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# UPDATE ON THE PROPORTION OF BIGEYE IN ‘YELLOWFIN PLUS BIGEYE’ CAUGHT BY PURSE SEINERS IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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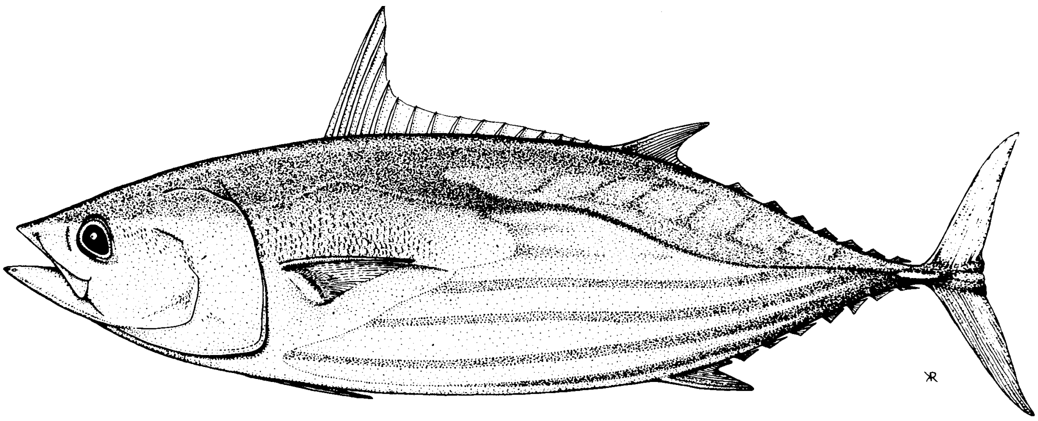

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## INTRODUCTION

Catches of bigeye tuna (*Thunnus obesus*) taken by purse seiners fishing in the Western and Central Pacific Ocean (WCPO) are usually recorded on catch and effort logsheets as yellowfin (*Thunnus albacares*), since juvenile bigeye and yellowfin are difficult to distinguish. Furthermore, the prices paid by canneries for bigeye and yellowfin are usually the same; hence, there is no incentive to record the catches and landings of the two species separately.

Species composition samples that are collected by port samplers and observers can be used to correct the bias introduced by the mis-identification of bigeye as yellowfin. Lawson (2003) used observer data held by the SPC Oceanic Fisheries Programme (OFP) to analyse the proportion of bigeye in the combined catch of yellowfin and bigeye ('yellowfin plus bigeye'). The relationship between the proportion of bigeye in 'yellowfin plus bigeye' and several variables, including calendar year, quarter, geographic area, fishing entity (or 'flag') and school association. Various analysis of variance (anova) models were examined and, as expected, school association was found to be the most strongly related variable.

The analysis presented in Lawson (2003) was conducted using observer data for 1998–2001. Since then, more observer data have become available, both through continued sampling during 2002–2003 and the evaluation of the quality of observer data collected during 1995–1997. Hence, the analysis is updated below using observer data for 1995–2003.

## SOURCE OF DATA

At the time of writing, the OFP held species composition data for 8,626 purse-seine sets sampled from 1993 to 2003 in the WCPO by observers from SPC and the national observer programmes of SPC member countries and territories. For the purposes of the present analysis, the data were screened in the following order:

- All samples were taken within the MULTIFAN-CL Bigeye Areas 2 and 3 (Figure 1), except for 6 samples from Area 4 and 73 samples from Area 5. Since there was insufficient data to examine the proportion of bigeye in yellowfin plus bigeye in Areas 4 and 5, and also because the MULTIFAN-CL analysis restricted purse seine to Areas 2 and 3, the present study was therefore restricted to Areas 2 and 3. As a result, the 79 samples that were not from Areas 2 and 3 were not used.
- There were 2,039 samples for which the school association was unknown. Since including a school association category of 'unknown' in the analysis would almost certainly decrease the information content of the data, in regard to school association, these samples were not used.
- There were 471 samples from 'skunk sets', which were defined as those for which the catch was less than or equal to 2.5 tonnes. Since these samples may not have been representative of the entire school, they were not used.
- There were 1,568 sets for which no yellowfin or bigeye were sampled; therefore, these samples were not used.
- There were 806 sets for which the total number of bigeye and yellowfin sampled was less than 10; these small samples were not used since several resulted in estimates of the proportion of bigeye in yellowfin plus bigeye that were considered to be outliers.
- There were 985 samples that were not used because the species composition samples were evaluated to be of poor quality.

