NMFS Assessment of North Pacific blue shark (May, 2000)

Reviewed by:

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Executive summary

General findings

Overall, a good start has been made on developing an assessment model for blue shark in the North Pacific Ocean. There are considerable problems with historical catch estimates, but the scientists involved are attempting to come up with the best estimates possible using available data. The estimates that have been produced are currently the "best available", and as such should be used in stock assessment. There may be some ways in which the catch estimation can be improved, and some suggestions have been made in the review. The modelling framework used to undertake the assessment is appropriate and has many advantages over "traditional" assessment methods. Foremost among these is the way the model forces assumptions to be explicit, resulting in a more honest and transparent analysis of the data. I encourage the scientists involved to continue with this approach.

Ultimately, consideration will need to be given regarding how the results of this model will be used in the management of blue shark incidental catches by the Hawaii longline and other fisheries. As well as fulfilling whatever domestic fishery management obligations that exist, I would suggest that ultimately management be pursued at an international level, probably through the new tuna (and related species) management commission that is nearing agreement. This would allow fishing mortality from all fisheries and stock responses to fishing to be considered from throughout the range of the stock, rather than that portion of it under U.S. jurisdiction. From the point of view of blue shark conservation, the advantages of such an approach over unilateral management action are compelling.

Specific recommendations for further work

A number of recommendations regarding further work on blue shark assessment have been made in the review. These were rated in terms of the relative time frame in which they should be undertaken – immediate, medium-term or long-term. Of course, the actual time it will take to carry out these tasks is dependent on the resources able to be devoted to further blue shark research and assessment. The recommendations are:

(i) Continue to refine the estimation of blue shark catches by the Japanese longline fisheries. In particular, investigate the utility of Japanese research data on the species composition of longline shark catches, and incorporate this into the estimation of catches if appropriate (see two dot points at the bottom of page 7). **Immediate.**

(ii) Create alternative data sets that effectively bound the uncertainty regarding the assumption of post-release blue shark survival (the current model assumes 100% mortality of released sharks). **Medium-term.**

(iii) Investigate alternative formulations of the model regarding the number of age classes included in the analysis and the possibility of non-von Bertalanffy growth for the initial age classes. **Immediate (but not as high a priority as the others).**

(iv) Investigate enhancing the spatial stratification of the model to include a longitudinal division of the northern area at around 160°E. **Immediate.**

(v) If further spatial stratification is not feasible, consider splitting the Japan longline shallow north fishery into two, based on the above longitudinal boundary. Selectivity and catchability parameters for these new fisheries should not be coupled. **Immediate.**

(vi) Regardless of (iv) and (v), de-couple the parameterization of selectivity and catchability between the Japan longline shallow north and south fisheries. **Immediate.**

(vii) Attempt to resolve with Japanese researchers the question of catchability increases in the longline fisheries. If the question cannot be resolved, treat the two models (constant vs. increasing catchability) as equally plausible alternatives. **Medium-term.**

(viii) Conduct model runs for all combinations of alternative data sets (e.g. as might result from ii) and model structures (e.g. as might result from vii). **Medium-term.**

(ix) Establish definitions of overfishing and overfished state, for example using an operational model of blue shark population dynamics and fisheries. **Long-term.**

(x) Estimate posterior probability distributions for reference point variables (e.g. stock biomass and fishing mortality) and integrate these with appropriate weighting across data set/model structure alternatives. **Long-term.**

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1. Introduction

This review deals with a stock assessment study on North Pacific blue shark (*Prionace glauca*) currently being undertaken by Dr. Pierre Kleiber of the National Marine Fisheries Service (NMFS) Honolulu Laboratory. The study is not yet complete; therefore, this review is largely one of a work in progress. This of course means that the review is not a definitive critique of the final product, but on the other hand allows greater freedom to suggest directions that the study might take in reaching its completion. The methodology adopted for the review involved the following:

1. Discussions held in person with Dr. Kleiber on 15–16 May, 2000 in Honolulu.
2. Examination of a draft document[1] describing the study.
3. Examination of data and preliminary results on the web site http://sai.nmfs.hawaii.edu.
4. Some independent analyses undertaken by the reviewer using the same data and methodological approach as used by Dr. Kleiber.

2. Blue shark biology and fisheries in the North Pacific

Blue sharks comprise the bulk of the non-target species in the catch of pelagic longline fleets in the North Pacific. Indeed, in many regions, blue shark is the most common species caught on longlines, even though they are not specifically targeted. Prior to the retention of shark fins becoming common practice, a large percentage of blue sharks caught were released alive (although the rate of post-release survival is unknown). Since the early 1990s, shark finning has become much more common, and therefore the rate of retention of blue sharks has increased dramatically. Whether that has led to an equally dramatic increase in the number of blue sharks killed depends on their survival rate when released alive, which, as noted above, is not well known.

In any case, it is likely that shark finning has resulted in an increase in the fishing mortality of blue sharks. However, blue sharks have previously suffered high fishery-induced mortality when they were a common bycatch species in the North Pacific pelagic diftnet fisheries that peaked in the 1980s (Bonfil, 1994). However, in spite of this history of fishing pressure, there is little evidence of dramatic

[1] "Assessment of the Blue Shark (*Prionace glauca*) Population in the North Pacific". A draft assessment document provided by Dr. Pierre Kleiber, Honolulu Laboratory, NMFS, Southwest Fisheries Science Center.

declines in catch per unit effort (CPUE) or changes in the size composition in the catch (Matsunaga and Nakano, 1999).

Because of their life history characteristics of slow growth, late maturity and low fecundity, sharks in general are known to be particularly vulnerable to stock collapse as a result of overfishing. However, of all the shark species, blue sharks display characteristics such as relatively high fecundity and growth rates that may make them more productive and therefore more resilient to fishing than the "average" shark.

3. Methodology

The methodology that has been applied to blue shark stock assessment is known as MULTIFAN-CL (Fournier et al., 1998). MULTIFAN-CL is a length-based, age structured model that uses statistical theory to fit the model to observed data. With the advent of faster computers, the application to stock assessment of complex (though more realistic) models of this class is becoming more widespread. Some of the features of this approach to stock assessment modelling, and of the MULTIFAN-CL software in particular, that have particular relevance to blue shark assessment are as follows:

- The statistical foundation of the model, which is fundamentally Bayesian, allows a structured approach to model development, i.e. statistical theory can be applied to determining the level of model complexity most appropriate to the available data, the biological characteristics of the stock, and the nature of the fisheries.
- The model can accommodate spatial heterogeneity, through the incorporation of spatial structure in the population and fisheries and fish movement. This is particularly important for blue shark assessment where there appears to be a fairly clear spatial segregation of the population by size (with smaller animals tending to occur further to the north).
- The model employs a structural time series approach to estimating catchability for each fishery defined in the model. This allows the usual and often unrealistic assumption of constant catchability over time to be relaxed. This may well be an important feature for blue shark assessment.
- The model allows the definition of multiple fisheries, each of which may have its own exploitation characteristics (selectivity and catchability coefficients). This flexibility is a fundamental requirement for blue shark assessment because of the use of different types of longline gear catching primarily adult sharks, and the occurrence of the squid and large-mesh driftnet fisheries in the 1980s and early 1990s catching primarily juveniles.
- As a consequence of the statistical fitting procedure employed by the model, a certain amount of missing effort and size composition data can be accommodated. It is therefore unnecessary to use arbitrary but often complicated schemes to "substitute" length-frequency data (in particular) into strata where no observations exist. The likelihood function consists only of contributions from data that were actually observed. This is of particular importance to blue shark assessment, where length-frequency data are not available for every fishery for all time periods.
- Information obtained from the fitting procedure can be used to compute approximate posterior probability distributions for model parameters and other quantities of interest. This procedure is amenable to comparison of current estimated stock status in relation to particular biological reference points and to assessment of future harvest strategies using risk analysis.

