A Review of the 1996 Assessment of School Shark in the Southern Shark Fishery

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NON TECHNICAL SUMMARY: PRO-FORMA

96/129 **Review of the 1996 Stock Assessment of School Shark in the Southern Shark Fishery**

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OBJECTIVES:

1. To ensure that best available scientific advice is available for management decisions and that industry has confidence in the outcome of the stock assessment.
2. To review estimates of abundance and basic biological parameters used in assessing school shark stock status.
3. To review statistical and modelling methods used in the school shark stock assessment.
4. To improve industry understanding of the stock assessment process and acceptance of the results.

NON TECHNICAL SUMMARY:

At the request of AFMA and for the benefit of the Southern Shark Fishery Management Advisory Committee (SharkMAC), I reviewed the 1996 stock assessment of school shark. My evaluation is that the school shark assessment is probably the most comprehensive of any shark population in the world.

In carrying out my review I spent time talking with AFMA management, fishing industry representatives and with the fisheries scientists involved in the assessment.

My review supports the general conclusion of the Southern Shark Fishery Assessment Group (SharkFAG) that the current biomass of the school shark resource is likely to be well below the unfished (virgin) biomass level . However, I would assign a greater degree of uncertainty to the estimate of the current biomass presented by SharkFAG.

A particular strength of the current school shark assessment was the process followed by SharkFAG. People from industry, management and the fisheries scientific community were all active members of the SharkFAG and contributed to the assumptions used in the assessment. Those contributions allowed the assessment to reflect a great deal of experience about the history of the fishery.

While supporting the comprehensive nature of the assessment and the process taken in producing it I must point out that the assessment was based on a very 'noisy' data set and

that substantial improvements could be made through developing a spatially disaggregated assessment based on more detailed data from various geographical regions of the fishery, as proposed by SharkFAG.

A spatially-disaggregated assessment, would also be useful as a policy evaluation tool to help resolve many relevant management issues. Reliable catch data and improved monitoring in the fishery would be important for such an assessment and I would strongly recommend that uniform detailed logbooks should be put in place throughout the range of the fishery and a further work to maximise benefits from tagging work.

I conclude that a reduction in catch is supported by information available at the present. However, SharkMAC may wish to consider that any reductions be phased -in over a five year period for following two reasons:

- a phase-in would allow fishermen a transition period in which to adjust their operations and adapt to altered modes of fishing;

- a phase-in would allow SharkFAG time to assess the school shark population using a spatially-disaggregated method and perhaps recommend changes in the phase-in schedule should they be warranted.

The risk analysis presented by SharkFAG is an excellent start to determining the consequences of changes in school shark exploitation, however, more work needs to be done, in my opinion, before a completely satisfactory evaluation of consequences is available to fisheries management. In particular I would recommend a quantitative assessment of the impact of any changes in school shark exploitation upon the gummy shark fishery and a similar spatially disaggregated assessment method should eventually be applied for gummy shark. This multi-species approach would provide SharkMAC with the tools needed to evaluate alternative hypotheses about changes in fishers' behaviours to changes in regulations about the fishery. However, the multi-species model is more of a long-range research topic.

Overall, I would say that as far as spatially aggregated models are concerned, the methods used in this assessment are comparable with the best work being done around the world. While I believe that some of the changes I have suggested as part of my review would result in a slightly more optimistic assessment about the resource and its chances for recovery, a catch reduction is still required to keep school shark above current stock levels in the medium-term.

KEYWORDS: **school shark, stock assessment, fisheries management**

1.0 Summary

This review of the 1996 stock assessment of school shark was prepared at the request of the Australian Fisheries Management Agency (AFMA) for the benefit of the Southern Shark Fishery Management Advisory Committee (SharkMAC) and other interested parties. My evaluation of the school shark assessment is that it is probably the most comprehensive assessment of any shark population in the world. Having said this, I should also add that the assessment is based on a very noisy data set and that substantial improvements can be made with the development of a spatially-disaggregated assessment.

A strength of the current school shark assessment is the process followed by the Southern Shark Fishery Assessment Group (SharkFAG). Members of industry, management, and the fisheries scientific community all were members of SharkFAG and contributed to the assumptions employed in the assessment. Those contributions allowed the assessment to reflect a great deal of experience about the history of the fishery. Members of the group gave expert opinions on such matters as the level of exploitation that one might expect to be sustainable by the school shark population. Such expert opinions were incorporated directly into the assessment procedure by the development of "prior" probability distributions, which describe the probability one would assign to a given value for a particular unknown, such as maximum sustainable exploitation, in the absence of the actual quantitative assessment. The Assessment Group reached consensus on important matters such as the types of interpolation and extrapolation rules used to estimate fishery catch rates in years and geographical regions for which there was poor data.

My review supports the general conclusion of the Southern Shark Fishery Assessment Group that current biomass of the school shark resource is likely well below the unfished (virgin) biomass level, although I would assign a wider range of uncertainty to the level of decline than is presented in their assessments. In part, my wider range of uncertainty reflects less confidence in the CPUE standardization schemes employed by the group. In particular, the extrapolation and interpolation of CPUE estimates for regions and years with poor data is likely to result in estimates of relative "selectivity-weighted" biomass less precise than the 10-15% estimated coefficient of variation. Extrapolated CPUE's, particularly those for earlier years, strongly influence conclusions of the assessment. CSIRO scientists ran a series of sensitivity analyses to address the effect of extrapolation "noise" on conclusions.

I strongly concur with the Assessment Group's decision to proceed with development of a spatially-disaggregated assessment method. Only with such a method would the Group be able to avoid some of the dangers of CPUE extrapolation/interpolation present in the current aggregated assessment. Furthermore, such a model would be able to address many relevant management issues at the appropriate degree of resolution. In particular, such a model would be able to examine consequences of shifts in spatial distribution of catches

both on the ability of the resource to recover and on the types of information likely to be available to future assessments. There is likely a trade-off between effectiveness of management controls to limit exploitation on the resource and the quality of information available to future assessments. For example, a system of area or depth closures might be a very effective and simple way to reduce exploitation but it would cause the loss of indices of shark abundance within the closed areas. One could imagine a scenario, such as apparent in the SBT fishery, where the lack of information in closed areas caused an increase in uncertainty about the status of the resource.

A reduction in exploitation rate of the resource is supported by information available at the present time. However, I would recommend that SharkMAC may wish to consider that any reductions they deem warranted be phased-in over a five year time frame for two principal reasons: (1) the phase-in would allow fishermen a transition period in which to learn how to adapt at altered modes of fishing, (2) the phase-in would allow the assessment group time to assess the shark population with the spatially-disaggregated method and recommend adaptive changes to the phase-in schedule should they be supported by the additional analyses.

