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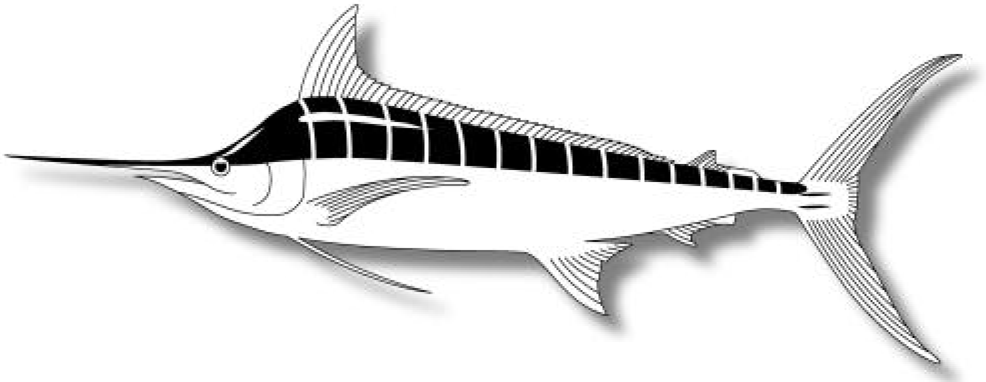
Update on Blue Marlin Stock Assessment



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Update on Blue Marlin Stock Assessment [1]

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Abstract

An assessment of blue marlin stocks in the Pacific presented last year at the 14th meeting of the Standing Committee on Tuna and Billfish indicated that the recent state of fish and fisheries is close to fully exploited. The assessment has now been rerun using the same input data but with an enhanced version of MULTIFAN-CL. The basic assessment results are substantially the same in this and the previous analysis. The results in both cases show furthermore that the catch has been hovering about the estimated maximum sustainable yield for almost three decades. However, stability over those decades is maintained by different population dynamic scenarios in this and the previous analysis. Confidence in the assessment results could be substantially improved by inclusion of tagging data and more complete as well as sex-specific sample data.

Introduction

A stock assessment of blue marlin in the Pacific was presented last year at the 14th meeting of the Standing Committee on Tuna and Billfish and subsequently at the 3rd International Billfish Symposium in Cairns, Australia (Kleiber et al., in review and attached herewith as Appendix I). The bulk of longline data for blue marlin in the Pacific were treated with a habitat-based effort standardization. Then longline and purse seine data were entered into a stock assessment model,

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[1] A working document submitted to the 15th Meeting of the Standing Committee on Tuna and Billfish, Honolulu, Hawaii, 22-27 July 2002.

MULTIFAN-CL. The results indicated that blue marlin were, at worst, close to a fully exploited state, i.e. the state of population and the fishery appeared to be somewhere near the top of the yield curve. Since that time, additional analyses have been run on the blue marlin data with somewhat different structural assumptions and using an enhanced version of MULTIFAN-CL. The motivation was to investigate the sensitivity of the last year's results to some of the assumptions that were made in setting up MULTIFAN-CL runs. The results presented herewith deal with the spatial distribution of blue marlin recruitment and the intensity and distribution of movement of blue marlin. Both these features were previously constrained to be spatially homogeneous, but in the present analysis those simplistic constraints are relaxed. Tests of sensitivity to other aspects of the model are contemplated for the future.

Assessment Method

MULTIFAN-CL is a length-based, age-structured, spatially structured, stock analysis model that makes use of catch, effort, and size sample data plus tag data if available. The model fitting procedure can accommodate some amount of missing catch, effort, or sample data. A detailed description of MULTIFAN-CL, it's population dynamics model, and parameter estimation techniques is given by Fournier et al., (1998) and Hampton and Fournier (2001). Since the blue marlin analyses reported last year, the model has been enhanced to produce estimates of maximum sustainable yield (MSY), and fishing mortality at MSY (Fmsy). Also, estimated time series of the ratios of F to Fmsy, biomass to biomass at MSY, and adult biomass to adult biomass at MSY can be output along with approximate confidence bounds.

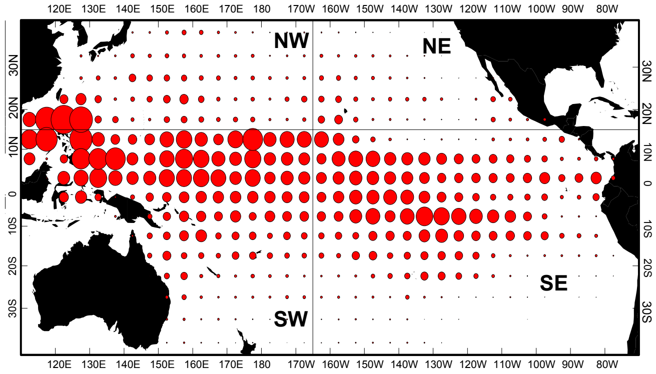

Figure 1. Distribution of blue marlin longline catch in the Pacific Ocean, 1962-1999. The definition of regions used in the assessment is shown. *Source: Standing Committee on Tuna and Billfish Public Domain Data.*

For the blue marlin assessment the model was structured as follows with differences from last year's analysis noted:

- Spatial structure... Four regions of the Pacific Ocean, separated latitudinally at 15°N and longitudinally at 165°W (Figure 1). Fourteen fisheries were defined in the model according to gear type, nationality and area of operation:

1—4	Japan and Mexico longline, regions NW, NE, SW, SE
5—8	Other nationalities longline, regions NW, NE, SW, SE
9—10	Purse seine, dolphin sets, regions NE, SE
11—12	Purse seine, floating object sets, regions NE, SE
13—14	Purse seine, unassociated sets, regions NE, SE

- Movement... Movement of fish between regions is governed by twelve transfer coefficients. In last year's analysis, movement rates of fish between regions was assumed to be rapid and was fixed to a uniform 0.1 yr^{-1} for all movement coefficients. In the present analysis the model was allowed to estimate independent values for the movement coefficients.

- Recruitment... Time series of recruitment estimates were estimated independently for each region. This is in contrast to last year's analysis where the recruitment time series was set equal for all regions in the model.

- Age and growth... Twenty yearly age classes were defined in the model starting at age 2 with the last age class including ages 22 and higher. Growth was assumed to follow the von Bertalanffy equation. For the purpose of calculating spawning biomass, most of the fish were assumed to mature by about age 6 yrs. Size at recruitment and Linfinity were estimated parameters, but as was the case last year, the growth rate K was fixed (0.2 per year). Estimating growth parameters was expected to be problematical because of missing size sample data in some of the fisheries and because of large sex differences in growth of blue marlin. The latter feature is not as yet accommodated in MULTIFAN-CL, and in any case size sample data by sex was not available.

- Catchability... MULTIFAN-CL estimates a time series of catchability for each fishery as constrained random walks. Steps were set to occur annually, and sinusoidal patterns of within-year variation were superimposed on the catchability time series.

- Selectivity... Constrained to be non-decreasing with fish size and also to be constant after age 12. Because size sample data were unavailable for "other" longline fleets (fisheries 5—8), selectivities for these fisheries were constrained to equal those of corresponding Japan/Mexican longlines in the same regions (fisheries 1—4).

- Natural mortality... Assumed to be constant in time, space, and age. Although MULTIFAN-CL can attempt to estimate variation in natural mortality by age, experience has shown with other species that such estimates are only possible with extensive tagging data.

Fishery Data

The assessment considered longline and purse seine catch, effort, and where available, size sample data -- the same input data as in last year's assessment (Kleiber et al.; see Appendix I). The longline data included Japan (1955-1997), Mexico (1980-1989), Taiwan (1967-1997), Korea (1975-1997), and French Polynesia (1992-1997). The purse seine data consisted of purse seine data from the eastern tropical Pacific separated by school type (free swimming, floating object, and dolphin). Standardized effort for the Japanese longlines was calculated from the nominal effort data by a habitat-based method (Hinton and Nakano, 1996). Details of data preparation are given by Kleiber et al. (Appendix I). As in the previous year, tagging data were not used.

Results

The model converged successfully when allowed to estimate the movement coefficients as well as independent recruitment trajectories for each region. The biomass estimates are shown in Figure 2 along with a hypothetical extra biomass that would have been achieved in the absence of fishing effort. The amount of this extra biomass relative to the sum of biomass estimates over all regions is indicative of the degree of impact of the fisheries. The calculation is based on the estimated trajectories of recruitment in each region shown in Figure 3.

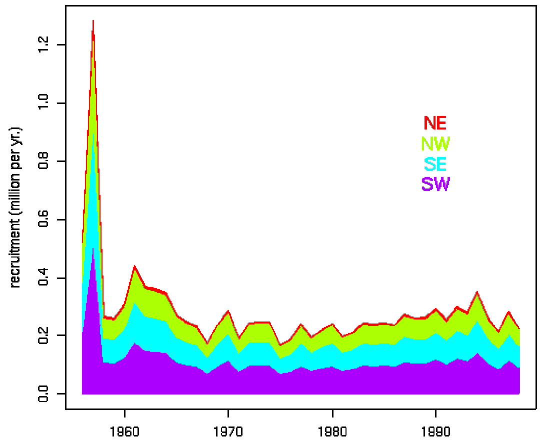

Figure 3. Annual recruitment by region.

Some results from the current study were notably different from corresponding results of last year's assessment. The natural mortality estimate was approximately half of the previous year's estimate: 0.18 yr^{-1} in this analysis versus 0.38 yr^{-1} in the previous analysis. Fishing mortality is higher than previously estimated for most of the time frame (Figure 4), and recruitment is lower overall and drops more precipitately early in the time frame (Figure 5).