For these reasons, I believe that MULTIFAN-CL is an appropriate framework in which to conduct blue shark stock assessment. In addition to the points made above, the model is implemented in optimized C++ computer code using advanced numerical features, such as computation of exact derivatives using automatic differentiation. These and other features allow highly efficient parameter estimation, which is essential for stock assessment using large, complex models in situations where, as always, time is limited.

4. Overall structure of the analysis

4.1. Definition of fisheries

MULTIFAN-CL requires the definition of "fisheries" that consist of relatively homogeneous fishing units. Ideally, the fisheries so defined will have selectivity and catchability characteristics that do not vary greatly over time (although in the case of catchability, some allowance can be made for time-series variation). However, it is seldom practicable or even necessary to stratify the data into a large number of fisheries so as to isolate all variability in these parameters. More fisheries means more parameter complexity, so a parsimonious approach is required. For most pelagic fisheries assessments, fisheries defined according to gear type, fishing method and region will usually suffice.

For the blue shark assessment, the following fisheries were defined:

1. Japanese longline, deep sets, southern region
2. Japanese longline, deep sets, northern region
3. Japanese longline, shallow sets, southern region
4. Japanese longline, shallow sets, northern region
5. Hawaii longline, tuna sets, southern region
6. Hawaii longline, tuna sets, northern region
7. Hawaii longline, swordfish sets, southern region
8. Hawaii longline, swordfish sets, northern region
9. Driftnet, large-mesh
10. Driftnet, squid (small-mesh)

The stratification of Japanese longline fishing activity into deep and shallow set fisheries was necessary because longlines set in different depth configurations often have different catchability and selectivity characteristics. Likewise, Hawaii longliners tend to set their gear deep or shallow, depending on whether they are targeting tuna or swordfish (and there are other operational differences apart from depth of the gear). Therefore, it is appropriate to define the longline fisheries in this way. For the driftnet fisheries, there would be *a priori* reasons to believe that different mesh sizes would result in different selectivity and catchability characteristics, so this division of driftnet fishing activity is also appropriate.

4.2. Spatial structure

As noted above, there is obvious size stratification by latitude in the North Pacific blue shark population, with smaller animals tending to occur further to the north. Furthermore, it is believed that this size stratification is driven by recruitment occurring primarily in the temperate region of the North Pacific (Nakano et al., 1985). These biological characteristics suggest that spatial structure should be included in the model. The main technical difficulty with incorporating spatial structure is in the estimation of movement rates. Even the simplest movement model would require the estimation of two movement parameters per shared region boundary. For spatially-explicit assessment models, tagging data are often incorporated into the likelihood function, thus providing considerable additional information regarding movement (e.g. Hampton and Fournier, in prep.; Punt et al. 2000). Unfortunately, no tagging data are available for North Pacific blue shark; therefore it was necessary to keep the number of regions (and hence number of movement parameters) to a minimum. A simple, two-area spatial stratification was adopted, with 25°N as the boundary between the areas. Given the disposition of the fisheries and the population characteristics of blue shark, this seems to be a reasonable initial spatial stratification.

4.3. Model assumptions

As with any model, various structural assumptions have been made in the blue shark model. Such assumptions are always a trade-off to some extent between the need, on the one hand, to keep the parameterization as simple as possible, and on the other, to allow sufficient flexibility so that important characteristics of the fisheries and population are captured in the model. The main structural assumptions made in the blue shark assessment are discussed below, with my own comments on their appropriateness.

4.3.1. Age and growth

The current version of the MULTIFAN-CL software uses a von Bertalanffy growth equation to constrain the estimates of the mean lengths at age, and therefore von Bertalanffy growth has been assumed to apply to blue shark in this assessment. In the absence of any information to the contrary, this is probably not an unreasonable assumption. The parameter bounds placed on the growth parameters to limit possible solutions also seem to be reasonable, based on growth parameter estimates for blue shark from other regions. Having said this, it would be desirable at some stage to check for any evidence in the length-frequency data of significant and persistent departure from von Bertalanffy growth. The MULTIFAN-CL software includes an option to estimate a specified number of initial mean lengths as independent parameters, i.e. not constrained by any growth equation. If such a growth formulation resulted in a significantly better fit to the data, then this would constitute evidence of non-von Bertalanffy growth, and this revised growth model could then be incorporated into the stock assessment.

For age-structured models in general, it is necessary to specify the number of significant age classes in the population, with typically the last age class being defined as a “plus group”, i.e. consisting of fish that age and older. In the current assessment, ten age classes have been used, but alternatives are yet to be tried. While ten years seems reasonable on the basis of various information regarding blue shark longevity (e.g. 10 years was the maximum age observed by Nakano (1994) in vertebral ageing samples), it would be useful to try alternative models with different numbers of age classes to see if the fit to the data could be improved (or not significantly degraded in the case of fewer age classes).

4.3.2. Recruitment

“Recruitment” in terms of the MULTIFAN-CL model is the appearance of age-class 1 fish in the population. Given the observation in the fisheries statistic that catches of juvenile blue sharks tend to occur mainly in the cooler temperate waters of the North Pacific and biological observations of the distribution of reproductive activity (Nakano et al., 1985), it was assumed that blue shark recruitment occurs only in the northern region of the model domain. This is a reasonable assumption, and in fact the existence of this type of biological “structure” probably makes the application of a spatial model possible in the absence of tagging data.

From visual inspection of the length-frequency data, and based on the apparent seasonality of reproduction (Nakano et al., 1985), it was further assumed that recruitment is an annual event that occurs in the third quarter of the year. This assumption also seems reasonable, based on the data and the biology of the species.

4.3.3. Catchability and selectivity

Selectivity is fishery-specific and was assumed to be time-invariant. Essentially, the model allows random variability in selectivity but time-series trends are assumed to be absent. Selectivity coefficients have a range of 0–1, and for the longline fisheries (which catch almost exclusively adult sharks) were assumed to increase with age and to remain at the maximum once attained. The coefficients are expressed as age-specific parameters, but were smoothed according to the degree of length overlap between adjacent age classes. This is appropriate where selectivity is thought to be a fundamentally length-based process (Fournier et al. 1998), which is probably the case here.

Catchability was allowed to vary slowly over time (akin to a random walk) for all fisheries using a structural time-series approach. Random walk steps were taken annually, but the variance of the catchability deviations was constrained to enhance the stability of the model. Seasonal variation in catchability was also modelled in order to explain the strong seasonal variability in CPUE for most of the fisheries.

Selectivity parameters were constrained to be equal for fisheries of the same nationality, gear, and fishing method, but occurring in different regions. This means that the gear is assumed to sample the population in similar ways in both regions, and that differences in observed size composition between the fisheries is due to differences in the size composition of the populations in the different regions.

These assumptions are quite reasonable for a preliminary analysis. However, some specific suggestions for relaxing some of them are made later in this review.

4.3.4. Natural mortality

Natural mortality was an estimated parameter, but was assumed to be invariant over time, age and region. This is an assumption made for most stock assessments. Estimation of age-specific natural mortality rate was attempted, but there appeared to be little information in the data to support this more complex model. This is not surprising – my experience with this model is that age-specific natural mortality estimation is generally only possible when extensive tagging data are incorporated into the estimation (e.g. Hampton and Fournier, in prep.).

5. Data compilation and treatment

5.1. Catch and effort data

The compilation of data on blue shark catches represented a significant part of the effort put into this assessment. Unlike the target species of pelagic fisheries in the Pacific, information on the catches of non-target species, including blue shark, have not been reliably recorded on fishing log books consistently over the history of the fishery. Therefore, catch estimates, by necessity, had to be derived from a variety of data sources, such as log books, observer data, and research cruise data. The following is my understanding of the data compilation process that has been followed:

(i) The longline fleets of Japan and U.S., and the driftnet fleets of Japan, Korea and Taiwan are assumed to comprise the total catch of blue shark in the North Pacific. A quick check of the SPC log book and observer databases indicated only minor catches of blue shark by the Taiwanese and Korean longline fleets (the other major longline fleets in the region) and the purse seine fishery, which would support the assumption made in the assessment.

