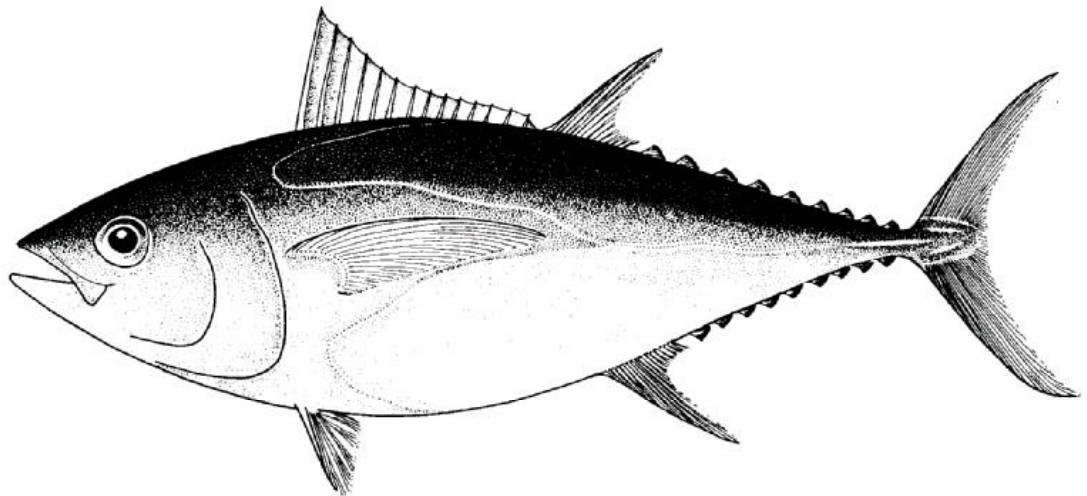




SCTB15 Working Paper

BET- 6

An update of the application of the A-SCALA method to bigeye tuna in the western and central Pacific Ocean



Chi-Lu Sun¹, Mark Maunder², George Watters², and Su-Zan Yeh¹

¹Institute of Oceanography, National Taiwan University
Taipei, Taiwan

²Inter-American Tropical Tuna Commission
La Jolla, California, USA

An update of the application of the A-SCALA method to bigeye
tuna in the western and central Pacific Ocean

By

Chi-Lu Sun¹, Mark Maunder²,
George Watters², and Su-Zan Yeh¹

¹ Institute of Oceanography, National Taiwan University
Taipei, Taiwan

² Inter-American Tropical Tuna Commission
La Jolla, California, USA

An update of the application of the A-SCALA method to bigeye tuna in the western and central Pacific Ocean

Chi-Lu Sun, Mark Maunder, George Watters, and Su-Zan Yeh

Abstract

An age-structured statistical catch-at-length analysis (A-SCALA) is applied to the bigeye tuna population in the western central Pacific Ocean (WCPO). The results suggest that the biomass at the start of 2002 is below the level that is required to produce maximum sustainable yield (MSY) and will reduce under average conditions and recent effort levels. The recent average weight of bigeye in the catch is much lower than the weight which would maximize yields suggesting that reallocation of effort from fishing methods that capture small bigeye to methods that capture large bigeye would substantially increase yields. This is also supported by MSY calculations carried out separately for each method type. The results of the analyses are very sensitive to the Indonesian fisheries, which catch a large number of small bigeye. Unfortunately, the amount and size structure of the catch from the Indonesian fisheries is highly uncertain and more data from these fisheries should be a priority for the management of bigeye tuna in the WCPO.

1. Introduction

Bigeye tuna (*Thunnus obesus* Lowe, 1839) are a commercially important species of tuna inhabiting the warm waters of the Atlantic, Indian, and Pacific Oceans. Adult bigeye tuna are caught mainly by longlines, but substantial numbers of juveniles are taken by purse seines (Sun et al., 2001).

In the western and central Pacific Ocean (WCPO), the area west of 150° W, bigeye tuna are taken by both surface gears (mostly as juveniles) and longline gear (as valuable adult fish). The longline catch has been typically 40,000-65,000 mt in the WCPO and reached a record high of 68,000 mt in 2000 (Hampton et al., 2001). In contrast, the purse seine catches of bigeye tuna in the WCPO are estimated to have been less than 20,000 mt per year up to 1996, mostly from sets on natural floating objects (Hampton et al. 1998). In 1999, that catch was the highest ever, almost 35,000 mt, but decreased to 28,800 mt in 2000 with reduced fishing on drifting FADs (Hampton et al. 2001). The total WCPO bigeye tuna catch in 1999 was a record 117,000 mt (including Indonesian, 14,800 mt, and the Philippines, 6,200 mt) with a similar catch recorded in 2000

(115,000 mt) (Hampton, 2002).

Maunder and Watters (submitted) developed an age-structured statistical catch-at length analysis (A-SCALA) following the MULTIFAN-CL method of Fournier *et al.* (1998) and applied this method to yellowfin, bigeye, and skipjack populations in the eastern Pacific Ocean (EPO) (Watters and Maunder 2001, Maunder and Watters 2001, Maunder and Watters 2002a). For more details of this analysis, readers are referred to Maunder and Watters (submitted). The purpose of this study is to assess the bigeye population in the WCPO by using the A-SCALA method. This paper is an update of Sun et al. (2001).

2. Materials and methods

2.1. Fishery data and biological information

2.1.1. Fishery data

Four regions and 15 fisheries are described and defined in Table 1 based on Hampton (2002). These fisheries are used to group the fishery data that have similar characteristics (selectivity and catchability). The fisheries are based on fishing method and region (Hampton et al. 2002). Catch, effort, and size-composition data for the time periods described in Table 1 were used to conduct the stock assessment of bigeye tuna in the WCPO. All data are summarized and analyzed on a quarterly basis. Catch is in numbers for the longline fisheries and in weight for the other fisheries. Effort for the longline fisheries was standardized using the habitat based method (Bigelow et al. 2002), for the Philippines and Indonesian fisheries was unknown, and nominal effort was used for all other fisheries.

2.1.2. Biological parameters used

2.1.2.1. Growth

Sun et al.'s (2001) estimates of von Bertalanffy growth parameters ($L_8=208.7$ cm, $K=0.201/\text{yr}$) (Figure 1) for WCPO's bigeye tuna were used in current stock assessment. Variation in length-at-age was calculated by fitting a von Bertalanffy model with the standard deviation of the process error a linear function of mean length to Sun et al.'s (2001) age-length data.

The following weight-length relationship, from Sun et al (2001), was used to convert length to weights in the current stock assessment:

$$W = 3 \times 10^{-5} FL^{2.9278}$$

where w = weight in kilograms and FL = length in centimeters.

2.1.2.2. Reproduction

The sex ratio by age (i.e. age-specific proportions of female) and batch fecundity used in the current assessment are from Sun et al. (1999).

2.1.2.3. Natural Mortality

The quarterly natural mortality rate was the same as used for the assessment of the eastern Pacific Ocean stock of bigeye tuna (Figure 2, Watters and Maunder 2001a). This mortality schedule was derived by assuming that M is relatively high for young (small) bigeye and that observed changes in size-specific sex ratios indicate increased M for older females. The natural mortality curve was estimated by fitting to some of the natural mortality estimates of Hampton (2000) and the sex-ratio data provided by Hampton *et al.* (1998).

2.2. Methods

An age-structured population dynamics model and information contained in catch, effort, and size-composition data are used to assess the status of the bigeye tuna stock in the WCPO. The model is described by Maunder and Watters (submitted), and readers are referred to that manuscript for technical details. The following is a general description of the model and follows the description in Watters and Maunder (2000a). The stock assessment model, termed an age-structured statistical catch-at-length analysis (A-SCALA), is based on the method described by Fournier *et al.* (1998). The term “statistical” indicates that the method implicitly recognizes that data collected from the fisheries do not perfectly represent the population; there is uncertainty in our knowledge about the dynamics of the system and about how the observed data relate to the real population. The assessment model uses quarterly time steps to describe the population dynamics. The parameters of the stock assessment model are estimated by comparing the predicted catches and size compositions to data collected from the fishery. After the parameters of the model have been estimated, the model is used to estimate quantities that are useful for managing the stock.