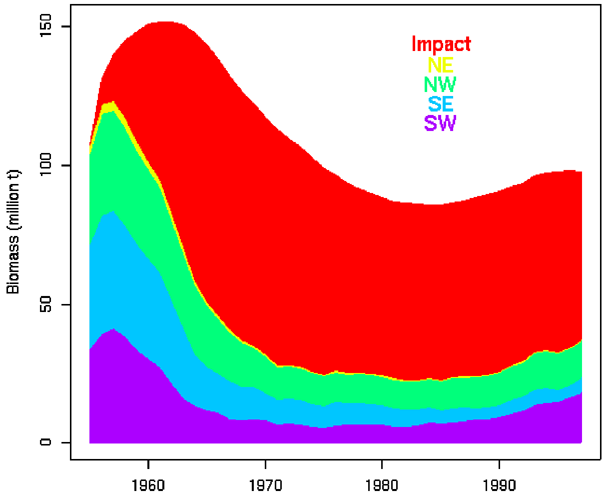

Figure 2. Estimated biomass for the four regions plus fishery "impact" -- a theoretical extra biomass in the absence of fishing.

The estimates of parameters governing movement between regions are given in Table 1. The movement coefficients show a strong movement to the southern regions, particularly out of the northeast region. There is lesser, but significant movement back to the north, particularly to the northeast region. Very little east-west movement is evident except in conjunction with north-south movement

Table 1. Movement parameter estimates. Units of yr^{-1}.

	To NE	To SE	To SW	To NW
From NE	–	0.82	0.78	<0.0001
From SE	0.41	–	<0.0001	0.05
From SW	0.17	<0.0001	–	0.08
From NW	<0.0001	<0.0001	0.08	–

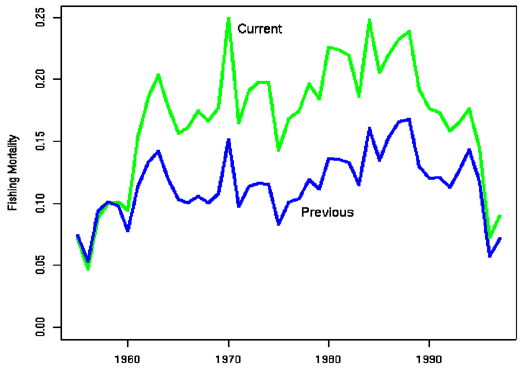

Figure 4 Total fishing mortality, current and previous results.

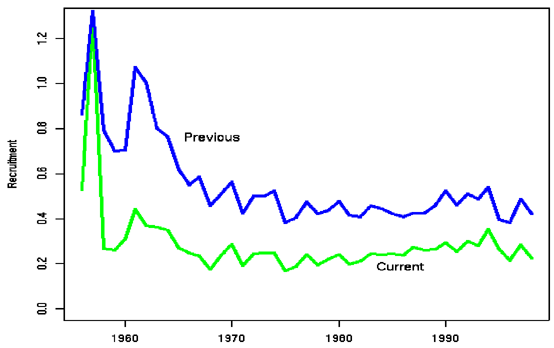

Figure 5. Total recruitment, current and previous results.

Similarities to the previous results included the estimated growth curve, trajectories of catchability, the selectivity curves, and fit to size distributions. In particular, the yield curve (Figure 6) is close to the two presented last year which were based on average fishing mortalities during the final five years of the time frame in one case and during the final two years in the other case (Appendix). The current results, which are based on a final five-year average, place the location of the peak yield (MSY and Fmsy) between the locations from the previous year's analysis. The uncertainty pattern is also similar in previous and current yield curves.

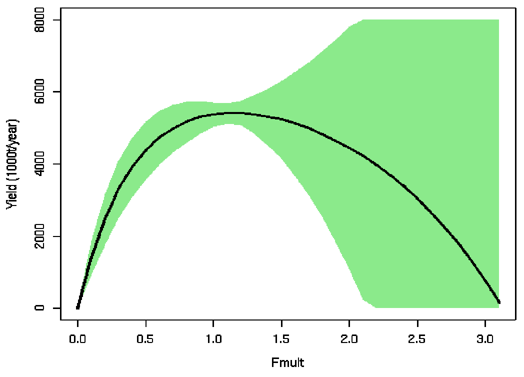

Figure 6. Yield as function of fishing mortality

A new feature of MULTIFAN-CL is output of estimated time series of various population dynamic variables relative to corresponding variables at MSY. Figure 7 shows the fishing mortality relative to fishing mortality at MSY (Fmsy), and Figure 8 shows adult biomass relative to adult biomass at MSY. Finally Figure 9 shows catch in relation to MSY.

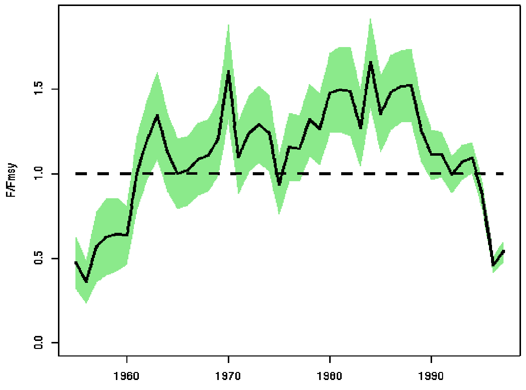

Figure 7. Ratio of fishing mortality to fishing mortality at MSY with approximate 95% confidence region.

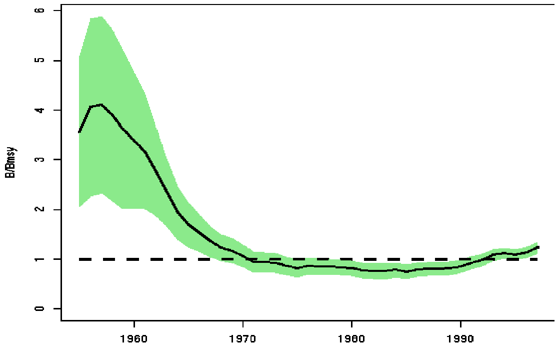

Figure 8. Ratio of spawning biomass to spawning biomass at MSY with approximate 95% confidence region.

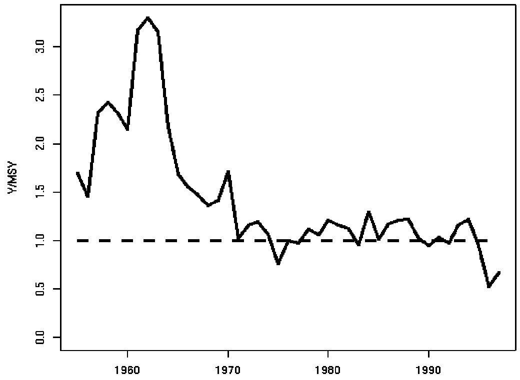

Figure 9. Ratio of annual catch in all fisheries to MSY.

Discussion

The similarity of the yield curve (Figure 4) to those of the previous assessment lends some measure of confidence to the conclusion that the blue marlin stocks are close to being "fully exploited", meaning that current levels of fishing are near to Fmsy. This is an indication of current, or recent, stock status. The history of the stock status is also of interest. Figure 2 indicates that the impact of fishing has been significant over most of the time frame of the analysis, but in spite of that the biomass has been stable or rising during the past three decades. The rising abundance is presumably fed by rising recruitment (Figure 3) starting around 1970. The increasing abundance is particularly evident in the southwest region which by the end of the time series has the greatest share of the population. The growth in the southwest must be fed in part by the strong migration from the north (Table 1). Although there is equally strong migration to the southeast, the abundance in that region declines over the whole time frame. This is presumably because the southeast is fed by migration from the northeast which has very low abundance and also because there is a fairly strong migration back to the north from the southeast.

The ratio curves in Figures 7—9 are also informative of stock history. Figure 7 implies that fishing mortality was higher than Fmsy for a considerable part of the past three decades. Thus the stock status in the past was apparently not as optimistic as it is at present. Not surprisingly, the spawning biomass is below its MSY level for much of the three decades (Figure 8). The surprising result is that the biomass did not continue downward and that the catch remained relatively stable at or slightly above MSY during three decades when F > Fmsy (Figure 9). The resolution of this apparent paradox is again in the rising recruitment (Figure 3) which apparently compensates for the high fishing mortality. The recruitment rises in spite of the fishing pressure, presumably driven by some environmental influence or other factors.

In the final few time periods fishing mortality and catch decline and spawning biomass increases in Figures 7—9. This may be a result of incomplete catch reporting at the end of the time series.

Some comparisons with results of the previous analysis are instructive. With natural mortality estimated to be lower and fishing mortality estimated to be higher over most of the time frame (Figure 4), the current analysis paints a scenario of considerably higher exploitation rate than in the previous analysis. Turning again to recruitment, Figure 5 shows that recruitment in the previous analysis was high and fairly stable during the last three decades whereas it was low but rising in the present analysis. The difference in recruitment trends is much more apparent in Figure 10 where recruitment trajectories relative to their means since 1970 are juxtaposed. The linear trend in the present analysis is 50 times steeper than in the previous analysis.

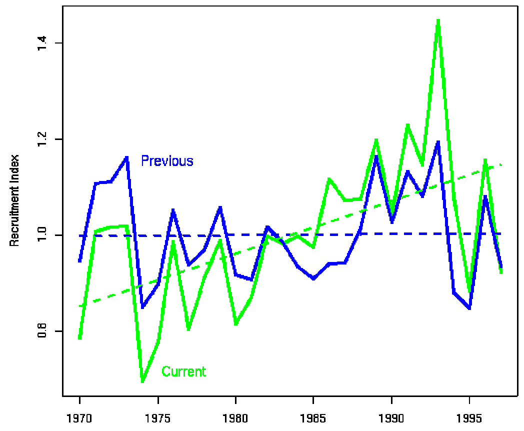

Figure 10. Previous and current recruitment indices

Thus we have two contrasting scenarios. In both, the fish population maintains itself in the face of fishing pressure, but in different ways. In the previous scenario, the population turns over rapidly, has high recruitment, and is therefore not overfished by the harvest it is subjected to. In the present scenario, however, the population has a slower turnover rate, with lower recruitment, and was experiencing what might be called overfishing during most of the time frame (i.e., F > Fmsy), but has managed to sustain the same harvest by dint of rising recruitment.