Recommendations

I recommend that:

1. a catch monitoring system be implemented in the fishery. Reliable catch data is important to the assessment (and management) of the resource

2. uniform detailed log-books throughout the fishery. Steps should be taken to ensure that data reported in log-books is accurate.

3. a discard monitoring system is needed to directly track the losses of school sharks in other fisheries

4. the assessment group assess the merits of "control" data collection by commercial gill-net.

5. a thorough research program be instituted to maximize the information obtained through tagging

6. proceed with development of a spatially-disaggregated assessment method

7. assessment of gummy shark with an approach similar to the one ongoing for school shark be placed as a follow-on to the school shark disaggregate assessment

8. the stock assessment method be modified to include uncertainty about catches, rather than at present where they are assumed known without error.

9. as far as feasible to avoid any extrapolation of "missing" data in development of CPUE indices for the spatially-disaggregated analysis

10. that GLM of data be done in highly parameterized models that allow for gear-by-region-by-month-by-year interactions (for the spatially-disaggregated analysis)

11. the use of a delta-gamma model or more generally a delta-Box-Cox model in which the zero's in the data are modeled separately from non-zero catch rates

12. that seasonal patterns and age patterns given by the fine-scale model, which has a daily and "block" level resolution, be assumed to hold true in the estimation model, which has a monthly and "region" level resolution, but that this constraint be gradually relaxed as data estimation permit.

13. binning the observed length frequencies in large enough bins so as to avoid over-fitting of the data. Whenever both age frequency and length frequency are available for a given stratum, I recommend that only the age frequency data be used in the estimation model, which should be binned particularly for the older age groups.

14. that alternative methods to estimate natural mortality be applied, such as the methods by Pauly, Hoenig, and Gunderson.

15. continue to use standard growth models, but that they be estimated separately for each gear-type, as data permits.

16. the "base case" assessment exclude the CPUE data in 1973-1975

17. decision makers may wish to consider that any reductions they deem warranted be phased-in over a five year time frame

18. that the assessment group calculate the required reductions in fishing mortality for a five-year phase-in.

19. that all projection results be presented in terms of changes in fishing mortality rate

20. MLE estimates only be viewed as a qualitative indicator of effects of changes in assumptions about the assessment model and rely upon results from the Bayesian analysis for quantitative answers

2.0 Introduction

I was contracted during 1996 by AFMA to conduct a review of the 1996 school shark stock assessment. Terms of reference for the review were given by the following objectives:

1. Review the age-structured spatially-aggregated stock assessment and advise on the adequacy of the data and methods used, on the adequacy of the current stock assessment approach to underpin decisions for resource management purposes, and make recommendations on any improvements that can be made.

2. Review the approach being developed to model the fishery on a spatially-disaggregated basis and advise on the feasibility of this approach and its potential merits, or otherwise, as compared to the existing assessment methods, and whether any improvements to this approach are required.

The objectives were meant to ensure that management action taken on the school shark be based on an assessment that has been subjected to a thorough review by an internationally recognized scientist.

The review process followed was scheduled as a ten-day trip allowing for consultation with the scientists, the management authority, and industry to ensure a balance of opinions was taken into account. On 22 July 1996, I met in Canberra with AFMA manager Mrs. Trysh Stone, consultants Mr. Barry Kaufman and Dr. Gerry Geen, and scientist Dr. Andre Punt. On 23 July 1996, I met in Melbourne with industry participants Mr. Brian Bailey, Mr. Brian Daff, Mr. Horst Fischer, Mrs. Debbie Lade, Mr. Wynn Hobson, Mr. Peter Riseley, Mr. Robert Wilson, AFMA manager Trysh Stone, and scientist Dr. Andre Punt. On 24-26 July 1996, I met in Queenscliff with scientists Dr. Andre Punt, Mr. Terence Walker, and Mr. Bruce Taylor. On 28 July 1996, I presented a brief summary of preliminary results to SharkMAC in Brisbane.

I relied on the following documents for this review: April 1996 School Shark Assessment Report by SharkFAG; SS/96/D8 document "Standardization of commercial catch and effort data for school shark" by Punt, Xiao, and Taylor; SS/96/D9 document "Stock assessment and risk analysis for 1996 for the school shark *Galeorhinus galeus* (Linnaeus) off southern Australia using a spatially-aggregated age-structured population dynamics model" by Punt and Walker; SS/96/D7 "Catches of school shark *Galeorhinus galeus* (1927 - 1994)" by Taylor, Punt, Walker, and Simpfendorfer; 1996 "Stock assessment and risk analysis for the school shark off southern Australia" by Punt and Walker; SS/96/D13 "Some thoughts related to evaluating alternative management measures for school shark *Galeorhinus galeus*" by Punt; 1996 Report to SharkMAC by SharkFAG; "Stock assessment report 1995 gummy shark" by Walker; "Fishery Assessment Report: The southern shark fishery 1995" by SharkFAG; Grant *et al* 1979 Aust. J. Mar. Fresh. Res, 30:

625-637. Additional material was utilized, primarily computer output of sensitivity analyses and alternative stock assessment projections, in-progress computer runs of the disaggregated movement models, and my own references.

The limited time for this review precluded me from an in-depth analysis of raw data and computer programs used for the school shark assessment. However, directed sensitivity analyses and alternative projections were made with deletions and down-weighting's of certain portions of the CPUE data that appeared to me to warrant those special studies.

3.0 Data sources and assumptions

3.1 Stock Structure

There are two main hypotheses about stock structure:

1. The southern school shark stock is a single population that ranges from NSW south to at least the eastern portion of WA; a map of the geographical zones in the fishery is shown in Figure 1. The population resides both inshore and offshore with a few individuals migrating as far away as NZ. The population breeds primarily along the coasts of Victoria and Tasmania. The southern school shark fishery catches primarily individuals from the southern school shark population, but can include a minor contribution of migrants from other populations as far away as NZ.

2. The southern shark stock is made up a collection of distinct populations distributed along the range of the southern school shark fishery. These distinct populations exhibit breeding along a wide stretch of near-shore waters encompassed by the southern school shark fishery.

Primary evidence for the single stock hypothesis consists of genetic analysis by Dr. Ward, CSIRO, with mtDNA and electrophoresis techniques. That work was not able to distinguish population differences among samples collected from waters off eastern and western Tasmania, Bass Strait, and West South Australia, although there were differences between this group and those of New Zealand. Additional evidence in favor of the single stock hypothesis is provided by the long-range movement of tagged school sharks in the southern area, as seen from recaptures. Other evidence is provided by the limited number of pupping areas found presently in the southern area (basically only near-shore waters of Tasmania and some limited areas off Victoria).

