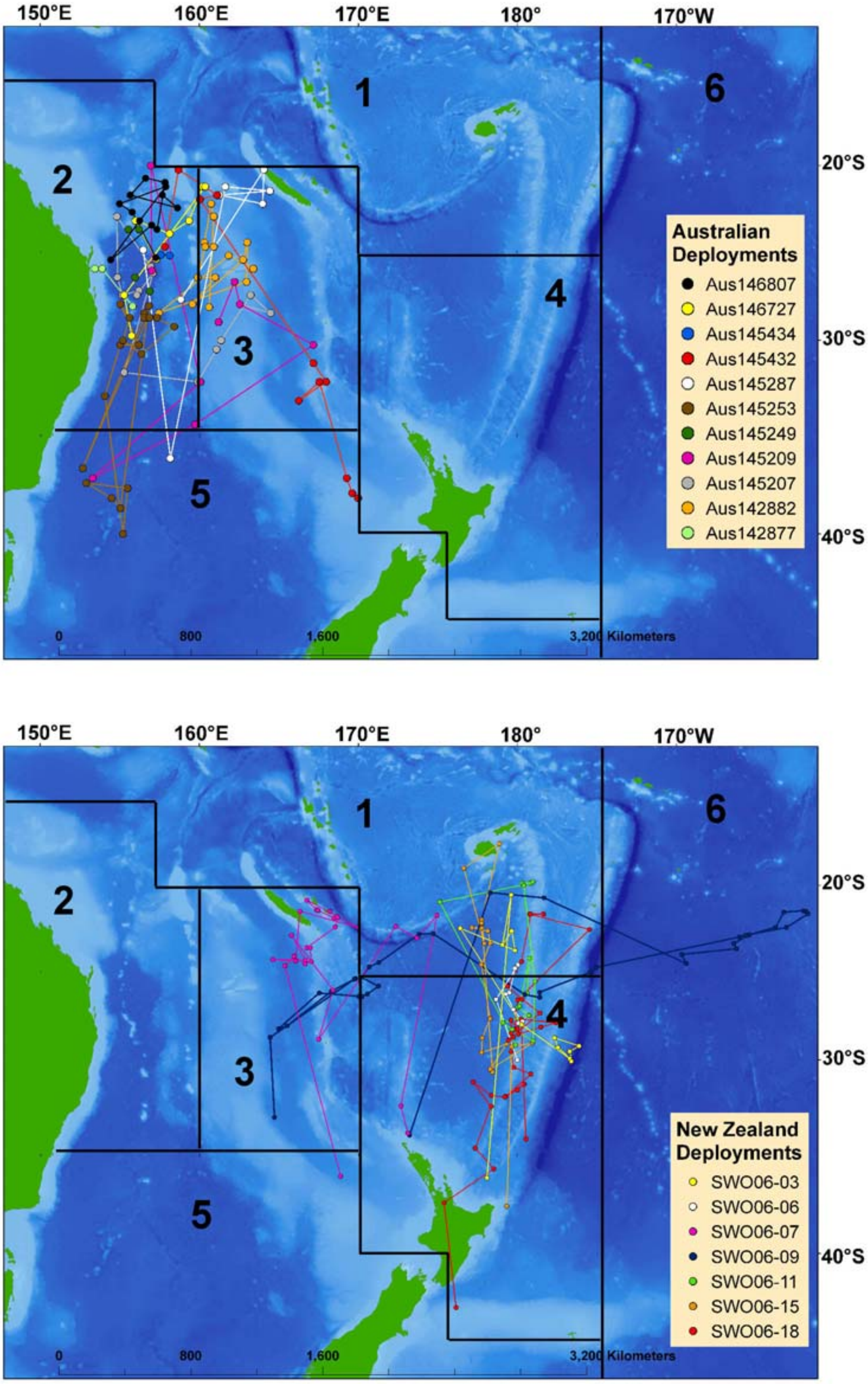

Figure 6. Estimated trajectories for Australian and New Zealand PSAT tagged swordfish in the SW Pacific. Figures from Holdsworth et al. (2007), Karen Evans and Chris Wilcox, CSIRO, unpublished data.

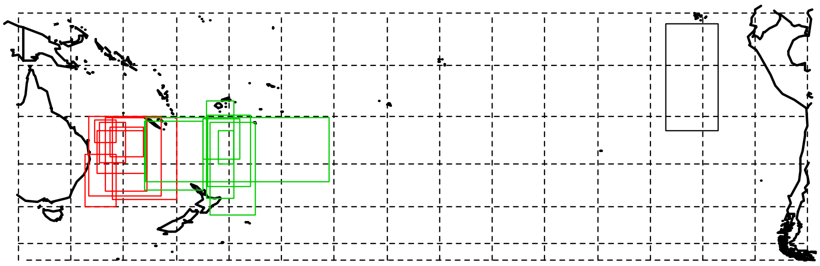

Figure 7. Boxes illustrating the maximum North-South and West-East extent of swordfish PSAT tag track releases from Australia (red), New Zealand (green) and Spain (black) for tags with pop-off times of 60+ days (the latter inferred from Abascal et al 2007).

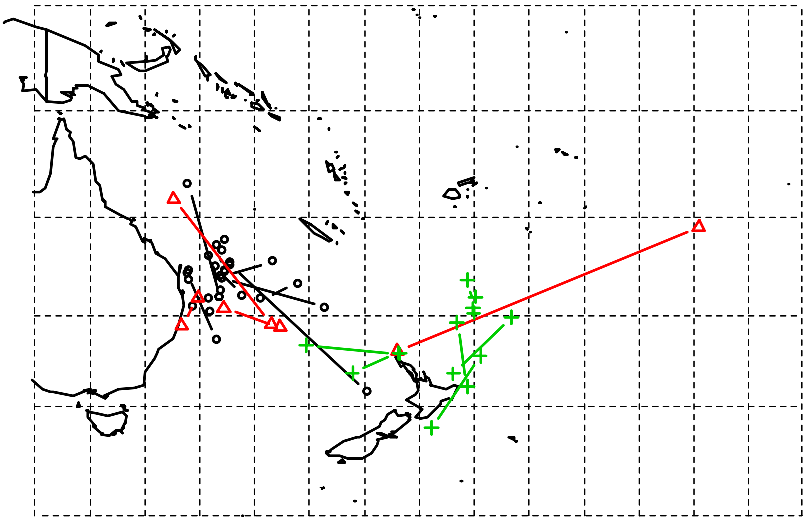

Figure 8. Release and pop-off points for Australian (black circles) and New Zealand (green "+") PSAT tags and convention tags (red triangles), for tags at liberty between 60 days and 6 years.

The PSAT tracks do not suggest much longitudinal migration in relation to spawning (as had been considered likely in 2006). While the tags are plausibly consistent with south-north spawning migrations, the Coral Sea does not seem to hold any special significance. This does not support the site-fidelity models as defined in the 2006 assessment (i.e. represented schematically in Figure 9), though site fidelity could still be important in different ways.

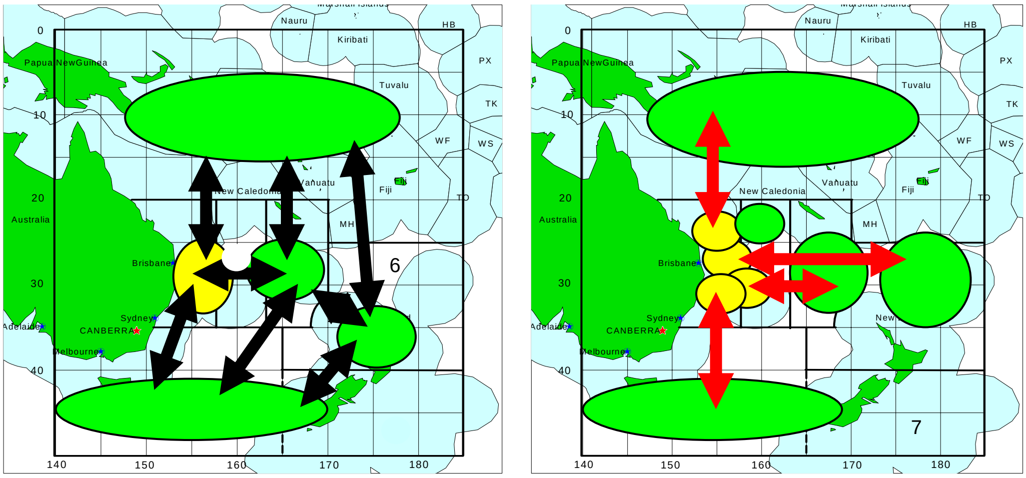

Figure 9. Migration hypotheses and stock structure explored in the 2006 assessment. Left panel illustrates a conventional homogenous mixing structure, while the right panel illustrates a site fidelity model with migration to shared spawning grounds.

In light of the new evidence, we consider the conceptual idea of homogenous mixing vs site fidelity to be more relevant on a broader scale (e.g. Figure 10), and note that the two mechanisms could work simultaneously and across a range of scales.

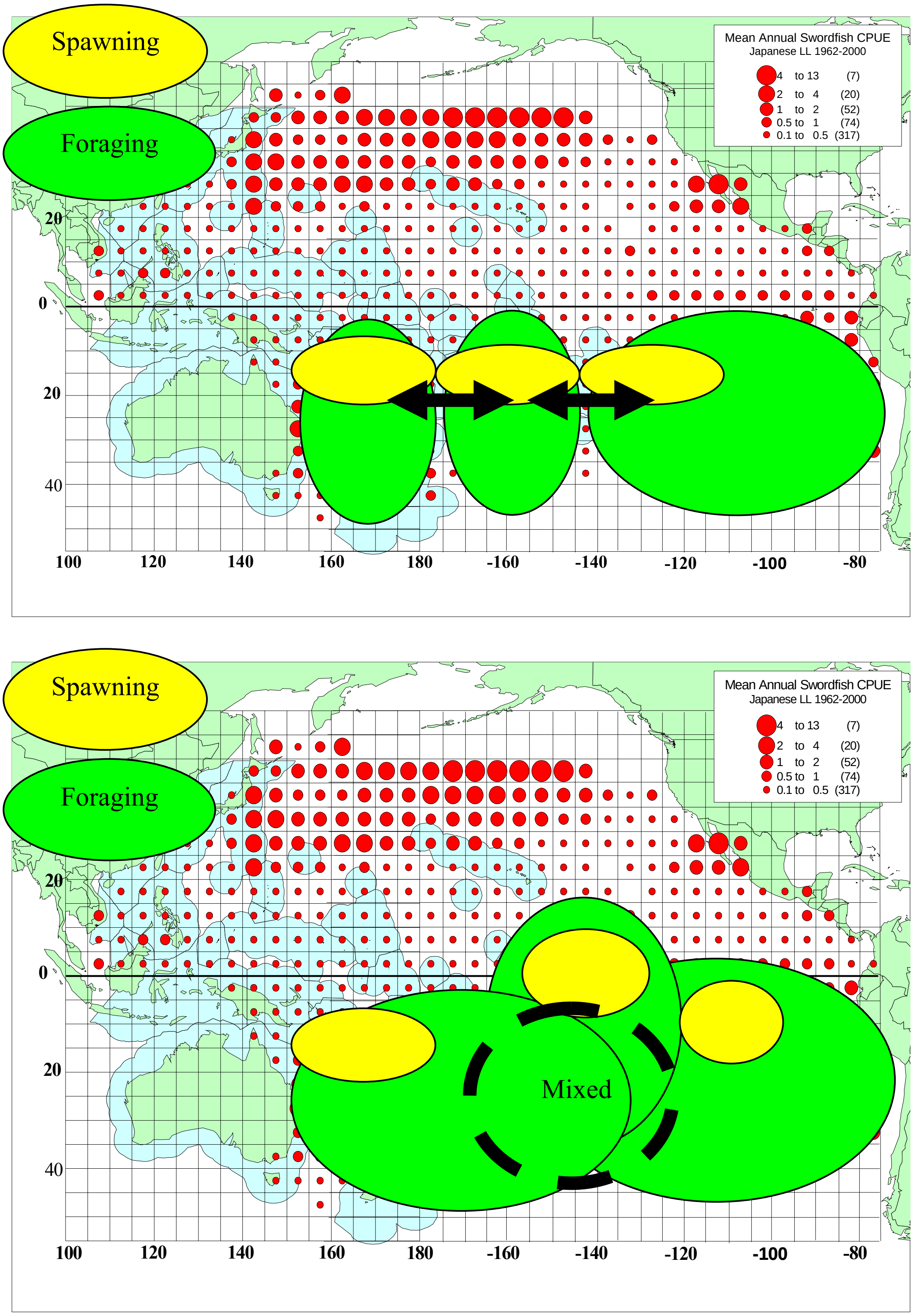

Figure 10. Schematic representation of two possible stock structure represenations for South Pacific swordfish: top panel = homogenous mixing, bottom panel = foraging site fidelity.

Modelling PSAT tracks as conventional tags

This is intended to be a simple approach for allowing PSAT tracks to be informative with respect to movement parameters in a stock assessment model. It does, however, require some model modifications relative to the conventional assessment model assumptions (i.e. a theoretical fishery with 100% tag recovery every time-step, and 0% exploitation of non-tagged fish)(Figure 11). The approach has the additional advantage of jointly estimating migration with the other population parameters. Given the non-representative pattern of PSAT releases, other data (i.e. seasonal CPUE and size distribution patterns), might provide additional constraints that prevent the estimation of dispersive migration estimates that might otherwise result if only half of the migration pattern is well observed. Problems with this approach include:

- Sequential PSAT track locations are not independent, and this would be expected to under-estimate the variance relative to the equivalent pattern that might be observed with truly independent release/recovery events.
- The short release durations available to date cannot fully describe seasonal movements.
- Multiple movements may occur within time-steps.

The conventional tag analogue model was not pursued in the 2008 assessment.

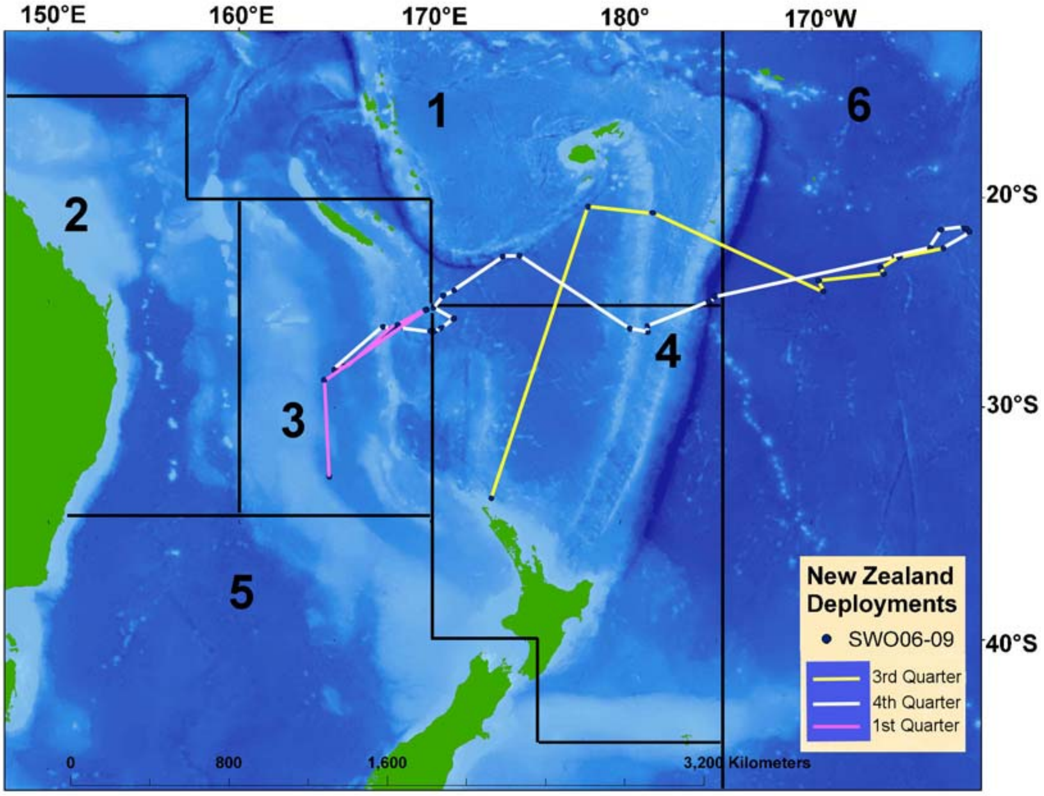

Figure 11. PSAT tag track split into 3 consecutive observations, analagous to conventional tag releases and recaptures.

Parameterization of Advection-Diffusion Models

There are a number of possible approaches for using tagging data to parameterize movement (e.g. Kleiber and Hampton 1994, Sibert et al. 1999) in population models. There is also speculation about the diverse migration characteristics that swordfish stocks are likely to have, including:

- Size/age-based migration/distribution
- Sex-based migration/distribution
- Homogenous mixing vs: site fidelity (with directed seasonal migrations)

We do not consider it feasible to attempt to estimate a full description of the migration dynamics, (i.e. including the potential ontogenic and sex-specific variability) from the available data. However, it is feasible to analyse the available data in the context of purely diffusive mixing. In the following, we attempt to estimate a diffusion rate for the SW Pacific swordfish population, purely in a longitudinal direction. Swordfish likely undertake substantive latitudinal migrations in the SW Pacific (e.g. very large, spawning age fish are found in the extreme south of the distribution, but spawning only occurs in the north; there are seasonal patterns in CPUE and size composition consistent with seasonal migration). However, there are two justifications for ignoring the north-south movements in the assessment at this time: 1) The latitudinal position estimates of the PSAT tags are not thought to be very reliable, and 2) the revised spatial structure of the assessment is being designed to integrate over North-South seasonal migration effects (i.e. assuming that seasonal catchability and selectivity can effectively represent the implications of migration on the population). We feel that it is reasonable to assume that individuals from the north and south in the same longitudinal band (within the SW Pacific) are more likely to be closely related than individuals located in the same latitudinal band an equivalent distance apart in a west-east direction.

A few summaries of Australian PSAT migration rates and migration distances as a function of time are illustrated in Figure 12 and Figure 13. From these plots it is evident that rapid migration appears to occur in the first few days, and then the rate decreases. There may be different mechanisms contributing to this effect, but we would consider the most parsimonious explanation to be the effect of position estimation error. The position estimation error would be expected to have a greater effect on the migration rate near the time at release. This error will be constant in magnitude over time, and hence larger in proportion to the actual displacement when the tagged fish has not had time to move very far.

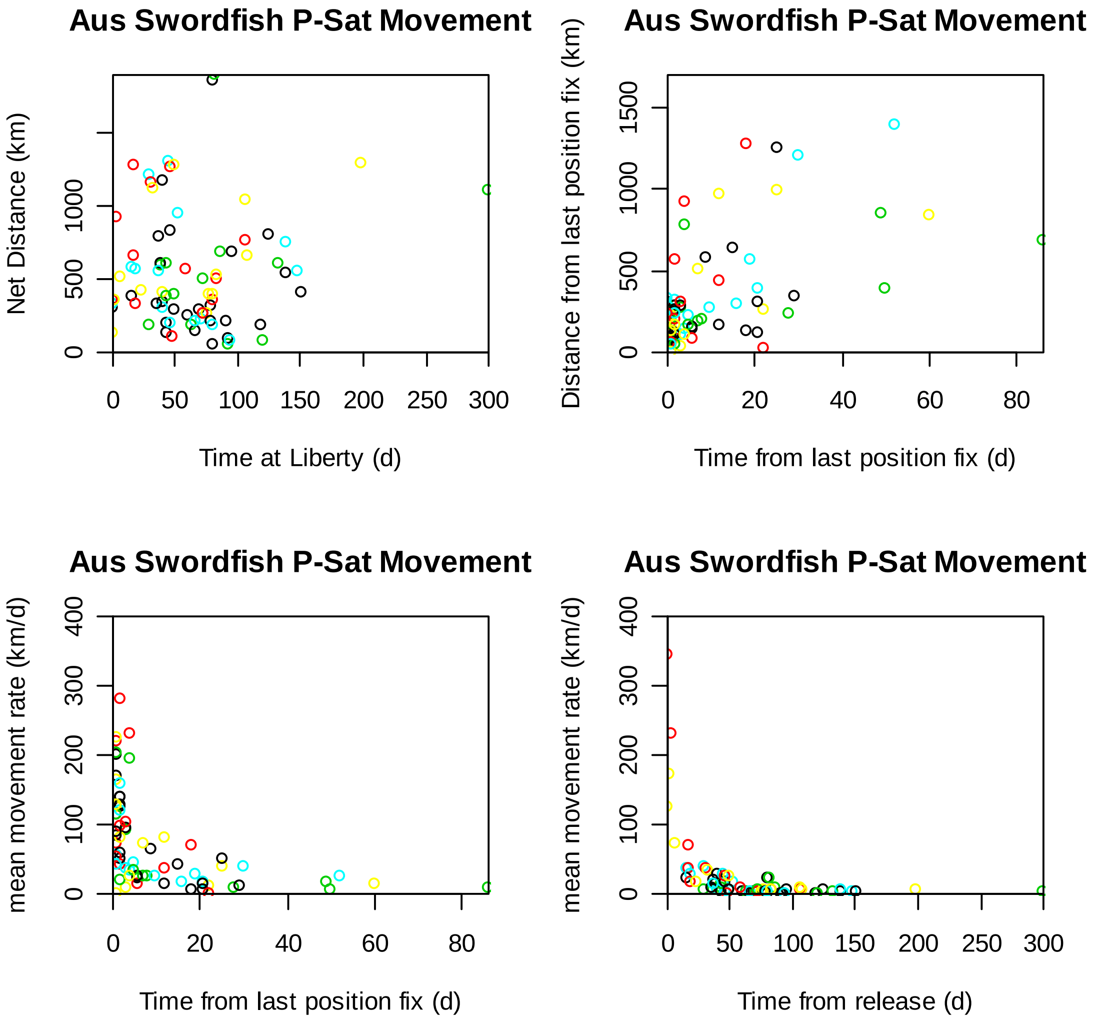

Figure 12. Australian swordfish PSAT tag displacements and movement rates over time (relative to the release point). All Australian PSAT tags are included (each circle represents an individual position fix and time interval since the previous position fix). Different colours represent different tags