Conclusion

This sensitivity test has shown that some of the detailed results of the MULTIFAN-CL model are changed when the spatial structures of recruitment and movement are changed from simple homogeneity to heterogeneous, and estimated, spatial patterns. Despite the differences in detailed outcomes, the basic conclusion of the previous and current assessments, namely that the present state of the blue marlin population and fisheries is in the neighborhood of MSY, is shown to be robust to the structural alternatives tested here. Further tests of these and other aspects of the model would add confidence to the basic assessment result.

In designing further analyses, it is important to consider details which were not as robust as the basic MSY determination. In particular, aspects of population turnover, i.e. recruitment and mortality, could have profound affects on future prospects of the blue marlin population if, for example, significant changes are made to the distribution and intensity of fishing or if recruitment were to change markedly. Improvements to the assessment model may help in dealing with some of these aspects, but it is likely that more extensive data, and different kinds of data, will also be necessary. This means tagging data to help get at movement and population turnover, more complete and accurate fishery statistics and sample data, and also sex-specific sample data which would require further enhancement to MULTIFAN-CL but would help deal with difficulties in estimating a single growth curve for a species in which males and females have very different growth curves.

Acknowledgments

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Kleiber, P., M.G. Hinton, and Y. Uozumi. (In review). Stock assessment of blue marlin (Makaira nigricans) in the Pacific with MULTIFAN-CL. (attached as Appendix I).

Appendix I.

DRAFT DOCUMENT--IN REVIEW

STOCK ASSESSMENT OF BLUE MARLIN (*Makaira nigricans*) IN THE PACIFIC WITH MULTIFAN-CL

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Stock Assessment of Blue Marlin (*Makaira nigricans*) in the Pacific with Multifan-CL

Pierre Kleiber, Michael G. Hinton, and Yuji Uozumi

ABSTRACT

In the Pacific, blue marlin are an incidental catch of longline fisheries and an important resource for big game recreational fishing. Over the past two decades, blue marlin assessments by different techniques have yielded results ranging from an indication of declining stock to a state of sustained yield at approximately the maximum average level.

Longline fishing practices have changed over the years since the 1950s in response to changes in principal target species and to gear developments. Despite increasingly sophisticated attempts to standardize fishing effort with changing fishing practices, the stock assessments to date are likely confounded to greater or lesser degree by changes in catchability for blue marlin. Yet only data from commercial longline fisheries targeting tuna provide sufficient spatial and temporal coverage to allow assessment of this resource.

To reassess the blue marlin stocks in the Pacific and also to assess the efficacy of a habitat-based standardization of longline effort, a collaborative analysis was conducted involving scientists at the National Research Institute of Far Seas Fisheries, Shimizu, Japan; the Inter-American Tropical Tuna Commission, La Jolla, California; and the NOAA Fisheries Honolulu Laboratory, Honolulu, Hawai'i. Using Multifan-CL as an assessment tool, we found considerable uncertainty in quantifying the fishing effort levels that would produce a maximum sustainable yield. However we found that at worst, blue marlin in the Pacific are close to a fully exploited state, i.e. the population and the fishery are somewhere near the top of the yield curve. We found furthermore that effort standardization using a habitat-based model allowed estimation of parameters within reasonable bounds and with reduced confidence intervals about those values.

Introduction

Blue marlin are harvested principally in longline fisheries targeting tunas. They are also taken in harpoon fisheries off Japan and Taiwan, and they are an important component of the catches of recreational fisheries targeting billfish relatively close to shore in various areas around the Pacific basin. Some blue marlin are also taken by purse seine vessels fishing for tunas. Biological (Graves and McDowell, 1995) and fishery data indicate that there is a single stock of blue marlin in the Pacific Ocean (Hinton, 2001).

Several studies have presented indices of abundance of blue marlin for parts or all of the Pacific (Hinton, 2001). Conclusions presented have ranged from statements (1) that the stock was overfished (Yuen and Miyake, 1980: using data from 1952 to 1975), (2) that it was not possible to state the status of the stock with respect to management objectives (Suzuki, 1989: using data from 1952 to 1985), and (3) that the blue marlin stock in the Pacific is in a healthy condition, with the current levels of biomass and fishing effort near the levels required to maintain average maximum sustained yield (Hinton, 2001: using data from 1955 to1997).

It is clear that "the data required to estimate the status of a species of fish with respect to the effects of fishing should span several generations. In the case of blue marlin, which may live relatively long periods, data should be collected over a period of decades. This introduces complications to stock assessment because the fisheries from which the data are obtained undergo changes in catchability as the fishermen change their vessels, gear, and strategies in attempts to maximize the net value of their catches." (Hinton, 2001). For the portion of the longline data for which information on gear deployment was available, we standardized the effort using the habitat-based model of Hinton and Nakano (1996). Also, as our principal analytical tool, we used Multifan-CL (Fournier et al., 1998; Hampton and Fournier, in press) in part because of its ability to estimate changes in catchability not accounted for by the effort standardization.

Assessment Method

Multifan-CL is a length-based, age-structured, spatially heterogeneous, stock analysis model that makes use of catch, effort, and size sample data. It can also make use of tag data if such are available, but the limited tag data available for blue marlin were not used in this case. Multifan-CL does not demand that missing catch, effort,[1] or sample data be filled in with ersatz or substituted data. It estimates parameters related to recruitment, growth, catchability, selectivity, natural mortality, and movement. From these basic parameters it predicts historical abundance by time, age class, and area. It can also predict theoretical abundances and yields under various hypothetical fishing regimes. Growth is assumed to follow a von Bertalanffy curve from time of recruitment with a normal distribution of individuals' sizes about the curve. The standard deviation of that distribution is assumed to change linearly with age.

Parameter estimation is accomplished by searching for a set of parameter values which minimizes an objective function. The objective function is composed of negative log likelihood of deviations between observed and predicted catch and between observed and predicted length frequencies. Penalties are added to the objective function to impose constraints on effort deviations and on estimates of selectivities, catchabilities, natural mortality, movement parameters, and recruitment. Most parameters are given upper and lower bounds so that Multifan-CL confines its search within a region of reasonable values. Parameter estimation proceeds in stages with more parameters being "activated"; i.e. introduced to the estimation procedure, at each stage. A detailed description of Multifan-CL, its population dynamics model, and parameter estimation techniques are given by Fournier et al., (1998) and Hampton and Fournier (in press).

Fourteen fleets were included in the model defined according to gear type and set location in one of four quadrants in the Pacific Ocean. The gear types were longline and purse seine. Purse seine was further divided by set type (dolphin associated, floating object associated, and unassociated). Longline was further divided into two groups of fleets based on the availability of gear configuration data: Japanese and Mexican (herein called "JPN longline") and other (including Taiwan, Korea, and French Polynesia and herein to be called "TKP longlines.

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[1] Of course, catch and effort cannot both be missing in a particular stratum.

Because size sample data were not available for the TKP fleets, these fleets were constrained to have the same selectivity pattern as JPN fleets occupying the same quadrant. To achieve stable convergence, selectivities were also constrained to be constant above 12 years of age. Also, in most runs, selectivities were additionally constrained to be nondecreasing with age.

Deviations in effort from the observed values were estimated under constraint of objective function penalties corresponding to an expected coefficient of variation (CV). The penalties were set to the equivalent of approximately 20%, except for the TKP fleets, which were allowed approximately 70% variation. Penalties for constraining interannual variation in catchability were set to a CV of approximately 10% year to year variation except for the TKP fleets, which were allowed approximately 70% variation. Seasonal variation was a sinusoidal curve for each fleet with a period of one year and amplitude constrained by a small penalty corresponding to approximately an order of magnitude variation. Natural mortality was constrained by a mildly informative prior with mean of 0.3 per year and CV of 50%.

The recruitment time series was constrained to approximately 20% CV. The model was structured with recruitment at age-2 and with 20 age classes from 2 to 21+ years. Maturity was assumed to be 50% at age-5, then 75%, 95% and 100% in the following 3 years. Time steps in the model were two months with one recruitment event per year.

The model spatial structure was four regions, or quadrants, separated latitudinally at 15°N and longitudinally at 165°W. Movement was modeled by transfer coefficients representing probability of movement in one time step from one region to another. Estimation of the transfer coefficients was constrained by priors consisting of the upper half of a normal distribution with mean zero and standard deviation of approximately 0.3.

In its internal computations, Multifan-CL deals with numbers of fish by age class and by length class. However, for reporting catch and abundance figures in biomass, it must calculate weight. For that it assumes that the length to weight function is similometric; i.e. that the exponent in the function has a value of 3. The scale constant of the length to weight function must be input to Multifan-CL. This constant was difficult to determine for blue marlin. Many values are reported in the literature (Royce, 1957; Skillman and Yong, 1974), and they are all for functions with exponents different from 3. In the end, this constant was set so that the annual catch in weight reported by Multifan-CL and averaged over the time frame of the model (1955-1997) would approximate the average over the same time period of blue marlin catch reported in volumes of the *Yearbook of Fishery Statistics* published by the Food and Agriculture Organization.