Evidence for the multi-stock hypothesis is provided primarily by the loss of certain historical pupping areas as present day nursery areas. In particular, at one time Port Philip Bay provided a large pupping area that is no longer utilized as a nursery area. A similar loss has occurred in S. Tas. In addition, some historical interpretations of the development of the southern fishery are consistent with a serial (that is, population by population) depletion of some smaller populations in the southern area. Standardized CPUE estimates for the different regions show different trends over time, which could indicate that separate populations reside in some of the regions.

Alternative interpretations are available for many of the observations on pupping areas, tagging data, and CPUE data. I view that information as equivocal. The genetic study is more definitive, although here too a multi-stock structure in which stocks share only a small gene flow may not be distinct populations in the genetic sense, but from a management point of view they may need to be managed as separate stocks.

In my opinion, the weight of evidence favors the single population hypothesis, although not so strongly as too be able to soundly reject a multi-stock structure. Thus, I would conclude that restrictions of the harvest of school sharks to a narrow range of areas in the southern area are more risky to the population(s) than a fishery which spreads the harvest over a large range of areas, but not so risky as to be the over-riding primary variable to be taken into account.

3.2 Catches

Catches utilized in the assessment of school shark are a subset of total removals of the resource in that they comprise reported landings only for the gillnet fishery, the shark longline fishery, and Tasmanian rock lobster fishery. Additional landings include roughly 100 tons annually made by the trawl fishery, on the order of 10 tons annually by the tuna longline fishery, and on the order of 15-100 tons annually in Western Australia, west of the areas currently considered in the assessment. Additional discarded catches of school shark occur in many other fisheries, but no estimates of those losses is incorporated in the assessment; the assessment treats the loss of these primarily juvenile fish as part of the "natural" mortality incurred by juveniles prior to their recruitment into the documented school shark fishery.

Both under-reporting and over-reporting of school shark catches have likely occurred, but neither of those biases have been quantified. The reporting errors occur for many reasons, including under-reporting of catches after the mercury ban went into effect in late 1972 and including over-reporting of catches later in time as fishermen were concerned that they needed catches recorded so that they would be included in any management permits issued for the fishery. My conversations with fishermen confirm presence of those reporting errors, but they were not able to state what the net effect of those off-setting errors has been on the average catch over the last twenty years.

Errors in the amount of annual landings increase the uncertainty in stock assessment and increase uncertainty regarding the consequences of any management actions contemplated for the stock. I recommend that the stock assessment method be modified to include uncertainty about catches, rather than at present where they are assumed known without error.

A catch monitoring system needs to be implemented in the fishery. Reliable catch data is important to the assessment (and management) of the resource. The SharkMAC may also wish to consider the fact that omission of trawl catches in the assessment means that any type of quota system based on results of current assessment would need to take that omission into consideration.

A discard monitoring system is needed to directly track the losses of school sharks in other fisheries. Such a program would allow management information needed to implement discard mortality controls, or other measures such as closures of documented "nursery" areas, should discards increase to levels detrimental to the stock.. The costs of such a program can be substantial because accurate discard data can only be obtained by "scientific observers" placed on vessels. Therefore, decisions about the need of permanent observer program should first be obtained from a pilot study, involving fewer observers but designed in such a way as to obtain representative estimates. Less costly alternatives may be available through VMS or other means of monitoring of locations and effort levels of vessels with the types of gears, such as trawlers, that could be responsible for high discard shark mortalities along with experimental catches in those areas to estimate catchability of school shark.

3.3 Catch per unit effort

General linear models (GLM) were applied to catch and effort data collected from logbooks of fishing in the southern school shark fishery since 1973. Considerable attention was made to select a group of "dedicated" shark vessels from those which have reported data over the 1973-present time period. The GLM models developed for the CPUE analysis are standard for fisheries assessment, including both the Poisson and log-normal error models. Catch per unit effort information can be a useful index of abundance if proper care is taken to standardize the index against changes in fishing practices. Because of changes in mesh size and in the targeting of school shark versus gummy shark, the reliability of the GLM estimates is difficult to assess. Fisheries in other parts of the world have shown that CPUE may be related to changes in catchability rather than changes in abundance. For this reason, assessments are best made with fishery-independent surveys whenever possible. Unfortunately, survey data are not available for school shark. The next best solution is to use an assessment framework that can incorporate information other than CPUE. The proposed spatially-disaggregated assessment model should provide a method with which to include tagging data, length and age frequency, along with the CPUE data.

After the CPUE data has been standardized, the estimates are aggregated to form a spatially-aggregated index of abundance. The main problem here is that many of the seven regions chosen for stratification of the school shark fishery do not have the types of CPUE data that were used in the GLM. The lack of data occurred for several reasons, including lack of fishing in a given area by gear-types chosen for analysis in the GLM. The aggregated abundance index requires that indices of abundance be input for each region in each year; therefore various rules were developed to fill in "missing" data.

The rules for "missing" data likely influence the results to the assessment to a greater degree than desired. In particular, the lack of adequate data in CSA and WSA prior to 1985 was very unfortunate; the school shark stock was thought by the Assessment Group to be in greater abundance in years prior to 1985 than in years after 1985. The estimates of CPUE, after application of the "missing" data rule is shown below on Figure 2 (from SS/96/D8). I say that the abundance prior to 1985 was thought to be greater because the rules for "missing" data were designed in such a way as to guarantee that indices of abundance in CSA and WSA prior to 1985 were above the post-1985 average. The "missing data" rules were made by scientists and industry together. I would prefer to have that type of consensus information included as a "prior" probability belief about the state of the resource, but the current spatially-aggregated method does not allow this flexibility.

A crude examination was made of consequences of treating pre-1985 CPUE indices as being less reliable than post-1985 CPUE indices. The examination was made by asking the assessment group to run several MLE scenarios, where each scenario has a different variance of the CPUE in the pre-1985 period relative to the variance in the 1985(+) period. As seen below the results show that as we decrease our confidence in the pre-1985 indices (by assuming a higher variance, given by σ^2, for that data), we generally increase our optimism about the current state and productivity of the resource. The smaller changes in B/K, as compared to relative changes in other quantities, indicate that evidence for stock decline is robust to a large range of alternative assumptions regarding the weighting of variances.

Quantity	σ	2σ	3σ	5σ	10σ
MSYR	0.03	0.032	0.047	0.11	0.12
MSY	553	597	785	1173	1230
B/K	0.25	0.28	0.29	0.30	0.35

The quantity *MSYR* is the rate of exploitation that leads to *MSY*, the maximum sustainable yield level, and *B/K* is the ratio of current mature biomass to biomass at the unexploited (virgin) biomass level.