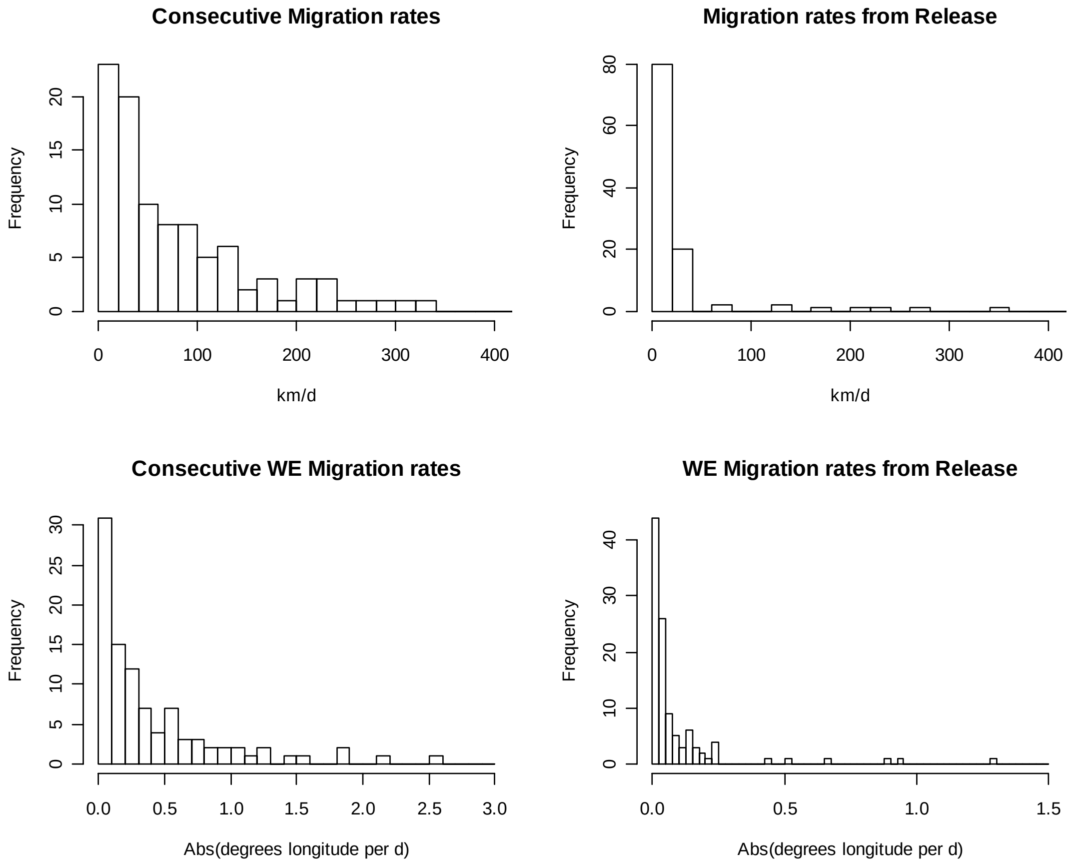

Figure 13. Estimated migration rates, between consecutive position estimates (left panels), and net from point of release (right) in absolute distance (top) and absolute longitude only (bottom).

In the following, we attempt to estimate a diffusive longitudinal mixing rate from the PSAT tracks, assuming that swordfish populations can be adequately described by diffusion. Sibert and Fournier (2001, based on Feller 1968), illustrate that a discrete-time random walk model results in distributions that are equivalent to continuous diffusive processes. In this case, we are only concerned with a one dimensional (unbiased) random walk. The probability density function for longitudinal positions, x, can be described by a normal distribution with variance 2Dt, where t is the time elapsed since release and D is the diffusion rate:

$$P(t,x) = \frac{1}{\sqrt{4\pi Dt}} \exp\left(-\frac{x^2}{4Dt} \right)$$

There is also a position error associated with each longitude estimate for the PSAT locations. This is large for the geo-positioning estimates, but expected to be much smaller for the release point and the final Argos position fix:

$$x_{observed,t} = x_t + \varepsilon_t ,$$

where $\varepsilon_t \sim Normal(\mu = 0, \sigma)$.

Assuming that the fish follow an unbiased random walk process, we can estimate the diffusion parameter D, and the longitudinal geo-positioning error, sigma, using the (negative log-)likelihood function:

$$L(x_{observed} \mid D, \sigma) = \sum_i \log\left(\sqrt{2\Delta t_i D + \sigma^2}\right) + \frac{x^2_{observed,i}}{2\Delta t_i D + \sigma^2}.$$

Where every position estimate, x(i), represents the longitudinal distance (degrees) from release and Δt_i is the elapsed time since release, corresponding to that position.

Two different datasets were fit:

A) Only the Australian PSAT tag data were included. All sequential light-based geo-position estimates (relative to the initial release time/location) from each tag were considered as independent observations. NZ track positions were not included because they were estimated using a different geo-positioning algorithm. One obvious problem with this model is the faulty assumption that every sequential track location is an independent observation, which would be expected to under-estimate the variance of the estimated parameters.

B) Australian and New Zealand PSAT tags were combined with conventional releases/recaptures. Only release and final Argos position estimates were included from the PSAT tracks. This uses all of the most reliable position data and ignores the light- and SST-based geo-positioning estimates.

The likelihood surface for the parameter estimates of the two datasets are shown in Figure 14, and seem plausibly consistent with one another. Model A is estimated to have a substantially higher observation error than model B (as expected, i.e. Argos and conventional tag recapture position errors would be expected to be smaller than light-based geo-positioning). Model B also has smaller diffusion rate point estimates than A. If migration is not a random diffusive process (e.g. if there are habitat constraints on the movements, or cyclic seasonal migrations), then we would expect diffusion rates estimated from the longer release durations (i.e. particularly the conventional tags) to be lower than the short releases.

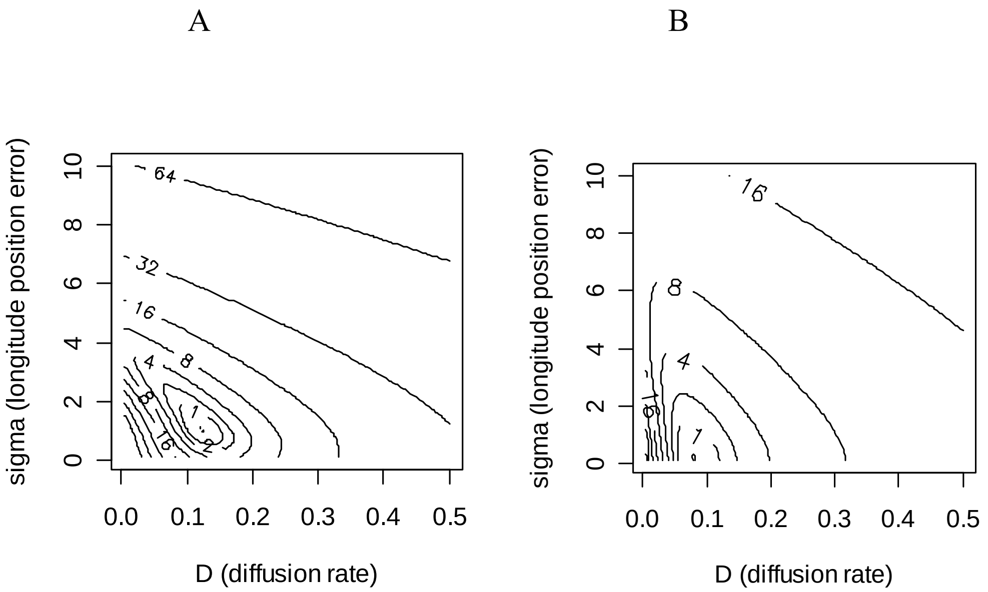

Figure 14. Negative Log-Likelihood surface for the longitudinal diffusion rate and longitudinal geo-positioning error estimated from the pure diffusion model, using A) the Australian swordfish PSAT tag data with all (sensible) geo-position estimates from each track, B) Combined Australian and NZ PSAT tags (Release and Argos pop-off locations only), plus the conventional tags.

Diffusion models rely on the important assumption that swordfish are actually swimming with an unbiased random walk behaviour. However, the conventional wisdom suggests that swordfish have habitat preferences, directed migrations (at least North-South), and potentially site fidelity in spawning/foraging migrations. Thus, a diffusion model would be expected to over-estimate movement rates if short-term tracks are extrapolated over the lifetime of a fish.

Two additional models were briefly explored to examine the appropriateness of the diffusion assumption. The second, more flexible model ("Flex") has pure diffusion (linear increase in longitudinal variance over time) as a special case, but a non-linear parameter allows the longitudinal variance to decrease, stabilize or increase over time, relative to what pure diffusion would predict. We used a Ricker (stock-recruitment) function to describe this situation. This is a convenient function for our purposes, but we do not intend to imply any specific mechanistic justification for it.

In Flex, the variance term $2\Delta t_i D$ is replaced by $2\Delta t_i D\exp(-k\Delta t_i)$, and the likelihood function becomes:

$$L(x_{observed} \mid D,\sigma) = \sum_i \log\left(\sqrt{2\Delta t_i D\exp(-k\Delta t_i) + \sigma^2}\right) + \frac{x^2_{observed,i}}{2\Delta t_i D\exp(-k\Delta t_i) + \sigma^2}$$

The additional parameter *k* is estimated. A third model, (SF for Site Fidelity) was examined, in which it was assumed that there was an explicit annual migration cycle, such that the variance in longitudinal position was described by a sine wave (A*sin(t*omega + phi))). The corresponding likelihood function is:

$$L(x_{observed} \mid D,\sigma) = \sum_i \log\left(\sqrt{A + A\sin(\Delta t_i\omega + \phi) + \sigma^2}\right) + \frac{x^2_{observed,i}}{2(A + A\sin(\Delta t_i\omega + \phi) + \sigma^2)}$$

In this case, the wavelength, ω, and phase angle, φ, were fixed (ω =π/365, φ = 0), and only the amplitude, *A*, and observation error σ were estimated. There is no reason why we would expect this particular waveform to be the most appropriate for describing the positional variance over time, however, it is a convenient caricature for describing possible annual migration pattern with perfect site fidelity (i.e. the key feature of the model is the oscillating expansion and contraction of the variance every 12 months).

When applied to only the Australian PSAT tags (dataset A), the three models all fit the data almost equivalently. The maximum likelihood parameter estimates and objective function values of the three models are listed in Table 1. The difference in likelihood is trivial and not statistically significant among the three. This is not surprising given that the estimated functions are very similar for tag release intervals of less than 100 days, and only 2 tag observations are of duration longer than 150d. On the basis of the Australian PSAT tags alone, we cannot conclude that continuous diffusion is more likely than seasonal migration with site fidelity, or something intermediate in character.

Longer duration tag releases are required to discriminate the differences (i.e. a minimum of one year would be expected to provide information on the seasonal patterns that we normally assume to be occurring). Furthermore, we note that even with a large number of quality observations, the Flex model would not actually disprove diffusion or seasonal migration. If swordfish move at random, but subject to habitat constraints (which of course they are), this will eventually provide a limit to the diffusive mixing that would otherwise be possible in an infinite habitat, so we would expect the pure diffusion assumption to break down eventually if movement rates are high. Similarly, swordfish could have seasonal migrations with perfect site fidelity, but this might be difficult to identify in this simplified analysis if the sine wave is grossly inappropriate for describing the seasonal movement (i.e. there could be short, rapid and asynchronous movements between foraging and feeding grounds).

The three models were refit with dataset B (Australian, New Zealand and conventional tags). Adding the conventional tags provides 4 observations of release duration greater than one year (including the single tag that was out for 6 years). The additional data also suggest that pure diffusion is a reasonable description of the longitudinal tag displacement, though removal of the longest time-at-liberty tag weakens the argument (Figure 15). Parameter values and likelihood estimates are provided in Table 1.

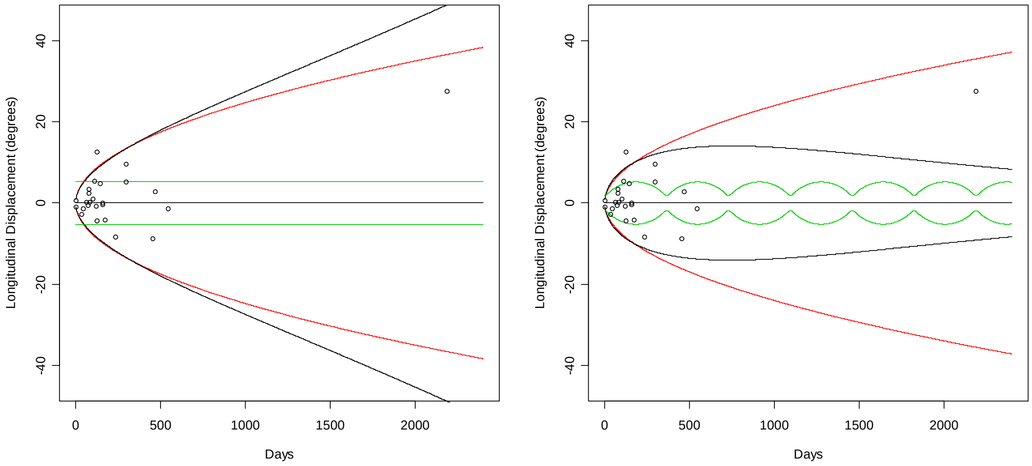

Figure 15. Models of swordfish diffusion based on the combined Australian (n=14) and New Zealand (n=6) PSAT (using only the final Argos position estimate) and conventional (n=5) tags (dataset A). Red bounds are the 95% confidence limits for longitudinal displacement based on the pure diffusion model, black bounds represent the "Flex" model, and green bounds represent the "Site Fidelity" sine wave model. Left panel models includes all points, right panel omits the single conventional tag observation that was at liberty for more than 2000 days from the model fitting.

We would tentatively conclude that the tagging evidence provides a reasonable justification for bounding longitudinal migration assumptions using diffusion rates as upper bounds on mixing. This is worth revisiting in light of additional tagging results and analyses, however, it seems as though more long duration release events will be required to provide convincing evidence. And toward this goal, we should not underestimate the importance of conventional tags relative to the sophisticated electronic tags.

Figure 16 illustrates how pure diffusion translates into longitudinal bulk transfer coefficients in an assessment context (i.e. the proportion of fish expected to move from one region to an adjacent region in a given time-step), relative to different spatial dimensions:

$$m = \int_{l=0}^{L} \frac{1}{\sqrt{4\pi DT}} \exp\left(-\frac{l^2}{4DT}\right),$$

where: m is the migration rate coefficient, T is the time interval (time-step used in the assessment model difference equations), l is longitude, and L is the longitudinal block size. Note that for relatively large values of D or T, or small values of L, a substantial number of fish would actually pass through the adjacent region into neighbouring regions.

Table 1. Parameter estimates for the swordfish movement models.

Model	DataSet	D	sigma	other	-ln(likelihood)
Diffusion	A	0.123	1.04		196.4
Flex	A	0.179	0.834	k=0.0051	194.9
Site Fidelity	A		0.947	A=32.3	196.6
Diffusion	B	0.0792	0.196		49.05
Flex	B	0.0714	0.334	k=-0.00031	48.91
Site Fidelity	B		(xxx)	A = 0.00	61.89
Diffusion	B*	0.0746	0.292		45.02
Flex	B*	0.0941	0.000	k=0.00135	44.89
Site Fidelity	B*		0.847	A=24.3	47.49

*excludes the single tag that was at liberty for six years

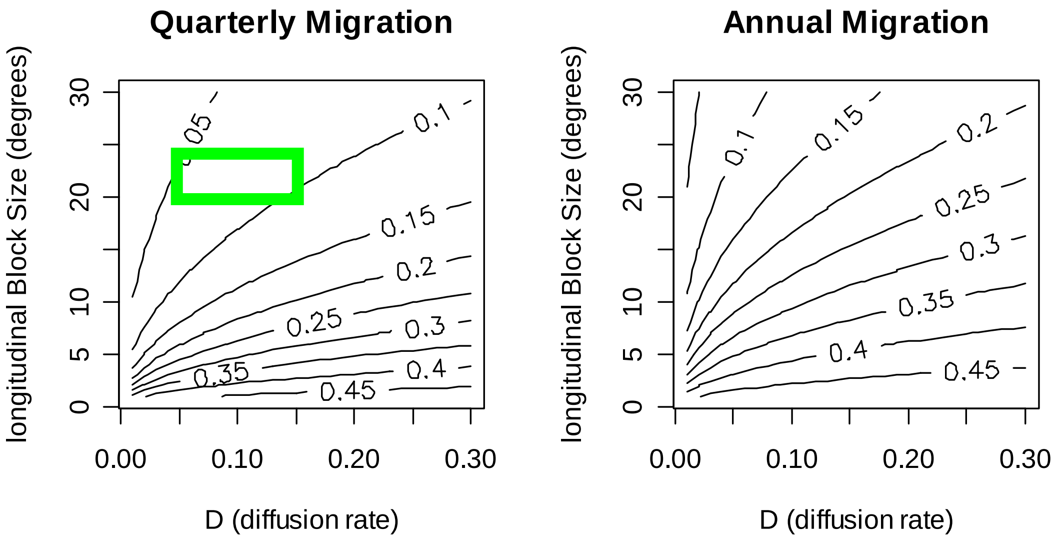

Figure 16. Contour plots of bulk transfer coefficients (i.e. proportion of net movement of fish expected to move from one region through to an adjacent region, at the end of the indicated time interval) corresponding to a range of diffusion rates, *D*, and spatial structures with longitudinal width of 0-30 degrees. Left panel corresponds to a quarterly time-step and right panel corresponds to annual. The green box roughly outlines the parameter space corresponding to the assessment model assumptions in Kolody et al. (2008) and Davies et al. (2008).

From this analysis, we adopted bounds on the diffusion rate of *D* = 0.05-0.15 for the assessment models. These values roughly correspond to the upper and lower bounds of the 2 likelihood unit contour in dataset B, (Figure 14) (the 1.92 likelihood unit contour would represent the 95% confidence limit). Model mis-specification is likely to lead to an overestimation bias in *D* (i.e. short duration tag releases, combined with habitat constraints and site fidelity would tend to over-estimate *D* and hence the mixing rates). However, given the small number of tags, uneven distribution of tag releases, and short durations at liberty, we would expect these values to be revisited in time. The bulk transfer coefficients corresponding to these diffusion rates, and the spatial structure assumed in the assessment model (Figure 17) are outlined in Figure 16.

We are aware of additional recent or planned PSAT tag deployments from French Polynesia, the Cook Islands, Australia, NZ, and Spain, which are not available for this analysis, and which should help to further refine our understanding of Pacific swordfish migration. Additionally, more substantive analyses of the individual tracks using updated geo-positioning algorithms, and in relation to environmental covariates is expected in the latter part of 2008-9 (Chris Wilcox, CSIRO, pers. comm.).

Review of spatial structure considerations in other swordfish populations and assessments

The following section provides a brief (and incomplete) overview of some spatial considerations in the biology and assessment of swordfish stocks in the Atlantic, Eastern Pacific, Northern Pacific and Indian Oceans.

Atlantic Ocean

A long time series of Atlantic swordfish sex ratios and maturity stages have been collected since 1990. Spatio-temporal variation in length-specific sex ratios indicate seasonal spawning migrations (Arocha et al. 1994). Certain parts of the Atlantic were identified as being important spawning areas. A range of studies of spatio-temporal sex-ratio at size in Atlantic swordfish and a 10 year time series were subsequently reviewed with the aim of identifying consistent patterns in sex ratios (Mejuto et al. 1998). Differences in the migrations of males and females were inferred from sex-specific CPUE, with females estimated to be more wide-ranging and associated with colder areas. From this it was hypothesised that preferential areas exist for reproduction and feeding, with migration corridors linking the two.

The complete time series of sex-specific observations was recently examined to describe spatio-temporal patterns in female swordfish reproductive activity in the Atlantic based on a large sample (~ 18 000) of gonads (i.e., gonad index, Mejuto & García-Cortés, 2007). Reproductive activity was found to be related to swordfish length and sea surface temperature, with distinct areas of intense reproductive activity being identified. A high proportion of males from 125 to 165 cm LJFL were associated with areas of intense reproductive activity. The results support the concept of a complex population structure segregated by sex and reproductive behaviour, with migration corridors linking areas of intense seasonal reproductive activity.

Given this population structural complexity, it therefore seems reasonable that a GLM used to estimate standardised CPUE indices for North Atlantic swordfish, 1963 to 2005, included area as a categorical variable (Ortiz et al. 2007). There are 14 relatively large zones in this analysis.

Despite the apparent spatial heterogeneity in the North Atlantic swordfish population, assessments have assumed a single homogeneous uni-sex stock. A length-based separable sequential population analysis (LSSVPA) was applied to Atlantic swordfish that fits to observations at length (Kimura & Scott 1994). The population estimates were similar to those of the VPA (age-based) used to routinely assess the population. No spatial disaggregation was assumed in either model.

After a 2006 workshop that reviewed available research on Atlantic swordfish stock structure, the existing stock structure assumed for Atlantic swordfish assessments, i.e. three separate stocks (Mediterranean, North Atlantic and South Atlantic), was not altered (Anon. 2007). The information reviewed is summarised in the Table below. The assessment models for the North and South Atlantic stocks assume discrete stocks, with no mixing and no spatial disaggregation. For the 2006 assessment, a Schaefer stock-production model was used, with a sensitivity test using a Fox model shape parameter. Additionally a VPA model was fitted (5 age classes) to 17 separate age-specific single sex CPUE indices (Anon 2007).