After screening the data, there were 2,678 samples remaining for 1995–2003, which represents 1,170 more samples than the 1,508 samples for 1998–2001 that were used in the analysis presented in Lawson (2003).

## ANALYSIS OF VARIANCE AMONG STRATA

The data were grouped into replicates for each strata of year – quarter – area – flag – school association, wherein each replicate represented the average proportion of bigeye in 'yellowfin plus bigeye' determined from samples within the stratum. In order to avoid outliers, only replicates that were based on at least five samples were included in the analysis. Schools associated with drifting FADs and logs were combined into an 'associated' category.

An analysis of variance was conducted with all first-order effects, after applying an arcsine–square root transformation to improve normality and homoscedasticity (Snedecor & Cochran 1989). However, interpretation of the results is complicated by the fact that the variables are unbalanced; that is, the number of replicates for a particular variable is not the same for each category of the other variables. When variables are unbalanced, the table of results of an analysis of variance should be interpreted as the effects of adding a variable to a model containing the variables above it. Therefore, the order in which the variables are listed in the table can affect the F values and the corresponding probablity levels. In order to minimise this problem, the residual sum of squares was determined after dropping each term from the model; the analysis of variance was then conducted with the results listed for variables in the order of their effect on the residual sum of squares.

The table below shows the effect of dropping each term from the analysis of variance with all first-order effects.

| | Df | Sum of Sq | RSS |
|---|---|---|---|
| sch | 1 | 2.60 | 5.09 |
| flag | 4 | 0.29 | 2.79 |
| yy | 8 | 0.30 | 2.80 |
| area | 1 | 0.03 | 2.53 |
| qq | 3 | 0.05 | 2.54 |

School association has the most important effect on the residual sum of squares, followed by flag, area, year and quarter, in that order. The results from the analysis of variance, with variables listed in order of their effect on the residual sum of squares, is given below. If variables with $p<0.001$ are considered strongly related to the proportion of bigeye in yellowfin plus bigeye and if variables with $0.001<p<0.01$ are considered weakly related, then school association is strongly-related and no other variables are statistically related.

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| sch | 1 | 2.63476 | 2.63476 | 106.5215 | < 2e-16 |
| flag | 4 | 0.29230 | 0.07307 | 2.9543 | 0.02354 |
| yy | 8 | 0.28579 | 0.03572 | 1.4443 | 0.18745 |
| area | 1 | 0.04654 | 0.04654 | 1.8817 | 0.17318 |
| qq | 3 | 0.04672 | 0.01557 | 0.6296 | 0.59755 |
| Residuals | 101 | 2.49818 | 0.02473 | | |

A further analysis of variance was conducted including two variables, school association and year, in order to capture the year effect in the adjustments of catch estimates.

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| sch | 1 | 2.63476 | 2.63476 | 99.8491 | <2e-16 |
| yy | 8 | 0.29330 | 0.03666 | 1.3894 | 0.2091 |
| Residuals | 109 | 2.87622 | 0.02639 | | |

The proportions of bigeye in 'yellowfin plus bigeye' predicted from this two-variable model, and their standards errors, are given in Table 1.