A major advantage to the spatially-disaggregated model is that it does not require estimates of CPUE for each region in each year. Therefore, the most serious problem with the "missing" data algorithm, namely the extrapolation component, can be eliminated from the assessment along with consequences it imparts to the assessment. One could then introduce a "prior" probability belief into the analysis about the abundance of the population prior to 1985 if one still wished to include the consensus opinion that the population was at a higher level of abundance during those years. The inclusion of more types of data from either longlines or 8" mesh gear, which are currently not in the GLM, may provide information about abundance prior to 1985 in the various regions. I recommend, as far as feasible, avoid any of the extrapolation of "missing" data in development of CPUE indices for the spatially-disaggregated analysis; furthermore, I recommend that GLM of data be done in highly parameterized models that allow for gear-by-region-by-month-by-year interactions.

The main purpose of standardization in the disaggregated model would be to obtain average catch rates in those strata that have vessel effect and targeting effect removed, as far as feasible. The assumption of a constant relationship between observed and predicted gill-net-based indices could then be reasonably applied to assessments, provided separate gear selectivities are included in the relationship. The relationship between observed and predicted indices may not be linear; in other studies, a power curve function has been a useful way to test for gear saturation effects. The situation is also complicated by what fishermen describe as the tendency for school sharks to become "spooked" by gear presence. Some simple ways to test for such effects are available, such as by GLM tests with an explanatory variable that represents fishing effort near a given stratum under investigation. However, those complications are difficult to quantify with the types of data available for the school shark assessment.

Neither of the two alternative error structures considered in the GLM is completely satisfactory because graphs of residual variance versus expected value do not look like ones from either a log-normal or a Poisson distribution (see Figure 3 of SS/96/D8). I recommend in the future that a more general transformation be utilized, such as the Box-Cox transformation and MLE estimates of the optimal transformation be used in the CPUE standardization. One caveat to this suggestion is that some weighting by the amount of fishing effort represented by each datum will likely be needed to insure that catch rates obtained by vessels fishing over a short time period with little gear are not over-weighted in the analysis. Another fruitful area to consider is the use of a delta-gamma model (such as in Stefansson's recent paper) or more generally a delta-Box-Cox model in which the zero catch rate entries in the data are modeled separately from non-zero catch rates.

The log-normal and Poisson error assumptions led to widely different assessments about the current state of the resource in the assessment reports. One closer inspection though it looks like the main difference between the two GLM models lies in their estimates of CPUE for the 1973-1975 time period, as seen in Figure 3 below (from Figure 5 of SS/96/D8). There are several reasons to discount catch rates estimated for the 1973-1975 time period, including (1) catches were likely under-reported in those years immediately following the mercury ban, (2) fishing behavior was likely altered because of the mercury ban, (3) many of the CPUE estimates are actually numbers estimated by the "missing" data algorithm, and importantly (4) those years are the main ones for which the two GLM methods can not agree. Thus, there seems to me to be justification for excluding those years in the stock assessment. A sensitivity analysis regarding the effects of those years is given below in the stock assessment report section.

The lack of useable log-book data for CPUE analysis is partly due to deficiencies in the log-book programs in place. Ideally the different reporting systems in Victoria, Tasmania, South Australia, The Commonwealth, and Western Australia would all collect uniform detailed information useful for assessment. Such information should include catch in numbers of fish by species, Loran location of shots, depth from which catch was taken, mesh size of the gear, and other pertinent data. I understand that a review of log-books is in progress now, which will hopefully recommend the collection of information suggested above. Steps should be taken to ensure that data reported in log-books is accurate, such as by collecting the log-book information at the time that catch is landed.

4.0 The quantitative assessment

4.1 The population dynamics model and risk analysis method

4.1.1 Spatially-aggregated approach

I have no major concerns about the model and risk analysis method, as far as spatially-aggregated models are concerned. The methods used are comparable with the best work being done around the world and this aspect of the stock assessment was particularly thorough and well done. My preference for a density-dependent pup survival function would be based on the Beverton-Holt model, but this would likely not change results significantly from the quadratic function now employed. A sensitivity analysis of a change in the survival function would be a good idea just to be sure.

4.1.2 Spatially-disaggregated approach

Several ideas were discussed with scientists about suitable modeling structures for the spatially-disaggregated model. This section includes some discussion regarding technical details that may not be clear to the casual reader--my apologies. The type of model envisioned by the assessment group appears quite feasible, but likely will require a pair of complementary models, as the group recognizes. They will need firstly a fine-scale movement model based on some 50+ "block" areas, in which to evaluate policy options and in which to develop the general pattern of movement of sharks throughout the southern area. Secondly, they need an estimation model, which is spatially-aggregated to the seven-region level, in which to "fit" observed data to predictions and thereby estimate magnitude of movement, abundance, and other parameters of the populations' dynamics.

The two models will need to interact together to produce good parameter estimates for both. One approach would be to use qualitative information from tag returns along with information about the biology of sharks to initially parameterize movement rates in the fine-scale model. Those movement rates would be aggregated to a monthly/regional basis and then transferred to the estimation model. The estimation model would select 7 unknowns, preferably the diagonal elements of the transition matrix, to be estimated, but would be constrained so that off-diagonal elements of the transition matrix are of the same general shape pattern given by the fine-scale model. Initially, I would recommend that seasonal patterns and age patterns given by the fine-scale model be assumed to hold true in the estimation model, but that this constraint be gradually relaxed as data estimation permit. The relaxation may proceed by first increasing the 7 unknowns by 2 seasons and by, say, 3 age groupings so as to allow flexibility to model juveniles, young adults, and mature adults in two seasons differently than given by the overall pattern of the fine-scale model. The optimal procedure for parameters to select for estimation is not an established result in fisheries assessment and thus some other ideas may be better than the suggested plan outlined above.

The estimation model uses information from a variety of sources to help parameterize the dynamics. Tag recovery and release information can be used in a multinomial or Poisson likelihood framework. However, there are likely some animals whose movement is not well represented by the simple models developed for this project. There are two ways to handle such situations: the likelihood framework describing recapture probabilities can include a non-negligible probability of recapture not described within the population dynamics model, so that effectively 5%, say, of the data are discarded; alternatively recaptures can be binned so that precise events are not predicted, so that for example recoveries of animals after 10 years from release are predicted in a single bin.

CPUE data would also be fitted to predicted quantities in the estimation model. Here it would be most appropriate to retain as many features of the original data as feasible, but in particular I would advise against aggregation of CPUE data across gear-types or regions or months. The estimation model can be written so that predicted quantities correspond to CPUE at that level of resolution. Some of the CPUE data will not be accurate measurements of relative abundance so that some trimming of the tails of the residual distributions may be needed. For example, a robust likelihood kernel, such as with Huber's function, would cause the likelihood to be penalized roughly as an absolute value of the residual -- rather than as a square of the residual -- for large deviations. As with the tagging data, the idea is to allow perhaps 5% of the data to be discounted.