(ii) Raised effort data for the Japanese longline fishery have been provided by Japanese scientists at a 5 ° square month resolution. These data were aggregated into quarterly time periods, latitudinal bands of 0–15°N, 15–25°N, 25–35°N, 35–45°N and north of 45°N, and even 20° longitudinal segments. The data in each of these area-time strata were then disaggregated into deep and shallow sets (on the basis of hooks per basket categories, a frequently used indicator of fishing depth), using set by set data aggregated into the same strata, and finally re-aggregated into the two spatial regions required for the MULTIFAN-CL analysis.

(iii) Blue shark catches by the Japanese fisheries were estimated by the following steps:

a) Identify in the Japanese longline log book data the longline trips that could be considered reliable in terms of reporting shark catches. A longline trip was considered reliable if at least 80% of the sets in the trip reported one or more sharks caught. Reported shark catches were assumed to represent mortalities, regardless of whether or not the shark was retained or released (information which, in any case, does not exist). Supporting analysis has been carried out to show that this “80% filter” procedure should not introduce any bias into the estimates as long as the overall shark CPUE is >2 per set (and shark CPUEs are generally well above this level).

b) Compute the shark CPUE for each of the area-time strata required for the assessment.

c) Compute the shark catch in these strata by multiplying the CPUEs by the respective raised efforts.

d) Compute the proportion of blue sharks in the total shark catch for the four Japanese fisheries using set by set data for the period 1994–1998 (when the species composition of the shark catch appeared to be reliably recorded).

e) Multiply the blue shark proportions by the respective total shark catches derived in c).

(iv) Effort data for the U.S. (Hawaii-based) longline fisheries have been compiled from log book effort records for these fisheries classified by fishing method categories (tuna and swordfish) based on operational data. The log book program is known to be of high compliance, so no additional data treatment (i.e. raising) was required.

(v) Blue shark catches for the Hawaii longline fishery were estimated directly from log book catch reports with a correction to account for under-reporting (by 24%). The correction factor was estimated from observer data collected over the period 1994–1999 (Walsh et al, in prep.) and was applied to reported catches by each of the four Hawaii longline fisheries defined in the analysis over all time periods. It was assumed that all reported blue shark catches were mortalities, regardless of whether retained for finning or released alive.

(vi) Catch and effort data for the driftnet fisheries were derived from annual catch (weight) and effort estimates supplied by Japanese scientists, which were then converted to numbers of sharks using average weights derived from length-frequency data and a length-weight relationship, and disaggregated into quarterly data using overage monthly distributions of catch and effort reported in the literature (Gong et al., 1993; Nakano et al., 1993).

For most assessments of target species, the catch and effort data used in the assessment are based on log book records that have been validated or corrected using supporting data such as observer and landings information. Unfortunately, for a non-target species such as blue shark, it is not possible to attain this level of data quality. The procedure that was applied to estimating blue shark catch and effort appears to be a good attempt to use all available data to develop the best estimates of catch and effort possible. However, two comments on the above procedure are worthy of note and represent areas where possibly some improvements could be made.

- For the Japanese and Hawaii longline fisheries, it was assumed that all shark catches recorded on log books resulted in mortalities. However, prior to the large-scale development of shark finning, some captured sharks would have been released and at least some of these would have survived the ordeal. Therefore, the catches estimated for these fisheries may over-estimate the actual fishery-induced mortality of blue sharks. As a first cut assessment, I think that this was the correct approach to take. However, in future, consideration could be given to using alternative assumptions regarding survival of captured but released blue sharks and incorporating this data uncertainty into the assessment by way of sensitivity analysis. For the Hawaii fisheries at least, information on the proportion of blue sharks released alive has been collected by observers, and this could be used as a basis for estimating blue shark kills by these fisheries.

- Possibly the weakest part of the estimation of blue shark catches by the Japanese longline fisheries is the assumption (steps (iii) (d) and (e) above) that the proportion of blue shark catch in the total shark catch has been constant over time. If it had been the case that blue shark abundance had fallen, it is possible that this might not be apparent in overall shark CPUE (although it could be argued with some justification that such a possibility is remote because of the high proportion of blue sharks compared to total sharks currently observed). I am a little puzzled as to why greater use here, and in blue shark catch estimation by the Japanese longline fisheries generally, has apparently not been made of the Japanese research longline data collected by the Japan Marine Fishery Resources Research Center (JAMARC) and fisheries training vessels over a long period of time. In making this comment, I am assuming that the research data would have records of shark catches to species level, which is implied by the use of blue shark length-frequency data collected by these vessels (see below).

5.2. Length-frequency data

Length-frequency data were compiled from available sources for each of the defined fisheries. The coverage of the length-frequency sampling is by no means uniform or complete (Fig. 1). Fortunately, the MULTIFAN-CL model does not demand that this be the case, as noted earlier. The model predicts the size composition of the catch for each fishery and will fit this to whatever length data are available. Of course, the less data that are available, the more uncertain will be the results.

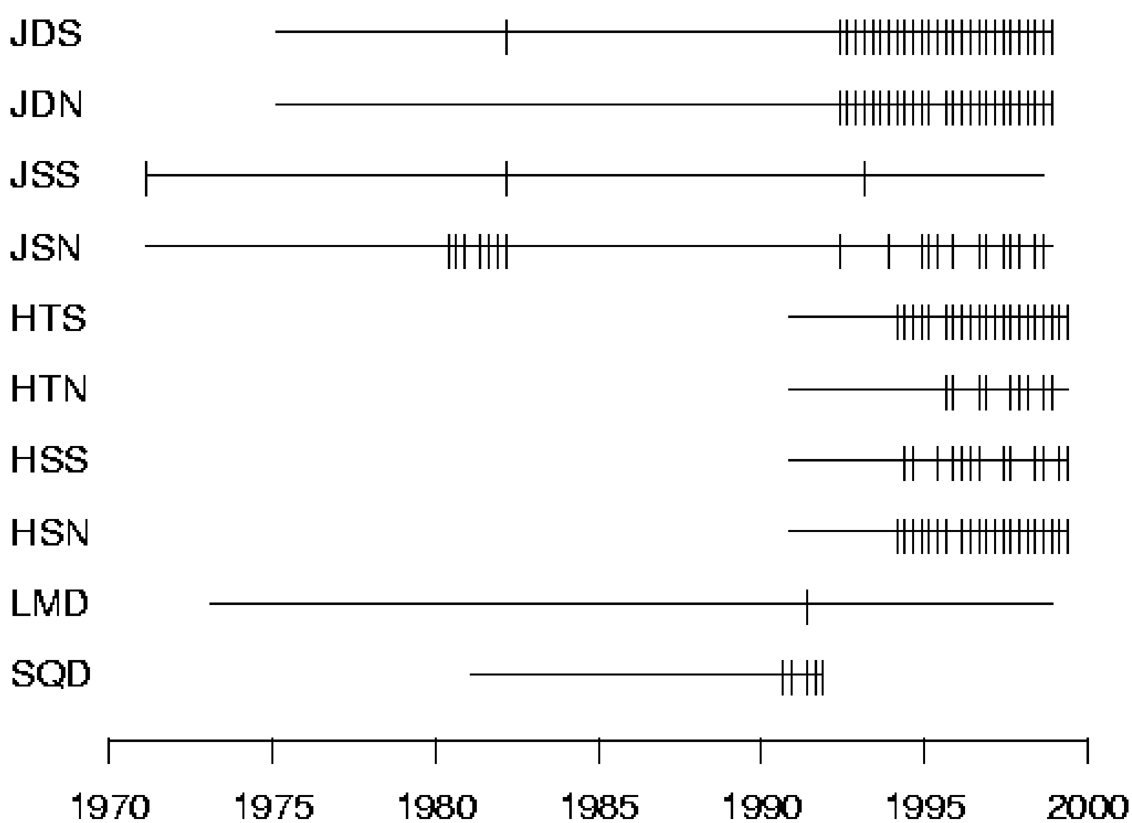

Figure 1. Availability of length-frequency samples. Vertical lines indicate years and quarters for which length frequency were obtained for the 10 fleets in the analysis. Horizontal lines indicate time periods for which catch and effort data were obtained.