The A-SCALA method includes several features that increase the ability of the assessment model to make predictions that are in agreement with the observed data (*i.e.* to provide a good fit). The A-SCALA method recognizes that, from quarter to quarter, there are short-term, random changes in the relationship between fishing effort and fishing mortality. The A-SCALA method also recognizes that there is temporal variation in recruitment and that different fishing methods usually catch fish of different

ages. The A-SCALA method includes the assumption that fishing mortality rates can be separated into an age-specific effect (selectivity) and a temporal effect (catchability). It is assumed that the age-specific effect is constant over time.

Unlike cohort analysis, the A-SCALA method does not require size-composition data from every fishery in every time period. The A-SCALA method uses a population dynamics model to predict the size composition of the population during times when there are no data. This method recognizes that the size-composition data collected from a single fishery do not perfectly represent the sizes of fish in the catch of that fishery. This assumption is consistent with the fact that the size-composition data is usually collected from a very small proportion of the fish that are caught. Because the size-composition data are from small samples of the catch, there will be times when the observed size-composition data are considerably different from those predicted by the assessment model.

Since fisheries data are complex, the ways in which the stock assessment model is allowed to fit to the observed data are constrained. The model is fitted to the observed data by finding a set of population dynamics and fishing parameters that maximize the likelihood of having observed the catch and size-composition data, given the amount of fishing effort expended by each fishery. This likelihood is calculated under a set of constraints. The following list identifies some of the important constraints that are used to fit the assessment model to the observed data on bigeye tuna:

1. If a fishery can catch fish of a particular age, it should also be able to catch fish that are of somewhat lesser and greater ages.
2. Bigeye tuna should become more vulnerable to longlining as they age, and the oldest fish should be the most vulnerable to this gear.
3. There are random events that can cause the relationship between fishing effort and fishing mortality to change slightly from quarter to quarter.
4. The data for fisheries that catch bigeye tuna in the Phillipines and Indonesia (Fisheries 6-8) provide relatively little information about biomass levels and that the data for the longline fisheries with the most fishing effort (Fisheries 2 and 3) provide the most information about biomass levels. The other fisheries provide an intermediate level of information about biomass levels (the standard deviations on the effort deviations are given in Table 1).

It is important to note that the assessment model can, in fact, make predictions that do not adhere strictly to constraints above. The constraints are designed so that they can be violated if the observed data provide good evidence against them.

There are large amounts of length-frequency data available for many of the fisheries. Much of the length-frequency data are not independent estimates of the length-frequency of the catch for each fishery. This is because bigeye tuna are often found in schools that are comprised of bigeye of similar size. For example, a sample from a purse seine set may only be equivalent to a single fish sampled because all the bigeye come from a single school. In addition, there are other processes, such as annual variation in growth, that are not modeled which cause differences in length-frequencies. To reduce the amount of weight that the length-frequency data has on the model fit we rescale the sample sizes so that the mean sample size for the non-longline fisheries is 20 and then truncate the sample sizes to have a maximum of 10. To be consistent we independently apply the same method to the longline length-frequency data.

The following parameters have been estimated in the current stock assessment of bigeye tuna from the WCPO:

1. recruitment in every quarter from the first quarter of 1962 through the first quarter of 2002 (This includes estimation of average recruitment, recruitment anomalies, and an environmental effect.);
2. catchability coefficients for the 15 fisheries that take bigeye from the WCPO;
3. selectivity curves for the 15 fisheries;
4. initial population size and age-structure.

The parameters in the following list are assumed to be known for the current stock assessment of bigeye tuna in the EPO:

1. natural mortality at age (Figure 2);
2. sex ratio at age (Sun et al. 1999);
3. age-specific fecundity schedule (Sun et al. 1999);
4. average lengths at age (Sun et al. 2001; Figure 1);
5. amount of variation in length at age (Figure 1);

It is important to recognize that there is uncertainty in the results of the stock assessment. This uncertainty arises because, as previously mentioned, the data collected from fisheries do not perfectly represent the population of bigeye tuna in the WCPO. Also, the stock assessment model may not perfectly represent the dynamics of the bigeye population nor of the fisheries that operate in the WCPO. Uncertainty is expressed as 95% confidence intervals around estimates of recruitment and a value

termed the spawning biomass ratio. The confidence intervals have been estimated under the assumption that the stock assessment model perfectly represents the dynamics of the system. Since, this assumption is not likely to be true, these values may underestimate the amount of uncertainty in the results of the current stock assessment.

3. Results

3.1. Fishing mortality

There have been important changes in the amount of fishing mortality on bigeye tuna in the WCPO. On average, the fishing mortality on bigeye tuna has increased since 1980 (Figure 3). The increase in average fishing mortality can be attributed to the expansion of purse seine fisheries (Fisheries 6-11) and Philippines and Indonesia fisheries (Fisheries 12-14). The floating object fisheries (Fisheries 6, 7, 9, and 10), and the Indonesian fishery (Fishery 14) catch substantial amount of small bigeye, selecting fish that are around 4-8 and 2-3 quarters old, respectively (Figure 4). The school and Philippines fisheries (Fisheries 8, 11-13) select fish that are about 12 to 28 quarters old (Figure 4). The selectivity for the longline fisheries (Fisheries 1-5 and 15) was assumed to be monotonically increasing and therefore is most selective for the oldest bigeye. Temporal trends in age-specific amount of fishery mortality on bigeye tuna are illustrated in Figure 5. The increase in fishing mortality rate on small fish due to the increase in effort from the floating object fisheries and the Indonesian fishery is clearly seen for ages 2-5 quarters. Temporal trends in catchability are shown in Figure 6. The most remarkable trends are seen in fisheries 3 and 15. Fishery 3, a longline fishery, is a main component of the catch and its downward trend in catchability may indicate that the population trend in region three may show a higher decline than the overall population. Fishery 15, the Australian longline fishery, is only a small component of the catch.

3.2. Recruitment

The estimated time series of bigeye recruitment is shown in Figure 7. The recruitment estimates show an increase trend in recruitment since 1980 with particularly large recruitments since 1995. The cause might be related to environmental variation or other factors, such as increasing catchability in the surface fisheries, and need to be further investigated.

3.3. Average weights of fish in the catch

Trends in average weights of bigeye captured by the fisheries that operate in the

WCPO are shown in Figure 8. In general, there is downward trend of the average weight of bigeye taken by longline fisheries (Fisheries 1-5 and 15) since the early 1970s except for the most recent few years that have shown an increase in the average weight. Similar trends have been seen in the other fisheries.

3.4. Spawning biomass ratios (SBRs):

A time series of spawning biomass ratio (SBR, the spawning biomass as a ratio of the spawning biomass in an unexploited population) estimates for bigeye tuna in the WCPO is shown in Figure 9. At start of 1962, the SBR was about 0.44 (Figure 9, bold line) slightly lower than the spawning biomass required to produce MSY ($S_{MSY}/S_0 = 0.45$, dashed horizontal line), then the SBR increased to around 0.6 in the 1970s. The SBR declined during the 1980s and fluctuated around S_{MSY} during the early 1990s. The SBR increased in the late 1990s, but fluctuated widely. The estimate of SBR at the start of 2002 is lower than S_{MSY}/S_0 .

Estimates of the average SBR projected to occur during from 2002 to the start of 2007 are also presented in Figure 9. The projection results indicate that, under average effort over the last two years and average recruitment, SBR is likely to be below S_{MSY}/S_0 in five years (see Section 3.7 for more details).

3.5. Yield per recruit

Watters and Maunder (2001) defined the critical age as the age when the gains due to growth exactly balance the losses due to natural mortality. The critical age can be converted to a “critical weight” by using a growth curve and a weight-length relationship. The critical age and critical weight for bigeye tuna in the WCPO are estimated to be about 14 quarters and 32.5 kg, respectively (Figure 10). Watters and Maunder (2001) also mentioned that if the average weight in catch is close to the critical weight the fishery is probably close to achieving the objective of maximizing the yield per recruit. In figure 10 (bottom panel), the average weight was above the critical weight during the period of 1962-1980. The large drop in average weight in 1970 corresponds to the initiation of the Indonesian fishery. The estimate of average weight of combined catch is increasingly lower than that of critical weight after 1980 (the period during which the surface fisheries start to expand) and suggests a sub optimal performance from a yield –per recruit perspective. The average weight of bigeye taken by the longline fisheries has generally been greater than the critical weight (32.5 kg) for the whole time period. The average weight of bigeye taken by the other fisheries have been lower than the critical weight.