Results from recent tagging studies in the North Atlantic raise questions about the spatial assumptions made in the assessment model. A PSAT tagging study goes some way to addressing the possibility of a division between eastern and western Atlantic stocks (Nielsen et al. 2007). Data have been collected from 23 PSAT units. The movement estimated from the PSAT data was generally North-South, with no trans-Atlantic migration despite long periods at liberty (> 1 year). There were indications of migrations toward and away from spawning areas (as identified from larval distribution studies), and foraging site fidelity for some tagged fish (i.e. returned to the same southern location after an apparent northward migration).

Table extracted from Anon. (2007):

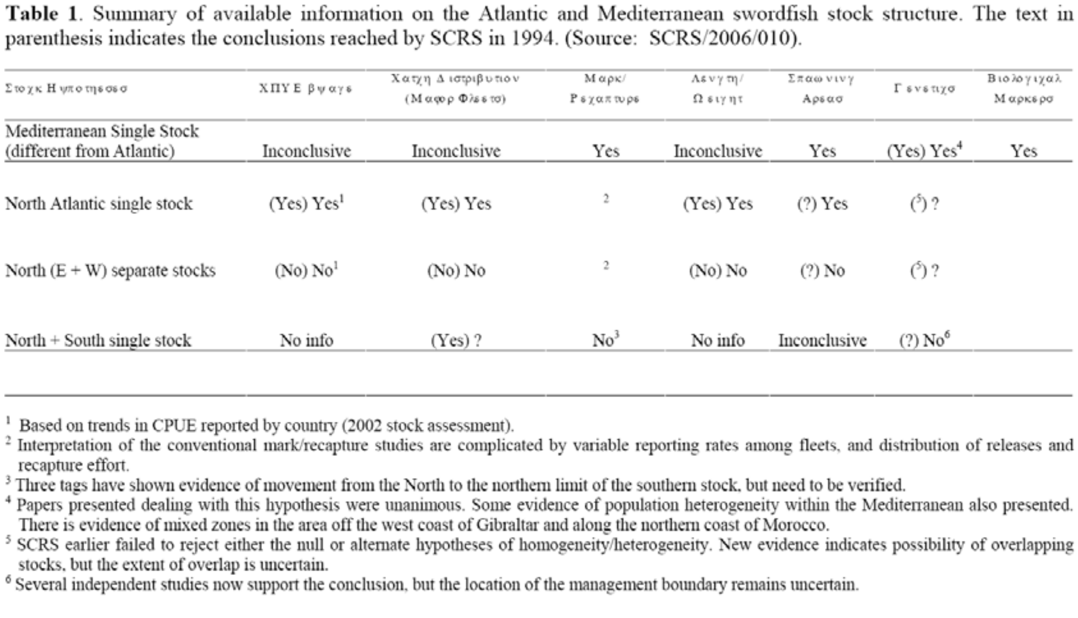

Table 1. Summary of available information on the Atlantic and Mediterranean swordfish stock structure. The text in parenthesis indicates the conclusions reached by SCRS in 1994. (Source: SCRS/2006/010).

Στοχκ Ηψποτηεσεσ	ΧΠΥΕ βψ αγε	Χατχη Διστριβυτιον (Μαφορ Φλεετσ)	Μαρκ/ Ρεχαπτυρε	Λενγτη/ Ωειγητ	Σπαωνινγ Αρεασ	Γενετιχσ	Βιολογιχαλ Μαρκερσ
Mediterranean Single Stock (different from Atlantic)	Inconclusive	Inconclusive	Yes	Inconclusive	Yes	(Yes) Yes[4]	Yes
North Atlantic single stock	(Yes) Yes[1]	(Yes) Yes	[2]	(Yes) Yes	(?) Yes	([5]) ?	
North (E + W) separate stocks	(No) No[1]	(No) No	[2]	(No) No	(?) No	([5]) ?	
North + South single stock	No info	(Yes) ?	No[3]	No info	Inconclusive	(?) No[6]	

[1] Based on trends in CPUE reported by country (2002 stock assessment).

[2] Interpretation of the conventional mark/recapture studies are complicated by variable reporting rates among fleets, and distribution of releases and recapture effort.

[3] Three tags have shown evidence of movement from the North to the northern limit of the southern stock, but need to be verified.

[4] Papers presented dealing with this hypothesis were unanimous. Some evidence of population heterogeneity within the Mediterranean also presented. There is evidence of mixed zones in the area off the west coast of Gibraltar and along the northern coast of Morocco.

[5] SCRS earlier failed to reject either the null or alternate hypotheses of homogeneity/heterogeneity. New evidence indicates possibility of overlapping stocks, but the extent of overlap is uncertain.

[6] Several independent studies now support the conclusion, but the location of the management boundary remains uncertain.

Eastern Pacific Ocean (EPO)

Standardised CPUE, biological and genetic data were reviewed for describing the structure of EPO swordfish to be used for structuring a stock assessment in 1998 (Hinton & Deriso 1998). Temporal shifts in relative abundance with respect to spatial zones (2° × 5° squares), and gonad condition were identified. It was concluded that a stock was centred in the Southern EPO. The population model was fitted to the relative mean annual CPUE weighted over all spatial zones making up the southern EPO and therefore assumed a single stock with no spatial disaggregation.

A 2006 assessment of southern EPO swordfish using SS2 repeated this stock structure assumption, such that EPO swordfish are assumed to have distinct stocks separated at 5˚S (Hinton & Maunder 2006). The western limit of the southern EPO stock was assumed to be 150˚W. Fisheries were defined with coastal and offshore subareas (separated at 90˚W). The 2006 assessment ignored the subarea structure used in the previous (2005) assessment, but rather defined six (or seven) fisheries in respect of unique selectivities and spatial structure.

In 2007, the results from analyses of standardised catch rates on a fine spatial scale, spatio-temporal size compositions and gonad condition for Pacific swordfish were reviewed (Hinton & Alvarado Bremer 2007). The review also included all Pacific swordfish genetic studies, including a recent study with a larger sample size, (Alvarado Bremer et al. 2006). This provided a basis for identifying stock separation in the Pacific. An hypothesis consistent with both sets of analyses points to four separate stocks in the Pacific Ocean: northwest (of the equator, 150W), northeast (of 5S, 150W), southwest (of the equator, 150W) and southeast (of 5S, 150W). It was recommended that separate assessments be conducted for the eastern and western stocks.

North Pacific

Kleiber & Yokawa (2002) described a preliminary swordfish assessment in the North Pacific (north of 10ºN), with 4 regions in respect of 30ºN, 160ºE: NW, NE, SW and SE. They found the estimated migration rates to be implausible (i.e. showing strong source-sink dynamics), and therefore fixed the migration rates in the model at a constant level of 10% per year.

Wang et al. (2006) describe a sex disaggregated model for the north Pacific. This model is spatially aggregated, although fleets were disaggregated on the basis of the 4 spatial units assumed by Kleiber & Yokawa (2002), with the equator forming the southern boundary.

Indian Ocean

Anon. (2006) describes a preliminary stock assessment for swordfish based on deterministic surplus production models for the whole of the Indian Ocean. While these aggregate models seemed plausible, it was noted that there is evidence for depletion in the area around La Reunion. It was recognized that these localized fishery effects should be examined more closely.

Proposed Alternative Spatial Structures

There is always a debate in any model formulation process about the optimal level of complexity. In this assessment, the debate is particularly formulated around stock structure and spatial structure (and to a lesser extent sex structure). If the model is not suitably disaggregated, there is a risk of statistical biases from the aggregation of non-homogenous units. If the model has too much disaggregation, the parameter estimation uncertainty is likely to be very high (and the problem becomes more technically and computationally demanding).

Depending on the biology of the populations, the available data, how the fishery operates, and the management objectives, there might be no reason to disaggregate the assessment. On balance, we think it is worth maintaining spatial disaggregation for the SW Pacific swordfish assessment at this time. The primary justification is the (potential at least for) non-homogenous units as a result of differential harvesting within the SW Pacific. If there are real conflicting trends in CPUE and size composition between two areas due to differential fisheries exploitation, this might not be describable on the basis of an aggregate population with two different selectivity assumptions. A two area model that fits all the data provides a much more satisfying description of the system than a compromise solution in which none of the data fits. We are proposing a spatial structure consisting of four longitudinal regions across the South Pacific convention area (Figure 17), for the following reasons:

- Genetics and fishery demographics suggest that 1) the Northern and Southern hemisphere swordfish stocks are reasonably isolated in the Western Pacific Ocean, and 2) the South-Eastern swordfish stocks are relatively isolated from the northern and south-western stocks.
- North-South migration within the Southern hemisphere cannot be well estimated at the moment, and the main fisheries tend to follow the seasonal swordfish concentrations.
- PSAT and conventional tags do provide a means for estimating East-West diffusive movement. While preliminary, these estimates are likely to represent an upper bound of mixing rates (i.e. if site fidelity and habitat constraints are important).
- The longitudinal stratification facilitates a direct comparison between the aggregate assessment results from the 2006 assessment and the 2008 assessment. Depending upon considerations of data quality and stock structure, it is easy to remove one or both of the more eastward extensions of the model domain.
- The revised spatial structure and tagging data downplays the importance of site fidelity models within the SW Pacific, such that the relatively small migration rates observed in West-East directions can probably be assumed to come from homogenous mixing.
- Four regions represents a tractable estimation problem.

Disadvantages of this spatial structure relative to 2006 include:

- The coarser spatial structure means that the model will have less capacity to describe localized depletion, and will potentially introduce biases by aggregating non-homogenous regions.
- The catch rate and size composition data in the South-Central Pacific is more sparse and poorly understood than the South-West Pacific. It may prove unreasonable to attempt an assessment in the South-Central region.

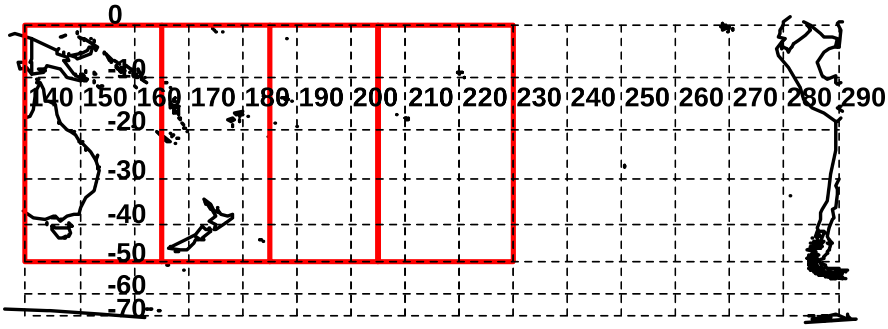

Figure 17. Proposed spatial structure for the 2008 South-West/South-Central Pacific Pacific swordfish assessment.

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Attachment 5. Report of the Southern WCPO Swordfish Assessment Workshop (convened 16-18 April, 2008, Secretariat for the Pacific Community, Noumea, New Caledonia). WCPFC-SC4-2008/SA-IP-1. (52p.)

SCIENTIFIC COMMITTEE
FOURTH REGULAR SESSION

11-22 August 2008
Port Moresby, Papua New Guinea

REPORT OF THE SOUTHERN WCPO SWORDFISH ASSESSMENT WORKSHOP APRIL 16−18, 2008

WCPFC-SC4-2008/SA-IP-1

Report of the Southern WCPO Swordfish Assessment Workshop

April 16−18, 2008

Secretariat for the Pacific Community
Noumea, New Caledonia

Report of the Southern WCPO Swordfish Assessment Workshop

Abstract

The *Southern WCPO Swordfish Assessment Workshop* was held at the Secretariat for the Pacific Community (SPC), Noumea, New Caledonia, April 16−18, 2008. The primary objectives of the meeting were to provide a technical review of data, analyses and stock assessment modelling assumptions underpinning the stock assessment of broadbill swordfish in the southern WCPO which is being undertaken by CSIRO (Australia) and NIWA (New Zealand) scientists during 2008. In addition to the workshop discussion, the report includes a summary of available fisheries data, relevant biological research, an agreed workplan for the assessment, and brief histories of the swordfish fisheries in the Cook Islands, New Caledonia and French Polynesia.

1. Introduction

The *Southern WCPO Swordfish Assessment Workshop* was held at the Secretariat for the Pacific Community (SPC), Noumea, New Caledonia, April 16−18, 2008. The meeting was chaired by Adam Langley of the SPC, and attended by 18 participants from a number of fishing nations and organizations throughout the Western and Central Pacific Ocean (WCPO). A list of meeting participants is provided as Attachment A.

The primary objectives of the meeting were to provide a technical review of data, analyses and stock assessment modelling assumptions underpinning the stock assessment of broadbill swordfish in the southern WCPO which is being undertaken by CSIRO (Australia) and NIWA (New Zealand) scientists during 2008. The assessment is being undertaken at the request of the Western and Central Pacific Fisheries Commission (WCPFC), in relation to WCPFC Conservation and Management Measure 2006-3, which places limits on the number of vessels permitted to target swordfish in the WCPFC convention area, south of 20°S:

> …*The Commission will review this measure in 2008, on the basis of advice from the scientific committee, following their consideration of an updated swordfish stock assessment that improves the understanding of stock structure and assesses the status of swordfish throughout its range and distribution in the South Pacific Ocean.*

The process for obtaining the updated assessment was described in the report of the Commission meeting held in December 2007:

> *72. Some CCMs raised questions regarding a planned assessment of southwest Pacific swordfish. Australia proposed that this will be a full assessment led by Australia and NewZealand on behalf of the Commission, peer reviewed by SPC, and submitted to SC4 for further review and consideration of management actions. Scientists from all CCMs are encouraged to contribute relevant data analyses and biological insight to the assessment, and an informal workshop is being held at SPC in April 2008 to facilitate this exchange of ideas."*

The results of the assessment will be presented to the 4th meeting of the Scientific Committee for the WCPFC in August 2008. Future swordfish research priorities discussed by the workshop are also included.

This report consists of a number of relevant points agreed by all workshop participants, while short summaries of the relevant parts of various working and background papers have been included as extracted by the rapporteurs (Robert Campbell, Nick Davies and Dale Kolody). The working papers have been circulated to all participants and other interested parties, however, they should not be cited without prior approval by their respective authors, as many of these papers were informal, or in a draft form. The order of the report has been altered somewhat from the order on the agenda, to improve readability and reflect the fact that many working papers were relevant to multiple agenda items and iteratively revisited.

Working papers were also submitted by a number of individuals unable to attend the meeting. A list of working and background papers discussed by the workshop is provided in Attachment B. The Agenda for the workshop is provided as Attachment C. Summaries of data and research available to the assessment is summarized in tabular form in Attachment D. Brief descriptions of the swordfish fisheries in the Cook Islands, French Polynesia and New Caledonia are presented in Attachment E.

1a. Background to the 2008 Southern WCPO Swordfish Assessment

A review of the 2006 stock assessment was presented (Kolody et al. 2006, Davies et al. 2006). The assessment represented a diverse exploration of stock assessment models and biological assumptions (e.g. see Figure 1). The final stock status summary was based on an ensemble of Multifan-CL models that were plausibly consistent with the fisheries data (catch in numbers, standardized CPUE, size composition) and biological research available at the time. The model selection uncertainty and parameter estimation uncertainty from this ensemble indicated that the stock status was highly uncertain, particularly with respect to MSY-related reference points (Figure 2).

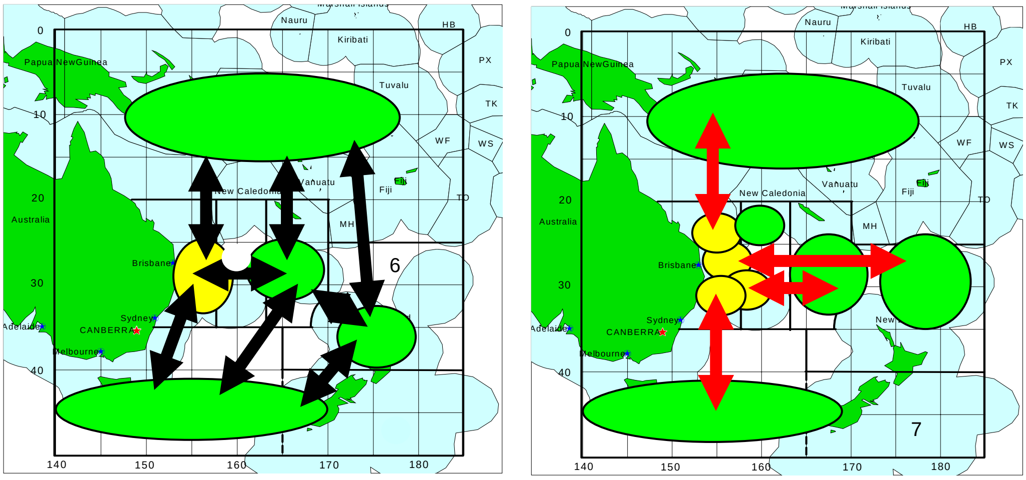


Figure 1. (from Kolody et al. 2006) Schematic representation of migration hypotheses and stock structure assumptions explored in the 2006 assessment. Left panel illustrates a conventional homogenous mixing structure (as used in the final Multifan-CL

assessment), while the right panel illustrates a site fidelity model with migration to shared spawning grounds (explored in the Davies et al. 2006 CASAL assessment).

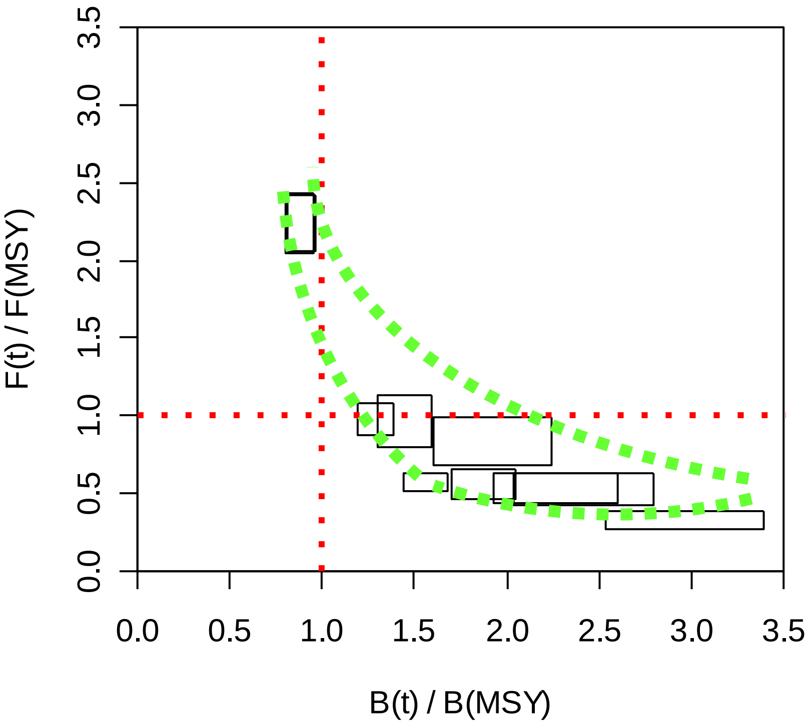


Figure 2. Plot of current biomass and current fishing mortality relative to MSY levels for the plausible ensemble. Each black box indicates the 95% confidence intervals (though not the correlation) associated with an individual model. The dashed (green) banana shape roughly outlines the space considered to be plausible (even though none of the models covered some of the region).

1b. Priority Issues identified from the 2006 Stock Assessment

A working paper summarized a number of issues that were identified in relation to the 2006 assessment (Kolody et al. 2008). These included:

The spatial domain of the 2006 assessment differed substantially from the management domain of CMM2006-3 (**Figure 3**).

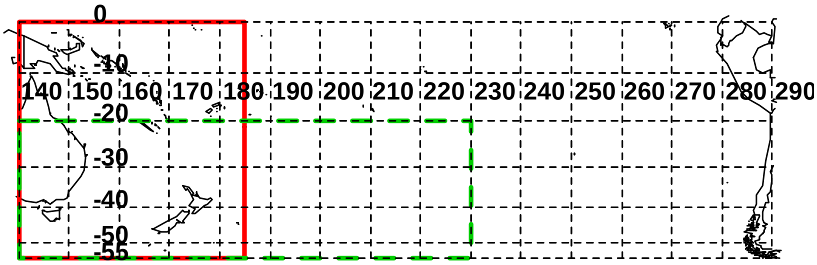


Figure 3. South Pacific map illustrating 2006 swordfish assessment domain (solid red box), and area of application of WCPFC Conservation and Management Measure 2006-3 (broken green box).

2) The data associated with the 2006 assessment extended only up to 2004, and the "one way trip" nature of the fishery history did not provide informative contrast to estimate stock productivity. In some key fisheries, recent declines in catch, and corresponding increases in CPUE may provide informative contrast to reduce productivity uncertainty.
3) Most large pelagic assessments are reliant on commercial CPUE trends as relative abundance indices, and are subject to biases from operational changes over time that cannot be easily detected or corrected. Additional data and analyses to help interpret catch rates is desirable.
4) The 2006 Multifan-CL assessment did not produce convincing estimates of seasonal migration within the sub-regions of the model. Conflicting trends in seasonal abundance between fleets that operate in the same region indicate a confounding between catchability and seasonal migration.
5) Growth (size-at-age) estimates used in the 2006 assessment for the SW Pacific swordfish stock suggest much slower growth rates compared to estimates from other Pacific populations. It is unclear whether this represents biological or methodological variation.
6) Maturity estimates from the SW Pacific indicate much older maturation than other studies in the Pacific (even after accounting for differences in age estimation).
7) Natural mortality is poorly quantified for swordfish.
8) Potential differences by sex in growth, maturity, mortality and migration are ignored in the assessment.