Blue shark length-frequency data for the Japanese longline fisheries were derived from Japanese longline research vessels and from JAMARC data. Samples were limited to those taken in the northern hemisphere between 140°E and 130°W. Samples were ascribed to the four Japanese fisheries (deep-north, deep-south, shallow-north, and shallow-south). Unfortunately, hooks-per-basket information (fishing depth proxy) were not available for sample data prior to 1981, but examination of the distributions of hooks-per-basket from 1981 onward showed that deep research sets did not begin till after 1982.

Therefore sample data prior to 1981 were ascribed to the shallow fleets. Length-frequency data for the Hawaii longline fisheries and the driftnet fisheries were obtained by scientific observers.

It is difficult to judge the quality of the length-frequency data as there are few details available on sampling protocols and measurement methods. However, as most of the sampling was carried out by scientific observers or research staff, I assumed that the data available are of good quality.

6. Results to date

The results obtained to date using the MULTIFAN-CL model are summarized in Kleiber (in prep.) and on the NMFS blue shark web site. A brief summary is as follows:

- The MULTIFAN-CL model was able to fit the data (total catch and length-frequency) reasonably well. Total catches are accurately predicted by the model, consistent with the assumption that observed catches are accurately measured (Fig. 2). I would note that this assumption could be challenged given some of the uncertainties that had to be dealt with during catch data compilation/estimation, but in almost all stock assessments that involve a population dynamics model, the accuracy of catch data is an underlying assumption. This model is no different from any other in that respect. Nevertheless, the ability of the model to accurately predict the catch data is a fundamental requirement, and at least indicates that the model has attained a basic level of stability.
- The length-frequency data are also reasonably well predicted by the model, even though the information on age structure and growth contained in the data is limited because of a paucity of samples for the driftnet fisheries (where modal structure would be expected because of the small size of the sharks captured). The fits to the length-frequency data for each fishery aggregated over time are shown in Fig. 3. It is clear that the general characteristics of the length data are captured by the model. One exception might be the Japan shallow south longline fishery, where the predicted size distribution is significantly smaller than the observed. This probably indicates a failure of the assumption that the selectivity coefficients for the two Japan shallow longline fisheries are the same (see section 4.3.3). As the model is further developed, I would suggest that the selectivity (and catchability) parameters for these fisheries be de-coupled and estimated separately. Discussions with Dr. Kleiber on this point indicated that the unusually small size of blue sharks caught in the Japan shallow north fishery was largely due to the small size of blue shark caught in the northern region close to the Japan coast and some concentration of effort in this area. Apparently, blue sharks caught further to the east in the northern region have a more typical longline size distribution. This strongly suggests that there is additional spatial heterogeneity in the blue shark population that is not captured by the current spatial configuration of the model. Therefore, further stratification of the northern region into western and eastern components should be a future priority development for the stock assessment model.

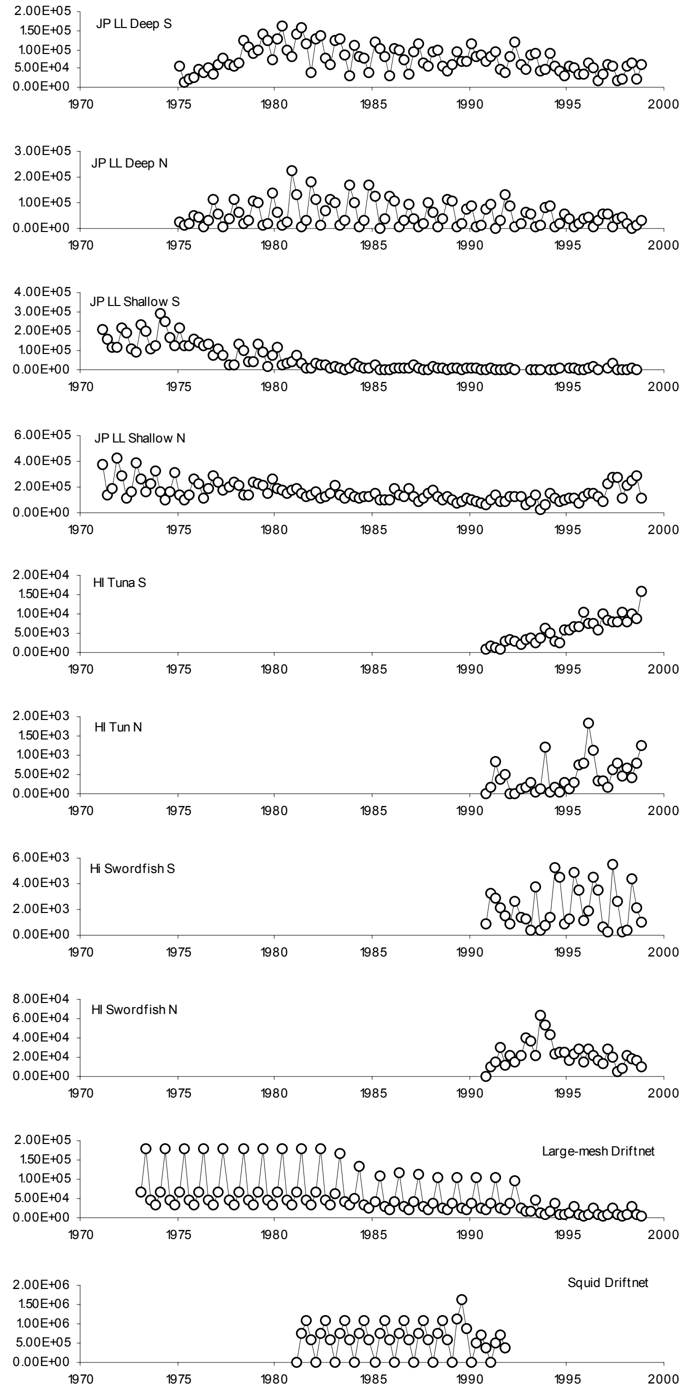

Figure 2. Observed (circles) and model predicted (lines) catches.