3.6. Maximum Sustainable Yield (MSY)

Maximum Sustainable Yield (MSY) is estimated to be equal to 57,400 mt per year. The current catch is much larger (95% more) than MSY and the effort levels need to be decreased by 39% to obtain MSY. The current spawning biomass is 73% of the spawning biomass required to produce MSY. This is because the spawning biomass required to produce MSY is large relative to the unfished spawning biomass (45%).

If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity (Figure 4) are maintained, the level of fishing effort that is estimated to produce MSY is about 61% of the current level of effort. Decreasing the effort to 61% of its present level would increase the long-term average yield by 8%, but such an action would increase spawning potential of stock by about 61% (Figure 11).

It is interesting to note that the equilibrium catch under current longline effort, assuming no other fishing, is 84,000 mt. This can be increased to 93,500 mt ($S/S_0 = 0.38$) if the longline effort is increased by 3.3 times. Increasing longline effort by this amount may not be realistic. However, due to the flat yield curve, a smaller increase in longline effort would achieve a yield similar to a longline only MSY.

3.7. Projections

The effort used in the projections for 2002-2006 is the average effort by fishery over the period 2000 and 2001. i.e. the effort assumed the same. The predicted catches taken by the longline fleet is shown in Figure 12. These projections suggest that catches will decrease to levels similar to those in the late 1980s early 1990s. The predicted catches taken by the purse seine fisheries are shown in Figure 13. The catch is predicted to initially increase and then decrease. The projection of SBRs for 2002 to the start of 2007 are shown in Figure 14. As mentioned before (in Section 3.4), the projection results indicate that SBR is likely to increase then decrease to a level similar to the start of 2002.

4. Discussion

This is an alternative assessment of the WCPO bigeye tuna stock using the A-SCALA method (Maunder and Watters submitted). The results from this analysis should be compared to the results from the WCPO (Hampton 2002) and Pacific wide assessment (Hampton et al. 2001) using the MULTIFAN-CL approach (Fournier et al. 1998). The main differences between A-SCALA and MULTIFAN-CL are 1) A-SCALA

does not include spatial structure in the population dynamics and 2) A-SCALA does not include tagging data. Comparison analyses show that when MULTIFAN-CL is configured to have the same assumptions as A-SCALA, the two methods produced similar results (John Hampton pers. com.). Therefore any differences in the results can probably be attributed to the spatial structure or the tagging data. However, we do use smaller length-frequency sample size, and different growth and natural mortality parameters.

One of the important results of this analysis is that the increasing catches from the Indonesian fishery (Figure 15) have a substantial influence on the yields of the other fisheries. This is because the catch is comprised of very small bigeye and therefore, from a yield-per-recruit perspective, much of the potential yield from individual growth is lost. In addition, these bigeye tuna are captured before they mature, which decreases the spawning biomass. Unfortunately, the catch and age-specific selectivity from the Indonesian fishery and the rate of natural mortality for small bigeye are highly uncertain. In addition, there are only three years of catch-at-length data for this fishery which is a mixture of gears. Therefore, the impact of the Indonesian fishery is potentially high, but very uncertain. More data is needed for the Indonesian fishery and this should be a priority for management of bigeye tuna in the WCPO.

The high S_{MSY}/S_0 is due to having a high fishing mortality on young bigeye and a high fishing mortality on old bigeye, but a low fishing mortality on intermediate bigeye. Therefore, the fishing mortality has to be low to allow the bigeye to grow and to be caught at an older age to maximize the yield per recruit. If there was only a high fishing mortality for young fish then the S_{MSY}/S_0 would be low due to the absence of a stock recruitment relationship (i.e. spawning biomass is not important) and because bigeye that are allowed to escape the fishery on young fish would not be caught at high enough levels at older ages to produce high yields. Alternatively, if there are high fishing mortality rates only for older bigeye, the fishing mortality rates at MSY would be high on these individuals because they are older than the critical age (i.e. more biomass is lost from natural mortality than gained from growth so they should be caught). In this case, S_{MSY}/S_0 would also probably be less than the current estimated level. The current levels of MSY and S_{MSY}/S_0 are highly dependent on the Indonesian fishery. This indicates that MSY and S_{MSY}/S_0 are not useful management tools unless the distribution of effort among fishing methods is taken into consideration (Maunder in press). The MULTIFAN-CL assessment (Hampton 2002) does not have this large sensitivity to the Indonesian fishery. The insensitivity is because of 1) the spatial structure in MULTIFAN-CL, 2) the independent estimates of recruitment for each region, and 3) that the fishing mortality for yield calculations is made over a larger number years and

ignores the most recent year in the average. This indicates that interactions between the fisheries, particularly with the Indonesian fishery, may be dependent on movement of bigeye among the regions. Unfortunately, there is little information on the movement of bigeye tuna.

Recruitment has been predicted to increase over time. This increasing recruitment corresponds to increased catch from the surface fisheries. Similar correlations have occurred in the EPO bigeye and yellowfin tuna stock assessments (Watter and Maunder 2002; Maunder and Watters 2002b). The A-SCALA and MULTIFAN-CL stock assessment methods trade-off trends in catchability with trends in recruitment. Therefore, it is difficult to know if the trend in recruitment is not a consequence of a trend in catchability in the surface fisheries.

The analysis does not include a stock recruitment relationship. Maunder and Watters (2002b) showed that including a stock recruitment relationship for yellowfin tuna in the EPO increased the reference point S_{msy}/S_0 and reduced the effort level required to achieve MSY. Therefore, because the estimate of current biomass is usually independent of the stock-recruitment relationship when there are lots of length-frequency data, including a stock recruitment relationship will change the relative position of the current biomass in relationship to this reference point.

5. Acknowledgements

We thank John Hampton of the Secretariat of the Pacific Community for supplying the catch, effort and length-frequency data, and for comments on the manuscript.

6. References

- Bigelow, K.A., Hampton, J., and Miyabe, N. 2002. Application of a habitat-based model to estimate effective longline fishing effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). *Fisheries Oceanography* 11(3): 143-155.
- Fournier, D.A., Hampton, J., and Sibert J.R. 1998. MULTIFAN-CL: A length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. *Can. J. Fish. Aquat. Sci.* 55: 2105-2116.
- Hampton, J. 2000. Natural mortality rates in tropical tunas: size really does matter. *Can. J. Fish. Aquat. Sci.* 57: 1002-1010.
- Hampton, J. 2002. Stock assessment of bigeye tuna in the western and central Pacific

- Ocean. SCTB15 Working Paper BET-1.
- Hampton, J., Bigelow, K., and Labelle, M. 1998. A summary of current information on the biology, fisheries, and stock assessment of bigeye tuna (*Thunnus obesus*) in the Pacific Ocean, with recommendations for data requirements and future research. Secretariat of the Pacific Community. Oceanic Fisheries Programme Technical Report 36, 46 pp.
- Hampton, J. and Fournier, D.A. 2001. A preliminary stock assessment model for bigeye tuna in the Pacific Ocean. SCTB14 Working Paper BET-1.
- Maunder, M.N. (in press). The relationship between fishing methods, fisheries management, and the estimation of maximum sustainable yield. *Fish and Fisheries*.
- Maunder, M.N. and Watters, G.M. 2001. Status of yellowfin tuna in the eastern Pacific Ocean. *Inter-Amer. Trop. Tuna Comm., Stock Assessment Report*, 1: 5-86.
- Maunder, M.N. and Watters, G.M. (submitted). A-SCALA: An Age-Structured Statistical Catch-at-Length Analysis for Assessing Tuna Stocks in the Eastern Pacific Ocean. *IATTC Bulletin*.
- Maunder, M.N. and Watters, G.M. 2002a. Status of skipjack tuna in the eastern Pacific Ocean. *Inter-Amer. Trop. Tuna Comm., Stock Assessment Report*, 2: 91-146.
- Maunder, M.N. and Watters, G.M. 2002b. Status of yellowfin tuna in the eastern Pacific Ocean. *Inter-Amer. Trop. Tuna Comm., Stock Assessment Report*, 2: 5-90.
- Sun, C.L., Chu S.L., and Yeh S.Z. 1999. Note on reproduction biology of bigeye tuna in the western Pacific. SCTB12/WP/BET-4. 6pp.
- Sun, C.L., Huang C.L., and Yeh, S.Z. 2001. Age and growth of the bigeye tuna *Thunnus obesus* in the western Pacific Ocean. *Fish. Bull.* 99: 502-509.
- Sun C.L., Maunder, M.N., Hampton, J., Watters, J., and Yeh, S.Z. 2001. Application of the A-SCALA method to bigeye tuna in the western and central Pacific Ocean. SCTB14, BET-4.
- Watters, G.M. and Maunder, M.N. 2001. Status of bigeye tuna in the eastern Pacific Ocean. *Inter-Amer. Trop. Tuna Comm., Stock Assessment Report*, 1: 109-211.