Data

Catch and fishing effort data for longline fisheries of French Polynesia (1992-1997), Japan (1955-1997), Korea (1975-1997), Mexico (1980-1989), and Taiwan (1967-1997) were included in the analyses. Data on gear configuration were available for the Japanese fishery for the period 1975-1997 and for the Mexican fishery. A shallow gear configuration was assumed for the JPN fishery for the period 1955-1974 (Hinton and Nakano, 1996; Hinton, 2001). The data were tabulated by years, bimonthly periods within years, and 5° latitude by 5° longitude areas for the period 1955-1970, and by 2° latitude by 5° longitude for the period 1971-1997. Data for year-bimonthly period-5° area strata with less than 20,000 hooks of nominal fishing effort were not used. Unless otherwise stated, analyses were conducted using estimates of the standardized fishing effort for JPN longline, which was calculated from the nominal effort data by a habitat-based method (Hinton and Nakano, 1996). For the TKP longline fleets, data on gear were lacking, so nominal effort was used.

Since the longline fishery was more widely distributed than are blue marlin, it was important to exclude data for fishing effort that occurred outside the range of that species. Nakamura (1985) stated that blue marlin inhabit surface and subsurface waters of the open ocean, most often where the sea-surface temperatures are greater than 24°C. Using data from acoustic tagging, Hinton and Nakano (1996, Table 1) found that blue marlin spent most of their time (~90%) in waters with temperatures within 1°C to 2°C of the sea surface temperatures (SST). After examining distributions of SST and average SST and catches of blue marlin, analyses to estimate effective fishing effort for blue marlin were based exclusively on data from 5° latitude by 5° longitude areas with average SST equal to or greater than 20° C .

Catch data in weight by area were required for the analyses and were available for the fisheries of French Polynesia, Korea (1994-1997), Mexico, and Taiwan. Catches in weight by bimonthly period and by area for fisheries of Japan and Korea (1975-1993) were estimated as the product of the catch in numbers of fish by bimonthly period and by area and the annual average weight of blue marlin in the Japanese fishery determined as follows.

Estimates of the total annual catches in metric tons and the numbers of blue marlin taken by the Japanese offshore and distant-water longline fisheries by bimonthly period and area were available for 1971-1997. The annual average weights of blue marlin during the 1971-1997 period were estimated by dividing the annual total catch in weight by the total catch in numbers. For the 1955-1970 period, however, the catches by these longline fisheries were available only in numbers of fish. A number of possible relationships between the catches of the Japanese offshore and distant-water fisheries and those of all Japanese fisheries have been examined for the 1955-1970 period (Hinton, 2001). During the 1971-1997 period there was no significant trend in the relationship between the catches of the offshore and distant-water longline fisheries and those of all Japanese fisheries, with the catches by the offshore and distant-water fisheries averaging about 75% to 80% of the catches of all Japanese fisheries. Herein it was assumed that the percentage of the total Japanese catch taken by the two fisheries remained constant over the 1955-1970 period (Hinton, 2001: Scenario 2), providing an estimate of annual total catch in weight to be divided by total catch in numbers to yield annual estimates of average weight for the 1955-1970 period.

Catch (numbers of fish) and numbers of sets by area, bimonthly period, and set type (free swimming school, floating object, and dolphin) for purse seine fisheries in the eastern Pacific Ocean were estimated using data from scientific observer programs and fishing logbooks (Anonymous, 1999). Eye-fork length (EFL) data were obtained for these catches of blue marlin. Weights of individual fish in the catches were estimated using the fork-length-to-weight relationship of Skillman and Yong (1974) following conversion of measured EFL to estimated fork-length (Royce, 1957). Annual average weight of blue marlin taken by purse seine fisheries was estimated as the average of these individual weights. Catches (weight of fish) by stratum were estimated using the products of catch in numbers and annual average weight.

For input to Multifan-CL, the catch and effort data were divided into the 14 fleets defined above. Within each of the 14 fleets the data were aggregated into bimonthly temporal strata. In a few cases the Multifan-CL results given below are from runs with unstandardized, or nominal, effort data for the JPN longline fleets, but unless otherwise stated results given here pertain to the standardized JPN effort as described above.

Aggregated catch and effort are shown in Figure 1. The TKP category for longline is a catch-all for fleets with less certain, or less complete, catch and effort data. The weight of these data in the Multifan-CL fitting process was adjusted to be much lower than for the JPN fleets.

Length sample data were treated in the same fashion as the catch and effort data, and were aggregated into 5-cm length bins. Sample data were not available for the TKP longline fleets. Therefore the selectivities of these fleets were constrained to be the same as the JPN longline fleet in the corresponding quadrant. For the other fleets sample data were also missing for some strata: 17% of the purse seine fleet strata and 39% of the JPN longline strata. Aggregate observed length frequencies are shown in Figure 2.

Summarized catch-per-unit-effort (CPUE) corresponding to the plots in Figure 1 is shown in Figure 3. JPN longline data shows an overall rising CPUE starting in the late 1970s and a leveling off in the late 1980s. By contrast, TKP longline data show general decline throughout the time series. The actual data presented to Multifan-CL are more complex than depicted. For example, within the JPN longline there are some similarities and some differences in the CPUE trends in different quadrants (Fig. 4). Likewise, Multifan-CL considers detailed size frequencies for each fleet by time stratum rather than the summaries shown in Figure 2.

Results

Conducting an analysis with a flexible assessment tool such as Multifan-CL necessarily involves considerable exploratory work to determine which parameters of population dynamics can reasonably be estimated from the data at hand and which need to be constrained or fixed to values estimated in other ways. In the case of blue marlin we found that growth was not well determined. The estimate of von Bertalanffy *K* tended toward zero. It was therefore fixed to a value of 0.2 per year, a rough average of various estimates reported by Skillman and Yong (1976) for blue marlin in the Pacific. Movement was also ill-determined. Activating the movement parameters produced multiple optima in the likelihood function, all producing unreasonable concentration of fish in one or another of the quadrants. Therefore movement coefficients were fixed to a relatively high exchange rate between quadrants of 0.1 per year, and differential estimation of recruitment by quadrant was disabled. The analysis was thus effectively converted to a spatially homogeneous case. The remaining results detailed below were estimated from the data input to Multifan-CL, with some constraints as noted.

The predicted and observed size distributions shown in Figure 2 fit better for the longline fleets than for purse seine fleet, where there was a tendency for Multifan-CL to predict smaller sizes of blue marlin than were observed in the catch. Note that the size data in Figure 2 are summed over the whole time frame, whereas the size data that Multifan-CL actually works with are the distributions for individual fleets in bimonthly strata.

Parameters of temporal variation in catchability allow within-year; i.e., seasonal, as well as interannual variation. Figures 5 and 6 show representative estimated catchability for short (3-year) portions of the time series to indicate the seasonal pattern of variation. Within JPN longline fleets, the northern fleets are mostly in phase with sharp peaks at mid-year (Fig. 5). The southern fleets do not have such a wide range of variation and are out of phase with the north and with each other, the western fleet having a high point in the second half of the year and the eastern fleet a high point in the first half of the year. The TKP longline fleets are more in phase with each other in the southern quadrants with peaks late in the year. In the northern quadrants the TKP longline fleets peak at the turn of the year in the west and at midyear in the east. Within the purse seine fleets (Fig. 6) catchability in all fleets in the south show peaks close to mid-year (n.b. gaps in the series indicate periods without fishing effort). The same pattern appears to hold for the school set fleet in the north, whereas catchability in the dolphin set fleet in the north seems to peak somewhat later in the year. The pattern for the floating object set fleet in the north is unclear because of the small amount of effort in this fleet.

Interannual variations in catchability and scaled effort deviations are shown in Figures 7 and 8. The catchability time series is smoothed to emphasize interannual trends. At each time step Multifan-CL calculates the effort deviations required to minimize the difference between predicted and observed catch, and the points in Figures 7 and 8 indicate those deviations. They are fitted to the smooth curves in such a way that they should be evenly distributed above and below the curves. An uneven distribution indicates variation in catchability that has not been explained by the fitted model. The longline fleets show more variation in catchability than do the purse seine fleets, especially the TKP longline fleets, which show a downward trend particularly in the western quadrants. For the JPN longline fleets there is a slight positive trend in catchability in the northwest quadrant and a lesser negative trend in the northeast quadrant. Note that the vertical scales in Figures 7 and 8 are all adjusted to the same logarithmic range so that the slope of the lines and scatter of points can be compared in the different plots.

As noted above, selectivities were constrained to be constant above a certain age (12 years) and also to be nondecreasing with age. Changing the number of older age classes forced to have constant selectivity did not have much effect on the outcome of the analyses, but outcomes were very sensitive to the nondecreasing selectivity constraint (NDSC). Because it is pertinent to discussion below, we show selectivity estimates with and without NDSC in Figure 9. When released from NDSC, the selectivities fall to very low values for older age classes of blue marlin for both longline and purse seine fleets, tending to reflect the size distributions in the catch shown in Figure 2. All other results shown here are from model runs with NDSC enabled.

Though differential recruitment by quadrant was disabled, total recruitment with time was estimated. Total recruitment (Fig. 10) shows a decline through the 1960s but is relatively stable thereafter. Estimated biomass of juveniles and adults shows a similar pattern (Fig.11) with total biomass at the end of the time series reduced to approximately half of that near the beginning. Also shown in Figure 11 is the additional biomass that would be expected to have existed in the absence of fishing effort. At the end of the time series, the total biomass is approximately two-thirds of what it might have been without fishing.

From catchabilities and selectivities, Multifan-CL calculates a detailed array of fishing mortality by time step, region, age class, and fleet. These values are used in the model to calculate a similarly detailed array of catches. As a summary of overall trends in fishing mortality, Figure 12 shows average fishing mortality calculated as the annual total catch by all fleets divided by the estimated abundance at the start of each year. For most of the time frame there is a general rising trend to a maximum of approximately 0.15 per year in the mid-1980s after which the fishing mortality drops steeply. By comparison, the natural mortality was estimated at 0.38 per year (approximate 95% confidence range of 0.30-0.45). Estimation of variation in natural mortality with age was not attempted.