Another improvement of the disaggregated method, as compared to the spatially-aggregated model, is that length frequencies and age frequencies can be fitted to predictive quantities. A reasonable plan would be to first use age/length data to estimate mean length and the CDF of residual length deviations from an underlying growth model, such as a von Bertalanffy model, or even more simply from the sample mean length. The CDF's and mean lengths would be taken as known quantities in the estimation model and used to construct marginal distributions of the length frequencies of animals predicted for each gear-specific catch. I would recommend binning the observed length frequencies in large enough bins so as to avoid over-fitting of the data. Whenever both age frequency and length frequency are available for a given stratum, I recommend that only the age frequency data be used in the estimation model, which should be binned particularly for the older age groups.

The estimates of transition movement probabilities obtained from the estimation model can be cycled back through the fine-scale movement model. The fine-scale model would then be "tuned" so as to agree with estimation model. Ideally a rapid method of "tuning" could be designed so that for any given vector of parameter estimates, the fine-scale model could be reparameterized to match.

Risk analysis can be evaluated with the estimation model, and perhaps with the fine-scale model provided the latter model is developed to rapidly match parameter estimate obtained by the estimation model. A faster numerical integration scheme than the SIR algorithm would likely be needed and during my trip I brought along a multivariate Metropolis algorithm that shows promise.

4.2 Parameter estimates

Several parameters are used in the assessment models. Some of these are "nuisance" parameters, which although essential to the construction of a proper population dynamics model and estimation model, nevertheless have relatively low importance in terms of the sensitivity of results to changes in their parameter values. Some are important, which I will review below.

Natural mortality

The 1996 assessment used M=0.10 in the "base case" along with alternative hypotheses of M=0.05 and M=0.15. The "best" estimate for M is based on analysis of tag release and recapture data of sharks released primarily in the 1940's-1950's, as analyzed in Grant *et al.* (1979). That estimate for M is based on first an estimate of total mortality rate and then secondly on an estimate of fishery exploitation rate. The approach used in Grant *et al.* (1979) is reasonable, although their assumption that all recaptured shark tags are reported to scientists is likely over-optimistic. As a consequence, the M=0.10 is probably an upper-bound estimate of "true" natural mortality. They also assume there was no initial tagging-induced mortality during the release process, which would also act to bias M upwards. Although gradual loss of tag retention would likely not occur in the internal tags used for those experiments, it could occur in the more recent tagging experiments and such tag losses would also cause M to be biased upwards.

An idea of the magnitude of bias in earlier estimates of M can be inferred. Suppose we assumed that a 50% total loss of tags occurred in those earlier tagging experiments, that is a 50% loss due to combination of non-reporting of recaptured tagged animals and from initial tagging mortality. That would cause the estimate of fishing mortality rate in the tag study to be low by a factor of 50%, and hence we would double the F=0.017 estimate in Grant (1979) to obtain F=0.034. The adjustments to estimates of M operate in the opposite manner and the adjusted M = 0.083 (0.10-0.017). If a 75% total loss of tags occurred then the adjusted M = 0.049.

All the kinds of biases that occur with tagging studies generally cause an upwards bias to M. On the other hand, the "true" M experienced by sharks in the earlier tag studies may be lower than the M in recent tag studies because other sources of mortality may now occur for school sharks. In particular, gill-net fisheries may not be able to land all netted fish either because of "drop-out" of fish during hauling or due to predation during the set, which was not a problem with the long-lines used for fishing during earlier years. Discards can occur in other fisheries. In the assessment one wants M to include all sources of mortality other than landed fishing mortality and thus a higher value of M may be reasonable in more recent years. Given the rather low fishing mortality rates in the directed landed fishery, I doubt the "drop-out" problem would increase M by more than 0.01 or so. Based on the information above, M is likely less that 0.10 and I recommend that the M=0.15 hypotheses considered in the Bayesian analysis be excluded from the assessment. A reassessment of that conclusion can be made when sharks at liberty for several years are recaptured from those sharks tagged in recent experiments.

I recommend that alternative methods be applied to school sharks in order to estimate natural mortality. The methods by Pauly, Hoenig, and Gunderson come to mind. Those alternative methods could be used to estimate a prior distribution for M, which could be incorporated in the Bayesian analysis. An additional parameter to cover non-reporting rate and initial tagging mortality could be included in the estimation model.

The U-shape assumed for change in natural mortality with age is reasonable, although the exact values in the U part are somewhat arbitrary.

Growth in length and weight

Estimates of growth in length and weight in the current assessment represent average values obtained by fitting standard length and weight models to sex-specific data. I recommend they continue to use such standard models, but that they be estimated separately for each gear-type, as data permits. The provision for gear-specific estimates is made in the equation structure for growth given in the assessment documents, but separate parameters by gear are not listed.

4.3 Assessment Results

My review supports the general conclusion of the Southern Shark Fishery Assessment Group that current biomass of the school shark resource is likely well below the unfished (virgin) biomass level, although I would assign a wider range of uncertainty to the level of decline than is presented in their assessments. In part, my wider range of uncertainty reflects less confidence in the CPUE standardization schemes employed by the group. In particular, the extrapolation /interpolation of CPUE estimates for regions/years with poor/none data is likely to result in estimates of relative "selectivity-weighted" biomass less precise than the 10-15% estimated coefficient of variation. The effect of the extrapolation of CPUE's during the earlier years for which CPUE was estimated is most influential to conclusions of the assessment in my opinion.

Tag results reported in Grant *et al.* (1979) are in general agreement with the assessment, which is encouraging given that estimates of fishing mortality from the tagging data were not used in the spatially-aggregated model. Grant *et al.* estimate an average fishing mortality rate *F* of 0.017, which I compared to the MLE estimates of *F* from the assessment assuming log-normal error (average full-recruitment *F* is roughly 0.02 in the 1950's) and MLE estimates of the assessment assuming Poisson error (average full-recruitment *F* is roughly 0.04 in the 1950's). Both of those MLE estimates were based on assessments that exclude the 1973-1975 CPUE data. The Bayesian analysis would likely contain the 0.017 fishing mortality rate well within the range of values used to compute probabilities, although a comparison of the rates between the Bayesian analysis and tag results was not made during my review.

A sensitivity analysis was made during my visit to examine the consequences to stock assessment results of omission of the 1973-1975 data on just two assessment "scenarios." As discussed previously in Section 3.3, the CPUE data in 1973-1975 could justifiably be excluded from the stock assessment and I recommend that the "base case" exclude that data. As seen in Figure 4 below, the effect of removal of that data is minimal on the Poisson model, but more substantial on the log-normal model. The two GLM models are in much closer agreement in their projections without the 1973-1975 data than they were with those three years of estimates. Due to time constraints, a complete new set of assessments has not been made. I believe that results of Figure 4 point to the general trend that would be exhibited by such a complete new assessment; namely that the new assessment would be slightly more optimistic about the resource and its chances for recovery, but still require reductions in exploitation rate to keep it above current stock levels in the medium-term future.