Table 1. Regions and fisheries of the ASCALA model for the bigeye tuna in the western and central Pacific Ocean, 1962-2001 (based on Hampton 2002).

DEFINITION OF REGIONS

Region 1 20N-40N, 120E-150W

Region 2 20N-10S, 110E-160E

Region 3 20N-10S, 160E-150W

Region 4 10S-40S, 140E-160E

Region 5 10S-40S, 160E-150W

DEFINITION OF FISHERIES

Fishery	Description	Region	Effort standard deviation	Catch data	Effort data	Length-frequency data
1	Longline	1	0.5	1962-2000	1962-2000 ³	1965-2000
2	Longline	2	0.2	1962-2000	1962-2000 ³	1965-2000
3	Longline	3	0.2	1962-2000	1962-2000 ³	1965-2000
4	Longline	4	0.5	1962-2000	1962-2000 ³	1965-2000
5	Longline	5	0.5	1962-2000	1962-2000 ³	1965-2000
6	Purse seine Log sets	2	0.5	1980-2001	1980-2001	1988-2001
7	Purse seine FAD sets	2	0.5	1985-2001	1985-2001	1988, 1993-2000
8	Purse seine school sets	2	0.5	1980-2001	1980-2001	1988-2000
9	Purse seine Log sets	3	0.5	1981-2001	1981-2001	1988-2001
10	Purse seine FAD sets	3	0.5	1987-2001	1987-2001	1989-1991, 1993-2001
11	Purse seine school sets	3	0.5	1982-2001	1982-2001	1989-2001
12	Phillipines other gears	2	2	1970-2000 ¹	None ⁴	1980-1987, 1993-1994
13	Phillipines handline	2	2	1970-1997 ¹	None ⁵	1980-1987, 1993-1994
14	Indonesia	2	2	1970-1999 ¹	None ⁶	1990-1992
15	Australian longline	4	0.5	1986-2001 ²	1986-2001 ²	None ⁷

¹annual data only

²only quarters 1 and 2 of 2001, effort data for quarters 3 and 4 equal to 2000

³effort data for 2001 equal to that for 2000

⁴effort data based on? And for 2001 equal to 2000

⁵effort data based on? And for 1998-2001 equal to 1997

⁶effort data based on? And for 2000-2001 equal to 1999

⁷selectivity for this gear set equal to that for fishery 4

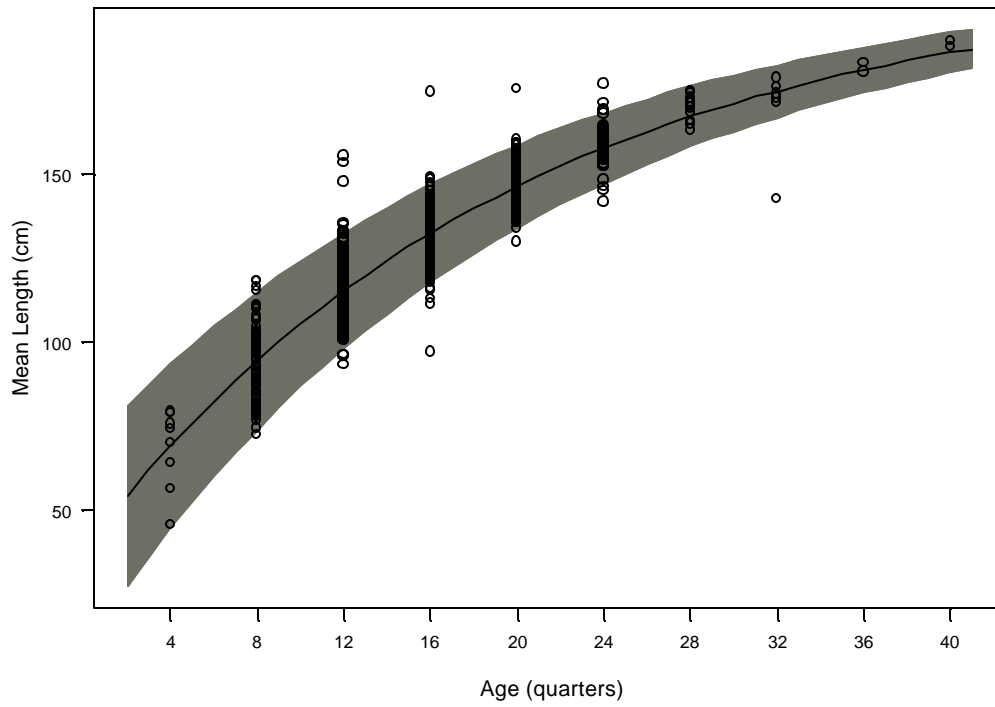


Figure 1. Mean length-at-age from Sun et al. (2001) used in the assessment. The shaded area represents the variance of length-at-age (± 2 sd). The circles represent the dorsal spine data from Sun et al. (2001).

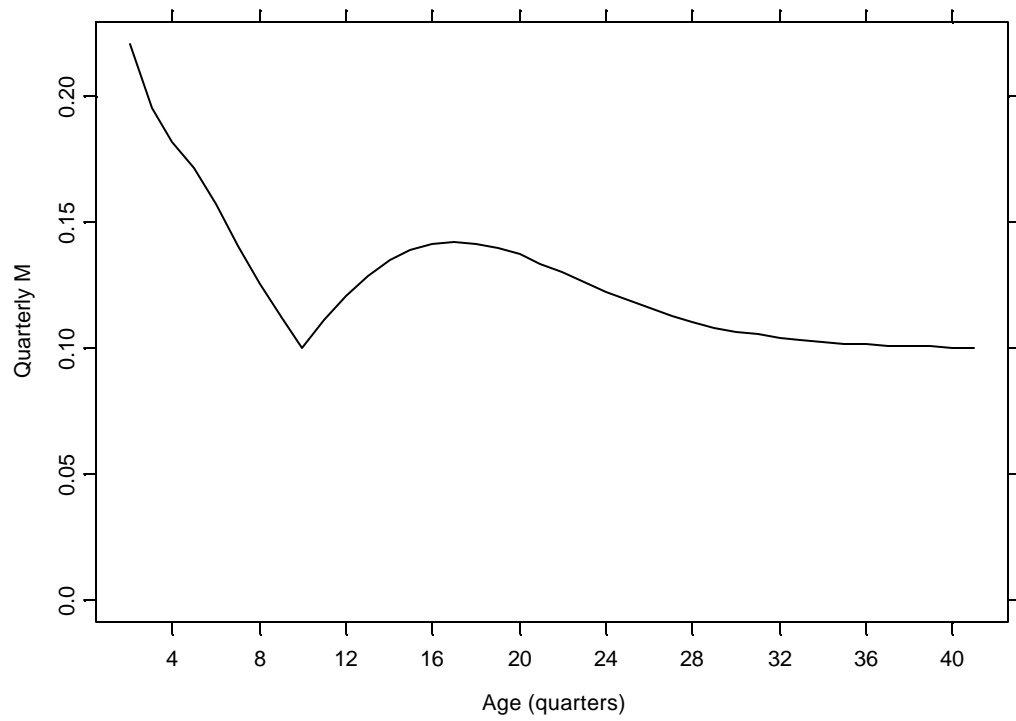


Figure 2. Quarterly age -specific natural mortality used in the assessment (from Watters and Maunder 2001).