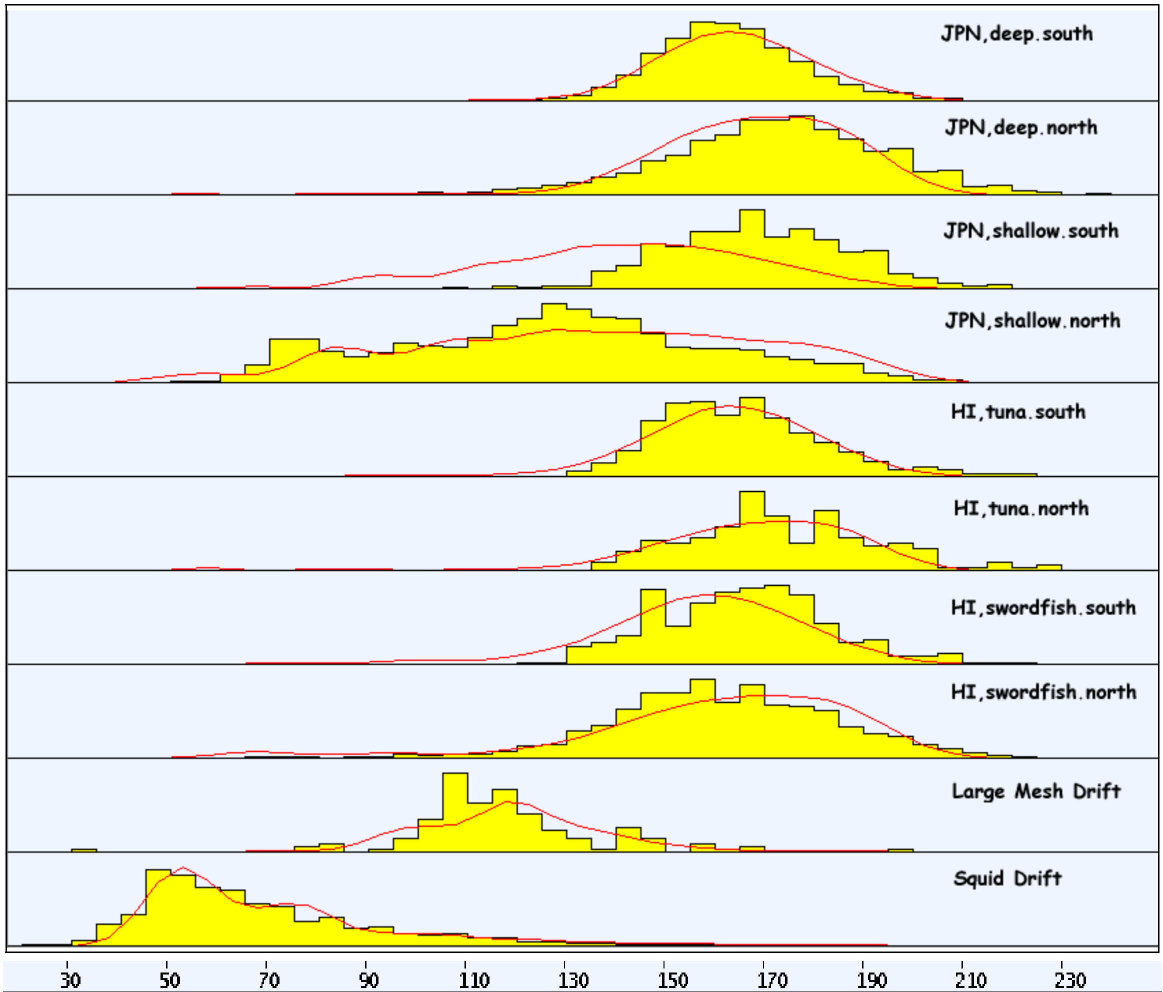

Figure 3. Overall blue shark size distributions (precaudal length in cm) in the catch of the ten fleets configured in MULTIFAN-CL: observed yellow; estimated by MULTIFAN-CL red.

- The estimates of some of the biological parameters of the model, such as the natural mortality rate and growth parameters, show considerable consistency with estimates of these parameters for the same stock and for blue shark stocks in other areas. This is of some reassurance. The posterior distribution for the estimate of natural mortality was surprisingly tight compared to its prior distribution, which was based on estimates from the Atlantic (Fig. 4). This suggests that the data are informative about the natural mortality rate. The estimated von Bertalanffy growth curve is also similar to those obtained from independent studies of North Pacific blue shark growth (Fig. 5).
- The assessment results of most interest from a management perspective are the time series of estimated recruitment, stock biomass, and fishing mortality. Recruitment appears to have been fairly stable over the time period of the study (Fig. 6), and there is no evidence of recruitment overfishing from the results so far obtained.

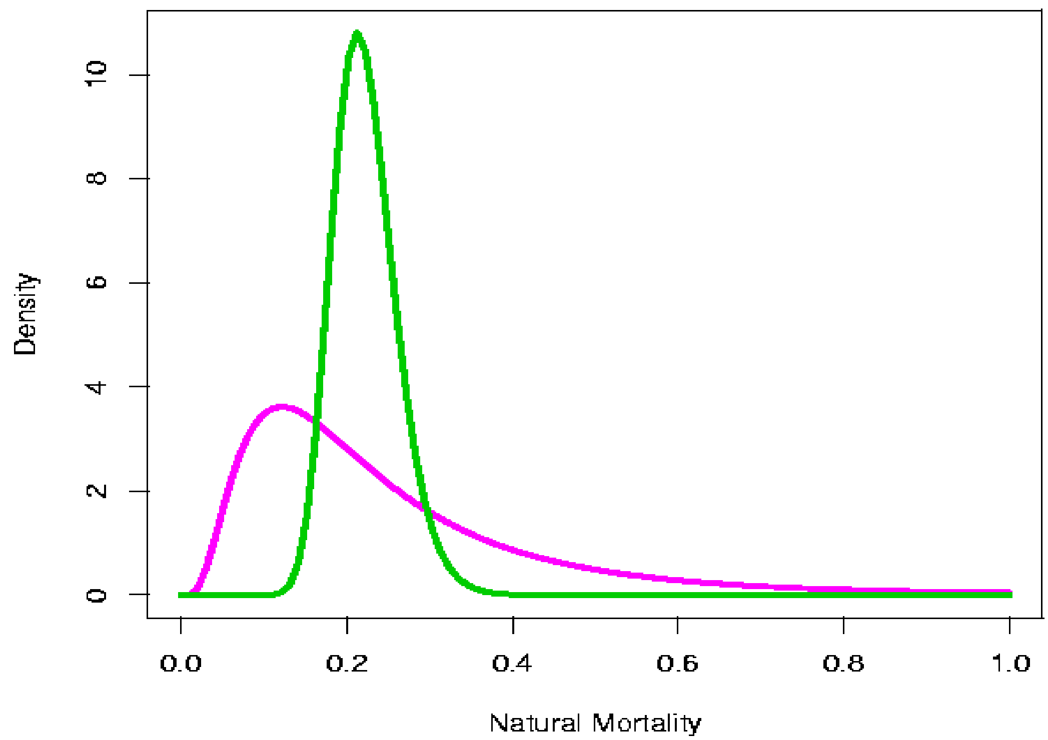

Figure 4. Prior (purple) and posterior (green) distributions for the natural mortality rate.