Using the CASAL modelling framework, one of a range of model structures explored in the 2006 assessment assumed migrations associated with spawning and site-fidelity. Under this scenario spawners migrated to a single area to spawn but then returned to their respective foraging grounds (without mixing) from whence they originally recruited (Figure 1). This essentially represents separate stocks, remaining mostly in their foraging ground, but there is a shared spawning area where fisheries operate upon a mixed population. Recruitment processes were specific to each stock. Other model structures examined alternative assumptions for homogenous mixing, mixing on the spawning area only, and a single stock area. The effects of the structural and statistical assumptions on the CASAL model uncertainty were not fully explored in the 2006 assessment given the relatively narrow range of model options investigated.

A working paper was presented which describes a partial exploratory update of the SW Pacific swordfish Multifan-CL assessment from 2006 (Kolody 2008). The paper investigated i) the implications of alternate growth curves and maturity ogives, and ii) the inclusion of three additional years of data for some fleets (2005-2007). The alternative growth curve and maturity schedule were based on some comparative age estimation work discussed in section 3 below. The faster growth curve was coupled with a lower age at maturity (50% aged 4 years as opposed to the previous assumption of 9 years). The new data consists of the old data (up to 2004) plus: catch from Japan in 2005, standardized effort from Australia (1997-2007), catch from Australia to 2007, catch from all other fleets to 2006, and catch-at-length/mass data for most fleets updated to include 2005-6 (2004 for EU/Spain).

Thirty-two model specifications were explored in a balanced factorial design of assumptions (a subset overlapped with the models explored in 2006 corresponding to the most optimistic and pessimistic of the models from the Most Plausible Ensemble). Models with the faster growth and maturity, and slower growth and maturity both seemed to be plausibly consistent with the other fisheries data. Plausible models with faster growth/maturity were more pessimistic than the faster growth/maturity assumptions in terms of current stock status, but equivalent or slightly more optimistic in terms of projected spawning biomass in 2009 (assuming 2004 effort levels). While (most) models seemed to converge successfully, all of the models fit to the new data failed to meet the minimum plausibility criteria defined in the 2006 assessment. The relative importance of the different data sets contributing to this problem had not been examined in detail. Potential problems included: i) an odd mix of missing effort observations and poorly approximated catch observations (i.e. catch substituted for missing values) might have led to model conflicts, ii) the large amount of size sampling data from the New Zealand domestic fishery in the last 2-3 years (due to the new port sampling program) might have implications for the pattern of selectivities shared across fleets, and iii) the recent upward trend in the Australian CPUE breaks the “one-way-trip” pattern observed in 2006, and there might be structural constraints that prevent the model from properly describing the recruitment and migration processes required to explain this trend. The paper recommended focussing on the revised spatial structure in 2008 (described in section 4), rather than pursuing the 2006 spatial structure further.

2. Compilation and Review of Fisheries Data

2a. Catch and Effort Data

The working paper Campbell (2008) was presented. This paper provided a detailed summary of the catch and effort and commercial size data available for the stock

assessment. The data described pertains to longline fleets operating in that part of the WCPFC convention area which generally lies within the south Pacific. In particular, the area of interest was bounded to the north by the equator and to the east by the eastern boundary of the WCPFC Area (130°W or 230°E) whilst the southern boundary was placed at 50°S and the western boundary at 140°E.
The catch and effort was compiled from the following sources:

- Aggregated (month by 5x5-degree) swordfish catch and effort data held by SPC for all fleets operating in the southern WCPO.
- Operational level logbook data held by the Australian Fisheries Management Authority relating to the Australian domestic longline fleet operating in the Eastern Tuna and Billfish Fishery off eastern Australia.
- Operational level logbook data held by the Ministry of Fisheries, NZ relating to the New Zealand domestic longline fleet operating around New Zealand.

A listing of the longline fleets for which catch and effort data was available is provided in Table 1. Data was available from24 fleets spanning the years 1952 to 2007. Annual summaries of the data, including nominal catch-per-unit-effort, by fleet and fleet type, within each of the spatial areas used in the stock assessment model (see below) are provided in the working paper, as well as maps displaying the spatial distribution of the catch across the southern WCPO for the main fleets catching swordfish.

The data were described in spatial units corresponding to the proposed spatial structure of the assessment as described in section 4 (Figure 4). These four Areas are defined as follows:

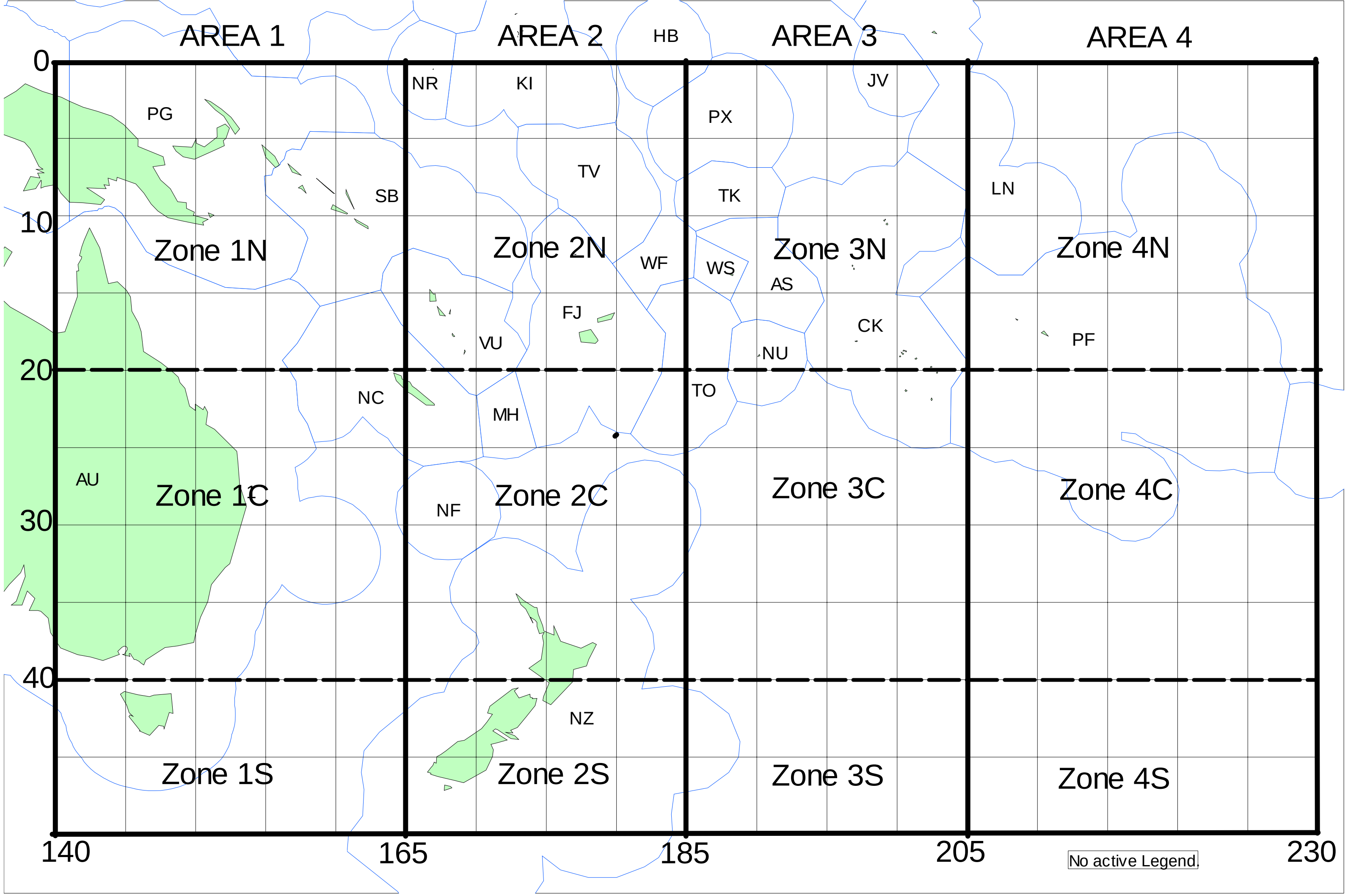
Area 1:	140-165°E, 0-50°S
Area 2:	165-185°E, 0-50°S
Area 3:	185-205°E, 0-50°S
Area 4:	205-230°E, 0-50°S

Table 1. Listing of the longline fleets operating in the southern WCPO for which catch and effort data are available. The following summary statistics are also provided: (a) Fleet Type used to categorise fleet, (b) The first and last years for which data was available, (c) The spatial extent of the data as defined by the number of 5x5-degree squares of latitude and longitude, (d) Total effort over all years (Hundreds of Hooks), and (e) Total Catch over all years in i) number of fish caught and ii) tonnes, estimated whole weight. The final year of data is not complete for some fisheries.

Nation	Abbrev.	Fleet	Data Years		Spatial	Effort	Catch	
	Flag	Type	First	Last	Extent	Hhooks	Number	Tonnes
Japan	JP	DWFN	1952	2005	169	29,488,014	1,135,130	76,750
Australia	AU	AU	1985	2008	34	1,279,098	346,953	18,692
Korea	KR	DWFN	1962	2006	151	25,793,328	375,143	16,384
Taiwan	TW	DWFN	1964	2006	146	15,794,200	180,058	11,491
New Zealand	NZ	NZ	1989	2007*	31	1,151,700	129,528	6,693
Spain	ES	DWFN	2004	2006	41	51,280	70,943	5,034
China	CN	DWFN	1996	2006	95	1,279,637	32,379	1,311
Fiji	FJ	PIN	1989	2006	38	3,221,827	25,458	1,222
French Polynesia	PF	PIN	1992	2006	39	1,652,488	16,555	965
Cook Islands	CK	PIN	1994	2006	41	299,627	10,809	587
Vanuatu	VU	PIN	1995	2006	120	838,675	7,622	372
Tonga	TO	PIN	1982	2006	28	445,592	6,298	294
New Caledonia	NC	PIN	1983	2006	24	691,675	5,331	290
American Somoa	AS	PIN	1996	2006	27	705,029	2,147	255
Papua NewGuinea	PG	PIN	1993	2006	19	533,055	5,281	236
Western Samoa	WS	PIN	1993	2006	4	637,193	3,121	202
Solomon Lslands	SB	PIN	1981	2005	14	381,116	1,418	72
United States	US	DWFN	1997	2004	7	11,935	104	6
Philippines	PH	OTH	2002	2003	4	1,818	99	5
Indonesia	ID	OTH	2004	2005	13	8,906	64	3
Nuie	NU	PIN	2005	2006	6	7,665	48	3
Kiribati	KI	PIN	2003	2003	5	1,985	31	1
Tuvulu	TV	PIN	2005	2005	2	65	1	0
Fed. States Micronesia	FM	PIN	1995	1998	2	565	5	0

* Quarters 1-3 only

Figure 4. Map of the southern Western Central Pacific Ocean indicating the Areas and Zones used to stratify the catch and effort data.



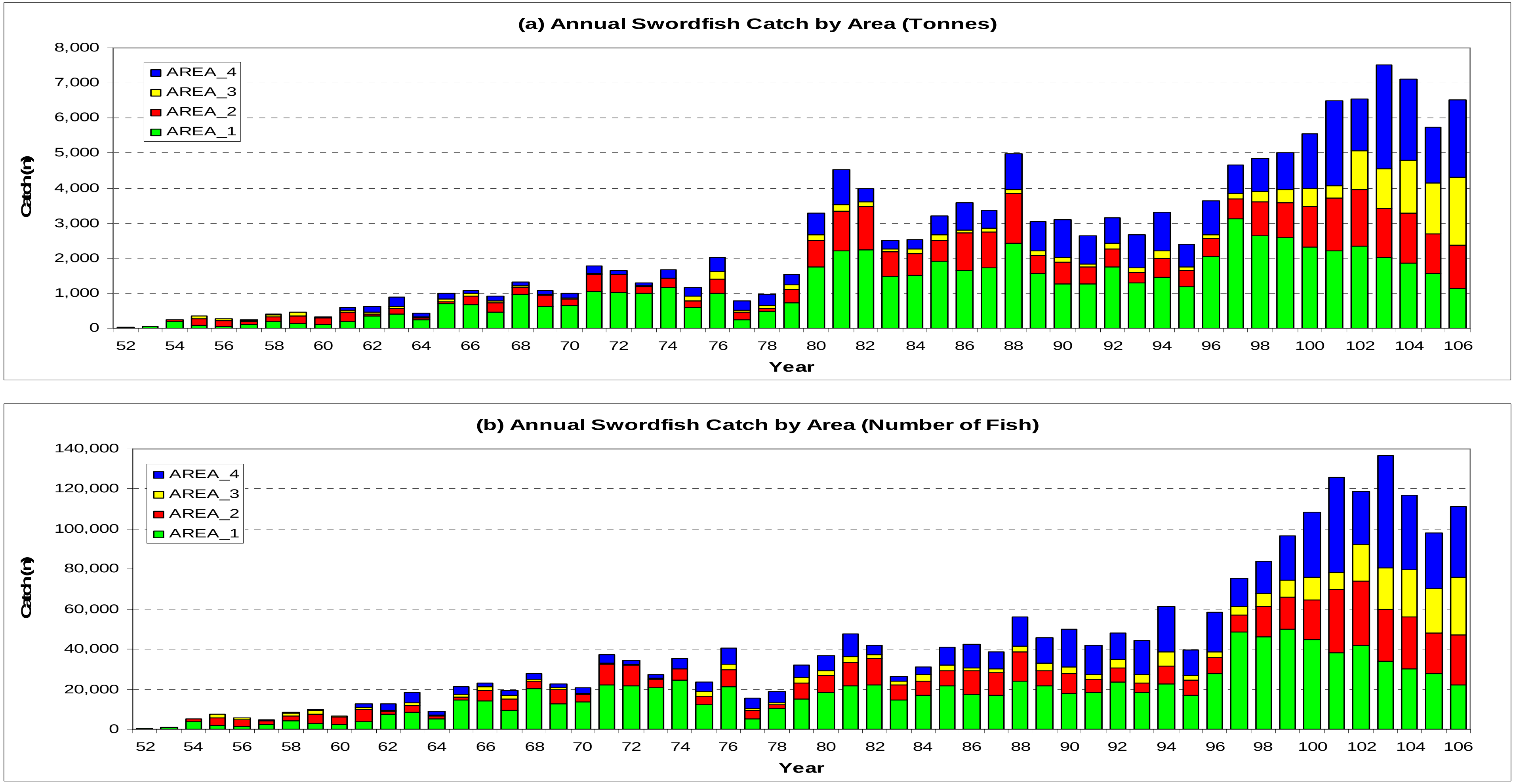


Figure 5. Annual catch, (a) tonnes, (b) numbers, of swordfish taken by longline fleets operating in each of the four assessment areas of the southern WCPO. (First year is 1952)

As the catch of swordfish is not homogenous across each Area, each Area was further stratified into a Northern (0-20^{o}S), Central (20-40^{o}S) and Southern (40-50^{o}S) region giving a total of 12 spatial-zones across the southern WCPO. Each of these zones is shown in Figure 4.

Total annual catch, stratified by assessment Area, is displayed in **Error! Reference source not found.**. Total annual catch was less than 2,000 t before 1980 and averaged around 3,000 t between 1980 and 1995. After this time, the total annual catch increased rapidly peaking at around 7,500 t in 2003. The preliminary catch estimate for 2006 is around 6,500 t. It was noted that there has been a large decrease in the catch of swordfish caught in the south-west Pacific over the past decade (mainly due to a decline in Area 1 from 3,110 t in 1997 to 1,140 t in 2006) though this decline had to some extent been offset by an increase in the catch of swordfish in Areas 3 and 4 (increasing from around 950 t in 1997 to over 4,300 t in 2006).

The working paper Mejuto et al. (2008b) was also tabled and discussed. This paper includes information about CPUE data from the Spanish fleet throughout the Pacific by size and sex. However, this paper is primarily focussed on reproductive activity and is summarized under fisheries independent research.

Summary of Workshop Discussion for Agenda Item 2a:

- The Workshop noted that the 2006 catch and effort data for Japan was still not available and that the 2006 data for Taiwan was largely incomplete. Only the fishery data for Australia and New Zealand fleets was available for 2007. As such, the Workshop recommended that the assessment be conducted up to the end of 2007 with the last available catch for each fleet used to substitute for the missing catches in 2006 and 2007.
- Workshop participants from Cook Islands, Tonga, Fiji, New Caledonia and French Polynesia noted the availability of operational data for their fleets and that this data is presently held by SPC. However, the Workshop also noted the possible limited utility of this data for CPUE standardization due to changing fleet structure and fishing strategies that might not be represented in logbooks. The Workshop requested a brief summary of changes in fleet operational characteristics from PIN participants (particularly over the last 10 years).
- The Workshop was informed of the existence of a large amount of operational level catch/effort data relating to Taiwanese vessels landing fish in Pago Pago. The Workshop recommended requesting this data to assist in the calculation of an abundance index (based on CPUE standardization) in Regions 3 and 4.
- The Workshop recommended that the project team identify specific data gaps limiting swordfish assessments in the WCPO.

2b. CPUE Standardization

Two working papers were discussed under this agenda item.

Campbell, Unwin and Davies (2008) provided a detailed description of the analyses undertaken to standardise the Australian and New Zealand catch and effort data to obtain an index of swordfish abundance (availability) within the central zones of Areas 1 and 2. For both fleets, operational level logbook data was available and a range of spatial-temporal and operational level factors were used to standardise effort.

The paper also described ongoing collaborative work being undertaken with Dr Miyabe at the NRIFSF in Shimizu, Japan to derive standardised CPUE indices based on 1x1-degree Japanese catch and effort data stratified by hook-per-baskets.

For the Australian fleet, comprehensive logbook data is available from the third quarter of 1997 to the end of 2007. A two-step model was used with the Binominal distribution used to model the probability of obtaining a non-zero catch with a log-Gamma distribution used to model the size of the positive catch rate. Each model included the following factors: *year, quarter, region, hooks-per-float, proportion of hooks with light-sticks, bait-type, start-time of set, moon-phase and southern-oscillation index*. Two factors accounting for competition between vessels were also incorporated into the models. Only the data pertaining to the "core" swordfish catch region in the Australian fishery was fitted to each model. For the New Zealand fleet the best available index was confined to the period from the first quarter of 1998 to the third quarter of 2007 and only used the data associated with "core" swordfish vessels. The analysis used a General Additive Model and fit a large number of operational and environmental variables.

A comparison of both the annual and quarterly standardised CPUE indices obtained for the Australian and New Zealand fleets is shown in Figure 6a-b with the trends in both displaying a good degree of agreement. The workshop noted that the indices

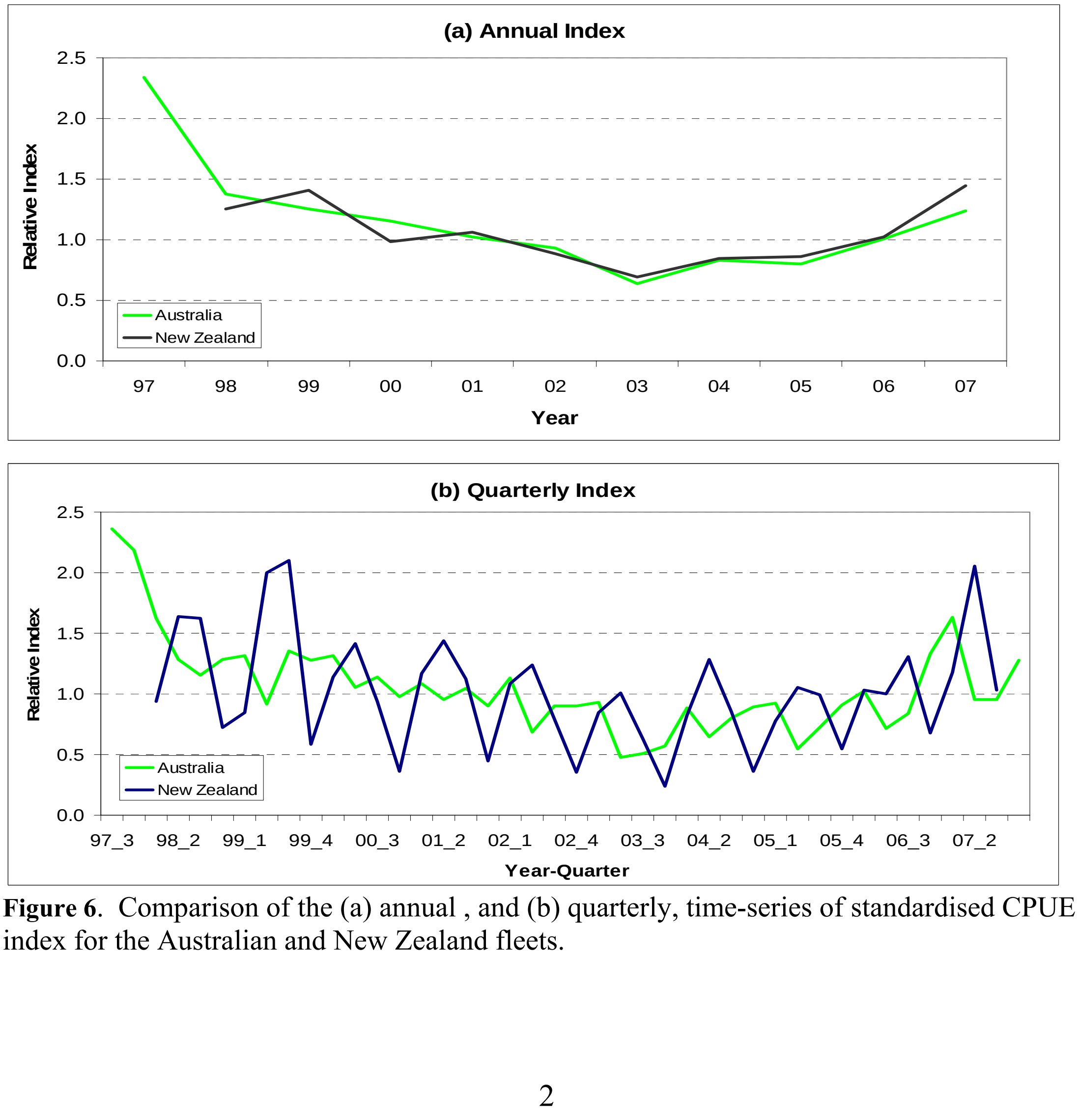


Figure 6. Comparison of the (a) annual , and (b) quarterly, time-series of standardised CPUE index for the Australian and New Zealand fleets.

based on the initial analyses using the Japanese data were somewhat inconsistent with the Australian and New Zealand indices in that they showed a continuing decline to 2005 (that last year for which data was available). However, it was noted that these results were preliminary and that further work was required to finalise these analyses.