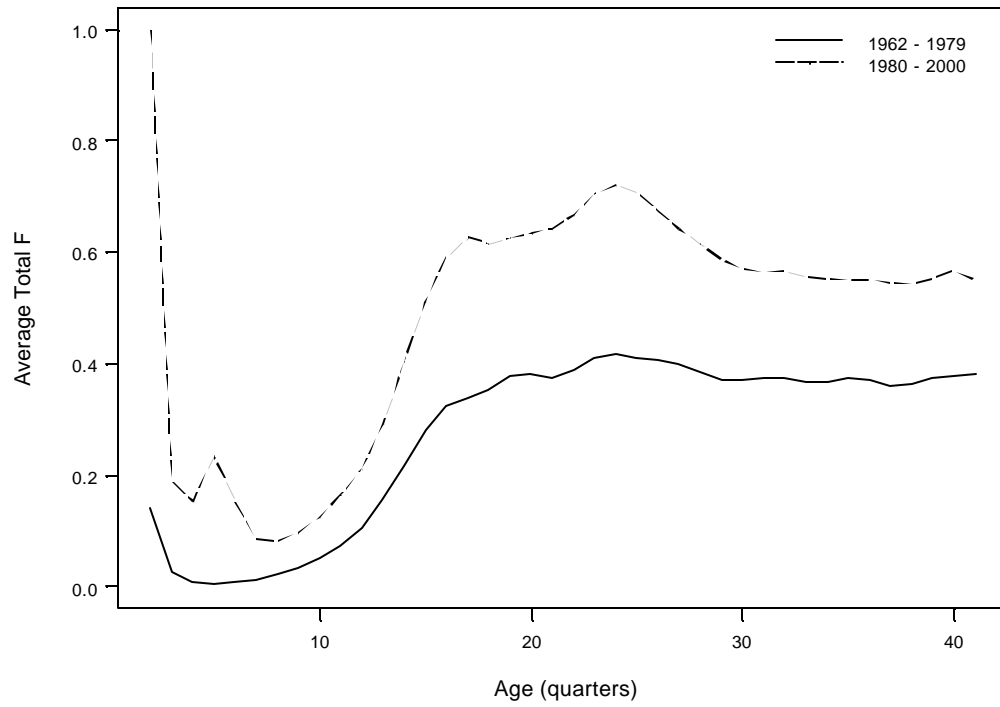


Figure 3. Average annual fishing mortality at age over two time periods. The earlier time period represents the time period before the floating object fisheries had been developed.

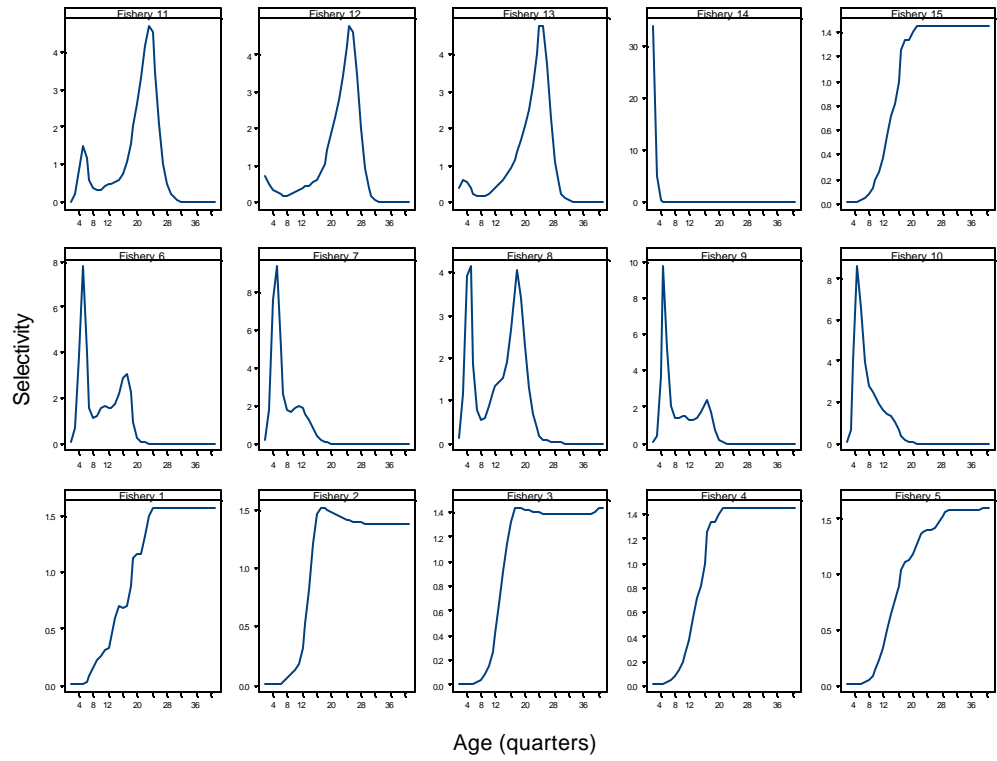


Figure 4. Estimated age-specific selectivity patterns for the 8 fisheries.

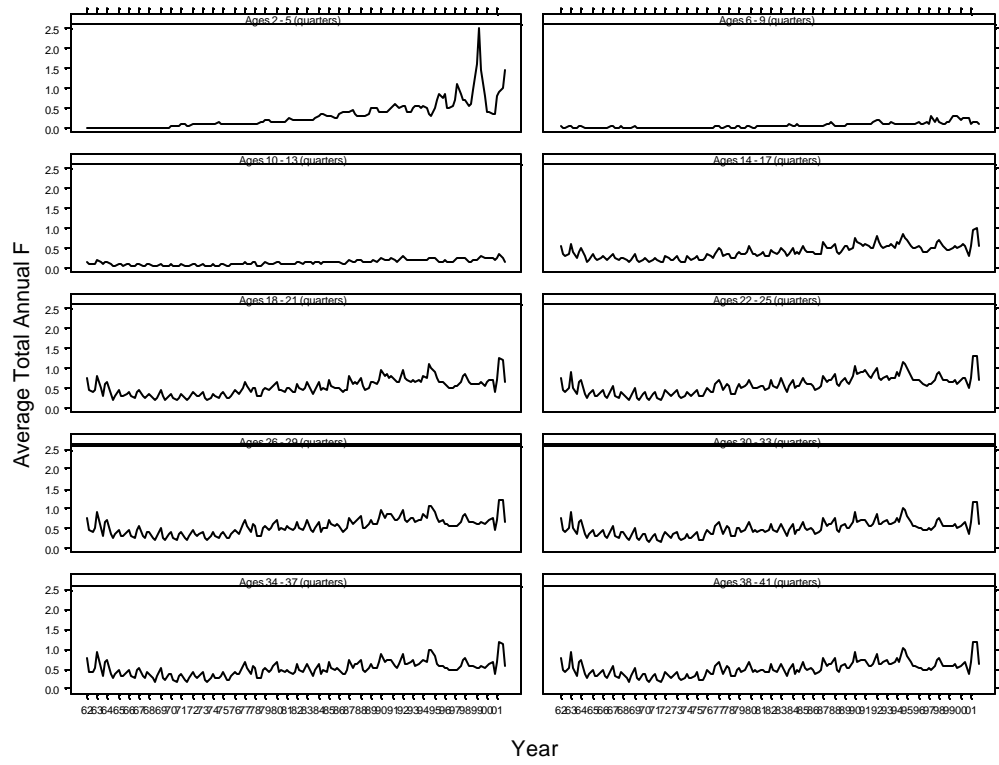


Figure 5. Time specific estimates for annual fishing mortality presented as the average for different age groups.