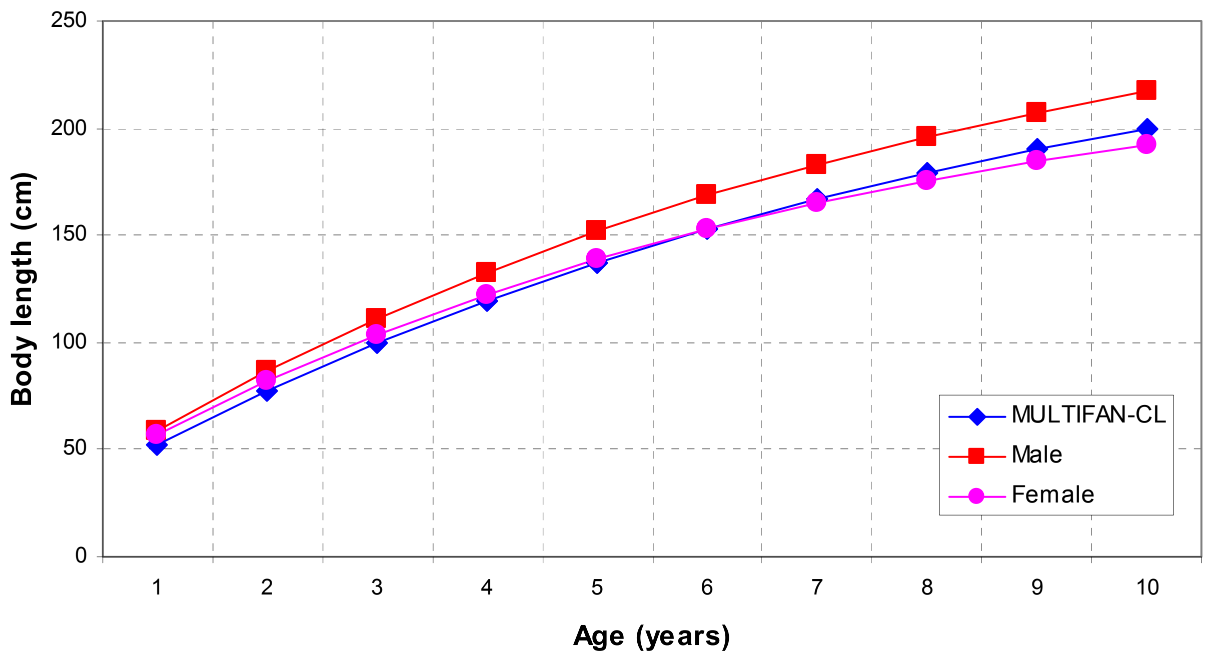

Figure 5. Growth curve estimated by MULTIFAN-CL (blue) compared to sex-specific growth curves derived from length-frequency modes and vertebral rings (Nakano, 1994).

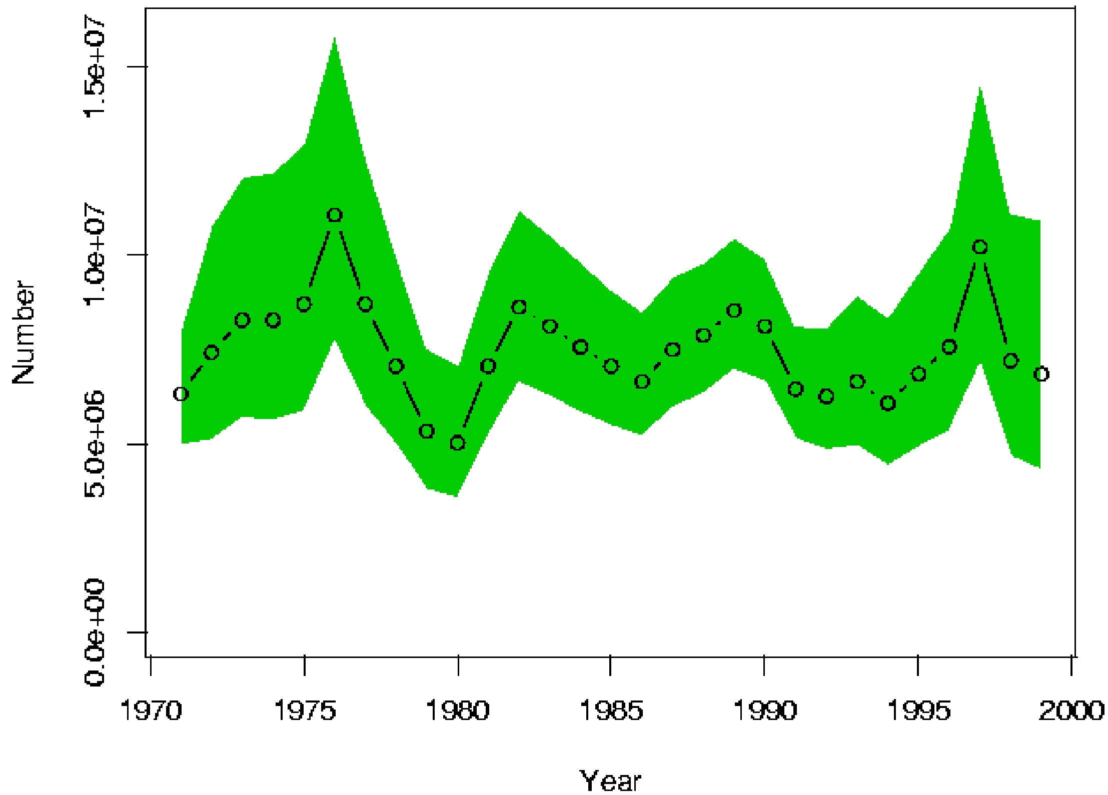

Figure 6. Estimates of recruitment, with approximate 95% confidence intervals (green).

- From the results obtained to date, there appear to be at least two possible interpretations of biomass trends. If catchability is assumed to have been constant (or, equivalently, if the variance of time-series catchability deviations is assumed to be small) over the time period of the analysis (an assumption made in most stock assessments), then the model predicts that stock biomass declined from the mid-1970s to about 1990, and then recovered to approximately the same level it had been at the beginning of the 1970s (Fig. 7). Alternatively, if sufficient freedom is given to the catchability deviations (i.e. the variance assumed to be somewhat larger) so that time-series trends can be estimated, the stock biomass is predicted to decline to about half of its early 1970s level and only recover slightly during the 1990s (Fig. 7), while the catchability is estimated to have increased strongly. These time series changes (in catchability or biomass) seem to be driven by the strong recent increases in CPUE by the major (in terms of recent catches) Japanese longline fisheries and the Hawaii longline fisheries (Fig. 8). I would also note that changes in the way that these fisheries have reported blue shark catches might also explain the increased CPUE in the 1990s, and this possibility requires further investigation with Japanese collaborators on the assessment.
- The time series of estimated fishing mortality rates by age class are shown in Fig. 9 for different assumptions about the degree of catchability variation. Of interest is the surge in fishing mortality of the youngest age class coincident with the operation of the driftnet fisheries in the 1980s. Fishing mortality for the older age classes looks to have increased since the start of the time series, although with some decline in the 1990s probably associated with declining effort in the Japan deep fisheries. (N.B. Some of this decline might also be due to incomplete data availability for the last year of the assessment.) The levels of fishing mortality for the older age classes depend fairly strongly on the catchability assumption. For catchability assumed constant, fishing mortality for all age classes, with the exception of age class 1 during the driftnet era, have been 0.20–0.25 yr^{-1}, the approximate level of

natural mortality. However, when catchability is allowed to vary, fishing mortality for the older age classes is significantly above the level of natural mortality, peaking at around 0.40 yr^{-1}.

- If we believed that catchability had indeed been constant over the period of the analysis, then we would probably conclude on the basis of the results so far that, while fishing mortality is (or was) close to F_{MSY} levels, the current biomass is close to that which existed in the early 1970s, and the stock would not be considered overfished. However, if we believed that catchability may have increased recently, then it is more likely that the fishing mortality has exceeded F_{MSY} levels and that the current level of the stock is around half its level of the early 1970s. These results have quite different management implications; therefore, the issue of the catchability assumption needs to be resolved if possible.