The standardised CPUE indices from the Australian and New Zealand fleets (together with the analyses of the Japanese 1x1-data) provide "abundance" indices for the central zones of Areas 1 and 2. Campbell et al (2008) also describes an attempt to obtain a CPUE-based index for other Areas and zones in the assessment model. In particular, if the current assessment is to extend the spatial coverage of the previous assessment (which was confined to the SW Pacific) to the east, and possibly out to the eastern boundary of the WCPFC convention area, then it would be important to obtain some index of swordfish abundance within these eastern regions. Unfortunately the coverage of the Japanese fleet in these regions (between 185-230E) is poor and as such is not sufficient to use to construct an index. The aggregated monthly-5x5-data was therefore used and nominal 5x5-and-quarter-stratified CPUE indices within a core catch area were calculated for each fleet.

The resulting indices were discussed by the workshop but it was noted that there was a considerable lack of consistency in the trends of the indices for different fleets within the same Area and zone. It was also noted that these differences are likely to be due to the fact that the fishing practices (i.e. target species) for many of the fleets differ and that many fleets have also undertaken significant shifts in fishing practices over the past 10-20 years. As the stratified-nominal indices presented had not been "standardized" to account for these changes it was likely that many would not be a good indicator of swordfish abundance. The workshop noted that if periods where fishing practices had remained relatively stable could be identified, then the associated indices during these periods may provide a better index of underlying swordfish abundance. For this purpose, representatives from the Cook Islands, New Caledonia and French Polynesia provided summaries of the tuna and billfish fisheries within their EEZs and the changes associated with these fisheries over time (Attachment E).

Mejuto et al. (2008b) described standardized catch rate analyses from the Spanish fleet. As the authors were not able to present this paper to the workshop, the abstract is provided here to describe its contents. Standardized catch rates in weight were obtained using General Linear Modeling (GLM) from sets carried out by the Spanish surface longline fleet targeting swordfish in the South central and South western Pacific areas during the 2004-2006 period. Year, quarter, area, gear-type and the ratio between swordfish and blue shark species were used as model factors. The model tested explained 75% of CPUE variability. As in the case of the Atlantic, most of the CPUE variability was attributed to the ratio between the two species and secondly, to the gear factor. Other significant, although less important factors were quarter and area and the interaction between the two, while the year was considered the least important of all the factors examined during this period. The time period covered is too short to be able to lead to any conclusions on the standardized CPUE trend, but the results suggest that activity was stable during the Spanish fleet's initial period of operation in these regions.

Summary of Workshop Discussion for Agenda Item 2b:

- The Workshop endorsed the use of the Australian standardised CPUE index for 1997-2007 as an abundance index for the Central zone in Region 1 and the use of the "core" NZ standardised CPUE index for 1998-2007 as an abundance index for the Central zone in Region 2.
- The Australian and New Zealand CPUE indices were noted to have similar trends over the past decade.
- When partitioned by size class, the increasing trend in Australian CPUE in recent years was seen to be largely a result of recent increases in the number of small fish being caught in the fishery, and evidence for an increase in recruitment in recent years (possibly at levels higher than observed in the late 1990s) .
- The Workshop was informed that collaborative work with Dr Miyabe in Shimizu was presently underway on calculating a standardised CPUE index for the Japanese fleet and encouraged this work to continue.
- The Workshop noted that a preliminary Japanese standardized CPUE index in Region 1C continues to decline and does not display the increasing trend observed in the Australian index.
- The Workshop noted the difficulties being experienced in undertaking the Japanese CPUE analyses and recommended that for future WCPO assessments a full exchange of data is needed to facilitate these analyses.
- The Workshop noted that it might be possible to use information on the catch of non-swordfish species in the total catch to help identify targeting practices for those fleets for which operational level data was not available.
- The Workshop noted that the Area-Quarter-stratified nominal CPUE indices calculated for the main fleets showed inconsistent trends over time within similar regions. It also noted that the Japanese index within Region 1C diverged from the standardized index in the same region. It was noted that these indices do not fully account for operational changes.
- The Workshop was informed that a large amount of operational level data relating to the Taiwanese distant-water fleet operating in the eastern region has been collected by the US from vessels landing in Pago Pago. Given the potential utility of this data to help construct a swordfish index within this eastern region, the Workshop recommended that a request be made to access this data for this purpose.
- A working paper provided to the Workshop by Spain indicated a flat trend in CPUE for the Spanish fleet for the years 2004-06. However, the Workshop noted that the index was based on data from a large spatial area (from tropical north Pacific through to the South-West-South-Central Pacific) and as such was not directly relevant to any of the regions in the assessment model. It was also questioned whether the "ratio" variable was a valid factor to be used in the standardizing model. As noted in the report of pelagic longline catch rate standardization meeting, held in Honolulu in February 2007 (Hoyle et al, 2007) the proportion of the 'other' species may be strongly confounded with the catch of the species of interest, and also affected by the abundance of the other species. Including this covariate may remove some of the temporal abundance signal from the data and is not recommended.
- The Workshop recommended maintaining the separation of fleets across the different zones and regions of the assessment model for possible use in the analysis of future management options.

The workshop concluded that the lack of reliable and consistent CPUE trends in the South-Central Pacific was a major impediment for producing credible assessment results for this region of the proposed assessment domain.

2c. Size and Sex Composition

The working paper Campbell (2008), presented under Agenda Item 2a, provided a detailed summary and description of the commercial size data collected from longline fleets in the assessment region which is available for the stock assessment. This data was compiled from the following sources:

i. Length (lower jaw to caudal fork) data held by SPC pertaining to individual swordfish sampled from longline fleets operating across the southern WCPO.

ii. Processor measured and recorded dressed weights (trunked) pertaining to swordfish landed at various ports within the Australian Eastern Tuna and Billfish Fishery operating off eastern Australia.

iii. Port sampling lengths (lower jaw to caudal fork) pertaining to swordfish landed within the domestic New Zealand longline fishery.

iv. Dressed weight and length (orbital-eye to caudal fork) data held at NRIFSF, Japan pertaining to individual swordfish sampled from longline fleets operating across the southern WCPO.

v. Length (lower jaw to caudal fork) provided by Spain pertaining to individual swordfish sampled from longline fleets operating across the Pacific Ocean.

A listing of the longline fleets for which size data was available is provided in Table 2. Data is available from 21 fleets spanning the years 1971 to 2007. Histograms of the size of swordfish caught by each fleet within each Area and quarter of the year, provided in the working paper, were noted.

Table 2. Listing of the longline fleets operating in the southern WCPO for which size sampling data for swordfish are available. The following summary statistics are also provided: (a) Fleet Type used to categorise fleet, (b) Source of the data, (c) Data type (DWT=dressed weight, OFL=Orbital-fork length, LJL=Lower jaw-fork length) (d) The first and last years for which data was available, (e) The spatial extent of the data as defined by the number of 5x5-degree squares of latitude and longitude, (f) Total number of individual swordfish sampled. The workshop noted that New Zealand port sampling data was missing from the is table.

Nation	Abbrev.	Fleet	Data	Size	Data Years		Spatial	Number
	Flag	Type	Source	Type	First	Last	Extent	Fish
Australia *	AU	AU	AFMA	DWT	1997	2007	32	244775
New Zealand	NZ	NZ	NIWA	LJL	2005	2007	16	13242
Spain	SP	DW	Spain	LJL	2004	2004	24	9548
Japan **	JP	DW	NRIFSF	OFL	1971	2002		8607
Japan	JP	DW	SPC	LJL	1987	2004	44	5291
Fiji	FJ	PN	SPC	LJL	1994	2006	24	1600
Papua New Guinea	PG	PN	SPC	LJL	1996	2006	11	1397
New Zealand	NZ	NZ	SPC	LJL	1992	2005	16	1387
Tonga	TO	PN	SPC	LJL	1995	2006	8	1235
New Caledonia	NC	PN	SPC	LJL	1993	2006	8	798
Taiwan	TW	DW	SPC	LJL	1997	2006	19	703
Cook Islands	CK	PN	SPC	LJL	1995	2005	8	432
Solomon Island	SB	PN	SPC	LJL	1996	2004	7	258
French Polynesia	PF	PN	SPC	LJL	1996	2006	13	253
Korea	KR	DW	SPC	LJL	1992	2006	16	231
Western Somoa	WS	PN	SPC	LJL	1998	2005	4	206
Vanuatu	VU	PN	SPC	LJL	2003	2005	14	158
Philippines	PH	OT	SPC	LJL	2003	2003	2	116
China	CN	DW	SPC	LJL	1996	2005	11	33
United Stats	US	OT	SPC	LJL	2004	2004	1	11
American Somoa	AS	PN	SPC	LJL	2002	2004	4	7
Marshall Islands	MH	PN	SPC	LJL	1993	1993	1	3
Fed. State Micronesia	FM	PN	SPC	LJL	2002	2002	1	1

* Trunked weights, ** Data aggregated by 10x20-degrees of latitude and longitude

The working paper Campbell, Davies and Griggs (2008) was presented. In this working paper a more detailed summary and description of the size and sex composition data collected from the Australian and New Zealand domestic longline fisheries is provided. This data is the most comprehensive available within assessment Areas 1 and 2.

Swordfish length, weight and sex observations have been collected by the New Zealand Scientific Observer programme since 1987 and these data have been used to derive length frequencies, length-weight relationships and sex ratios for the catches. Between 12 and 705 swordfish have been sampled annually by observers from 1987 to 2007, though the samples collected before 1996 were almost exclusively from foreign licensed vessels targeting southern bluefin tuna. Since July 2005, a port sampling programme has been implemented in New Zealand with the aim of estimating the annual length, weight, and sex composition of swordfish in landings from the New Zealand tuna longline fishery. Individual fish weights in the processed state were collected from fish processors and were converted to estimates of total fish length using a relationship derived from observer measurements of fish fork length and processed weight. Length-specific sex ratios derived from samples collected by scientific observers on board vessels were then used to apportion the port sample length frequencies by sex.

Within Australia a size sampling program commenced in mid-1997 and has collected processed weight data for swordfish handled by the main processors and market facilities along the east coast. Between July 1997 and June 2007 a total of 244,784 individual swordfish weights have been collected under this program, representing around 78% of the swordfish landed in the fishery. These data have been used to derive a range of size-based indicators for the fishery, including the size-compositions, by quarter, of swordfish landed within each the main regions of the fishery, quarterly time-series of mean and 95-percentile weights, and the proportion of small, prime and large fish, within each of the main regions along the east coast. The workshop noted that there has been a significant decline in the weights of swordfish sampled in the principal landing port of Mooloolaba over time (Figure 7a) and that there has also been a corresponding decline in the proportion of prime and large fish in these samples (Figure 7b).

The working paper also provided some details of the sex of swordfish collected by observers from both Japanese and Australian longliners operating off eastern Australia. The data from the Japanese fleet covers the years 1991-97 whilst the data from the Australian fleet covers the years 2001-07. Of the 3890swordfish sampled in the ETBF the sex ratio between male and female fish is close to 50:50 (52%: 48%) while the 2832 swordfish sampled on Japanese vessels the sex ratio is 75%:25% female to male. The reasons for these differences presently remain unknown, but may be due to differences in the locations fished as the Japanese fleet, in general, fished in the more southern regions off eastern Australia. The sex ratios of New Zealand swordfish catches also indicate higher proportions of females, particularly in the large size classes.

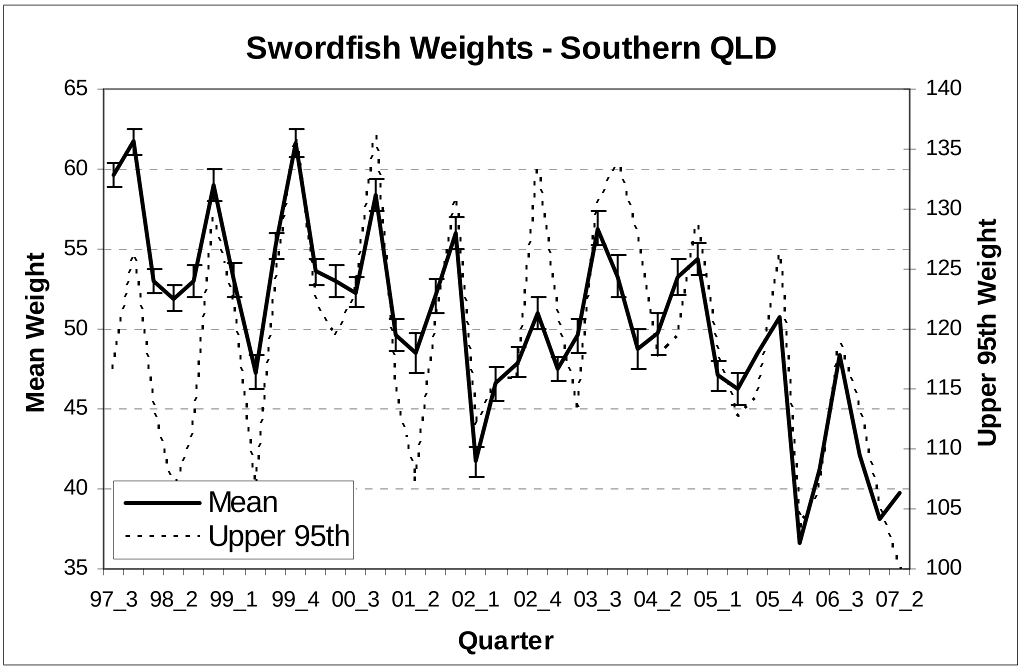


Figure 7a. Time series (by quarter) of the mean and upper 95th weight of broadbill swordfish sampled in Mooloolaba. (Note: 95 % confidence intervals on the mean weights are also shown.).

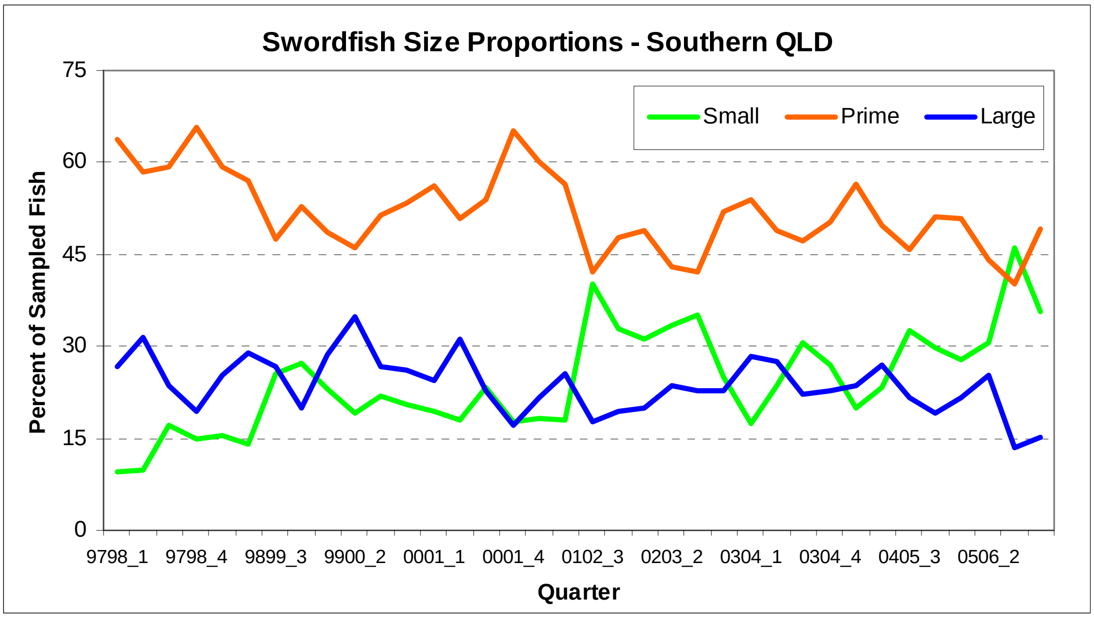


Figure 7**b. Time series (by quarter) of the estimated proportion of broadbill swordfish within each size category landed and sampled in Mooloolaba**.

Workshop Discussion Summary for item 2c:

- The Workshop noted that the size-data for 2005-06 was not available for the Japanese and EU fleets and that size data from some of the Pacific Island Nations was also not yet available in recent years. The 2006 size data for the Taiwanese fleet is also likely to be incomplete.
- The Workshop agreed that further size analyses, with data compared over similar spatial and temporal periods, needed to be undertaken to decide which fleets had sufficient data, and sufficiently distinct size composition to merit separation by fleet.
- The Workshop recommended using New Zealand observer size data up to 2005 and port-sampling size data thereafter.
- The Workshop noted that the large amount of size composition data (and the associated high levels of sampling, generally greater than 70% coverage of the commercial catch) available for both the New Zealand and Australian fleets and the generally much poorer levels of size data associated with most other fleets.
- The time-series of mean weights of swordfish landed in Australia indicates a decrease over time in the average size of swordfish caught by the Australian fleet. In order to investigate whether this decrease could be associated with spatial shifts in the location of the fleet and a spatial heterogeneity in the size distribution of swordfish, the Workshop recommended that this analysis needs to be undertaken at a finer spatial/temporal resolution.
- The Workshop noted that some size data collected from the Japanese commercial fleet operating in the south-west Pacific in the 1950s had a high proportion of a large fish and was quite distinct from other size composition data collected from other regions of the Pacific. Noting the unusual features of the data and the fact that the origins of this data remain uncertain, as do the

sampling methods used to collect the data, the Workshop decided that this data should not be included in the assessment.

- The Workshop was informed by participants from Fiji and Cook Islands that individual swordfish packing weight data are available. It was recommended that that a request is made to obtain this data.
- The Workshop noted a general lack of sex composition data for most fleets (with the exception of some observer collected data on Japanese operations in Australian and New Zealand waters and recent Australian and New Zealand domestic fleets). The Spanish fleet also collects considerable sex composition data, but this has not been made available to the assessment team. It was recommended that this data be summarized as part of the assessment, but the Workshop considered that not enough data was available to justify fitting a sex-disaggregated model.

3. Fisheries Independent Research

3a. Growth Studies

Two working papers were discussed in relation to item 3a.

Young et al. (2008) was presented to the workshop, describing recent work in comparing estimates of growth rates (and maturity described in section 3b). Large differences in growth rates are estimated for different swordfish populations, and it is unclear whether this is the result of real biological differences or methodological differences between labs. Readings of anal fin rays (at this stage the most reliable measure of swordfish age) were compared between readers from two laboratories (NMFS Honolulu and CSIRO Hobart). Because there is considerable variability in the clarity of fin ray bands within and between fish, there is a degree of subjectivity in the readings made, particularly between different readers. A random selection of fin ray sections taken from Australian-caught fishes were reread using characters described in DeMartini et al (2007) and compared with fin ray counts previously determined for the same sections (Young and Drake 2003). Results are shown in Figure 8. Recounts of fin ray sections from the CSIRO collection by a NMFS scientist were less than original CSIRO estimates. The same rays were reread by an independent CSIRO scientist who had previous experience with the reading methodology. These last readings agreed closely with the counts made by the NMFS. The paper concluded that the initial CSIRO readings were consistently higher than the subsequent readings and the need for independent age validation research was stressed.

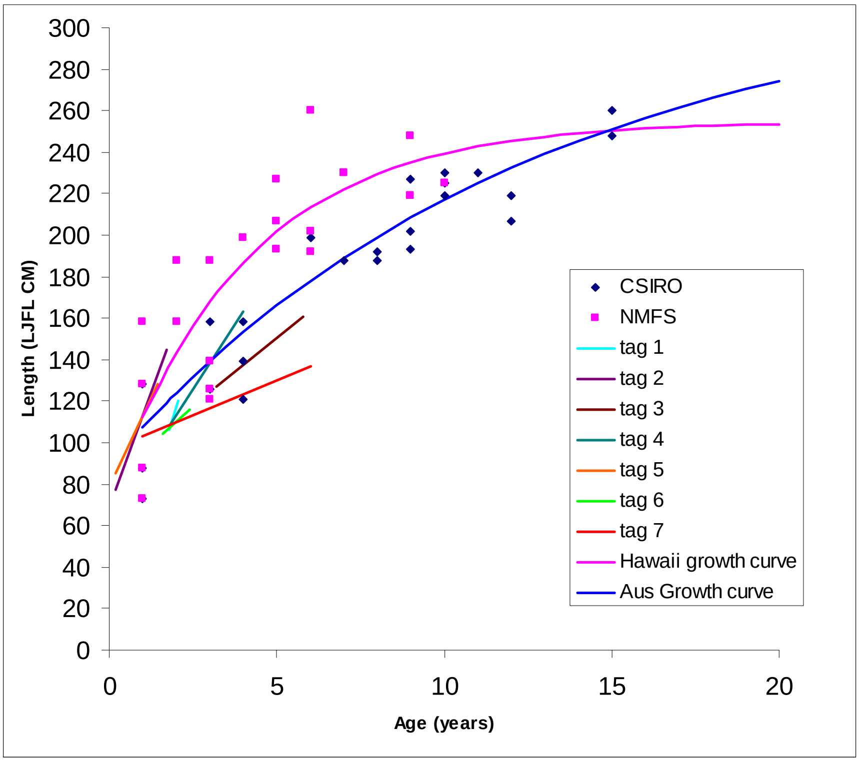


Figure 8. Female swordfish fin ray age estimates from a small number of Australian samples from readers at two different labs (original CSIRO readings and NMFS) (Figure 6 from Young et al. 2008). The superimposed growth curves are derived from comprehensive studies of Australian and Hawaiian swordfish. Tag growth increments represent swordfish samples from Australian and New Zealand tagging (of unknown sex).