**Table 1. Proportions of bigeye in 'yellowfin plus bigeye' for 1995–2003 predicted from school association and year using observer data, and standards errors**

| Year | Associated | | Unassociated | |
|---|---|---|---|---|
| | P | SE | P | SE |
| 1995 | 0.119 | 0.058 | 0.000 | 0.009 |
| 1996 | 0.230 | 0.045 | 0.025 | 0.022 |
| 1997 | 0.260 | 0.045 | 0.038 | 0.024 |
| 1998 | 0.253 | 0.032 | 0.035 | 0.016 |
| 1999 | 0.186 | 0.042 | 0.011 | 0.015 |
| 2000 | 0.159 | 0.028 | 0.005 | 0.008 |
| 2001 | 0.235 | 0.037 | 0.027 | 0.017 |
| 2002 | 0.244 | 0.031 | 0.031 | 0.016 |
| 2003 | 0.218 | 0.101 | 0.021 | 0.048 |
| Average | 0.212 | 0.047 | 0.022 | 0.019 |

## PROPORTION OF BIGEYE IN 'YELLOWFIN PLUS BIGEYE' PRIOR TO 1995

Observer data prior to 1995 are not available to estimate the proportion of bigeye in 'yellowfin plus bigeye'. However, the National Marine Fisheries Service has conducted port sampling of the United States purse-seine fleet landing in Pago Pago, American Samoa since 1988. The proportions of bigeye in 'yellowfin plus bigeye' determined from the port sampling data for 1989–1994 (Coan, pers. comm.) are given in Table 2.

**Table 2. Proportions of bigeye in 'yellowfin plus bigeye' for 1989–1994 determined port sampling data covering the United States fleet**

| Year | Associated | Unassociated |
|---|---|---|
| | P | P |
| 1989 | 0.160 | 0.005 |
| 1990 | 0.116 | 0.003 |
| 1991 | 0.101 | 0.010 |
| 1992 | 0.139 | 0.007 |
| 1993 | 0.129 | 0.009 |
| 1994 | 0.116 | 0.004 |
| Average | 0.127 | 0.006 |

Lawson (2003) noted that the proportions for associated sets based on the observer data for all fleets, for 1998–2001, were considerably different from those based on port sampling data for the United States fleet, for the earlier period, 1988–1995. This difference is evident in Tables 1 and 2 above, which show that the average value of the proportion for associated sets, based on the port sampling data for 1989–1994, is 12.7%, compared to 21.2% based on the observer data for 1995–2003. The proportion determined from the observer data for 1995, 11.9%, is consistent with the 1989–1994 average determined from the port sampling data, which suggests that the difference between the earlier period and later period is not a statistical artifact and that a significant increase in the proportion of bigeye in 'yellowfin plus bigeye' occurred in 1996.

Figures 2 and 3 show the proportions of bigeye in 'yellowfin plus bigeye' for associated schools and unassociated schools respectively. Confidence intervals based on two standard errors are available for the estimates for 1995–2003 determined from the observer data, but not for the estimates for 1989–1994 determined from the port sampling data.

## EXAMINATION OF THE PROPORTION OF BIGEYE IN 'YELLOWFIN PLUS BIGEYE' BY FLEET

The proportions of bigeye in 'yellowfin plus bigeye' determined from various data sets that have been provided to the Oceanic Fisheries Programme were compared to proportions determined by adjusting the data sets on the basis of the analysis presented above for those data sets which the OFP does not adjust on a regular basis. Catch estimates for the period prior to 1989 were adjusted using the average proportions for 1989–1994. The results of the comparisons are presented below.

### *China*

**Table 3. Comparison of the percentages of bigeye in 'yellowfin plus bigeye' for the Chinese purse-seine fleet determined from (a) annual catch estimates for the WCPO provided by China and (b) annual catch estimates adjusted by the OFP using Tables 1 and 2**

| Year | Annual Catch Estimates | Adjusted Annual catch Estimates |
|---|---|---|
| 2001 | 0.0 | n/a |
| 2002 | 0.0 | 11.0 |
| 2003 | 0.0 | 5.2 |

In Table 3, the annual catch estimates for 2001 have not been adjusted due to the lack of operational catch and effort data that are needed to determine the catch by school association. Based on the comparisons for 2002 and 2003, it would appear that the annual catch estimates provided by China have not been corrected for the misidentification of bigeye as yellowfin.