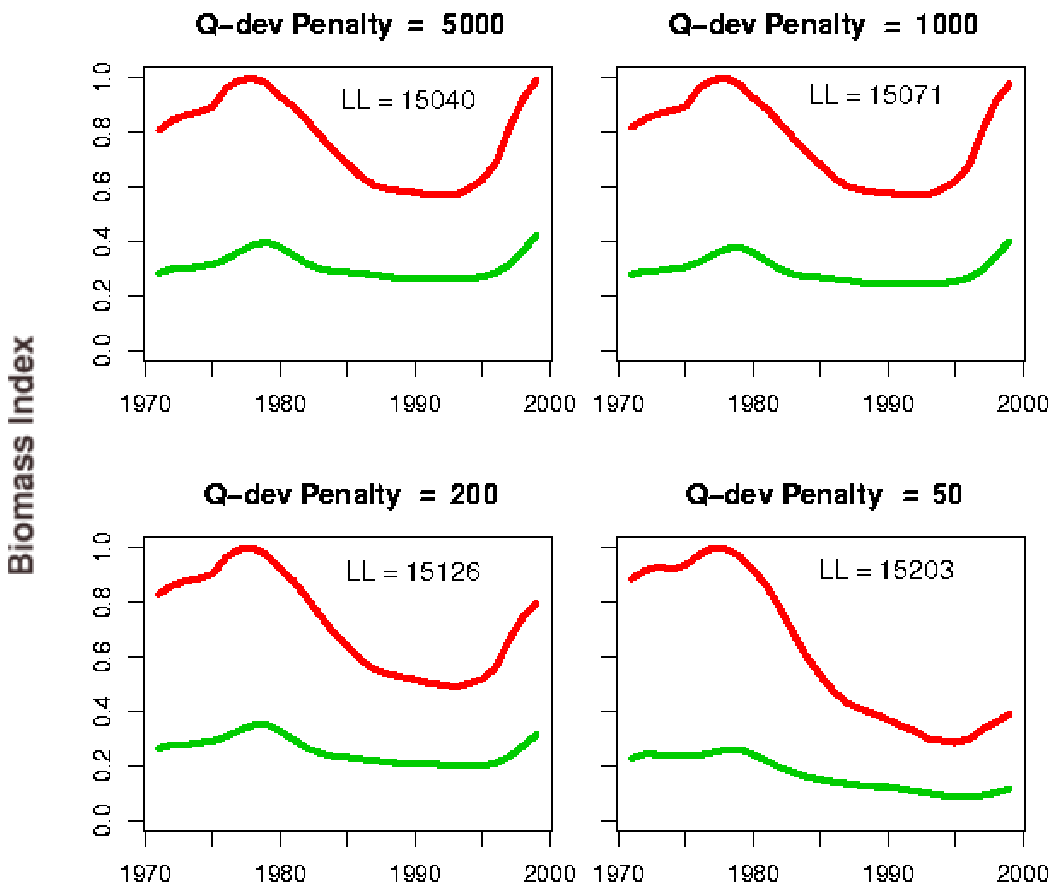

Figure 7. Estimates of relative biomass in each model region (red = north, green = south) under different assumptions concerning time-series variation in catchability. Q-dev penalty = 5000 is equivalent to constant catchability, while Q-dev penalty = 50 allows annual catchability deviations to vary with a CV of 0.10.

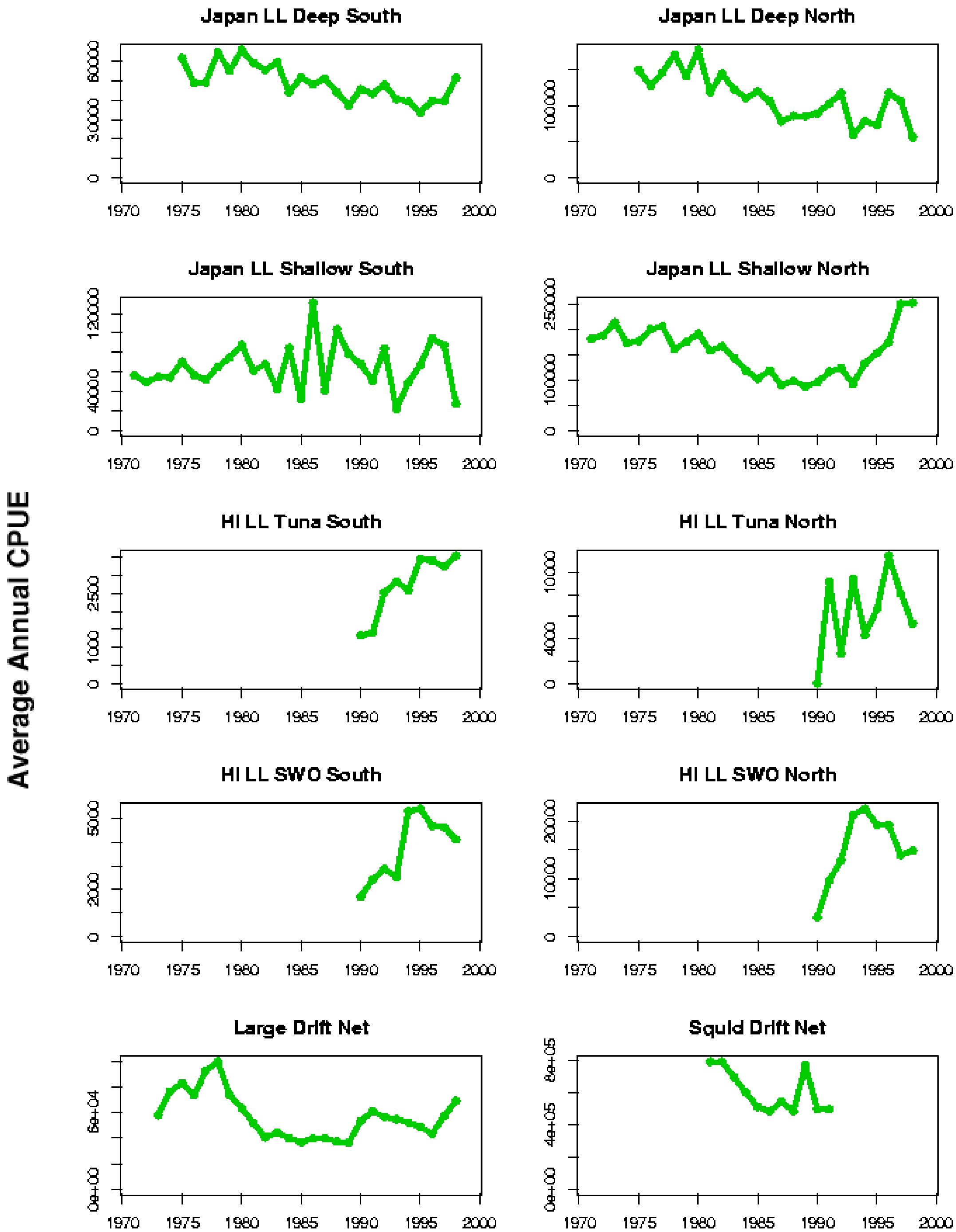

Figure 8. CPUE (in annual form) for the fisheries defined in the analysis.