Valeiras et al. (2008) describes swordfish age and growth studies in the North-West Pacific. A total of 450 anal fin spines were analyzed from years 2005 to 2006 for ageing and growth studies. The lower jaw fork lengths of the aged individuals ranged from 74 to 235 cm for the males and from 71 to 294 cm for the females. Fish ages ranged 0 to 13 years old and the mean lengths by age were calculated for males and females. Growth parameter estimates were calculated from 406 cut spine sections which provided readable growth annuli by sex. The preliminary growth parameters based on standard VB growth function are the following: for males, L_∞ (asymptotic length)=271.4 cm, k (growth coefficient)=0.121, t_0 (age at zero length)=-1.543; for females, L_∞=376 cm, k=0.0701 , t_0=-2.162. The relationships between LJFL and anal

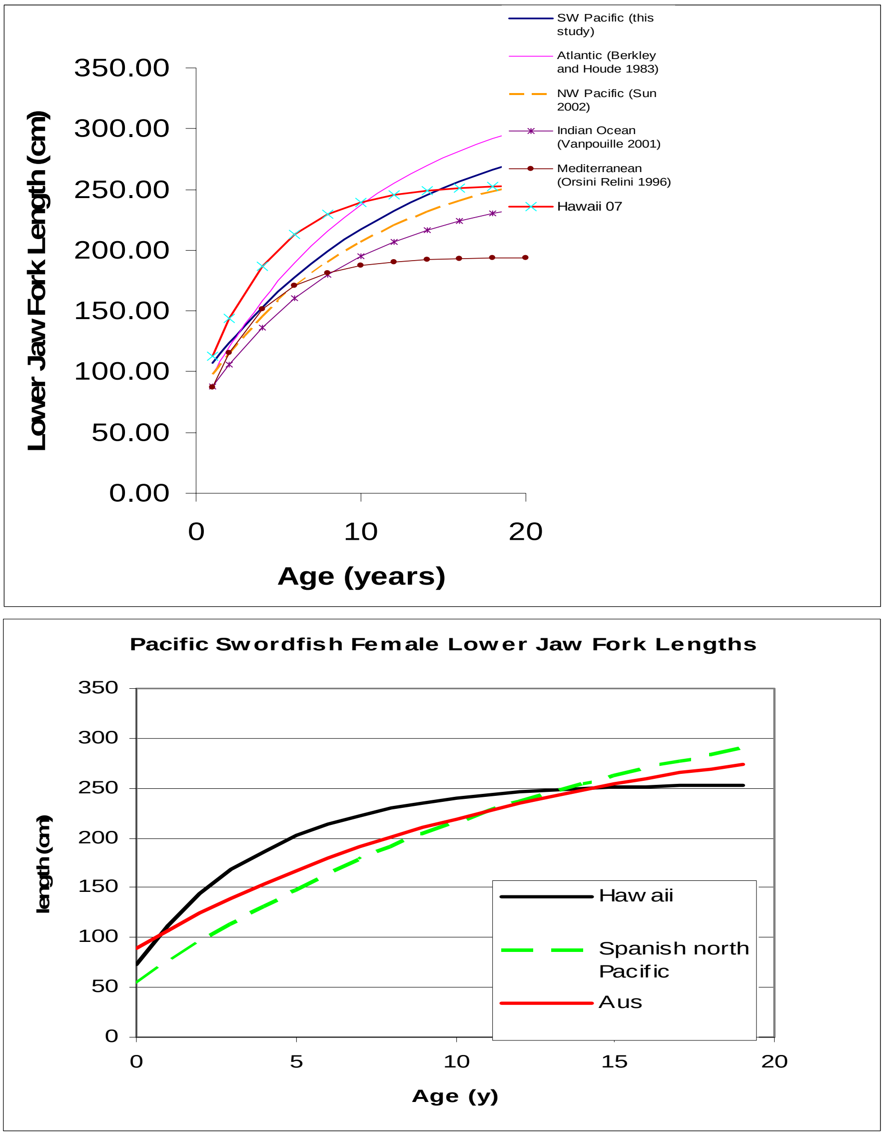


Figure 9. Comparison of swordfish female growth curves from various studies. Top panel from Young et al. (2008). Bottom panel produced at workshop.

fin spine radius were calculated for both sexes. The trends in the monthly marginal increment ratio was not conclusive regarding growth bands formation along the year. A comparison of female growth curves estimated from different studies is show in Figure 9.

Summary of Workshop Discussion for Agenda Item 3a:

- The Workshop noted that a number of differences exist between the results of age and growth studies undertaken on swordfish throughout the Pacific. In particular, significant differences had been observed in the results of recent studies undertaken by Australia and Hawaii.
- The Workshop was informed that ongoing work investigating the reasons for these differences, and including the comparison of age estimation methods between Australian and Hawaiian labs, had indicated substantial differences among readers and that a rereading of some of the Australian data indicated a closer fit to the Hawaiian growth curve. Despite this recent work, the

Workshop noted the need to undertake age validation studies to help resolve remaining uncertainties in these studies.

- Despite the above work, the Workshop noted that two alternative growth curves were recognized to be plausible on the basis of the different readings, and a refitting of stock assessment models to the data available in 2006. The Workshop agreed that both these two growth curves should be used in the 2008 assessment.
- The Workshop noted a working paper provided by Spain detailing the results of a recent growth study on swordfish. However, the Workshop noted that this study was undertaken in the north-west Pacific, and noting studies which indicate that the swordfish resource in this region is highly likely to be a separate stock from that found in south-west Pacific, recommended that this growth curve not be included in the 2008 assessment.

3b. Age-at-Maturity

One working papers were presented under this Agenda item.

Young et al. (2008) discussed potential causes for differences in maturity estimates from different swordfish populations. This variability may reflect the response of these fish to differing physical and biological oceanographic conditions both within and between oceans. However, these differences could also result from different methodologies and interpretations of collected data. In the Pacific Ocean there are a number of differing estimates. Those from the southwestern Pacific gave a preliminary estimate of age at 50% maturity between 8 and 10 years (Patterson et al. 2002). In contrast, De Martini et al. (2000) reported an age at maturity of between 4 and 5 years from the Hawaiian swordfish fishery. A study was carried out by the authors at the Aiea Labs in Hawaii on original material of archived slides of gonads from swordfish collected from the eastern Australian and Hawaiian longline fisheries. During June 25-July 4, 2007 the authors reviewed histological slides of female swordfish gonadal sections in various stages of reproductive development. Some potential sources of discrepancy were identified, including i) differences in the age/size relationships (section 3a above) have a major effect on the age of maturity estimates (but not maturity-at-size), ii) Sample preservation methods are important (all of the Hawaii slides used ovarian tissues fixed at sea when fish were first brought aboard ship, while Australian observers are not permitted to use fixatives aboard ship), and iii) distinguishing immature from mature-resting fish is very difficult based on histological features alone.

Summary of Workshop Discussion for Agenda Item 3b:

- The Workshop noted that the results of separate studies undertaken on swordfish throughout the Pacific indicate a range of ages at 50%-maturity.
- The Workshop also noted that a methodological review being undertaken by Australian and Hawaiian scientists indicated that some of these differences are based on differing interpretations of maturity. Differences in the histological methods used in the original Australian and Hawaiian studies also appear to have contributed to differences in interpretations. Age-at-50% maturity was also influenced by differences in alternative growth curves.

- The Workshop noted that two alternative maturity schedules were plausible based on the different maturity studies and a refitting of stock assessment models to the data available in 2006, and recommended that these two maturity schedules be used in the 2008 assessment.

4. Spatial issues in the assessment

In addition to the papers described previously, 4 working papers were discussed under this agenda item.

Kasapidis et al. (2008) described recent genetic work from Spanish swordfish samples throughout the Pacific. Abstract: The genetic structure of swordfish (Xiphias gladius) in the Pacific Ocean was assessed by analyzing 594 individuals from 6 different regions, genotyped with 13 microsatellite loci. The results showed very low genetic differentiation among the different geographical areas, which was not statistically significant. These data confirmed the low genetic differentiation of swordfish within Pacific and were not able to reveal any genetic structure.

Abascal et al. (2008) described preliminary results from recent PSAT deployments from Spanish commercial vessels operating in the Eastern Pacific Ocean. Between March-June 2007, a total of 21 SWO generally above 50 kg round weight were tagged and released around Nazca Ridge (off northern Chile). Swordfish showed the typical diel vertical migration pattern, being close to the surface at nighttime and deep during the day, usually reaching depths of around 400-600 meters. Light-level based geolocations are still being processed. Based on the preliminary results of the Kalman filtered tracks, it seems none of the fish tagged moved north of 2ºS, nor west of 105º25'W. But it cannot be ruled out that fish would continue to move further north and west after tag detachment. Further analysis is expected to provide useful information on habitat preferences, fish associations, and population structure that will contribute to future stock assessments.

Mejuto et al. (2008a) described reproductive studies on swordfish from Spanish longline operations throughout the Pacific. Abstract: A total of 23,639 swordfish females were analysed. The percentage of females larger that 145 cm shows important differences among areas. Maximum percentages were obtained in temperate waters South of 25º S and the lowest values in warm areas where small females were observed. The overall sex-ratio obtained was 51%. The sex-ratios at size suggest that females are predominant as of 170 cm although different patterns of sex-ratio at size were obtained between zones. The gonad index detects areas as producing the most intense maturation activity in females, ranging from the central Pacific between 10ºN and 10ºS to the West of 120ºW where the greatest gonad development was observed. The results would indicate that reproductive activity is mostly carried out in certain areas of the central-western Pacific but that there may also be sporadic-seasonal or moderate reproductive events in some of the other areas adjacent to these. At the same time, the SE Pacific show resting females with active feeding behaviour. The most active areas with maturity events are linked to warm waters where the characteristic spawning patters of sex-ratio at size are caused by the higher abundance/catchability of males over females within particular size ranges. The results match well with similar indicators observed for the Atlantic swordfish. However, the Pacific shows somewhat broader warm areas than the Atlantic, suggesting that the potential spawning areas for the Pacific swordfish could be relatively broader and eastern than those reported for the Atlantic. Figure 9 shows the spatial pattern of swordfish gonad indices from the Spanish fleet in the Pacific Ocean.

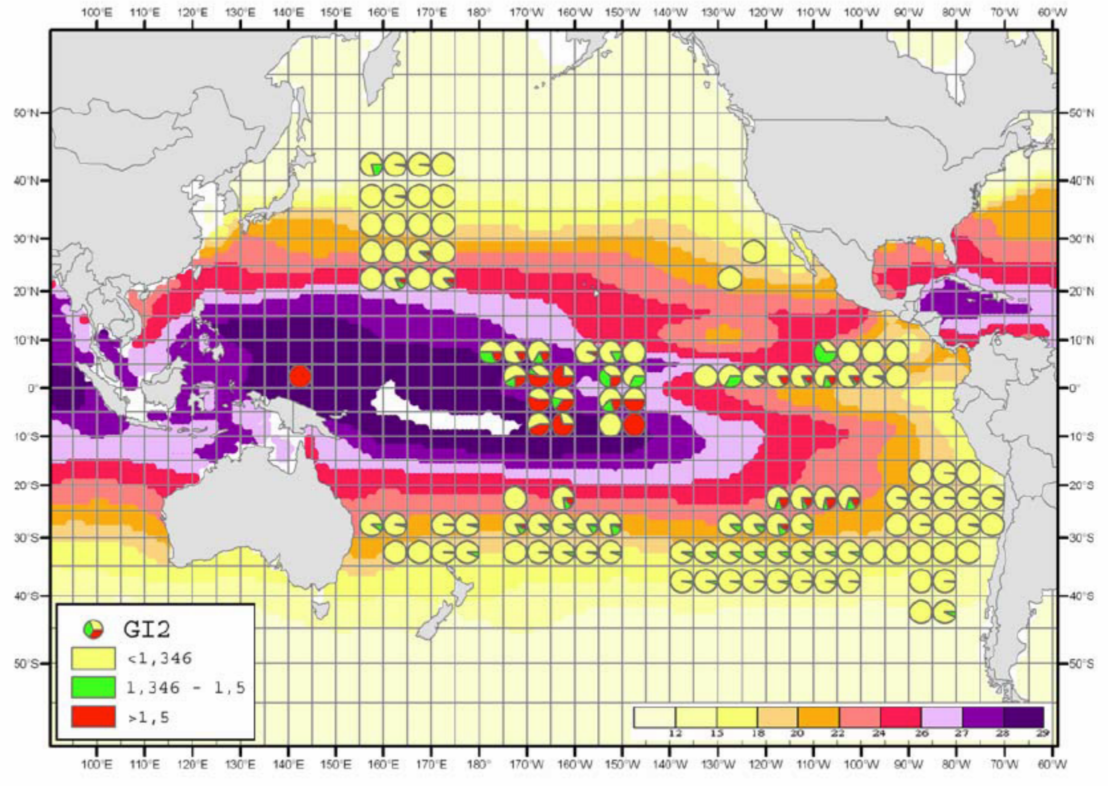


Figure 9. Ocurrence of each of the three gonad index (GI2) ranges defined, in each 5^ox5^o square observed F in the Pacific ocean, for females with sizes LJFL>=145 cm and for all observations combined. (Figure 7 from Mejuto et al (2008a).

Kolody and Davies (2008) provided a general review of the research and hypotheses associated with south Pacific swordfish stock structure and migration dynamics, and spatial considerations used in other swordfish assessments. The evidence discussed included population genetics, larval surveys, fishery characteristics (distributions and seasonal patterns in catch, CPUE, and size composition), and inferences from recent Pop-up Satellite Archival Tags (PSAT) and conventional tags deployed in Australia and New Zealand. The paper recommended a southern WCPO assessment domain with 4 longitudinal sub-units (**Figure 3**). The revised structure was argued on the basis of: it i) provides compatibility with CMM06-3, ii) reduces problems related to representing latitudinal seasonal migration, iii) is suitably disaggregated to represent differential harvesting in different sub-regions, iv) can be iteratively revised with different eastward boundaries in relation to evolving opinions about data quality and stock connectivity with the Eastern Pacific Ocean.

This paper also discussed how the homogenous mixing and spawning site fidelity migration hypotheses (Figure 1) might be more appropriately considered in a broader Pacific context in the future (Figure 10). Exploration of a broad-scale spawning site fidelity model would likely require data from outside of the WCPO, however there is no evidence at this time to indicate that it is more appropriate than the homogenous mixing model proposed.

Kolody and Davies (2008) also described a preliminary analysis of PSAT and conventional tags, in which it was argued that the longitudinal movement of swordfish seems to be consistent with a diffusive process. The paper illustrates that other simple movement models are also plausibly consistent with the small amount of tagging data that are available. It was suggested that the adoption of the movement parameters estimated from the diffusion model should be interpreted as an upper bound on migration rates. If the alternative models are actually more “correct” (e.g. if swordfish undertake directed longitudinal seasonal migrations in the SW Pacific), then the extrapolation of movement estimates based on short term tag displacements would be expected to over-estimate the actual amount of random diffusive displacement experienced in the long term. Estimates for longitudinal observation error variances, and diffusion rate parameters were provided. A simple process was described in which diffusion rates could be estimated and translated into bulk transfer coefficients that are compatible with the structural assumptions of the assessment models.

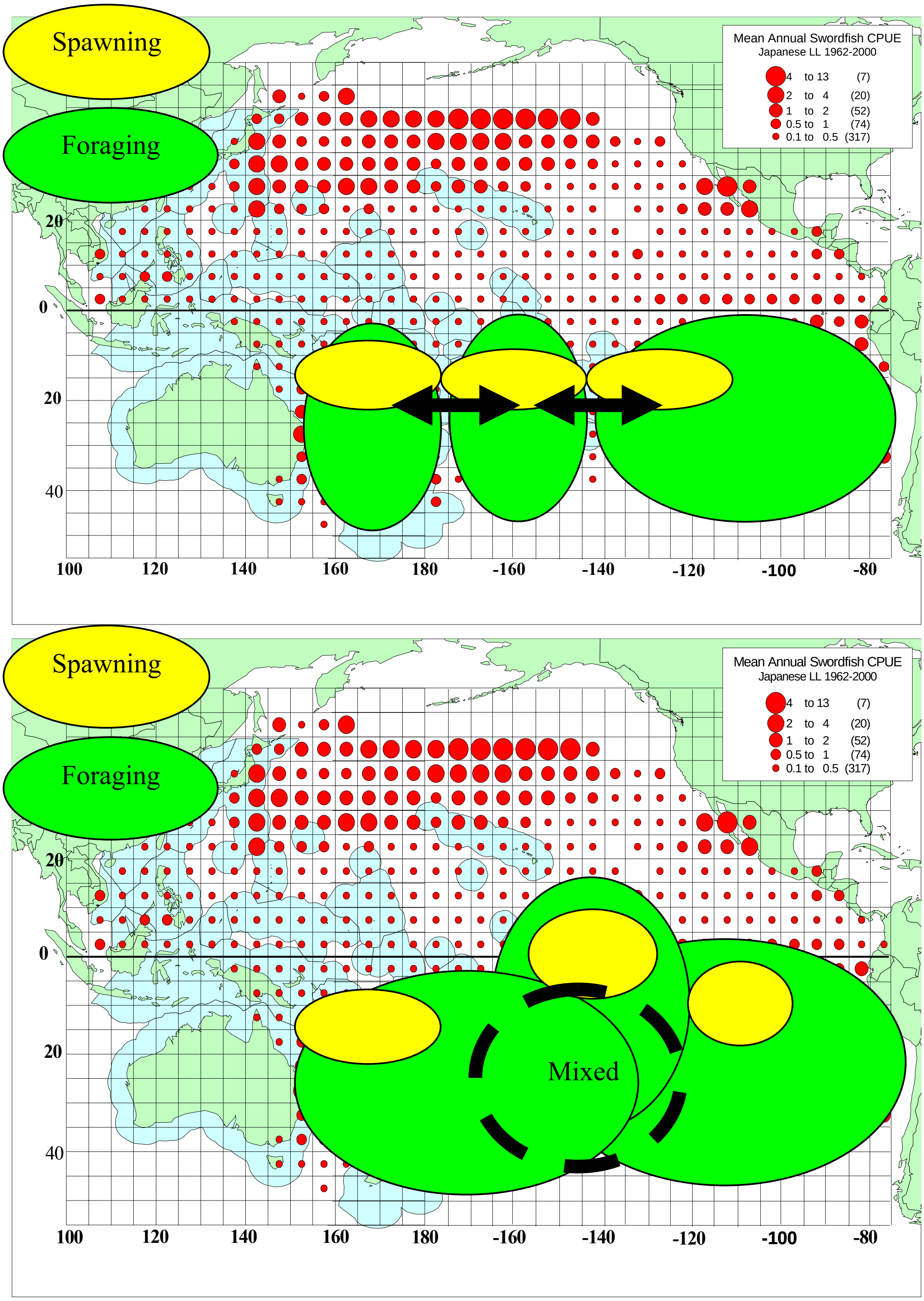


Figure 10. (from Kolody and Davies 2008) Schematic representation of two possible stock structure represenations for South Pacific swordfish: top panel = homogenous mixing, bottom panel = foraging site fidelity.