***Japan***

**Table 4. Comparison of the percentages of bigeye in 'yellowfin plus bigeye' for the Japanese purse-seine fleet determined from (a) annual catch estimates for the WCPO provided by Japan; (b) catch and effort data for the WCPO aggregated by 1° latitude, 1° longitude and month, provided by Japan; and (c) annual catch estimates adjusted by the OFP using Tables 1 and 2**

| Year | Annual Catch Estimates | 1x1 Data | Adjusted Annual catch Estimates |
|---|---|---|---|
| 1970 | 0.0 | 0.0 | 5.5 |
| 1971 | 4.3 | 4.3 | 7.0 |
| 1972 | 2.8 | 2.8 | 10.0 |
| 1973 | 2.4 | 2.4 | 8.5 |
| 1974 | 3.4 | 3.4 | 7.4 |
| 1975 | 4.5 | 4.5 | 8.7 |
| 1976 | 4.9 | 4.9 | 9.2 |
| 1977 | 4.2 | 4.2 | 11.0 |
| 1978 | 6.7 | 6.7 | 10.7 |
| 1979 | 3.6 | 2.1 | 8.4 |
| 1980 | 2.7 | 2.3 | 9.0 |
| 1981 | 3.3 | 3.1 | 11.0 |
| 1982 | 3.5 | 3.5 | 9.3 |
| 1983 | 4.5 | 4.5 | 9.1 |
| 1984 | 1.8 | 1.8 | 8.7 |
| 1985 | 2.8 | 2.8 | 9.0 |
| 1986 | 3.3 | 3.3 | 9.1 |
| 1987 | 3.5 | 3.5 | 8.2 |
| 1988 | 2.0 | 2.0 | 11.5 |
| 1989 | 3.6 | 3.6 | 11.9 |
| 1990 | 5.3 | 5.3 | 6.5 |
| 1991 | 3.9 | 3.9 | 5.4 |
| 1992 | 4.6 | 4.6 | 7.0 |
| 1993 | 3.2 | 3.2 | 6.2 |
| 1994 | 4.0 | 4.0 | 6.2 |
| 1995 | 3.5 | 3.5 | 5.5 |
| 1996 | 5.7 | 5.7 | 15.5 |
| 1997 | 12.8 | 12.9 | 18.9 |
| 1998 | 6.7 | 6.3 | 10.9 |
| 1999 | 7.4 | 7.4 | 14.6 |
| 2000 | 11.6 | 11.6 | 9.8 |
| 2001 | 15.4 | 15.4 | 13.5 |
| 2002 | 19.3 | 19.3 | 17.0 |
| 2003 | 15.8 | 15.8 | 14.5 |
| Total | 6.2 | 5.9 | 10.2 |

In Table 4, the proportions determined from the annual catch estimates are similar, if not identical, to the proportion determined from the aggregated data. This would suggest that the species composition of the aggregated data is adjusted, and then the species composition for the WCPO based on the adjusted aggregated data is used to estimate annual catches.

The proportion for 1970–1995 combined is 3.6% for the annual catch estimates and 3.5% for the 1° x 1° data, much lower than the proportion for 1996–2003 combined, 11.9% and 11.6% respectively. Japan has published catch estimates based on (a) landings and (b) statistics corrected with port sampling data, for the equatorial fishery for 1996–2003 (Miyabe et al. 2004), which suggests that the annual catch estimates and the aggregated data have been adjusted for 1996–2003, but not for the earlier period, 1970–1995.

The proportions determined from the annual catch estimates and the 1° x 1° data for 1970–2003 combined are 6.2% and 5.9% respectively. The proportion resulting from adjustments using Tables 1 and 2, for 1970–2003 combined, is higher, 10.2%.

**Table 5. Comparison of the percentages of bigeye in 'yellowfin plus bigeye' for the Japanese purse-seiners in the equatorial fishery determined from (a) catch and effort data aggregated by 1° latitutude, 1° longitude and month; (b) landings data; (c) statistics corrected with port sampling data; and (d) annual catch estimates determined from 1° x 1° data, adjusted with the proportions presented in Tables 1 and 2**

| Year | 1x1 Data | Landings | Port Sampling | Adjusted |
|---|---|---|---|---|
| 1996 | 3.5 | 6.8 | 9.5 | 15.3 |
| 1997 | 12.4 | 19.0 | 20.8 | 16.3 |
| 1998 | 5.7 | 10.1 | 11.9 | 8.6 |
| 1999 | 6.9 | 10.1 | 11.8 | 18.3 |
| 2000 | 10.5 | 14.3 | 19.6 | 14.6 |
| 2001 | 14.6 | 16.7 | 18.5 | 12.7 |
| 2002 | 17.7 | 16.6 | 21.4 | 15.7 |
| 2003 | 13.7 | 11.3 | n/a | 15.2 |