The estimated growth curve is given in Figure 13a. As noted, von Bertalanffy *K* was fixed to 0.2 per year, but the average sizes at recruitment and oldest age class were estimated along with the trend in standard deviation about the growth curve. To investigate the effect of standardization of the JPN effort data, an analysis without such standardization was conducted. The resulting growth curve is shown in Figure 13b. In the unstandardized effort case the variance increases enormously with age. In fact, the estimated rate of increase in standard deviation with age was pushed to its upper bound. Estimates of all other quantities examined in the nominal case also had wider confidence intervals than in the standardized case, although the point estimates were not much different in the two cases.

In a final stage of model fitting, Multifan-CL was set up to fit a Beverton-Holt stock-recruitment curve to the estimates of recruitment and adult biomass, from which projected yield as a function of fishing mortality was derived. The stock-recruitment curve (Fig. 14) covers a relatively wide range of adult biomass, and there is some indication that recruitment is somewhat diminished at the lower end of the adult biomass range but not at the upper end of the range. Therefore, there is no indication that a more complex stock-recruitment curve, such as a Ricker curve, would be preferable to the Beverton-Holt curve. Two yield curves are shown (Fig. 15), with fishing mortality reckoned relative to a “nominal” fishery. The nominal fishery should represent recent fishing conditions. This was defined as the fleet composition and average fishing mortality estimated for the final 5 years of the time frame in one case and the final 2 years in the other case. For the five-year average, the height of the peak is 12.6 thousand metric tons (t) and its location (Fmult) is somewhat below (0.7 times) current fishing mortality. The 2-year average peak yield is 12.7 thousand t with Fmult somewhat above (1.3 times) current fishing mortality. The scale of biomass yield in Figure 15 depends on the assumed constants in the length to weight relationship used to translate numbers at length into biomass. The uncertainties in that relationship are not included in the uncertainty regions in Figure 15. Nevertheless, the uncertainty regions are wide and expand rapidly in both cases as fishing mortality increases beyond current levels. The wide confidence bounds to the right of the peak in both plots is not unexpected. The yield curve in that area is an extrapolation because there are no data for fishing effort much beyond the peak.

Discussion

Because JPN longline data comprise the predominant amount of data in the analysis, it might be expected that the abundance predicted by Multifan-CL would resemble the trends shown by JPN longline CPUE. It does so, broadly speaking, starting with a high point early in the time frame followed by a decline and a rising trend and partial recovery near the end. (Figs. 3 and 11). But there are some differences in detail. The lowest part of the CPUE series occurs in the 1970s, whereas the abundance estimated by Multifan-CL reaches a low point a decade later. The differences result from temporal variation of catchability in the fleets (Figs. 7 and 8).

The theoretical extra blue marlin biomass that might have prevailed in absence of fisheries (Fig. 11), and the location of current fishing mortality near the point of maximum yield (Fig.15) indicate that the population is significantly affected by fishing. It appears to be producing almost as high a yield as could be expected in the long run. The major difference between the yield curves in Figure 15 is a matter of scaling of the x-axis resulting from two different definitions of the nominal fishery. The decline in fishing mortality in the final decade of the time frame (Fig. 12) means that the average of the final 5 years is higher than that of the final 2 years. The distribution of effort among the fleets was also changing (Fig. 1a), which means that the selectivity characteristics were different in the two cases in Figure 15, accounting for subtle differences between the curves beyond simple scaling of the x-axis.

Two arbitrary choices of the nominal fishery have placed recent fishing effort levels on either side of the peak of the yield curve. One result implies overfishing; the other does not. Note that the uncertainty is not symmetrical. It is easier to imagine a true yield curve both within the uncertainty region and with a peak far to the right of the estimated curve than with a peak much to the left. Given that, and the sensitivity to choice of nominal fishery, the most that can be confidently said on the basis of Figure 15 is that the recent state of the fishery is somewhere near the lower end of the range of probable peak locations.

Furthermore, this conclusion about the state of the fishery is contingent on the assumption that selectivities do not decrease, or at least do not decrease significantly, with age. In this case Multifan-CL interprets the right hand limbs of the size frequency plots (Figure 2) to indicate declining abundance with size or age. As we have seen, without NDSC, Multifan-CL tends to interpret the right hand limbs of the frequency plots to indicate declining susceptibility to the fisheries with age (Fig. 9 b and d). The expected additional biomass in the absence of fisheries was essentially undetectable is this case, and the total biomass was several orders of magnitude higher than estimated with the constraint. The catchability estimates (and therefore the fishing mortality estimates) were also lower by several orders of magnitude than those estimated with NDSC. Thus without NDSC, the model results indicate a huge blue marlin population experiencing a minuscule impact from fishing. The absurdly high biomass estimates lead us to presume that the results with NDSC are probably much closer to the truth. However, some decline in selectivity with size in the longline and purse seine fisheries cannot be ruled out, and any decline in selectivity with size would lead to an assessment of the blue marlin stock indicating that maximum yields would be higher than indicated in Figure 15. Effort levels corresponding to the maximum would also be higher. To determine to what degree susceptibility to these commercial fleets might decline with size it would help to include data from recreational fisheries because they target large fish.

The interpretation of this analysis is further complicated by the fact that male and female blue marlin are known to have very different growth curves with females growing more quickly and reaching much larger sizes than males (Skillman and Yong, 1976). Given the mixture of males and females in the data, it is unlikely that clear modes and modal progressions will show up in the size distributions. As a result, the estimated growth curve, which represents both males and females, has large confidence bounds (Figure 13a), and it was not possible to estimate von Bertalanffy *K*. These results may be improved by including data from recreational fisheries to include information on the large females they capture. It would also be useful to adapt Multifan-CL to handle sex-specific catch and sample data where such are available.

The difficulties in estimating growth from the size frequency data also pertain to estimation of movement. In the absence of tagging data, differences in size distributions among regions would be the only information that could bear on movement. Good tagging data, perhaps including archival tag data, would be more promising for estimating movement parameters than just size composition.

As mentioned above, the JPN longline effort data that were input to Multifan-CL were standardized to account for variations in catchability due to variation in placement of hooks relative to preferred habitat of blue marlin. If that were the only factor affecting catchability and if the standardization worked perfectly, the time series of catchabilities estimated by Multifan-CL for the JPN longline fleets should be perfectly flat for the case of the standardized effort (Fig. 7). The JPN catchability trends indeed appear to be flatter than those of the TKP fleets, which had nominal effort data, but then the penalty structure allowed more catchability variation in TKP fleets than in the other fleets. A good corroboration of the efficacy of the effort standardization would have been to find greater temporal variation in results from nominal JPN data compared with standardized JPN data. Unfortunately, with nominal JPN data, the model converged with unreasonably large variance about the growth curve (Fig. 13a) and at least one parameter estimate pushed to an outer boundary. A forced fit with growth parameters fixed to estimates from the standardized JPN data yielded catchability results (not shown) only subtly different from the standardized case. The principal effect of standardizing the JPN data was allowing Multifan-CL to obtain reduced confidence intervals with none of the parameter estimates pushed against a boundary of unreasonability.

Conclusion

The most conservative interpretation of our results is that current fishing effort is producing close to the maximum expected yield of blue marlin. However, because of uncertainty in projected yield curves, and because of sensitivity of the model to some structural assumptions (notably selectivity assumptions), the actual situation may well be more optimistic, with current effort levels significantly less than those that would produce maximum yield. The assessment could be improved by inclusion of data from other fisheries. Plans are under way to include Hawai'i longline data and perhaps recreational fishery data. In the longer run, tagging data would also be useful as well as possible developments in Multifan-CL, such as the ability to deal with sex-specific catch and size sample data.

Acknowledgments

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FIGURES

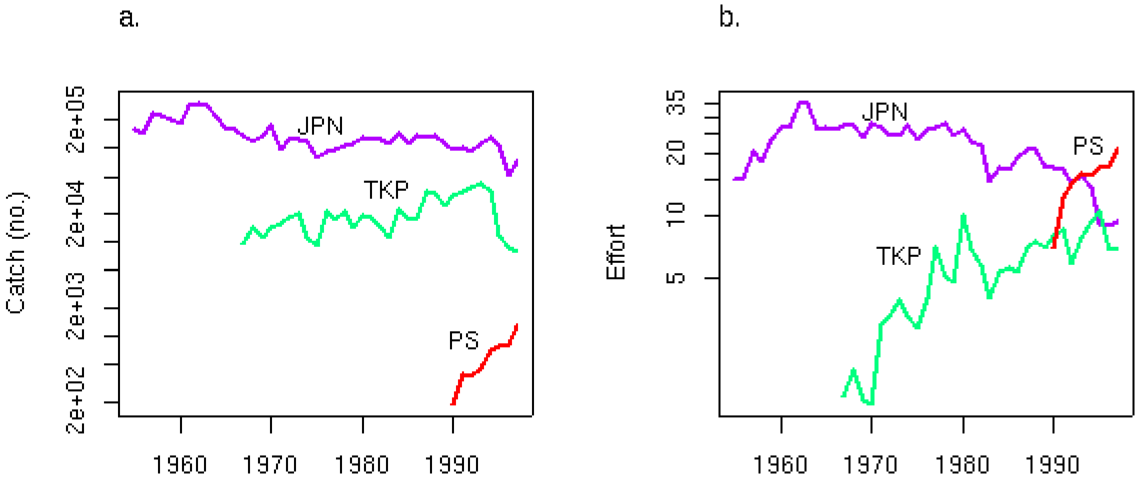

Figure 1. Blue marlin catch (a.) and effort (b.) aggregated over all quadrants and bimonths within years (note the y-axis log scales). Effort units are millions of hooks for longline (JPN and TKP) and thousands of sets for purse seine (PS).