Summary of Workshop Discussion of Agenda Item 4:

- The Workshop endorsed a model domain within the southern WCPO (0-50 S, 140E-130W) as encompassing the main region of interest for assessing the swordfish stock located within the south-west and south-central Pacific Ocean (Figure 4).
- Given the spatial distribution of fishing effort of individual fleets and the associated catch of swordfish across this domain, the following 4 region structure:
  - Region 1: 140-165°E
  - Region 2: 165-185°E
  - Region 3: 185-210°E
  - Region 4: 210-230°E

  with an additional three zones defined within each region:
  - North: 0-20°S
  - Central: 20-40°S
  - South: 40-50°S

  was also endorsed as a reasonable delineation for fishery definitions across the model domain.
- Noting the:
  - continuity of catch and CPUE across the Tasman Sea for Australian and Japanese fisheries,
  - similarities in CPUE temporal trends for the main fleets catching swordfish in these regions, and
  - some movement of tagged swordfish from region 1 to 2,

  the Workshop considered that there was a compelling argument to consider the swordfish resources located in Regions 1 and 2 to be part of the same stock
- The Workshop noted that there was no strong evidence supporting the assumption of a single stock across the southern Pacific, but noted that there is some evidence based on the distribution of catch, CPUE, genetics and spawning locations suggesting the possibility of two separate stocks:
  - Whilst swordfish are mainly caught within the central temperate zones in regions 1 and 2, the catch of swordfish in regions 3 and 4 is mainly within the northern equatorial zone.
  - The spatial distribution of Japanese CPUE suggests a possible discontinuity between south-western and north-eastern equatorial areas of the southern WCPO (though the central zones of regions 3 and 4 do indicate high Japanese and Spanish CPUE).
  - The generally decreasing trends in nominal CPUE for the major fleets catching swordfish in regions 1 and 2 (Japan, Australia and New Zealand) are dissimilar with the generally increasing nominal CPUE trends of the major fleets catching swordfish in the northern zones of regions 3 and 4 (Japan, Korea and Taiwan).
  - Larval surveys and reports of very small swordfish found within the waters of French Polynesia indicate spawning in the northern zone of Region 4. However, the workshop noted that spawning in this region may be associated with EPO stocks, which are not known to spawn in the cooler waters near South America.
  - Based on larval sampling there was little evidence of spawning in Region 3, though the workshop noted that recent research undertaken

    by Spain indicated the presence of ripe spawners in this region. However, the Workshop noted that this research was based on a gonad condition index which could not be taken as conclusive evidence that spawning was taking place in this region and that a histological study would provide more compelling evidence. It was also noted that very small swordfish were observed within the southern region of the Cook Islands during 2007 though this is seen as unusual.
  - Observations of swordfish movement within the EPO, based on recent Spanish tagging, seemed to be consistent with movement assumptions adopted in the IATTC, and were not informative with respect to the south-western and south-central stock structure.
  - Genetic evidence from all sources remains inconclusive, though
    - Reeb et al. (2000) provide compelling evidence for a distinction between north-west and south-west populations
    - Bremer et al. (2006) provide a compelling argument for distinguishing between north-east and south-east populations and between south-west and south-east populations, with the boundary uncertain (and not well sampled)
    - The most recent work, Kasapidis et al. (2008), did not identify compelling evidence for South Pacific stock structure (but the Workshop noted the low statistical power of the genetic method used).
  - While the workshop noted that the spatial distribution of catch and CPUE on their own provide only indirect and inconclusive evidence regarding stock structure, the combination of information from all sources (including genetic and reproductive studies) may provide stronger evidence.
- The Workshop was informed that a run of the 2006 assessment model updated to include the more recent catch and effort data failed to produce plausible results. The complicated migration dynamics assumed in the highly disaggregated spatial structure used in this model were thought to be one of the problems and was seen as justifying the simpler spatial structure adopted for the 2008 assessment model.
- Analysis of the recent tagging data undertaken in Regions 1 and 2 indicate that North-South (probably spawning) migrations appear to be more dominant than East-West movements. Estimation of diffusion rate coefficients in the longitudinal direction based on this tagging data provides bulk transfer coefficients that can be input into the spatially disaggregated assessment model.

Based on the above information, the Workshop reached the following conclusions:

1) There is strong evidence for treating the swordfish within Regions 1 and 2 as a single stock unit as in the 2006 assessment. However, the eastern extent of this population remains uncertain, as does the appropriate management boundary in relation to the WCPO and the EPO.
2) It was considered plausible that the swordfish located in the Central zones of Regions 3 and 4 might be more closely linked to the populations from Regions 1 and 2 than the swordfish located in the Northern zones of Regions 3 and 4 (the latter may be more closely linked to the EPO stock).

3) The Workshop noted the need to extend the examination of the spatial distribution of catch and CPUE between the southern WCPO and the EPO (as this information was not available at the workshop).
4) Given the lack of compelling evidence for a single stock across all 4 regions of the southern WCPO, and the lack of reliable swordfish abundance indicators in regions 3 and 4, the Workshop recommended that the primary focus of the 2008 assessment should be on the swordfish resource located in the southwest Pacific (Regions 1-2), and that additional sensitivity analyses should be undertaken to include regions 3 and/or 4 (with the northern zones excluded) if possible. If problems are encountered in extending the assessment that qualitative stock status statements should provided on the basis of data-based indicators.

5. Stock Assessment Workplan

After consideration of the points raised and discussed during the workshop, the following workplan of tasks was outlined for completing the 2008 southern WCPO swordfish stock assessment:

Final Data Assembly (to be completed by 9 May 2008):

- Workshop requested a brief summary of changes in PIN fleet operational characteristics (particularly over the last 10 years)
- Obtain Cook Islands, Tonga, Fiji, New Caledonia, French Polynesia operational data (workshop noted possibly limited utility for CPUE standardization, due to changing fleet structure and fishing strategies that might not be represented in logbooks).
- Obtain Japanese 2006 catch and effort data
- Obtain Taiwanese 2006 catch and effort data
- Obtain Spanish 2005-7 length and sex composition data
- Request Taiwanese operational level catch/effort data for the fleet landing in Pago Pago (from USA).
- Request other principle species catch composition for purposes of identifying targeting shifts
- Obtain swordfish packing data from Fiji and Cook Islands.

Additional Data analyses:

- Qualitative examination of spatial continuity of CPUE patterns from Japanese fisheries
- Comparison of size frequency distributions for all fleets disaggregated by year, quarter, area and zone over comparable strata for determination of fleet definitions (noting that disaggregation might be worthwhile for exploring management options).
- Explore CPUE trends in PIN fleets to identify periods of stable fleet operations
- Fine spatial-scale disaggregation of Australian size composition data over time
- Taiwanese CPUE standardization using operational level data
- Complete Japanese CPUE standardization

- Consider use of non-swordfish species catches as a proxy for operational variables for targeting practices
- Comparative plots of stratified nominal CPUE indices versus species catch composition over time (e.g. for Taiwan and Korea)
- Summarize sex composition from all observer data.

Assessment modelling:

- Software:
    - Multifan-CL
    - CASAL
    - Stock Synthesis 2/3 was discussed as an option but discouraged in the short term because the most recent developments (related to migration) were largely untested
- Structural assumptions
    - Spatial units:
        1. Areas 1 and 2 as the highest priority
        2. Areas 3 and/or 4 to be included if reliable data can be obtained
    - Time-steps – annual vs quarterly – it was recognized that selectivity may need to differ by quarter to account for seasonal migration in the new model structure.
    - Growth and Maturity
        - Two alternative growth curves were recognized to be plausible on the basis of Young et al. (2008) and Kolody (2008)
        - Two alternative maturity schedules were recognized to be plausible on the basis of Young et al. (2008) and Kolody (2008)
    - Natural Mortality – the range of options is to be revisited in relation to the new growth curves
    - Sex dimorphism –
        - Considered a low priority considering existing uncertainty in growth curves. Might be explored with CASAL
    - In the first instance, migration rates will be imposed on the basis of diffusion rate estimates from tagging studies. Migration rates may be estimated as part of model fitting if this leads to substantive improvements in model fit and plausible migration estimates.
    - Use of PSAT tag tracks directly in models (assuming that each track can be analysed as a series of conventional tag recaptures)
        - Considered a low priority given small number of tags and unrepresentative release times. Might explore with CASAL
    - Fleet disaggregation with respect to selectivity
        - Maximum of 4 Areas x 3 zones x number of nations
        - Reduce number of fleets on the basis of length frequency comparisons and shared selectivity assumptions
        - Seasonally-variable selectivity may be required to explain seasonal changes in size composition due to migration
    - Fleet disaggregation with respect to catchability
        - Depends on how many informative CPUE series can be defined (maximum of 6)
        - Regional scaling factors need to be derived in relation to shared catchabilities

        - Seasonal catchability estimates are expected to be required to explain differences in seasonal CPUE due to seasonal migration (and potentially the confounded effect of seasonal targeting)

- Uncertainty Quantification
    - MPD grid – Confounded Experimental Design might be used to capture 2 way interactions if full factorial design not computationally fesasible.
        - Grid includes relative weightings of different data sources in the objective function
    - Model plausibility diagnostics need to be defined
    - Generate credibility intervals for MPD selection
- Reference Points to report:
    - Total and Spawning Stock Biomass = TSB, SSB
    - TSB(2007)/TSB(1997)
    - SSB(2007)/SSB(1997)
    - TSB(2007) / TSBNF(2007)
    - SSB(2007) / SSBNF(2007)
    - TSB(2007)/TSB(MSY)
    - SSB(2007)/SSB(MSY)
    - F(2007)/F(MSY)
    - Projections:
        - 10 year constant catch projections
        - Constant effort (maximum effort from years 2001-5, as per CMM2006-3)
        - Alternative Catch/Effort scenarios: +50%, +100%
        - Ensure low future recruitment scenarios are included
    - TSB(2012) / TSB(2007)
    - SSB(2012) / SSB(2007)
    - TSB(2012) / TSB(1997)
    - SSB(2012) / SSB(1997)
    - TSB(2012) / TSB(MSY)
    - TSB(2017) / TSB(MSY)
    - Likelihood profiling of ratio reference points when appropriate

6. Research priorities for reducing South Pacific Swordfish Stock Assessment uncertainty

The workshop discussed a number of longer term research items for reducing swordfish stock assessment uncertainty. It was noted that most of these initiatives should involve collaborative work with broader Pacific Ocean initiatives (North Pacific, IATTC).

Area of uncertainty	**Issue(s)**	**Examples of past & current work**	**Tasks**
Size/age/ maturity	• Estimate age at maturity, spawning frequency and	• Young & Drake (2004)	• Ad hoc – observer data

Area of uncertainty	**Issue(s)**	**Examples of past & current work**	**Tasks**
	fecundity, identify spawning areas and seasons • Discrepancies between east Australian estimates and those from other fisheries • Regular collection of hard parts (fin rays) and estimation of age- and sex composition of catches • Refinement of length-age key	• Young et al. (SC3-BI-WP-1)	and biological samples • Dedicated – data and sample analysis and desk-top comparison with other studies. • Ad hoc – sample collection and observer data on sex composition • Independent validation from conventional tagging studies and oxy-tetracycline marking • Radiocarbon ageing • Sampling of very small swordfish in tropics
Movement and mixing rates	• Describe size- and sex-dependent movement patterns, e.g., spawning grounds, forage areas. • Local depletion around bathymetric features, such as seamounts • Particular uncertainty of population linkages in the South-Central Pacific region	• satellite tagging (Holdsworth et al. SC3_BI_WP-3, CSIRO)	• logbook data mining and analysis, sourcing additional fleet data, • conventional tagging • sex determination from conventional tags on recapture • PSAT tagging in representative time/area strata • Long-term

Area of uncertainty	**Issue(s)**	**Examples of past & current work**	**Tasks**
			dispersal estimates from conventional tagging • Sex determination from genetics
Stock structure	• genetic and otolith micro-chemistry sampling to determine population structure, e.g., homogenous Pacific-wide vs. limited mixing among sub stocks • Particular uncertainty of South-Central population dynamics • Preliminary exploration of parasite markers in New Zealand was not encouraging	• Reeb et al. (2000)	• Otolith and genetic sample collection • South-Central Pacific sampling very weak • Otolith microchemistry methods need development for pelagic fisheries • analysis of size composition data to identify homogenous spatial units
Fishery Size and sex composition data	• Size composition from 1950s commercial fishery identified		• Investigate historical size data for Japanese longline fleet 1950s • Expand port sampling and observer programs
Catch rates	• Distinguish swordfish targeting from targeting of other species • Habitat use and variations in fishing power and catchability • Develop time-series for	• observer and logbook programs	• observer and port sampling logbook collecting operational level data for sex-specific length frequencies

Area of uncertainty	**Issue(s)**	**Examples of past & current work**	**Tasks**
	fleets other than distant-water Japanese longline • Sex-specific catch rates		• Experimental validation of CPUE standarization assumptions • Explore proxies for quantifying targeting • Analyses of Oceanographic variability impacts on catch rates
Fishing mortality rates	• Verified catch estimates for all fleets • Discards and under- or non-reporting of catches	• Observer, landings and logbook programs	• Compare size compositions from observed and unobserved sets in appropriate strata.
Abundance indices	• Fisheries independent • Recruitment indices (Cook Islands, French Polynesia)		• .Identify which fleets are catching small fish • Explore relation between small fish catch and subsequent recruitment in core fisheries as recruitment index • Understand recording/retention practices and encourage consistent reporting

Area of uncertainty	**Issue(s)**	**Examples of past & current work**	**Tasks**
Assessment Model Estimator performance	• Not sure how well models perform, or how robust to assumption violations • Can simple models/analyses replace more complicated assesments		• Simulation testing to describe estimator performance • Compare models of differing complexity with data-based indicators
Management Strategy Evaluation	• Need to define robust harvest strategies to meet management objectives		• Conduct pilot MSE • Expand to broader WCPFC

Attachment A: List of Participants

AUSTRALIA

Dale Kolody
CSIRO Marine and Atmospheric Research
PO Box 1538
Hobart TAS 7001
Australia
Ph: +61-3-6232-5121
dale.kolody@csiro.au

Robert Campbell
CSIRO Marine and Atmospheric Research
Private Bag No.1
Aspendale VIC 3195
Australia
Ph: +61-3-9239-4681
Robert.Campbell@csiro.au

Kevin McLoughlin
Bureau of Rural Sciences
GPO Box 858
Canberra ACT 2601
Ph: +61-2-6272-4015
kevin.mcloughlin@brs.gov.au

COOK ISLANDS

Pamela Maru
Ministry of Marine Resources
P.O Box 85
Rarotonga
Ph: 682-28721
Fax: 682-29721
P.Maru@mmr.gov.ck

FIJI

Jone Amoe
Oceanic Fisheries Officer
Fisheries Department
Ministry of Agriculture, Fisheries and Forests
Takayawa Tower, Toorak
Suva, Fiji
Ph: 679-330-1611
fishfinderfj@gmail.com

FRENCH POLYNESIA

Marie Yonger
Fisheries Officer
Service de la pêche de polynésie française
B.P.20, 98713 Papeete-TAHITI
Polynésie française
Ph: 689-50-25-50
marie.yonger@peche.gov.pf

NEW CALEDONIA

Regis Etaix-Bonnin
Gov. of New Caledonia/SMMPM
BP 36-98845 Noumea Cedex
New Caledonia
Ph: 687-27-26-26
regis.etaix-bonnin@gouv.nc

NEW ZEALAND

Nick Davies
NIWA
P.O Box 1020
Wellington, NZ
Ph: +64-4-819 4716
n.davies@niwa.co.nz

Stephen Brouwer
Ministry of Fisheries
ASB House, 101-103
The Terrace, Wellington
Ph: +64-4-819-4249
Stephen.brouwer@fiah.govt.nz

TONGA

Ulunga Fa'anunu
Department of Fisheries
PO Box 871
Nuku'alofa
TONGA
Ph: 676-21399/676-23730
ulungaf@tongafish.gov.to

FORUM FISHERIES AGENCY

P.O. Box 629
Honiara, Solomon Islands
Ph: 677-21124

Wez Norris
wez.norris@ffa.int

Samasoni Sauni
samasoni.sauni@ffa.int

SECRETARIAT OF THE PACIFIC COMMUNITY (SPC)

BP D5 98848 Noumea Cedex
New Caledonia
Ph: 687-262000

Adam Langley
Principal Fisheries Scientist
adaml@spc.int

John Hampton
OFP Programme Manager
johnh@spc.int

Simon Hoyle
Senior Fisheries Scientist
simonh@spc.int

Brett Molony
brettm@spc.int

Don Bromhead
donb@spc.int

WCPFC SECRETARIAT

SungKwon Soh
Science Manager
P.O Box 2356
Kolonia, Pohnpei 96941
Federated States of Micronesia

Ph: 691-320-1992/1993
sungkwons@mail.fm

Attachment B: List of Working and Background Papers

1. Working Papers for the Southern WCPO Stock Assessment Workshop (Note that many of these are draft and informal papers should not be cited without prior approval by the authors. Many of them will be revised and submitted to the WCPFC-SC in 2008.)

Abascal, F.J., Mejuto, J., Quintans, M. and Ramos-Cartelle, A. 2008. Swordfish Pop-Up Tagging in the Southeastern Pacific Ocean. Draft Working Paper to the 4th meeting of the Scientific Committee for the WCPFC.

Campbell, R. 2008. Data summary pertaining to the catch of swordfish by longline fleets operating in the southern WCPO.

Campbell, R., N. Davies and L. Griggs. 2008. Swordfish size and sex composition for Australian and New Zealand Longline fisheries.

Campbell, R., M. Unwin and N. Davies. 2008. Swordfish CPUE trends across the southern WCPO.

Kasapidis, P., A. Magoulas, B. García-Cortés, J. Mejuto. 2008. Stock structure of swordfish (*Xiphias Gladius*) in the Pacific Ocean using microsatellite DNA markers.

Kolody, D. 2008. Exploratory update of the 2006 South-West Pacific swordfish Multifan-CL assessment.

Kolody, D., N. Davies and R. Campbell. 2008. Review of issues in the 2006 SW Pacific swordfish assessment.

Kolody, D. and N. Davies. 2008. Spatial structure in South Pacific Swordfish Stocks and Assessment Models.

Mejuto, J., B. García-Cortés and A. Ramos-Cartelle. 2008a. Reproductive activity of swordfish (*Xiphias Gladius*) in the Pacific Ocean on the basis of different macroscopic indicators.

Mejuto, J., B. García-Cortés and A. Ramos-Cartelle. 2008b. Standardized Catch Rates in Biomass for the South Central and Western Pacific Swordfish (*Xiphias Gladius*) from the Spanish longline fleet for the period 2004-2006.

Valeiras, X., J. Mejuto, M. Ruiz. 2008. Age and growth of swordfish (*Xiphias Gladius*) in the North Pacific.

Young, J., R. Humphreys, J. Uchiyama and N. Clear. 2008. Comparison of swordfish maturity and ageing from Hawaiian and Australian waters.

Background papers cited in the workshop report:

Alvaredo Bremer,J.R. Hinton, MG. and Greig,T.W. 2006. Evidence of the spatial genetic heterogeneity in Pacific swordfish revealed by the analysis of *LDH*-A sequences. Bull. Mar. Sci. 79(3): 493-503.

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Attachment C: Agenda for Southern WCPO Swordfish Stock Assessment Workshop

16-18 April 2008
SPC, Noumea

1. (Wed) Introduction
   - Workshop Objectives
   - 2006 Assessment Overview
   - Major uncertainties in 2006 assessment:
     - a) Stock boundaries
     - b) Internal migration
     - c) Size-at-age
     - d) Maturity
     - e) M

2. (Wed) Spatial Structure
   - South Pacific Stock Structure
   - Internal structure within the assessment

3. (Wed-Thurs) Review and Compilation of Fisheries Data
   - Catch and Effort Data
     - a. Coverage by fleet
     - b. changes in fishing behaviour
   - Catch rates
     - a. Standardization
   - Size and sex Composition
     - a. Space/time coverage by fleet
     - b. Japanese samples from the early 1950s

4. (Thurs) Review of Fisheries Independent Research
   - Size-at-age by sex
   - Maturity
   - Tags
     - a. Conventional
     - b. P-Sat
   - Genetic connectivity
   - Information from other swordfish stocks

5. (Thurs-Fri) 2008 Assessment
   - Major Assumptions
   - Input data analyses
   - Software
   - Sensitivity Analyses / Uncertainty quantification
   - Model diagnostics / selection
   - Workplan

6. (Fri) Research priorities for reducing assessment uncertainty

Attachment D: Summary Tables of swordfish data by area (as defined in the Report of the Southern WCPO Swordfish Assessment Workshop Figure 4) and actions arising as a result of the Workshop.