In Table 5, the proportions determined from the 1° x 1° data are less than those determined from landings, which, in turn, are less than those determined from port sampling, except for 2002. It is therefore not obvious how the landings and/or the port sampling data have been used to determine the species composition of the 1° x 1° data.

The proportions determined from the 1° x 1° data adjusted using Tables 1 and 2 are consistent with those determined from the landings and port sampling data for certain years (1997, 1998, 2000, 2002 and 2003), but not others (1996, 1999 and 2001), and are greater than those determined from the unadjusted 1° x 1° data for all years in Table 4 except 2001 and 2002.

*Republic of Korea*

**Table 6. Comparison of the percentages of bigeye in 'yellowfin plus bigeye' for the Korean purse-seine fleet determined from (a) annual catch estimates for the WCPO provided by Korea and (b) annual catch estimates adjusted by the OFP using Tables 1 and 2**

| Year | Annual Catch Estimates | Adjusted Annual Catch Estimates |
|---|---|---|
| 1980 | 6.3 | 7.4 |
| 1981 | 43.1 | 7.7 |
| 1982 | 2.1 | 12.7 |
| 1983 | 3.2 | 12.1 |
| 1984 | 1.3 | 12.5 |
| 1985 | 12.1 | 9.5 |
| 1986 | 7.0 | 6.5 |
| 1987 | 1.3 | 7.1 |
| 1988 | 0.3 | 8.4 |
| 1989 | 0.3 | 5.4 |
| 1990 | 2.3 | 5.9 |
| 1991 | 0.6 | 4.4 |
| 1992 | 0.2 | 6.6 |
| 1993 | 0.3 | 4.7 |
| 1994 | 1.8 | 4.6 |
| 1995 | 0.1 | 4.0 |
| 1996 | 4.9 | 9.1 |
| 1997 | 0.8 | 13.2 |
| 1998 | 1.1 | 7.1 |
| 1999 | 5.5 | 6.7 |
| 2000 | 0.3 | 2.8 |
| 2001 | 0.8 | 4.0 |
| 2002 | 0.4 | 7.2 |
| 2003 | 0.4 | 4.0 |
| Total | 1.2 | 6.1 |

In Table 6, the proportions determined from the annual catch estimates provided by Korea are generally lower than the proportions determined from the adjusted annual catch estimates, although they are higher for 1981, 1985 and 1986. For 1980–2003 combined, the proportion determined from the annual catch estimates provided by Korea is 1.2%, compared to 6.1% for the adjusted annual catch estimates. It would therefore appear that, for most years, the annual catch estimates provided by Korea have not been adequately corrected for the misidentification of bigeye as yellowfin.

*Chinese Taipei*

**Table 7. Comparison of the percentages of bigeye in 'yellowfin plus bigeye' for the Chinese Taipei purse-seine fleet determined from (a) annual catch estimates for the WCPO provided by Chinese Taipei and (b) annual catch estimates adjusted by the OFP using Tables 1 and 2**

| Year | Annual Catch Estimates | Adjusted Annual catch Estimates |
|---|---|---|
| 1983 | 0.0 | 12.3 |
| 1984 | 0.0 | 10.7 |
| 1985 | 0.0 | 10.9 |
| 1986 | 0.0 | 12.4 |
| 1987 | 0.0 | 12.6 |
| 1988 | 0.0 | 12.0 |
| 1989 | 0.0 | 14.2 |
| 1990 | 0.0 | 11.1 |
| 1991 | 0.0 | 9.0 |
| 1992 | 0.0 | 8.5 |
| 1993 | 0.0 | 4.5 |
| 1994 | 0.0 | 3.9 |
| 1995 | 0.0 | 2.7 |
| 1996 | 2.0 | 8.9 |
| 1997 | 4.5 | 13.1 |
| 1998 | 0.3 | 5.9 |
| 1999 | 7.4 | 11.2 |
| 2000 | 4.7 | 2.7 |
| 2001 | 4.7 | 6.2 |
| 2002 | 9.2 | 11.0 |
| 2003 | 8.7 | 8.1 |
| Total | 2.5 | 7.8 |