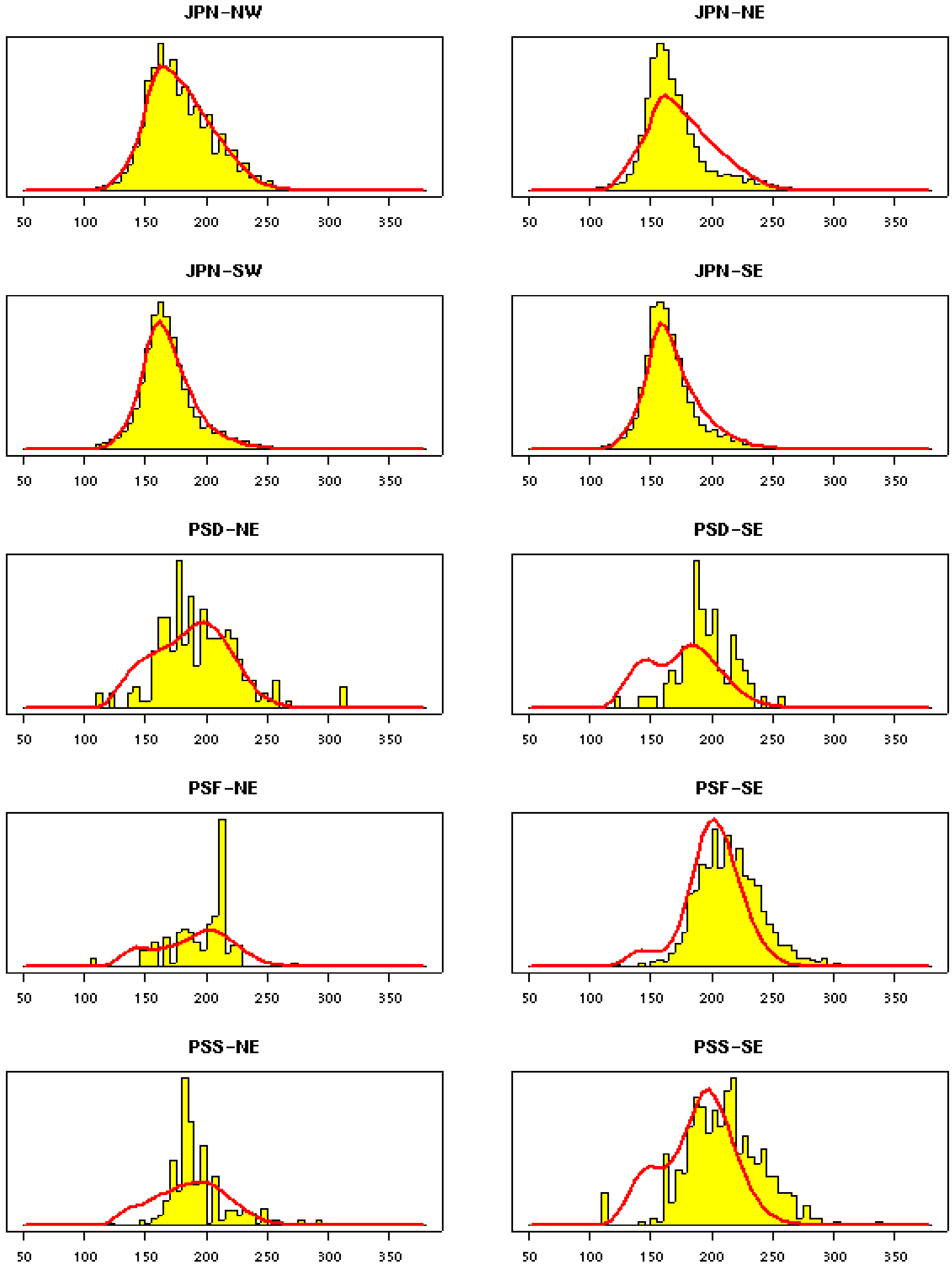

Figure 2. Observed (histograms) and predicted (curves) size frequencies. Predictions are for the analysis with a nondecreasing constraint on selectivity. Size is eye-to-fork length in cm. Plots for the TKP longline fleets are not shown because there were no sample data available for these fleets.

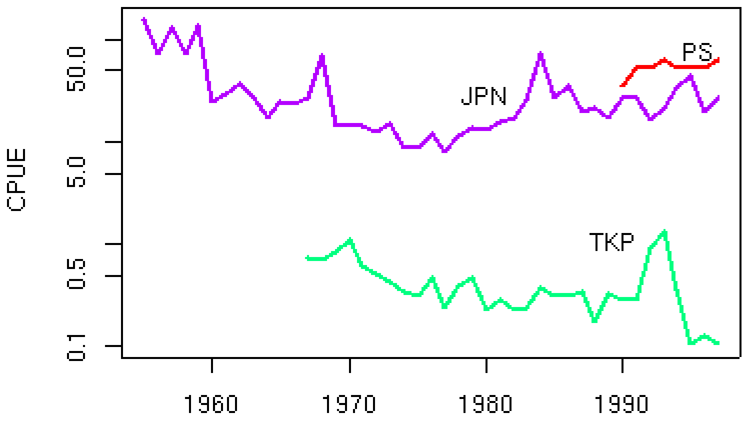

Figure 3. CPUE aggregated over quadrants. Units for longline is number per thousand hooks and for purse seine is number per thousand sets.

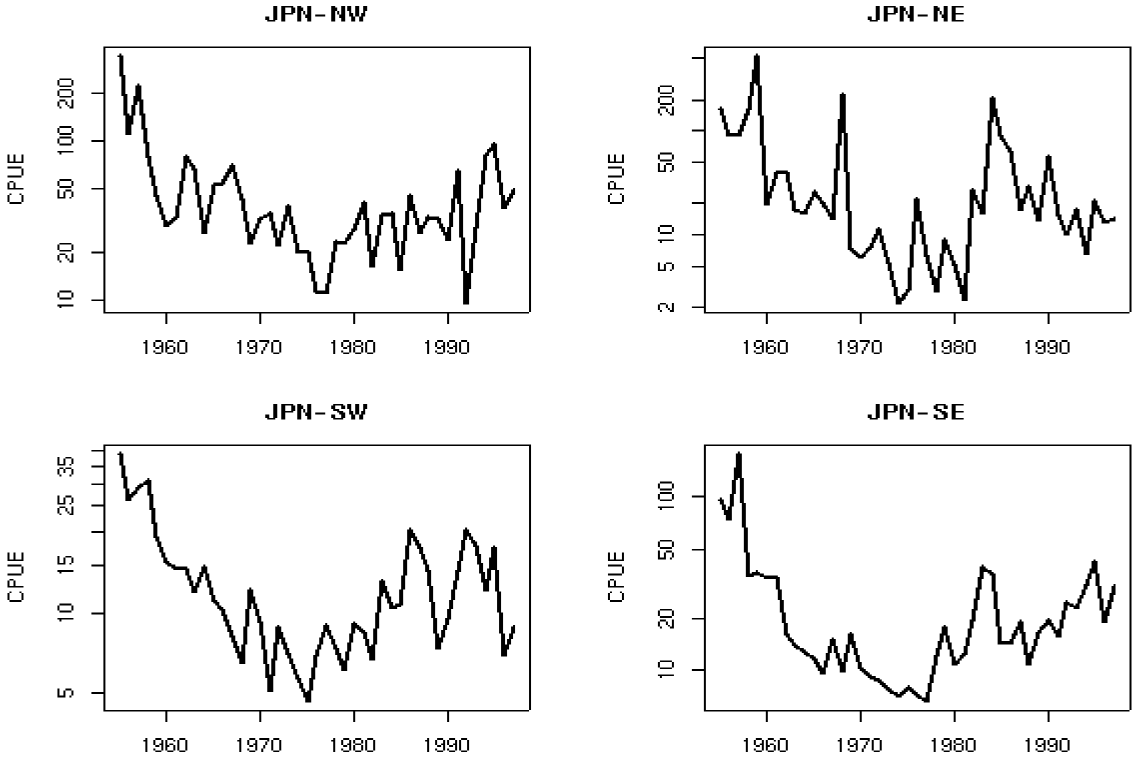

Figure 4. JPN longline CPUE in four quadrants of the Pacific divided by 15° N latitude and 165° W longitude.

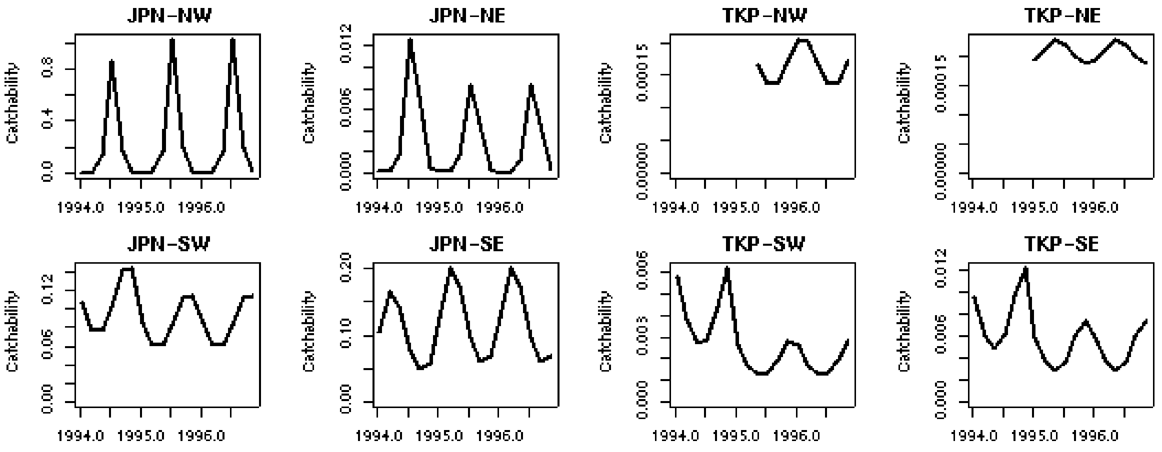

Figure 5. Seasonal variation of catchability in the longline fleets.