Fisheries Data available for stock assessment	**Area 1**	**Area 2**	**Area 3**	**Area 4**
Catch and effort data	Operational catch and effort data from **Australian** domestic fleet including specific gear and operational information to conduct standardisation.	Operational catch and effort data from **New Zealand** domestic fleet including specific gear and operational information to conduct standardisation (issues – potential bias in recent years due to explicit swordfish targeting).	Korean, Taiwanese and Spanish fleets have largest fisheries in this area. Issues: 5x5 catch and effort data available but operational level data not accessible to assessment team for CPUE standardization	Korean, Taiwanese and Spanish fleets have large fisheries in this area. Issues: 5x5 catch and effort data available but operational level data not accessible to assessment team for CPUE standardization
	New Zealand fishery very small in this region	Australian fishery small in this region		
	Aggregated (5x5xmonth) catch and effort for **Japanese** fleet (issues – 1x1xMonth standardisation and analysis is being conducted in Japan through liaison with stock assessment team in Australia)	Aggregated (5x5xmonth) catch and effort for **Japanese** fleet (issues – 1x1xMonth standardisation and analysis is being conducted in Japan through liaison with stock assessment team in Australia)	Japanese swordfish catch insignificant in this region	Aggregated (5x5xmonth) catch and effort for **Japanese** fleet (issues – 1x1xMonth standardisation and analysis is being conducted in Japan through liaison with stock assessment team in Australia)
	Standardised **Spanish** CPUE has been provided by Spain (issues: standardization applied to aggregate of these 4 areas plus equatorial regions north of the equator; concerns about the use of non-target/target species ratio as a standardisation factor; only years 2004-6 covered)			
	Aggregated and operational catch and effort data from **Pacific Island Nation** domestic fleets (issues – most fisheries are very small, assessment team has insufficient understanding of fleet operational characteristics and fishery history)			
	Papua New Guinea and New Caledonia are most substantial PIN fisheries	Fiji is most substantial PIN fishery	Cook Islands is most substantial PIN fishery	French Polynesia is most substantial PIN fishery
	Australian and New Zealand data available to 2007 Japanese and Taiwanese data unavailable (or incomplete) for 2005 and			

	2006 All other fleets data available through 2006	
Size data	Comprehensive coverage of size data from **Australian** port sampling and observer program (issue – observer data not yet included).	Comprehensive coverage of size data from **New Zealand** port sampling and observer program (issue – port sampling only in recent years).
	Comprehensive **Spanish** size composition data collected, but only 2004 has been made available for the assessment team	
	Size sampling sparse and inconsistent for most fleets	
Sex data	Limited sex data available historically. This is changing for some fleets through recent sampling and observer programs	

<table>
<tr><th>Fisheries Independent (and semi-independent) research</th><th>Area 1</th><th>Area 2</th><th>Area 3</th><th>Area 4</th></tr>
<tr><td rowspan="4">Tagging data</td><td>PSAT tagging conducted by Australia over previous 18 months (issues – small number of tags and short release durations; analysis incomplete). Suggests spawning occurs in area 1.</td><td>Minor movements of fish tagged in Area 1 into Area 2.</td><td></td><td></td></tr>
<tr><td>Minor movements of fish tagged in Area 2 into Area 1.</td><td>PSAT tagging conducted by New Zealand over previous 18 months (issues – small number of tags short release durations). Suggests spawning occurs in area 2.</td><td>Minor movements of fish tagged in Area 2 into Area 3.</td><td></td></tr>
<tr><td colspan="3">Conventional tag release/recovery data (issues – small number of releases, dependent on fisheries for recovery and returns; program poorly publicized outside of Australia and New Zealand</td><td></td></tr>
<tr><td colspan="4">PSAT tagging from Northern and Eastern Pacific Ocean (issues – low numbers, short durations). No movements reported into Southern WCPFC convention area.</td></tr>
<tr><td rowspan="4">Genetic data</td><td colspan="4">Reeb et al (2000) suggests that North-west and South-West Pacific populations are distinct, while most other Pacific populations cannot be distinguished</td></tr>
<tr><td colspan="4">Bremer et al (2006) suggests that North-west and South-West Pacific populations are distinct, and South-West and South-East stocks are distinct. Significant differences in other populations not identified.</td></tr>
<tr><td colspan="4">Kasapidis et al (2008) suggest no genetic differentiation within Pacific, though there is weak evidence for distinction between North-West and South West populations and between South-West and South-Central populations.</td></tr>
<tr><td colspan="4">Issues: genetic studies may not be able to identify important sub-population structure</td></tr>
<tr><td rowspan="2">Maturity Studies</td><td colspan="4">Mejuto et al 2008 found high proportions of spawning-ripe swordfish in the equatorial Pacific (10N-10S, 170W-45W), and to a lesser extent the South-East Pacific (east of 120W), and limited numbers of spawning-ripe swordfish elsewhere. Samples were large but coverage was not uniform, and seasonality not described.</td></tr>
<tr><td colspan="4">Young and Drake (2002) found high proportions of spawning-ripe swordfish in the SW Pacific. Samples were primarily limited to the spatial extent of the Australian fishery.</td></tr>
</table>

	Young et al (2008) describe difference in the interpretation of age at maturity for female swordfish depending on the quality of histological samples, analytical methodology and size-at-age estimates.
Japanese Larval Surveys	Nishikawa et al 1985 describe large concentrations of swordfish larvae in Area 1, but lesser concentrations were observed throughout the tropical South Pacific, except for the far eastern region. Larval survey coverage was not uniform in space or time, with large gaps in the south-central Pacific.
Age/growth	Young et al (2008) compare growth rate estimates from different regions. It is unclear to what extent different growth rates are estimated due to differences in methodology, or due to regional biological differences. Mejuto et al (2008) estimate swordfish growth rates from the North Pacific. The estimates are similar to the Young et al 2003 estimates for the SW Pacific, However, they differ from the DeMartini et al. (2006) North Pacific swordfish estimates and from the Young et al (2008) comparative readings from a second Australian reader and a Hawaiian reader. Independent age validation methods should be pursed for swordfish

recommended actions	**Area 1**	**Area 2**	**Area 3**	**Area 4**
Catch and effort data	Use only “core” **New Zealand** fleet CPUE in area 2. (omit recent spatial expansions)		Attempt to acquire Taiwanese operational level logbook data from U.S. (acquired in Pago Pago)	
	Use only “core” Australian fleet CPUE in area 1.		Explore utility of Japanese, Korean and Taiwanese CPUE in areas 3 and 4. Provide comparison of CPUE trends among fleets operating in the same area and for the same fleet using catch rates standardized with and without operational level data as an indication of value of operational level data.	
	Complete Japanese CPUE standardization for areas 1 and 2			
	Request operational level data and fishery development descriptions from **PINs** to help interpret catch rates as abundance indices (this is a long term objective).			
	Request Japanese and Taiwanese catch data for 2006 with primary urgency, all fleet data for 2007 would be ideal			
	Do not use the spatially aggregated Spanish CPUE indices at this time			
Size data	Include **Australian** observer data. Analyze **Australian data with spatial disaggregation** to ensure that size trend is not a spatial effect.	Obtain packing data from **Fiji** to acquire individual fish size information.	Obtain packing data from **Cook Islands** to give individual fish size information.	Inquire about French Polynesia packing data.
	Re-iterate request for Spanish size composition data. Encourage size sampling for all fleets in the future			
Sex data	No assessment action at this time. Encourage further sampling and data circulation for all fleets			
Tagging data	Seek to update tagging analysis if substantial numbers of additional tag results becomes available.			
Genetic data	No assessment action at this time. Encourage further sample collection, particularly from South-Central Pacific (areas 3-4)			
Maturity Studies	Assessment to consider alternative maturity schedules consistent with the differing maturity interpretations. Encourage further sampling and analytical work.			
Age/Growth Studies	Assessment to consider alternative growth curves, consistent with the different studies. Encourage comparisons of ageing methodology among labs. Methods of direct age validation should be pursued (e.g. conventional tagging coupled with oxy-tetracycline marking).			

Attachment E: Brief descriptions of the swordfish fisheries in the Cook Islands, New Caledonia and French Polynesia.

1. Cook Islands fishery summary

The Cook Islands longline fishery is characterised by two distinct fishing techniques, vessels fishing in the northern part of the zone (above 15º South) target albacore tuna, setting lines with an average of 30 hooks per basket, and trip lengths averaging 6 weeks. Some vessels retain swordfish catches to be sold on the local market (Pago Pago), while others (usually Asian captains) discard swordfish to keep space for tuna catches. All vessels operating in the northern fishery unload to canneries in Pago Pago.

Vessels fishing in the southern part of the zone cater to the fresh fish market, with specific swordfish targeting beginning in 2002, when fishermen from the East Australian swordfish fishery introduced the targeting techniques of shallow night setting and the use of light sticks. The average number of hooks per basket is 15.

The distribution of effort for the northern fleet spans right throughout the northern CK zone, and although in the past vessels roamed above and below 15º south, in recent years this has become less frequent with the fleet usually keeping fishing activity north of approximately 14º south.

From 2002 to 2005, the fleet structure of vessels operating out of Rarotonga consisted of vessels ranging in length from 10m to 34m and GRT ranging from 8 to 275mt, with vessels above 16m targeting tuna for the export markets. The larger vessels would roam between the northern and southern bounds (15º south) of the zone. Fishing activities for the smaller scale vessels concentrated around Rarotonga, and sea mounts in the southern part of the zone.

The fleet structure of vessels operating out of Rarotonga changed from 2006 onwards, consisting of 7 small scale vessels with length and GRT ranging from 11m to 16m and 10mt to 35mt, respectively. These vessels target swordfish to cater for local demand. In 2007 this was reduced to 5 vessels.

Based on anecdotal information bait preferences varied among fishing companies with squid being the preferred bait for swordfish, or using a mix of squid and pilchards. However in recent times the use of pilchards has become preferable due to the rise in squid prices.

In 2007, Steve Beverly carried out some work on Rarotonga based vessels. During this time a tagged swordfish was landed with a conventional tag. There was heavy fouling on the tag and difficult to identify. Fishermen mentioned that they had seen this before but thought it was a parasite, or some sort of growth on the fish. There was also a high number of 'rats' (length <50cm, weight <5kg) caught in the fishery that year.

Data sources for the fleet include logsheet, unloadings, port sampling and some observer data.

2. New Caledonia fishery summary

From 1983 to 1993 the New Caledonian longline fleet was dominated by large (40 meters in length) freezer vessels originally from Japan which were operated by joint-venture domestic companies.

On these large vessels, the Japanese fishing masters had imported Japanese fishing strategies which were especially implemented in the early 80s. In particular, since the fishing activity was directed to export to Japan, the vessels had much more seasonal fishing patterns and albacore was not at all a target species at this time. These fishing practices changed however slightly during the 80s when it appeared that albacore could be sold at an interesting price on the domestic market. This market grew regularly in volume over time.

The first 100% New Caledonian fresh longliners (from 16 to 20 meters) were first introduced in 1994 and progressively improved their catch rates. Despite the objective of exporting most of the catch to Japan albacore was more and more predominant and almost all other species, including swordfish, became by-catch.

A major event occurred in 1999 with the opening of a second fishing port in New Caledonia where small fresh vessels were based. This doubled the number of longliners. Due to smaller cruising range these vessels however fish closer to the port. This may explain why in 1999, there is a drop in the CPUE of swordfish whose fishing grounds in the EEZ appear to lay far from the ports.

The regular decrease in this CPUE since then can be explained by a New Caledonian fleet targeting more and more albacore.

3. French Polynesia fishery summary

i) Foreign longline fleet (DWFN)

The tuna fishery in the French Polynesia EEZ was dominated by DWFN between 1950 and 1992. Catches of albacore averaged approximately 4,000 mt per year until the mid 1960s when DWFN started targeting bigeye in the northern part of the EEZ, north of 10ºS. Catches were dominated by bigeye and yellowfin tunas in more recent years. While very high catches were estimated for some years, total catches by the DWFN averaged 3,300 mt between 1990 and 2000. No DWFN have operated in the French Polynesia EEZ since 2001 as access licences for these fleets were not renewed.

Japan and Korea were the only DWFN fleets licensed to operate within the French Polynesia EEZ, with 65 vessels operating within the EEZ in 1988. Up to 49 Japanese longline vessels fished within the French Polynesia EEZ between 1984 and 1991. No activity has been recorded by Japanese longline vessels in the French Polynesia EEZ since 1992.

Korean longline vessels operated in the French Polynesia EEZ between 1984 and 2001, with a peak of 46 vessels in 1999. Only three Korean vessels were reported in the French Polynesia EEZ in 2001 with no vessels reported in subsequent years. Relatively few vessels from other DWFNs (Taiwanese longline vessels) have reported any activity in the French Polynesia EEZ and most effort was reported from areas near the northern boundary of the French Polynesia EEZ.

The number of longline hooks set by DWFNs in the French Polynesia EEZ peaked at over 6 million per year in 1988, although the number of hooks set was less than 4 million per year for most years between 1984 and 2000, with an average of approximately 2.8 million hooks per year. Longline sets by DWFN used an average of approximately 2,450 hooks per set between 1984 and 2000, with the hooks per set being relatively stable for this period.

Steadily increasing swordfish CPUEs were reported by the Japanese fleet until the early 1980s when swordfish CPUEs declined and stabilised at low levels. The declines in CPUEs of swordfish may be due to a shift in targeting and areas of operations, as both species are more abundant in sub-tropical and temperate waters. As all DWFN focussed on the northern areas of the EEZ since at least the early 1980s, the CPUEs for temperate species were expected to decline. The CPUEs for swordfish for Taiwanese and Korean vessels have been relatively low and constant.

All this data for foreign fleets which have operated in the French Polynesia EEZ were reviewed in the French Polynesia National Tuna Report n#9 (Brett Molony, SPC-OFP, March 2006).

ii) Domestic fleet

Three major categories (fleets) of domestic fishing vessels operate in the French Polynesia EEZ: tuna longliners, *bonitiers* (pole-and-line) and *poti-marara*. Both the *bonitier* and *poti marara* fleets operate in coastal waters (less than 25 nm from islands) in the French Polynesia EEZ and are considered coastal fleets. A large number of these vessels exist, but the cumulative catch of tuna and other species by this fleets are not easy to quantified because they operate from a large number of islands and data holding are relatively low. Nevertheless, no swordfish catch has been recorded in logsheet data since 1992.

Since 1990, the number of domestic longline vessels in the French Polynesia EEZ has expanded, especially since the mid 1990s. In 2006, the domestic longline fleet of French Polynesia consisted of 39 fresh tuna longline vessels (13–20 m in length), 4 mixed (fresh and frozen vessels) longline vessels (21 m in length) and 28 freezer vessels (23–26 m in length).

Logsheet data for the domestic longline fleet dates back to 1992. Since 1997, annual catches by the domestic longline fleet have averaged approximately 5,800 mt per year. The major target species are albacore tuna (an average of 3,400 mt per year since 1997), with lesser amounts of bigeye (500 mt) and yellowfin (660 mt) tunas. Sharks (260 mt), blue marlin (260 mt) and other fishes (760 mt) are also retained by this fleet. Effort has increased rapidly since 2000, with a total estimated effort exceeding 21 million hooks for 2004.

Albacore catch rates in the French Polynesia EEZ peaked during 1998, before declining to low levels, especially since late 2002. Yellowfin and bigeye CPUEs also declined throughout the main longline fishing areas during the same period. Catches and CPUEs of all three species have remained at relatively low levels since 2002.

Swordfish is not targeted by French Polynesia longline fleet, and has to be considered as a bycatch (83 mt in 2006, 1.6% of total catch). Concerning size data, very small swordfish (< 60 cm LJFL) are seasonally caught in the northern part of French Polynesia EEZ. The Marquises Islands Area is considered a spawning area. Swordfish CPUEs of the domestic longline fleet have declined through time, especially since 2000. However, some of the trends may be due to changes in fishing strategy: a single vessel targeted swordfish in the south of the EEZ in 1996 and two vessels in 2006. But difficulties faced by wholesalers to export this product did not allowed development of this fishery.

Those trips were experimental trip to target swordfish. The first one occurred in September and October 1996 with a Hawaiian fishing master: the longline vessel Arevamanu was targeting swordfish in the seamounts area around Rapa Island (23°S-32°S/150°W-140°W). Results were encouraging concerning the resource: 33 days at sea, 17 sets, 12.310 hooks, 13.1 mt total catch, 9.6 mt swordfish catch. The second one occurred in November and December 2006: two longline vessels, Moorea Rava'ai 6 and Vaeanapa were targeting swordfish in the southern part of French Polynesia EEZ (155°W-140°W/24°S-31°S). They used typical longline setup for swordfish: set at night, use of light sticks (3 per basket), shallow setting (12 hooks per basket).Concerning the setting practice to target swordfish, results were encouraging too:

- Moorea Rava'ai 6: 30 sets, 36.332 hooks, 261 fish and 85 swordfish (average length: 182 cm LJFL);
- Vaeanapa : 30 sets, 46.896 hooks, 403 fish and 83 swordfish (average length: 175 cm LJFL).

All those data are available at SPC-OFP. The southern swordfish stock is very interesting for French Polynesia, as for other small islands developing states, as a good resource in complement of albacore tuna resource. French Polynesia want to contribute to study this stock, and to participate in a collaborative tagging project.

Attachment 6 . WCPFC Conservation and Management Measure 2008-05. Conservation and management of swordfish. (5p.)

FIFTH REGULAR SESSION

8-12 December 2008
Busan, Korea

CONSERVATION AND MANAGEMENT OF SWORDFISH

Conservation and Management Measure 2008-05[1]

The Commission For The Conservation And Management Of Highly Migratory Fish Stocks In The Western And Central Pacific Ocean

In accordance with the Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean and the provisions of UNCLOS:

Noting that the stock assessment undertaken for swordfish in the South Western Pacific region indicated an increase in south-west stock abundance in recent years and the model projections predict further increase at current levels of fishing mortality. Plausible assessments indicate that overfishing is not occurring and the south western Pacific swordfish stock is not in an overfished state;

Noting that due to the uncertainty in the 2008 stock assessment for south-western Pacific swordfish, the SC recommended that there be no further increase in catch or effort in order to keep the stock above its associated reference points;

Further noting that the Scientific Committee has recommended that there be no increases in fishing mortality for south-central Pacific swordfish as a precautionary measure given the lack of a formal assessment and that constraining fishing mortality to current levels is recommended until there is a better understanding of fishing impacts in the south-central Pacific stock and the relationship between this stock and other south Pacific stocks is more certain;

Further noting that the south-east Pacific swordfish stock is considered by the IATTC scientific Secretariat not to be overfished or in an overfished state;

Recognising that well managed stocks of swordfish in the central south Pacific represent an important source of long-term economic opportunities for the domestic fisheries of small island development States and participating Territories;

Noting that there is significant uncertainty in the 2005 annual catch of swordfish taken by one of the key fishing CCMs in this fishery;

Adopts, in accordance with the Article 10 of the WCPFC Convention that:

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[1] To replace CMM 2006-03

1. Commission Members, Cooperating Non-Members and participating Territories (CCMs) shall exercise restraint through limiting the number of their fishing vessels for swordfish in the Convention Area south of 20°S, to the number in any one year between the period 2000-2005 (listed in Annex 1). CCMs shall not shift their fishing effort for swordfish to the area north of 20°N, as a result of this measure.

2. In addition to vessel limits established under paragraph 1 (listed in Annex 1), CCMs shall exercise restraint through limiting the amount of swordfish caught by fishing vessels flagged to them in the Convention Area south of 20°S to the amount caught in any one year during the period 2000 – 2006.[2] CCMs shall not shift their fishing effort for swordfish to the area north of 20°N, as a result of this measure.

3. No later than 30 April 2009 CCMs shall nominate the maximum total catch of swordfish that it shall continue to be permitted to fish in the area south of 20°S in 2009. This amount shall be no more than their maximum verified catch declared to the Commission for any one year in the period 2000-2006.

4. The catch limits established under paragraph 2 will apply for 2009.[3]

5. In order to reconcile significant changes in catch of swordfish south of 20°S by swordfish vessels reported to the Commission, all operational level catch and effort data for swordfish vessels flagged to the relevant CCM shall be subject to an independent catch verification review funded by the CCM to whom the data relates, and carried out in 2009. The verification review will be undertaken by SPC-OFP in cooperation with the flag state's relevant authority and in accordance with an appropriate confidentiality agreement. The verification review shall occur in the flag State to whom the data relates. The results of the verification review shall be reported to the Scientific Committee and the Technical and Compliance Committee, and taken into account by the Commission in determining any future catch limits.

6. Paragraphs 1 to 4 and paragraph 10 shall not prejudice the legitimate rights and obligations under international law of small island developing State and participating Territory CCMs, in the Convention Area who may wish to pursue a responsible level of development of their own fisheries in the Convention Area south of 20°S.

7. For the purposes of these measures, vessels operated under charter, lease or other similar mechanisms as an integral part of the domestic fleet of a coastal State, shall be considered to be vessels of the host State or Territory. Such charter, lease or other similar mechanism shall be conducted in a manner so as not to invite IUU vessels. The Commission shall consider the implementation of a Charter Arrangements Scheme at its 6th Session in 2009.

8. CCMs shall cooperate to protect the long-term sustainability and economic viability of the fisheries for swordfish in the Southwest Pacific, and in particular shall cooperate on research to reduce uncertainty with regard to the status of swordfish stocks.

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[2] The catch for the European Community shall be limited to a maximum of 3107 tonnes for 2009.

[3] Noting the limits established under paragraph 2, Australia and New Zealand (historically the two largest catchers of swordfish south of 20°S taking around 75 percent of the catch) have limited their catch for 2009. Australia's domestic total allowable catch for swordfish in the Convention Area is limited to 1400 tonnes for 2009. New Zealand's domestic total allowable commercial catch within its EEZ is currently limited to 885 tonnes.

9. CCMs shall report to the Commission the total number of vessels that fished for swordfish and the total catch of swordfish for the following:

a. vessels flying their flag anywhere in the Convention Area south of 20°S;
b. vessels operating in their EEZ south of 20°S under charter, lease or other similar mechanism; and
c. any other vessels fishing within their waters south of 20°S.

This information shall be provided in Part 1of each CCM's annual report. Initially, this information will be provided in the template provided at Annex 2 for the period 2000-2008 and then updated annually.

10. As an interim measure, until the Commission adopts a scheme relating to compliance with CMMs which includes responses when a flag State exceeds any limits assigned to it, if the catch of vessels flying the flag of a CCM exceeds the total catch specified for them under paragraph 6 above, that CCM will be subject to a reduction in their catch limit in the next year equal to the exceeded amount.

11. The Executive Director shall compile and disseminate the information provided to the Commission by CCMs in accordance with paragraphs 6 and 7 above to the Technical and Compliance Committee each year. The Technical and Compliance Committee shall monitor and review compliance with this measure and make recommendations to the Commission as may be necessary.

12. The Commission will review this measure at its 6th Regular Session in 2009, on the basis of advice from the Scientific Committee on the implications for a swordfish stock assessment following investigation of data uncertainties

13. This measure replaces CMM 2006-03.

ANNEX 1 –

NUMBERS OF CCM-FLAG VESSELS THAT HAVE FISHED FOR SWORDFISH IN THE CONVENTION AREA SOUTH OF 20°S DURING THE PERIOD 2000 – 2005 (Maximum number of vessels per CCM are indicated in **Bold) [taken from WCPFC-2009/DP04, Annex 1]**

Year	**Australia**	**EC**	**Korea**	**New Zealand**	**New Caledonia (by-catch)**	**Chinese Taipei**	
						Seasonal	Bycatch
2000	140	0	22	103	15	10	41
2001	159	0	22	132	12	10	41
2002	144	0	22	151	11	10	42
2003	134	0	24	132	15	12	55
2004	121	8	22	99	25	8	39
2005	100	14	23	57	18	6	40
Limit	**159**	**14**	**24**	**151**	**25**	**12**	**55**

Annex 2 –

REPORTING FORMAT FOR THE CATCH OF SWORDFISH PER FLAG CCM AND COASTAL CCM (TO BE SUBMITTED IN EACH CCMS ANNUAL REPORT (PART 1))

Year	CCM-flagged vessels south of 20S		Chartered vessels fishing within the CCM's waters south of 20S		Other vessels fishing within the CCM's waters south of 20S		
	Catch (tonnes)	Vessel numbers	Catch (tonnes)	Vessel numbers	Flag	Catch (tonnes)	Vessel numbers
2000							
2001							
2002							
2003							
2004							
2005							
2006							
2007							
2008							