A reduction in exploitation rate of the resource is supported by information available at the present time. However, I would recommend that SharkMAC consider that any reductions they deem warranted be phased-in over a five year time frame for two principal reasons: (1) the phase-in would allow fishermen a transition period in which to learn how to adapt at altered modes of fishing, (2) the phase-in would allow the assessment group time to assess the shark population with the spatially-disaggregated method and recommend adaptive changes to the phase-in schedule should they be supported by the additional analyses. I recommend that the assessment group calculate the required reductions in fishing mortality for a five-year phase-in.

The stock projections are presented for different levels of change in "effective" effort. The concept of "effective" effort can be misleading; therefore I recommend that all projection results be presented in terms of changes in fishing mortality rate. This recommendation is mainly one of semantics because in the current projections, reductions in "effective" effort are calculated by changing a multiplier of current fishing mortality rate. In principle, management of the school shark by control of exploitation rate (or equivalently fishing mortality rate) is a well-respected method of harvest control in fisheries throughout the world. As a practical matter, catch quotas are often established, but those quotas are calculated by applying a desired exploitation rate to current estimates of the abundance of the resource. For a long-lived, low mortality population such as school sharks, one could just as well calculate a quota and leave it fixed for some few years before readjusting it to a different level.

Both MLE and Bayesian posterior estimates were produced for several quantities relevant to the current condition of the resource. I recommend that the MLE estimates only be viewed as a qualitative indicator of effects of changes in assumptions about the assessment model. The Bayesian analysis produces results that incorporate a realistic level of uncertainty about many of the processes and parameters of importance.

4.4 Research Priorities

4.4.1 Measuring stock status

The biggest problem with the current assessment of school shark is that there are no indices of abundance other than ones developed by fishery CPUE data. The tagging data from recent releases provides an opportunity to improve this situation dramatically. I recommend that a thorough research program be instituted to maximize the information obtained through such tagging. The research program should address the issues of initial tagging mortality, tag reporting rates, tag retention rates, optimal distribution of tag releases with respect to age and area, and frequency of tag releases. Successful research in this area would likely involve a combination of field research, close cooperation with industry, and analysis utilizing the spatially-disaggregated model. The tagging program should be viewed as an ongoing commitment to monitor the health of the resource, although tagging may not be needed every single year.

One technique to improve the utility of fishery CPUE data is through the collection of "control" data, which is a recommendation of industry. I agree that the concept has much promise and may offer a means to avoid some of the negative consequences to stock monitoring that could occur with management measures that resulted in the contraction of fishing into smaller areas in the southern shark fishery. From an assessment point of view, one should consider control catches from gill-nets of 7" or even 8" mesh, as those gears would provide a better direct measure of mature adults than smaller mesh gear. I recommend the assessment group assess the merits of "control" data collection by commercial gill-net.

4.4.2 Methodological development

Spatially-disaggregated method

I strongly concur with the Assessment Group's decision to proceed with development of a spatially-disaggregated assessment method. Only with such a method would the Group be able to avoid some of the dangers of CPUE extrapolation/interpolation present in the current aggregated assessment. Furthermore, such a model would be able to address many relevant management issues at the appropriate degree of resolution. In particular, such a model would be able to examine consequences of shifts in spatial distribution of catches on the recovery of the resource and on the types of information likely to be available to future assessments. There is likely a trade-off between effectiveness of management controls to limit exploitation on the resource and the quality of information available to future assessments. For example, a system of area or depth closures might be a very effective and simple way to reduce exploitation, but would cause the loss of indices of shark abundance within the closed areas. One could imagine a scenario, such as apparent in the SBT fishery, where the lack of information in closed areas caused an increase in uncertainty about the status of the resource.

Gummy shark spatially-disaggregated model

A major consequence of reductions in exploitation of school shark is the potential increase in exploitation of gummy shark. Recent assessments of gummy shark are optimistic about the health of that resource, but those assessments are based on methods and technologies inferior to ones now in development for school shark. After the school shark disaggregate assessment model has been completed, modification of the model to adapt it to gummy shark assessment should not require as much work as devoted to the original developmental work. I recommend that assessment of gummy sharks with an approach similar to the one ongoing for school sharks be placed as a follow-on to the school shark disaggregate assessment.

Multi-species model

The risk analysis presented by the stock assessment group is an excellent start to setting up policy consequences of changes in the exploitation of school shark. However, more work needs to be done, in my opinion, before a completely satisfactory evaluation of consequences is available to fisheries' management. Missing from the current analysis is a quantitative assessment of the consequences of changes in the exploitation of school shark on the gummy shark fishery. While the gummy shark assessment model recommended above will help to establish the capacity of gummy sharks to increased exploitation, more needs to be done. A multi-species model of school shark and gummy shark and fleet dynamics would allow scientists the tools needed to evaluate alternative hypotheses about changes in fisher's behaviors to changes in regulations about the school shark fishery. The multi-species model is more of long-range research topic.