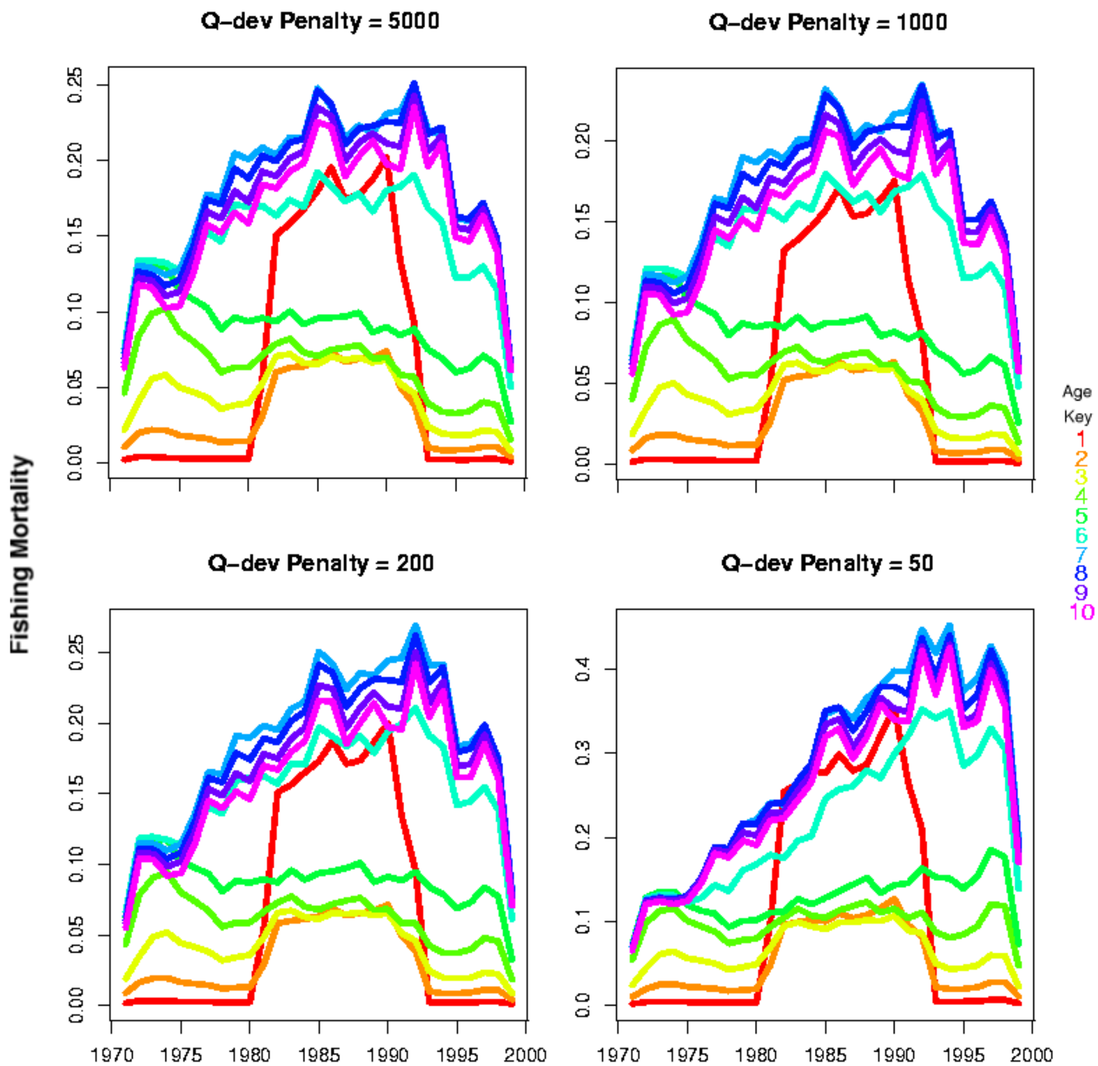

Figure 9. Estimates of fishing mortality rate by age class under different assumptions concerning time-series variation in catchability. Q-dev penalty = 5000 is equivalent to constant catchability, while Q-dev penalty = 50 allows annual catchability deviations to vary with a CV of 0.10.

7. Summary of suggested further work

As noted at the beginning of this review, the North Pacific blue shark assessment is very much a work in progress and there is much more work that could and should be done before the assessment is considered a solid scientific foundation for fishery management. My suggestions for further work on the model and how the model might be used in a formal assessment context are as follows, with an indication of relative time frame in which these tasks might be undertaken (immediate, medium-term, long-term):

(xi) Continue to refine the estimation of blue shark catches by the Japanese longline fisheries. In particular, investigate the utility of Japanese research data on the species composition of longline shark catches, and incorporate this into the estimation of catches if appropriate (see two dot points at the bottom of page 7). **Immediate.**

(xii) Create alternative data sets that effectively bound the uncertainty regarding the assumption of post-release blue shark survival (the current model assumes 100% mortality of released sharks). **Medium-term.**

(xiii) Investigate alternative formulations of the model regarding the number of age classes included in the analysis and the possibility of non-von Bertalanffy growth for the initial age classes. **Immediate (but not as high a priority as the others).**

(xiv) Investigate enhancing the spatial stratification of the model to include a longitudinal division of the northern area at around 160°E. **Immediate.**

(xv) If further spatial stratification is not feasible, consider splitting the Japan longline shallow north fishery into two, based on the above longitudinal boundary. Selectivity and catchability parameters for these new fisheries should not be coupled. **Immediate.**

(xvi) Regardless of (iv) and (v), de-couple the parameterization of selectivity and catchability between the Japan longline shallow north and south fisheries. **Immediate.**

(xvii) Attempt to resolve with Japanese researchers the question of catchability increases in the longline fisheries. If the question cannot be resolved, treat the two models (constant vs. increasing catchability) as equally plausible alternatives. **Medium-term.**

(xviii) Conduct model runs for all combinations of alternative data sets (e.g. as might result from ii) and model structures (e.g. as might result from vii). **Medium-term.**

(xix) Establish definitions of overfishing and overfished state, for example using an operational model of blue shark population dynamics and fisheries. **Long-term.**

(xx) Estimate posterior probability distributions for reference point variables (e.g. stock biomass and fishing mortality) and integrate these with appropriate weighting across data set/model structure alternatives. **Long-term.**

8. Conclusions

Overall, a good start has been made on developing an assessment model for blue shark in the North Pacific Ocean. There are considerable problems with historical catch estimates, but the scientists involved are attempting to come up with the best estimates possible using available data. The estimates that have been produced are currently the "best available", and as such should be used in stock assessment. As suggested above, there may be some ways in which the catch estimation can be improved. Once all avenues for this have been exhausted, I would recommend that remaining areas of data uncertainty be treated by sensitivity analysis, as recommended in the previous section.

The modelling framework used to undertake the assessment is appropriate and has many advantages over "traditional" assessment methods. Foremost among these is the way the model forces assumptions to be explicit, resulting in a more honest and transparent analysis of the data. I encourage the scientists involved to continue with this approach.

Ultimately, consideration will need to be given regarding how the results of this model will be used in the management of blue shark incidental catches by the Hawaii longline and other fisheries. As well as fulfilling whatever domestic fishery management obligations that exist, I would suggest that ultimately management be pursued at an international level, probably through the new tuna (and related species) management commission that is nearing agreement. This would allow fishing mortality from all fisheries and stock responses to fishing to be considered from throughout the range of the stock, rather than that portion of it under U.S. jurisdiction. From the point of view of blue shark conservation, the advantages of such an approach over unilateral management action are compelling.

9. Acknowledgements

Thanks go to Dr. Pierre Kleiber from the NMFS Honolulu Laboratory for his co-operation in making available data and model results during the course of this review.

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STATEMENT OF WORK

Consulting Agreement Between The University of Miami and John Hampton

May 11, 2000

General

The practice of shark finning, under the purview of the Western Pacific Regional Fisheries Management Council (WPRFMC), is a potentially controversial issue among the council, industry, conservation groups, and the National Marine Fisheries Service (NMFS). The WPRFMC has conducted a North Pacific blue shark stock assessment upon which management decisions concerning the practice of finning shall be based.

The consultant shall be provided with background documents, including a draft manuscript describing the analysis, background papers on previous analyses of Japanese catch and effort statistics, description of the fisheries, relevant parts of the WPRFMC's Fishery management Plan, and summary information on biological parameters of blue sharks. Other information shall be provided in the form of web pages prepared by Japanese collaborators. The consultant is responsible for conducting a review of the North Pacific blue shark stock assessment, covering methods used considering data availability and time allotted for the analysis, as well as a review of the conclusions regarding stock assessment.

Specific

1. Read and become familiar with the relevant documents provided in advance to the consultant;

2. Discuss stock assessment methods and conclusions regarding stock status with scientists in Honolulu, Hawaii, over May 15-16, 2000;

3. No later than June 2, 2000, submit a written report of findings, analysis, and conclusions. The report should be addressed to the "UM Independent System for Peer Reviews, " and sent to David Die, UM/RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149 (or via email to ddie@rsmas.miami.edu).

Signed_____________________________________ Date_______________
John Hampton

PRELIMINARY BUDGET

1. Salary	$8400
2. Airfare	$1600
3. Hotel	$440
4. Meals	$280
5. Car rental	$200
TOTAL	$10,920