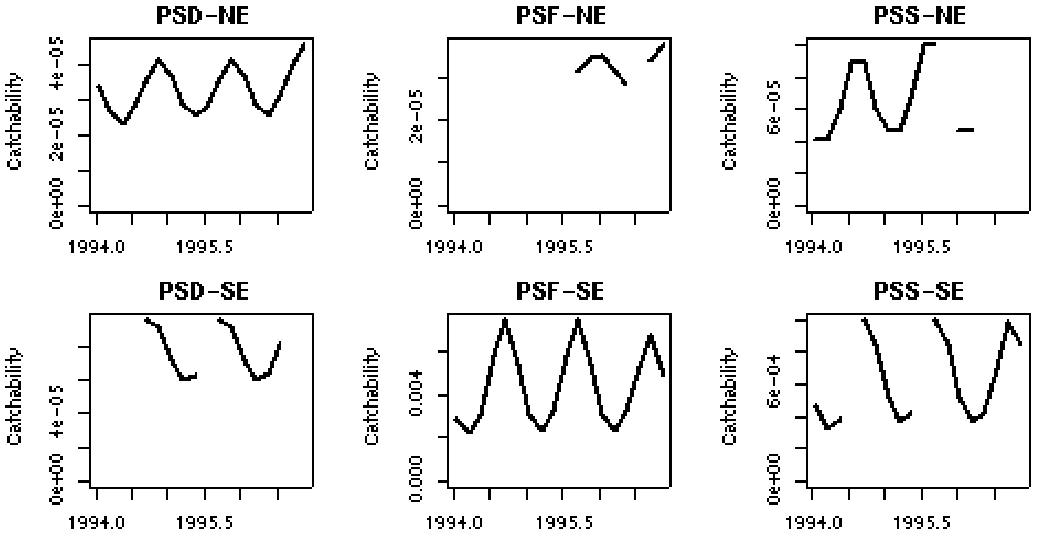

Figure 6. Seasonal variation of catchability in the purse seine fleets.

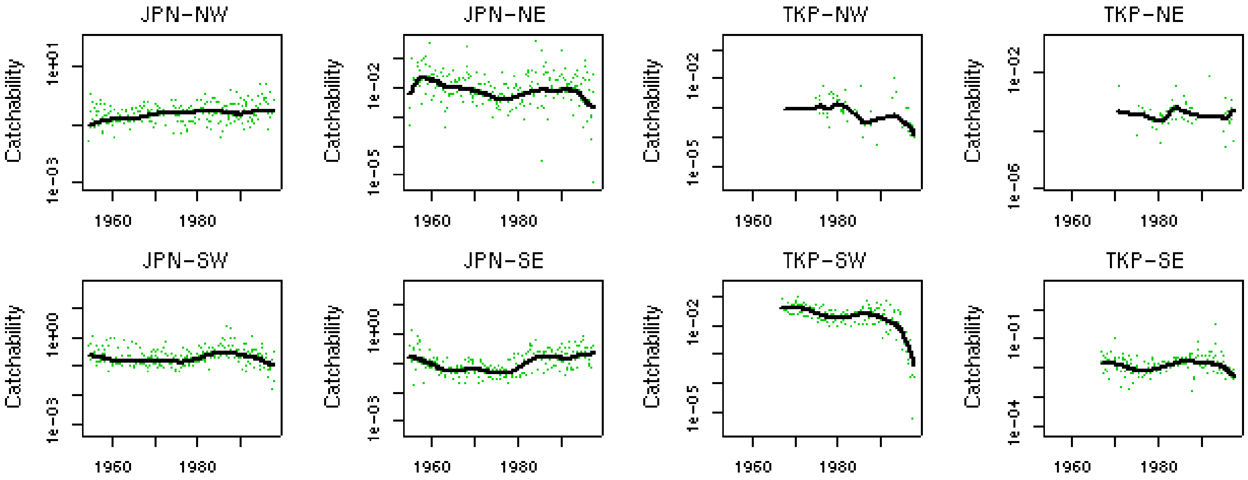

Figure 7. Catchability trends in the longline fleets. Lines are the time series of catchability smoothed to remove seasonal variation. Points indicate effort deviations expressed in units of catchability and scaled to the smoothed lines.

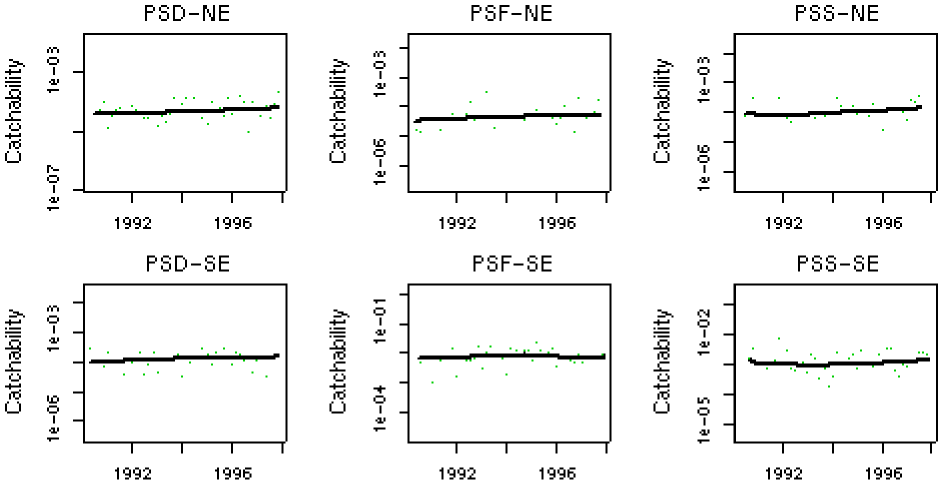

Figure 8. Catchability trends in the purse seine fleets. Lines are the time series of catchability smoothed to remove seasonal variation. Points indicate effort deviations expressed in units of catchability and scaled to the smoothed lines.

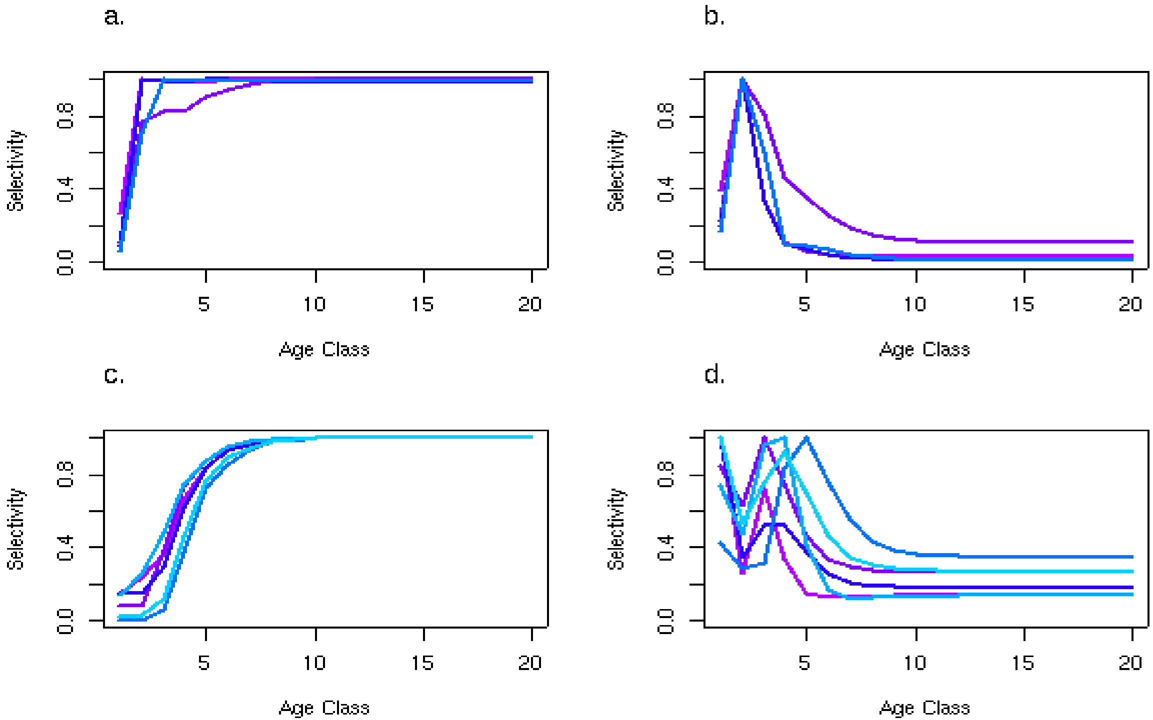

Figure 9. Estimated selectivities by age class: (a) longline, with NDSC, (b) longline without NDSC, (c) purse seine with NDSC, (d) purse seine without NDSC.