In Table 7, it would appear that the annual catch estimates provided by Chinese Taipei have been adjusted for 1996–2003, but not for 1983–1995. It is not known how the estimates for 1996–2004 were adjusted. In any case, the proportions are lower than those determined from the estimates adjusted by the OFP, except for 2000 and 2003, which are higher.

*United States of America*

**Table 8. Comparison of the percentages of bigeye in 'yellowfin plus bigeye' for the United States purse-seine fleet determined from (a) annual catch estimates for the WCPO provided by the United States and (b) annual catch estimates adjusted by the OFP using Tables 1 and 2**

| Year | Annual Catch Estimates | Adjusted Annual catch Estimates |
|---|---|---|
| 1988 | 9.4 | 6.7 |
| 1989 | 5.3 | 5.1 |
| 1990 | 3.3 | 2.5 |
| 1991 | 4.0 | 3.2 |
| 1992 | 7.4 | 6.8 |
| 1993 | 7.5 | 6.6 |
| 1994 | 2.9 | 1.8 |
| 1995 | 9.1 | 4.3 |
| 1996 | 33.7 | 18.1 |
| 1997 | 15.5 | 16.6 |
| 1998 | 12.5 | 10.9 |
| 1999 | 35.1 | 18.3 |
| 2000 | 26.0 | 12.9 |
| 2001 | 21.9 | 14.1 |
| 2002 | 17.6 | 10.0 |
| 2003 | 14.7 | 11.1 |
| Total | 13.6 | 9.2 |

In Table 8, the annual catch estimates provided by the United States have been adjusted with port sampling data. For 1988–1994, the proportions are similar to those determined from the estimates adjusted by the OFP, since the OFP also used the port sampling data for the United States fleet (Table 2) to adjust the estimates.

For 1995–2003, the OFP used observer data (Table 1) to adjust the estimates. For this period, the proportions determined from the estimates provided by the United States are significantly higher than the proportions determined from the estimates adjusted by the OFP, except for 1997 and 1998, for which the proportions are similar.

The discrepancies for 1995–1996 and 1999–2003 could be due to the fact that the observer data cover all fleets, while the port sampling data cover only the United States fleet. However, the average proportions of bigeye in 'yellowfin plus bigeye' determined from the observer data for United States vessels and non-United States vessels, for 1995–2003, are similar, 17.6% and 18.1% respectively, which suggests that the difference in the fleets that are covered by the port sampling data and the observer data is irrelevant. Instead, the differences in the proportions determined from the port sampling data and the observer data may be due to other factors, such as the sampling protocols.