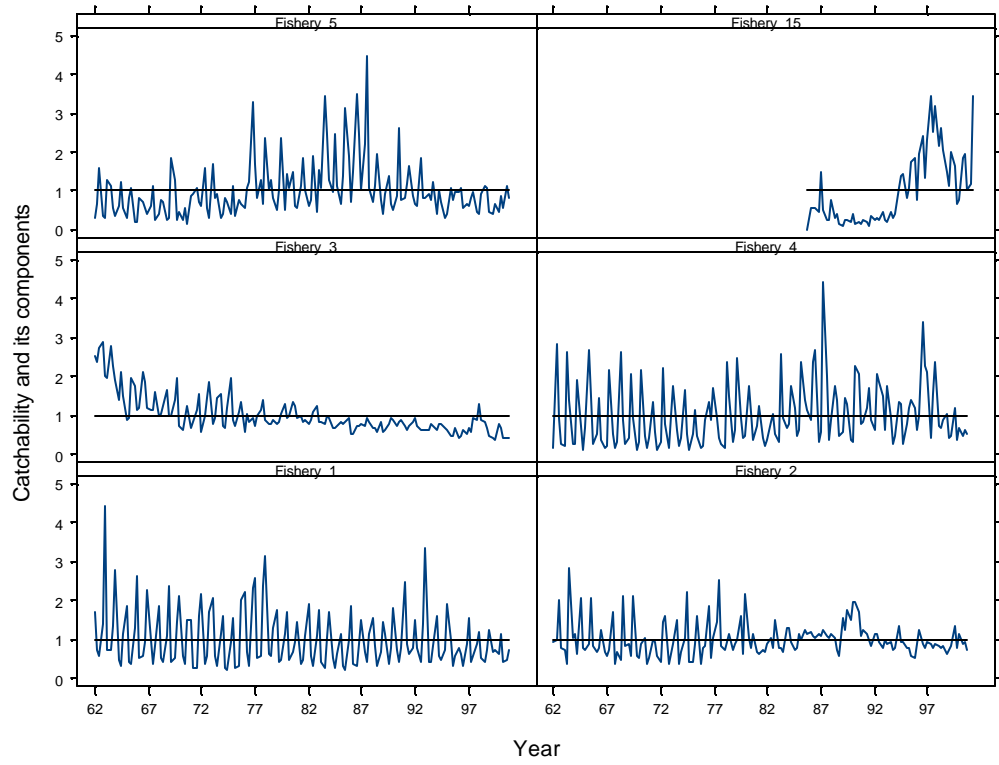


Figure 6a. Time specific estimates of catchability for the longline fisheries.

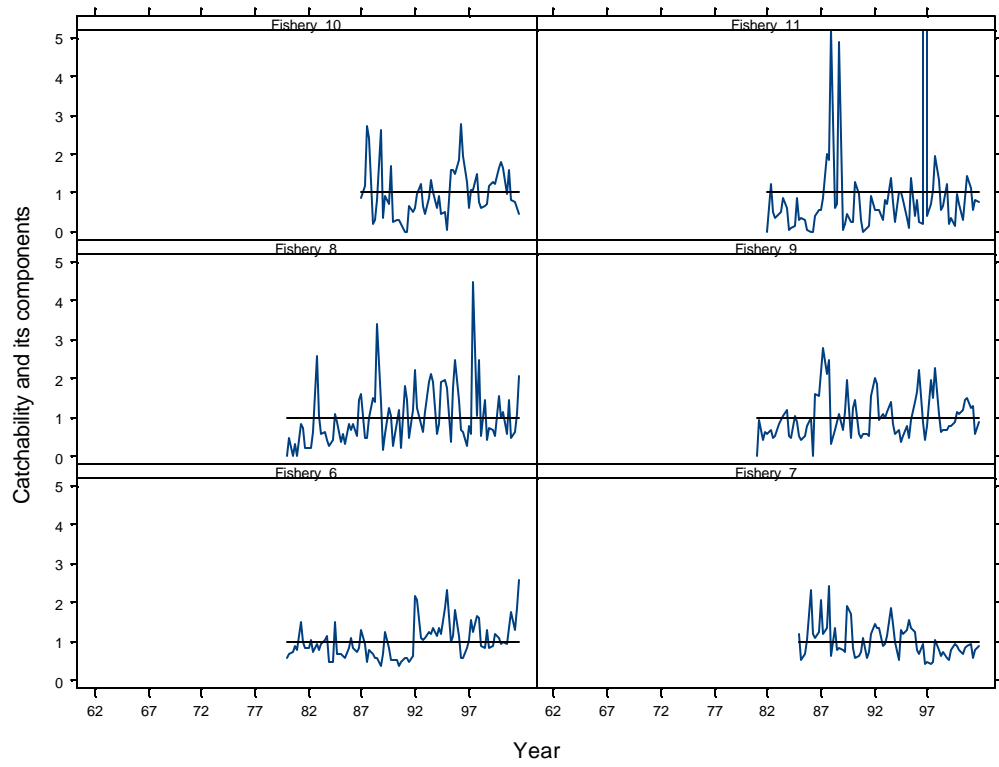


Figure 6b. Time specific estimates of catchability for the surface fisheries.

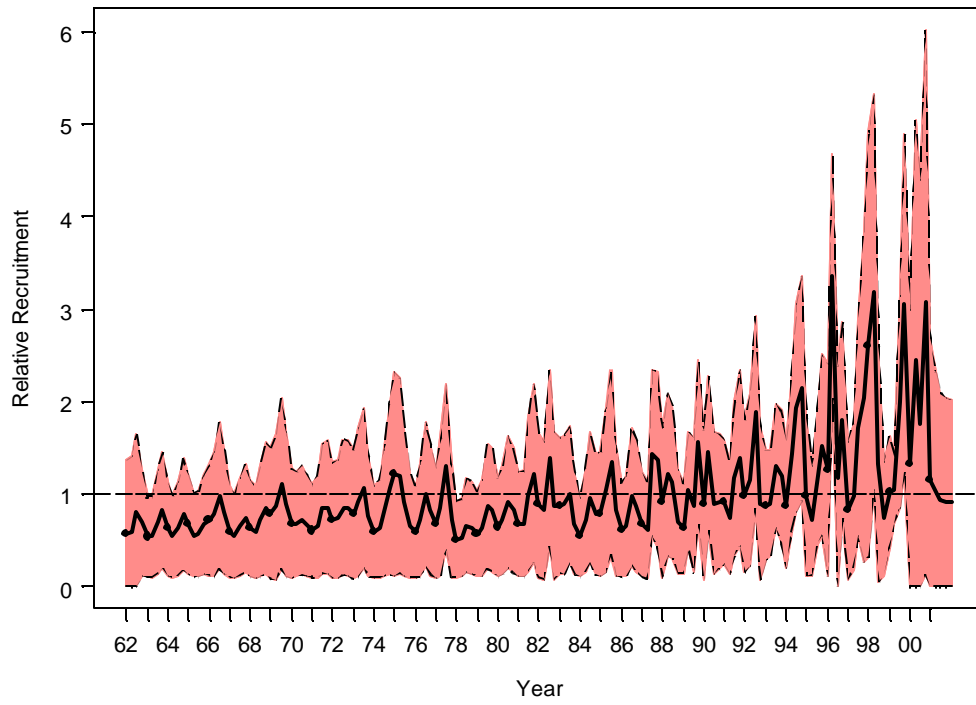


Figure 7. Quarterly estimates of recruitment scaled so the average is equal to 1.0. The shaded area represent approximate 95% confidence intervals.