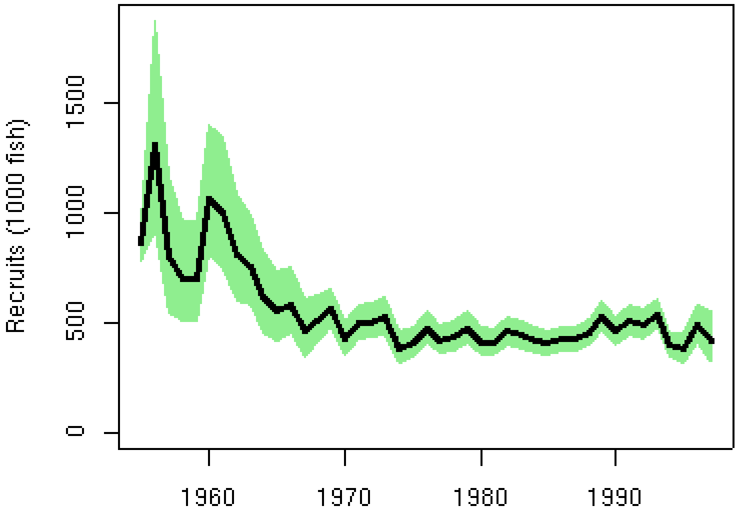

Figure 10. Annual recruitment to age-2. Shaded area is approximate 95% confidence region.

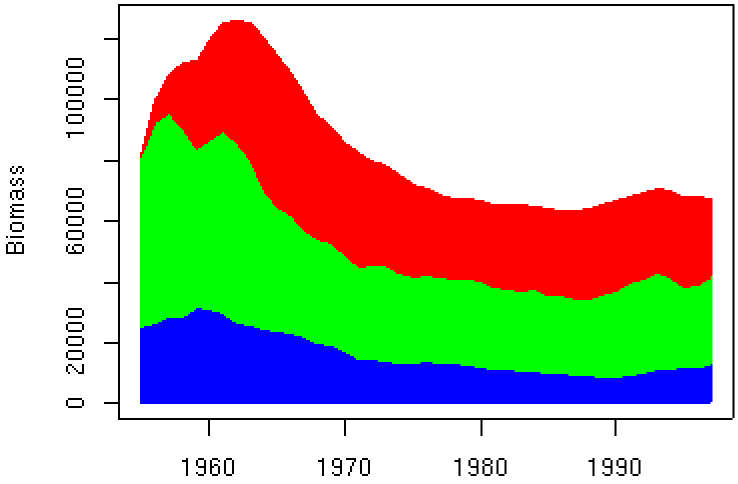

Figure 11. Estimated blue marlin biomass (1000s of t). The dark region on the bottom represents adults, the lightest region in the middle represents juveniles, and the upper region represents hypothetical additional biomass if there had been no fishery.

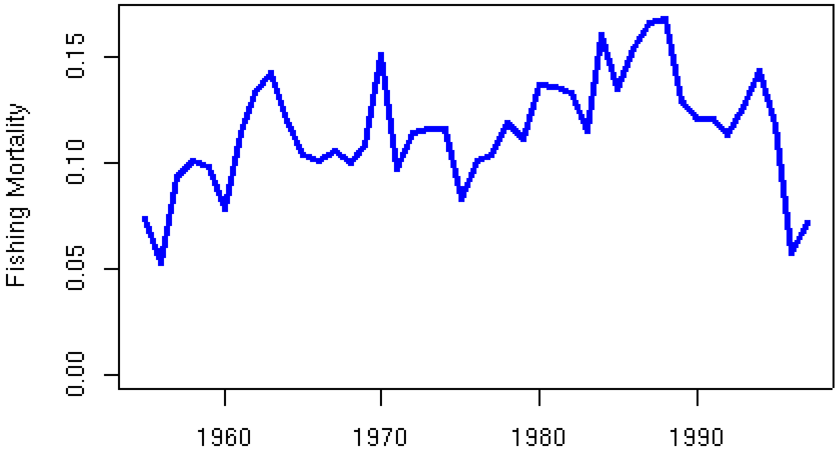

Figure 12. Fishing mortality aggregated over all fleets calculated as total catch in numbers in each year divided by estimated blue marlin abundance at start of each year.

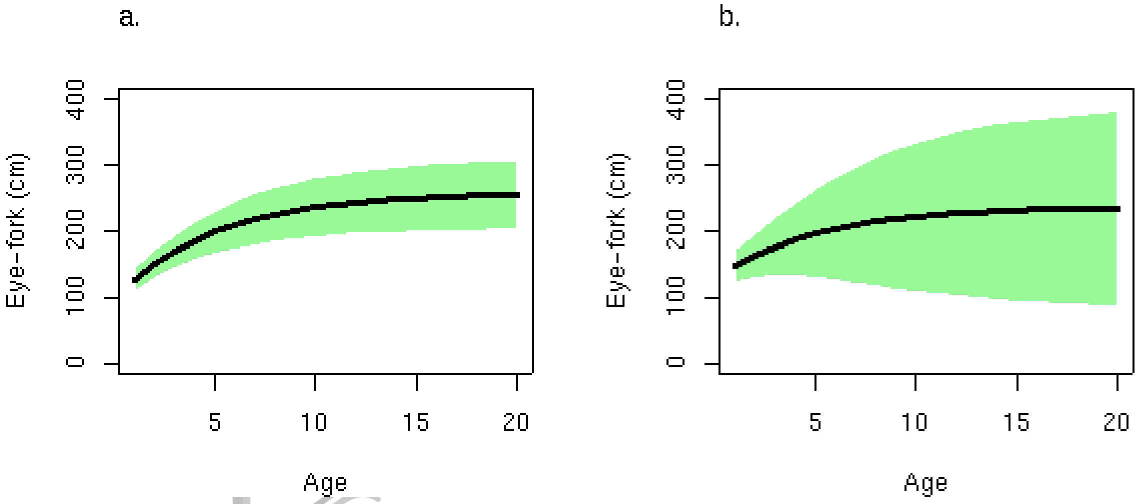

Figure 13. Estimated growth curve: (a) standardized JPN effort, (b) nominal JPN effort. Shaded area is approximate 95% confidence region.

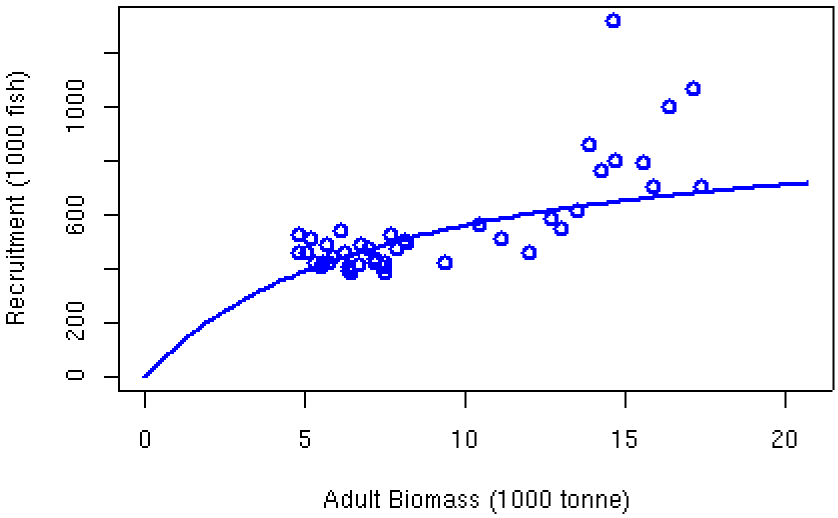

Figure 14. Stock-recruitment curve Points are recruitment each year versus adult biomass 2 years earlier. Line is estimated Beverton-Holt recruitment function.

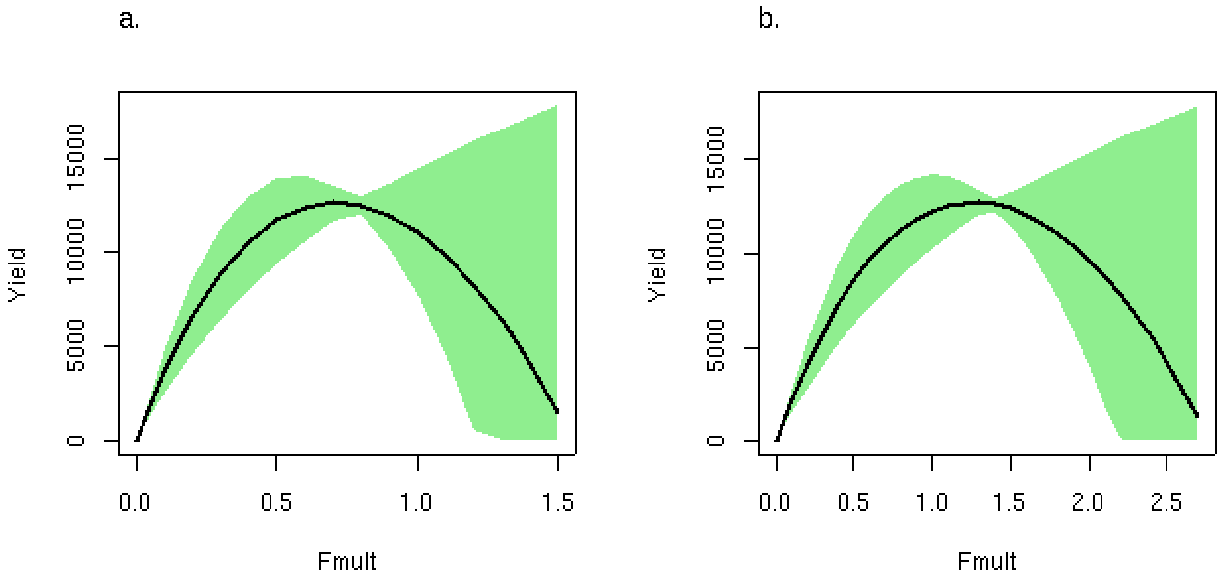

Figure 15. Projected yield against Fmult, the fishing mortality relative to average fishing mortality. The averages are over: (a) the last 5 years of the time frame and (b) the last 2 years of the time frame. Shaded areas indicate approximate 95% confidence bounds.