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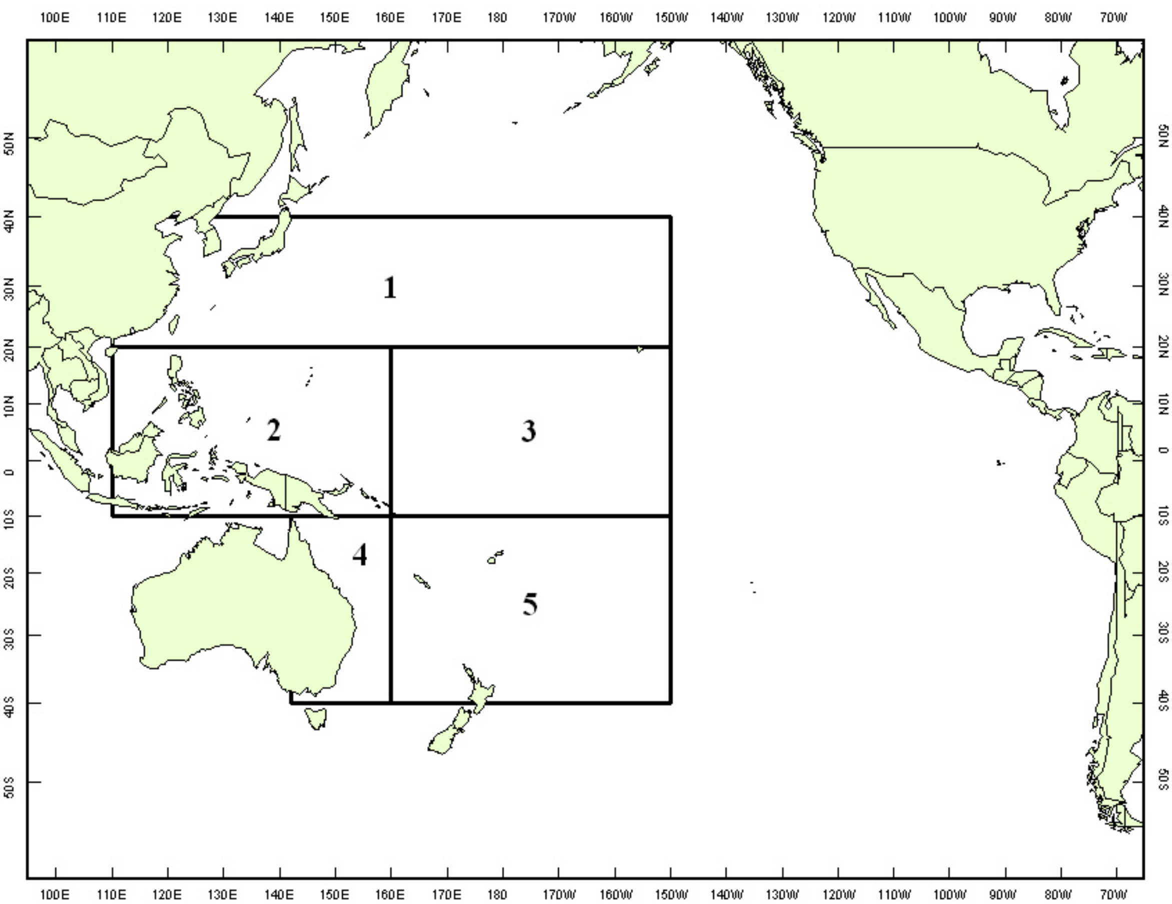