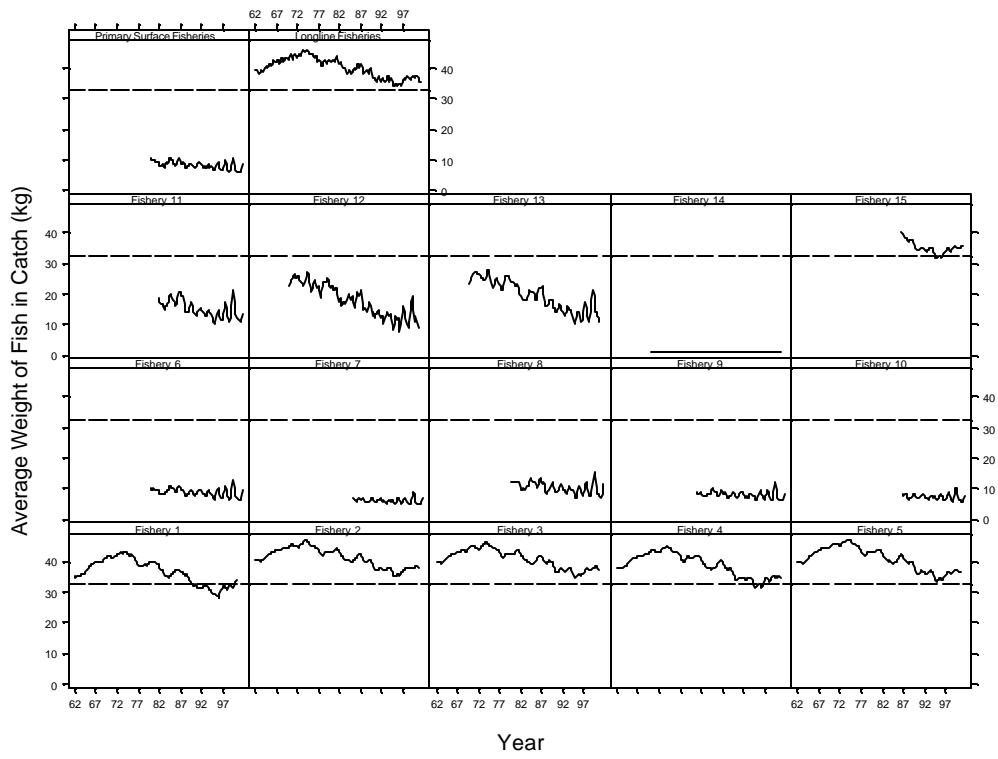


Figure 8. Estimated average weight for the 8 fisheries. The horizontal dashed line represents the critical weight.

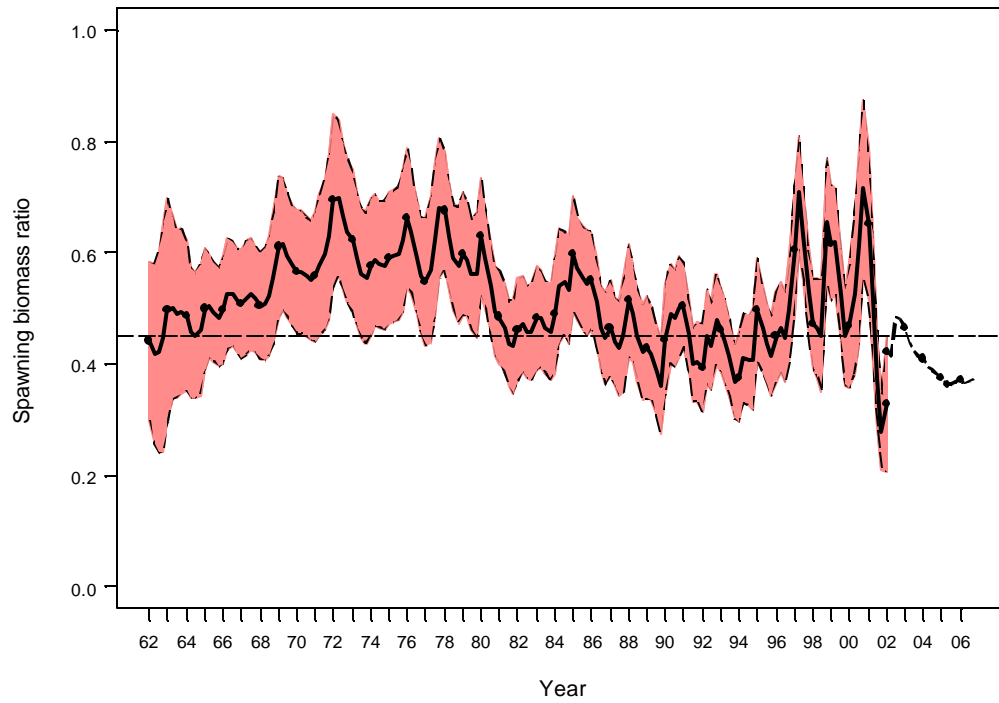


Figure 9. Estimated time series of spawning biomass ratios. The horizontal dashed line represents the spawning biomass ratio that would produce maximum sustainable yield under the current effort distribution. The shaded area represent approximate 95% confidence intervals.

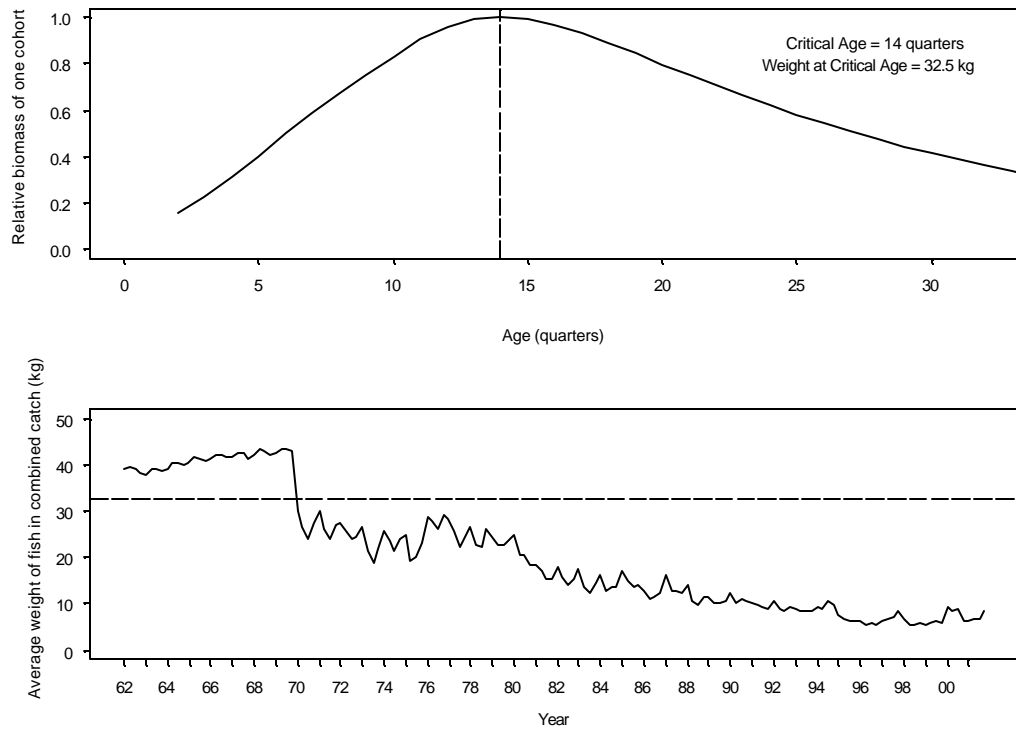


Figure 10. Representations of the critical age and critical weight (top panel) and the average weight of fish in the catch (bottom panel). The critical weight is drawn as a vertical dashed line in the top panel and as a horizontal dashed line in the bottom panel.

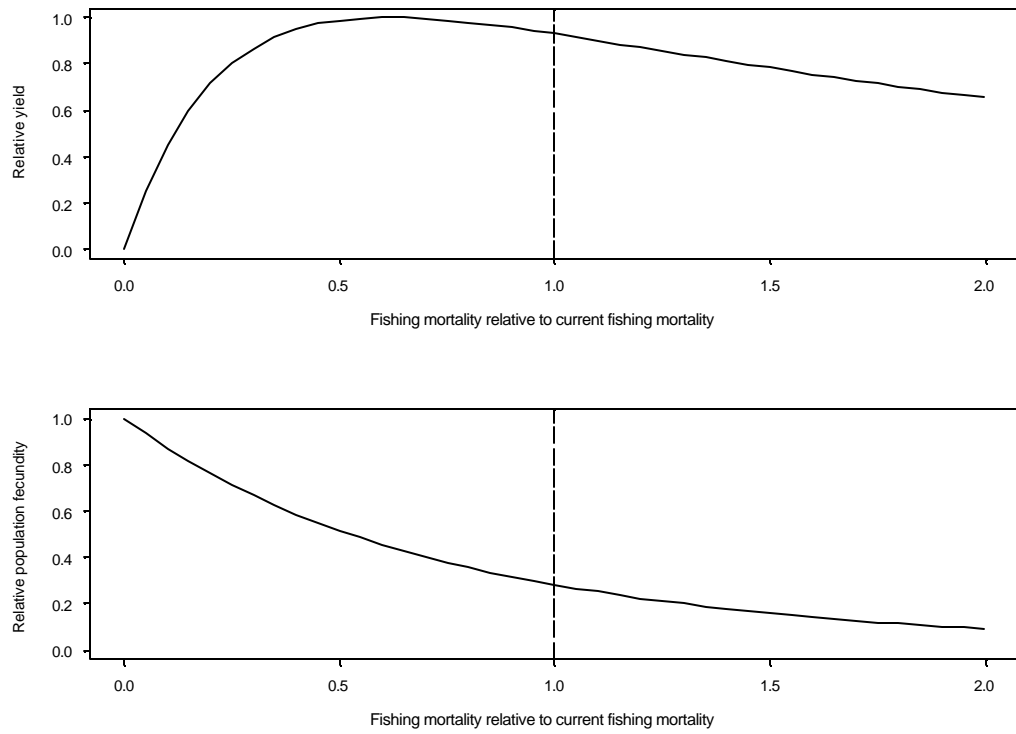


Figure 11. Relative yield for different levels of fishing mortality as a proportion of the current fishing mortality (top panel). Relative population fecundity for different levels of fishing mortality as a proportion of the current fishing mortality (bottom panel).