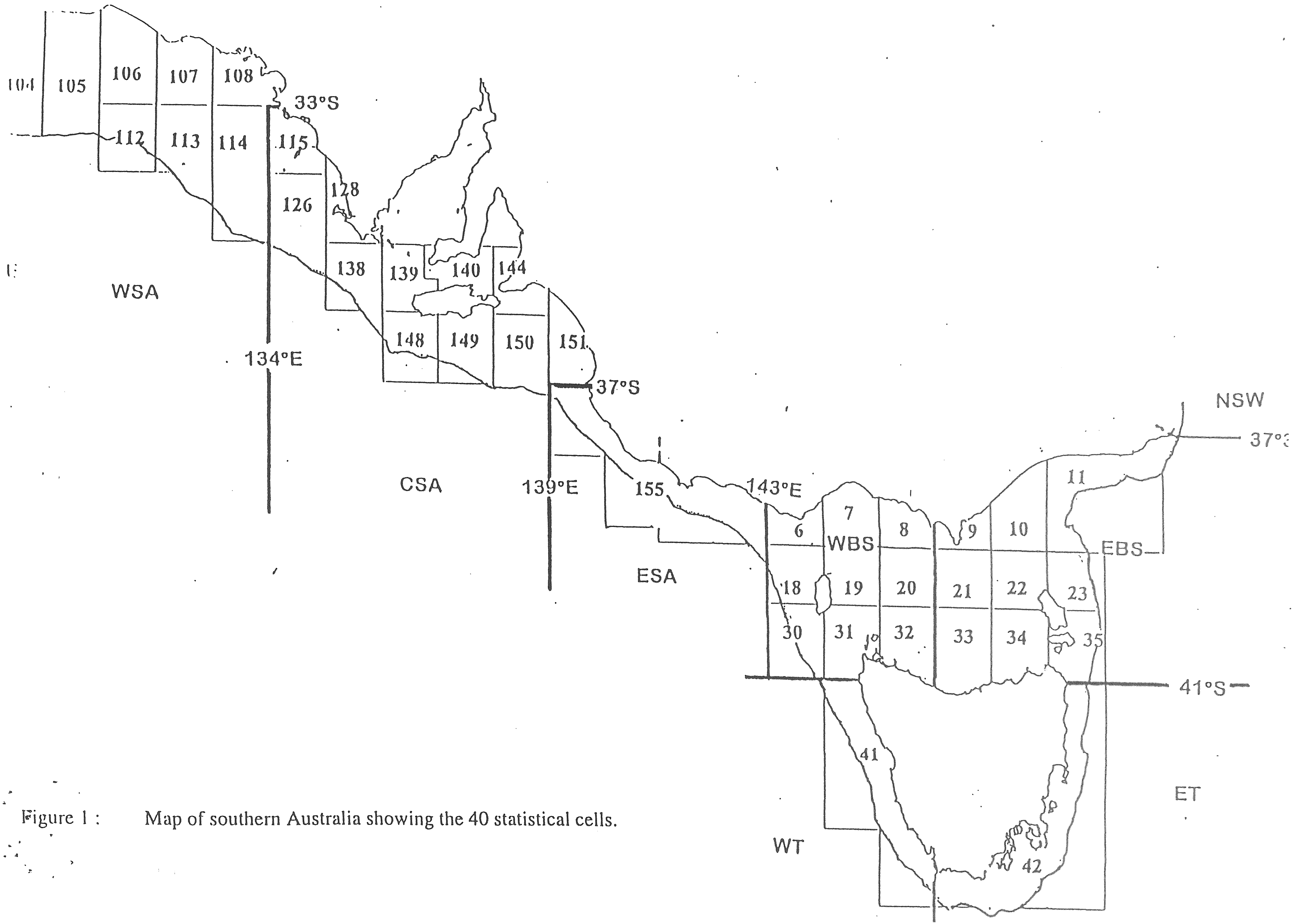


Figure 1 : Map of southern Australia showing the 40 statistical cells.

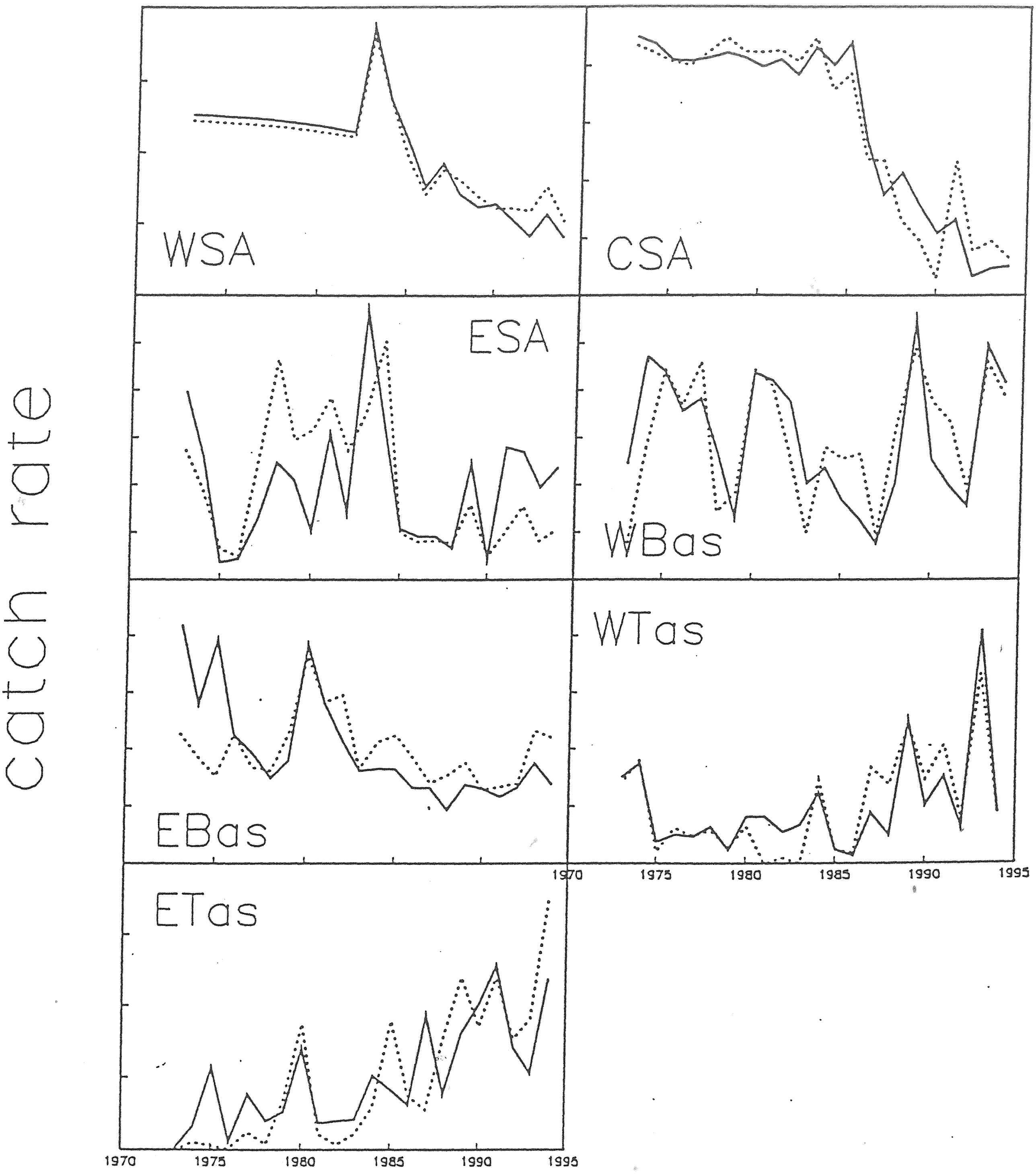
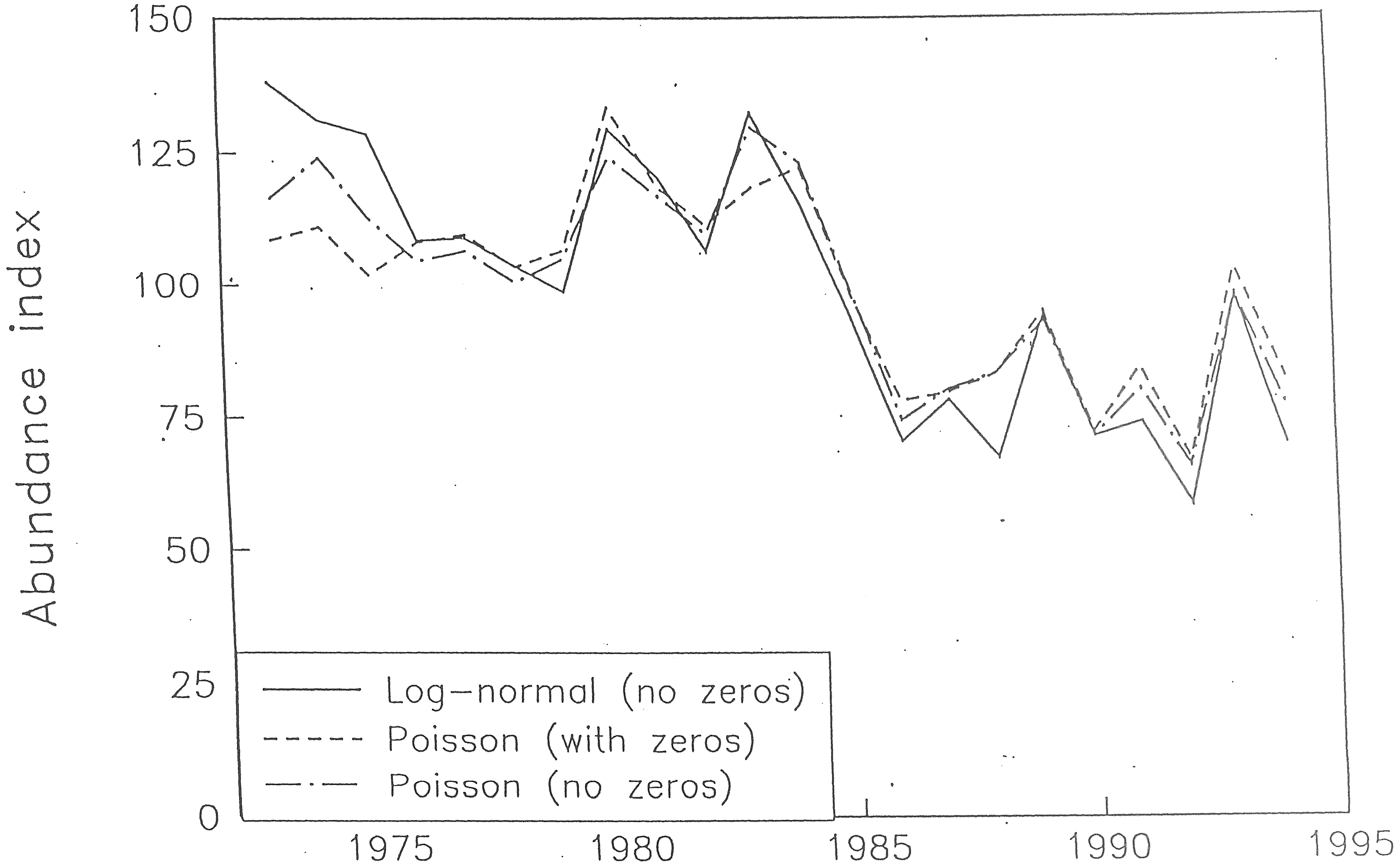