**Figure 1. Areas used in the MULTIFAN-CL assessment of bigeye (Hampton 2002)**

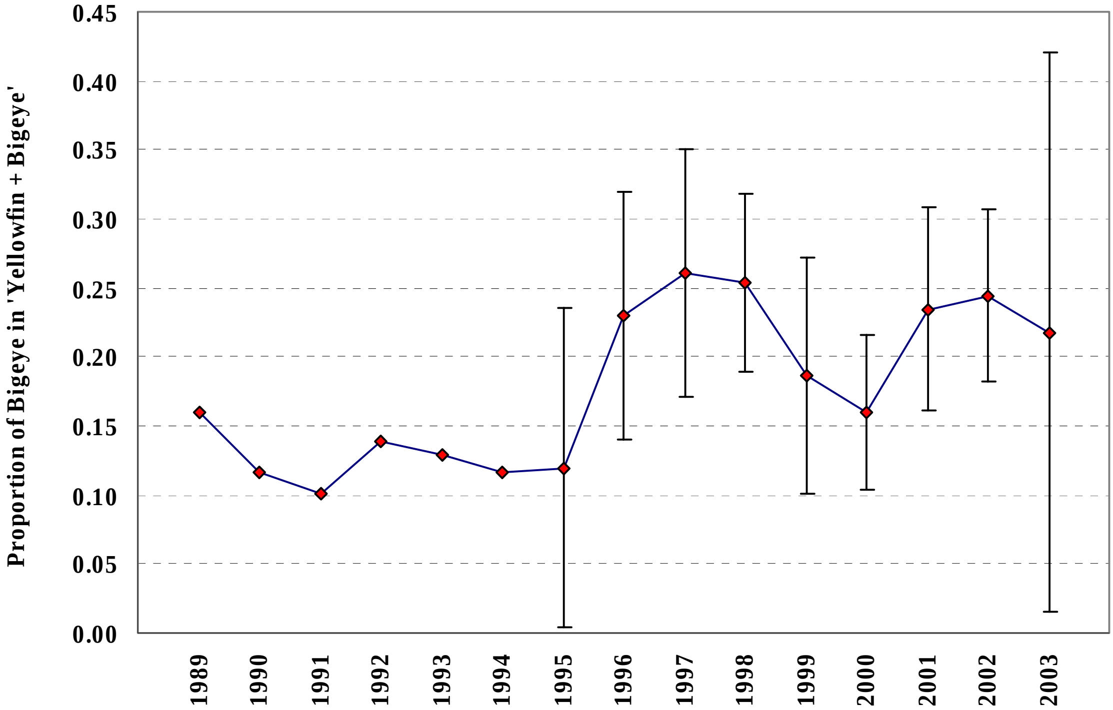


**Figure 2. Proportion of bigeye in 'yellowfin plus bigeye' for associated schools determined from port sampling data for the United States purse-seine fleet (1989–1994) and observer data for all fleets (1995–2003). Bars for the proportions determined from observer data represent plus or minus two standard errors.**

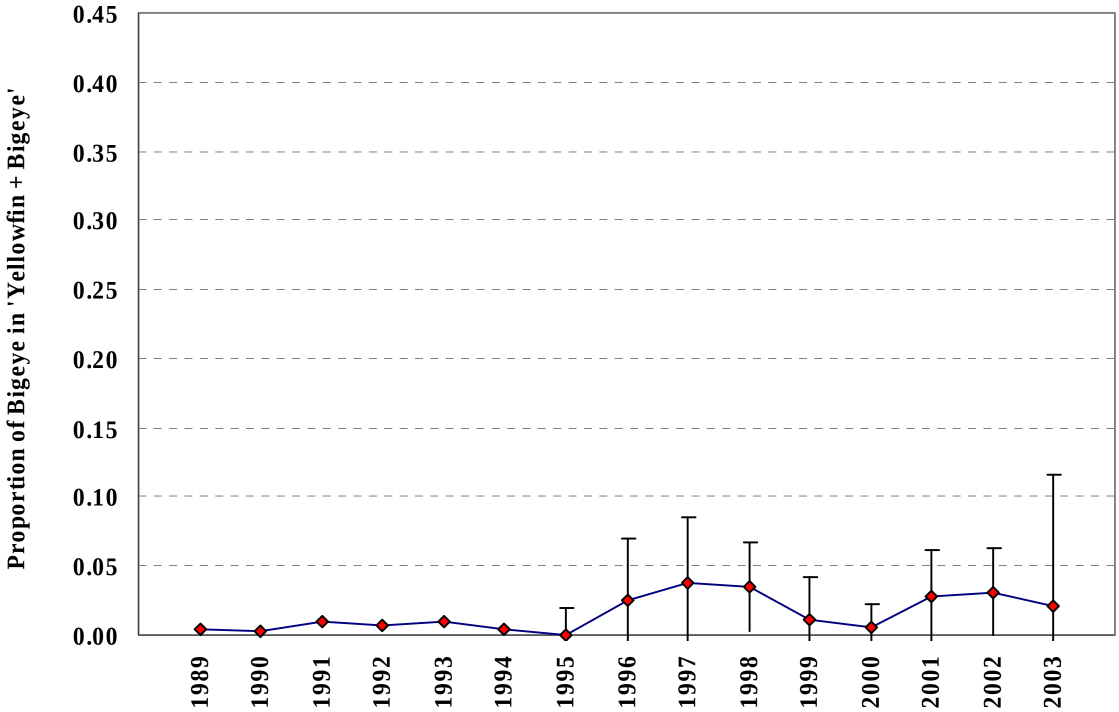


**Figure 3. Proportion of bigeye in 'yellowfin plus bigeye' for unassociated schools determined from port sampling data for the United States purse-seine fleet (1989–1994) and observer data for all fleets (1995–2003). Bars for the proportions determined from observer data represent plus or minus two standard errors.**