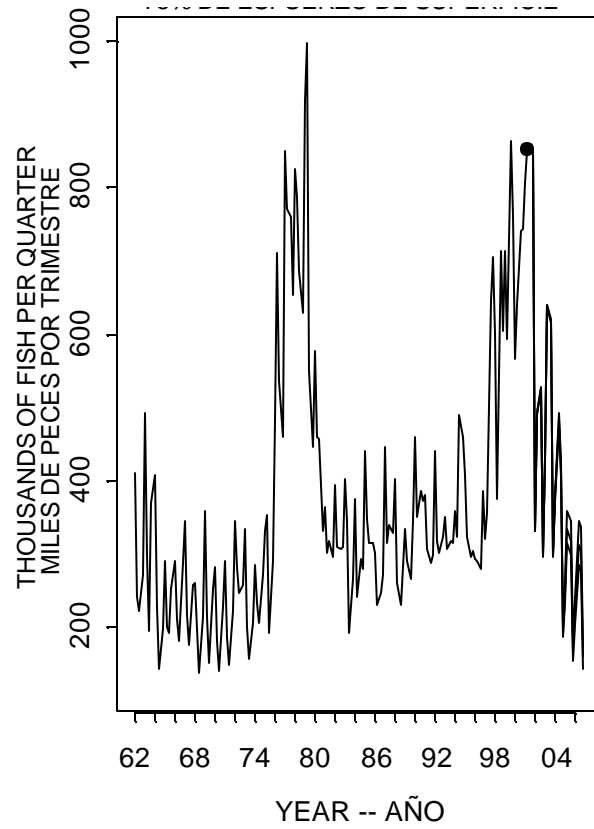


Figure 12. Projected longline catch.

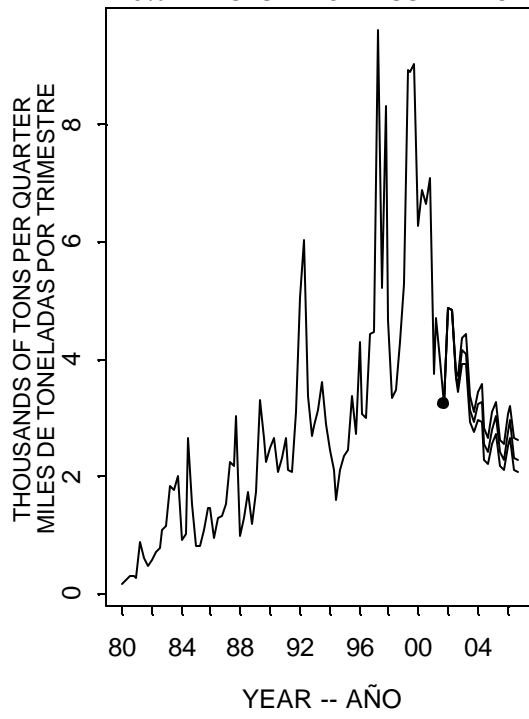


Figure 13. Projected catch from the purse seine fisheries.

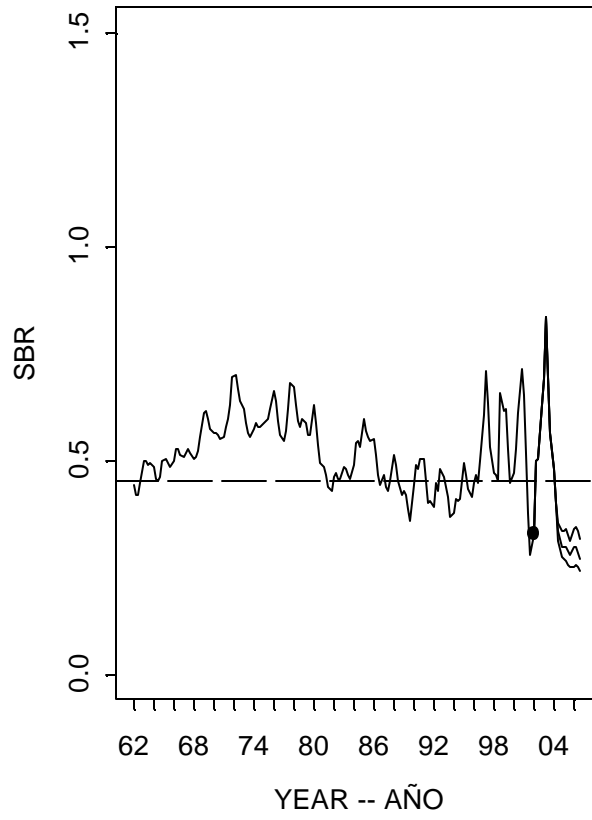


Figure 14. Projected spawning biomass ratio.

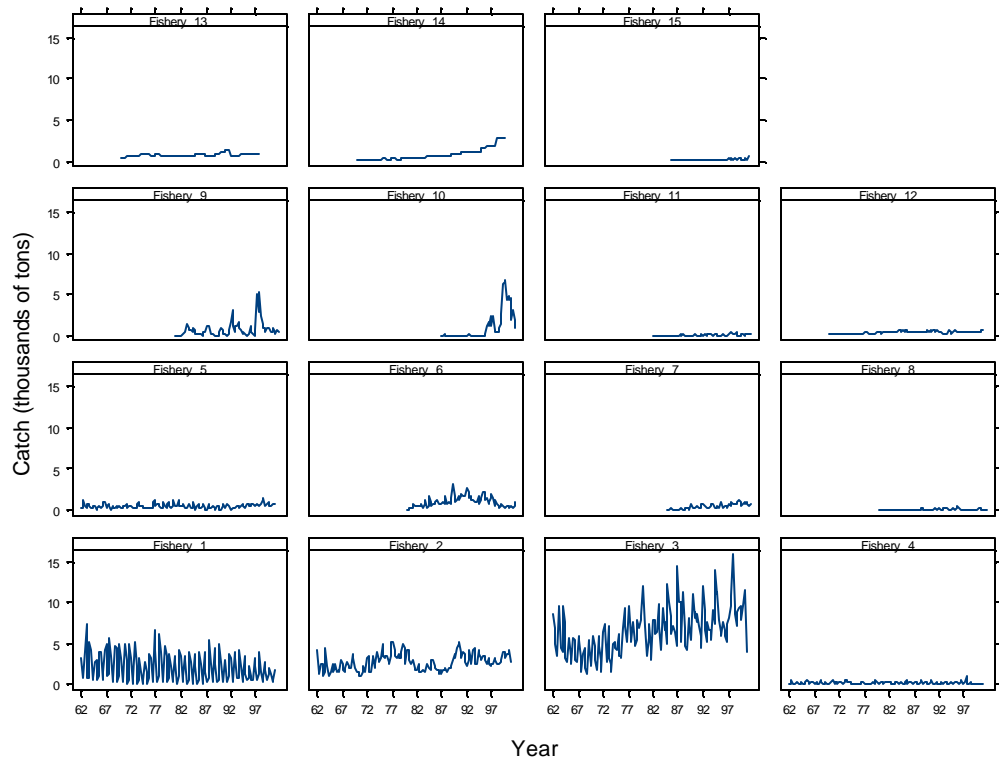


Figure 15. Quarterly catch for the 15 fisheries.