Figure 2. Annual catch-rate indices for the seven regions within the school shark fishery for the base-case "log-normal (no zeros)" (solid lines) and base-case "Poisson (with zeros) (dotted lines) analyses. (Figure 7 of SS/96/D8)

Figure 3. Annual catch-rate indices for the school shark fishery computed from the base-case model and the base-case data set. Results are shown for the "log-normal (no zeros)" analysis and two analyses based on the Poisson error model (Figure 5 of SS96D8).



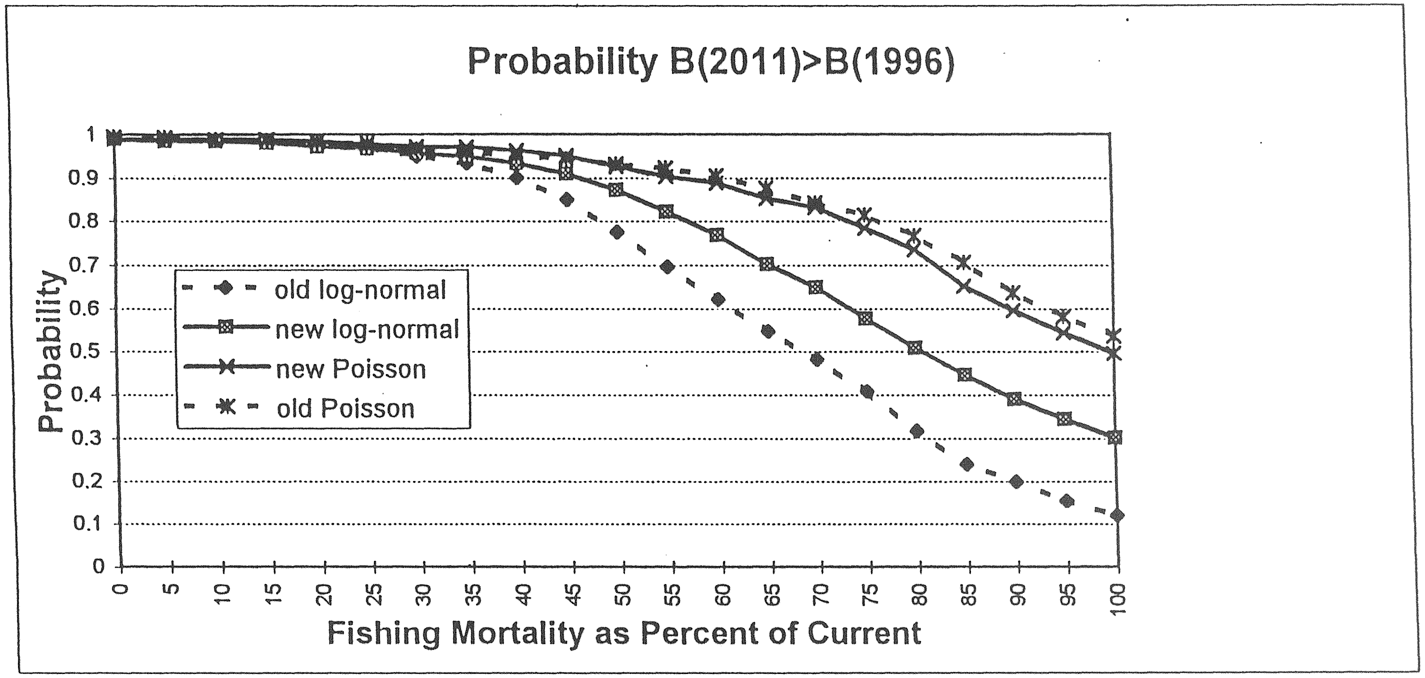


Figure 4. Results of a sensitivity analysis. Probability that stock biomass in 15 years exceeds current biomass. Old results use all years of CPUE data. New results exclude 1973-1975 data.