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TUNAS AND BILLFISHES IN THE EASTERN PACIFIC OCEAN IN 2004

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INTRODUCTION

This report provides a summary of the fishery for tunas in the eastern Pacific Ocean (EPO), an assessment of the stocks of tunas and billfishes that are exploited in the fishery, and an evaluation of the pelagic ecosystem in the EPO.

The report is based on data available to the IATTC staff in March 2005. Section E (Pacific bluefin tuna) and the three sections on billfishes (G, H, I) are unchanged from IATTC Fishery Status Report 2, published in 2004.

All weights of catches and discards are in metric tons (t).

A. THE FISHERY FOR TUNAS AND BILLFISHES IN THE EASTERN PACIFIC OCEAN

This section has not yet been completed; it will be presented as a separate document (SAR-6-06) at this meeting

B. YELLOWFIN TUNA

An age-structured, catch-at-length analysis (A-SCALA) was used to assess yellowfin tuna in the eastern Pacific Ocean (EPO). The analysis method is described in IATTC Bulletin, Vol. 22, No. 5, and readers are referred to that report for technical details. The stock assessment details are available on the [IATTC web site](http://www.iattc.org), www.iattc.org.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, fishing effort, and the size compositions of the catches from several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure have also been made. The assessment for 2004 differs from that carried out in 2003 in the following ways. Catch and length-frequency data for the surface fisheries have been updated to include new data for 2004 and revised data for 2000-2003. Effort data for the surface fisheries have been updated to include new data for 2004 and revised data for 1975-2003. Monthly reporting of catch data for the longline fishery provided, at the time of the assessment, complete 2004 catch for Japan and the Republic of Korea and partial catch data for the other nations. Catch data for the Japanese longline fisheries have been updated for 1999-2002, and new data for 2003 have been added. Catch data for the longline fisheries of Chinese Taipei have been updated to include new data for 2002. Catch data for the longline fisheries of the Peoples Republic of China have been updated to include new data for 2003 and revised data for 2001 and 2002. Longline catch-at-length data for 2001-2002 have been updated, and new data for 2003 added. Longline effort data based on standardization of catch per unit of effort with a generalized linear model have been developed, using data for 1975-2003. The catches are shown in Figure B-1.

Significant levels of fishing mortality have been observed in the yellowfin tuna fishery in the EPO (Figure B-2). These levels are highest for middle-aged yellowfin. Both recruitment (Figure B-3) and exploitation have had substantial impacts on the yellowfin biomass trajectory (Figure B-4). Dolphin-associated fishing has had the greatest impact on the yellowfin tuna population (Figure B-4). It appears that the yellowfin population has experienced two different productivity regimes (1975-1983 and 1984-2004), with greater recruitment during the second regime. The two recruitment regimes (Figure B-3) correspond to two regimes in biomass (Figure B-4), the high-recruitment regime corresponding to greater biomasses. The spawning biomass ratio (the ratio of the current spawning biomass to that for the unfished stock; SBR) of yellowfin in the EPO was below the level capable of supporting the average maximum sustainable yields (AMSYs) during the low-recruitment regime, but close to that level during the high-recruitment regime (Figure B-5). The two different productivity regimes may support two different levels of AMSY and associated SBRs, and the AMSY reported here is an average for the period 1975-2004. The current SBR is below the SBR level at AMSY (Figure B-5). However, there is substantial uncertainty in the most recent estimate of SBR, and there is a moderate probability that the current SBR is above the level that would support the AMSY. The effort levels are estimated to be above those capable of supporting the AMSY (based on the current distribution of effort among the different fisheries). Because of the flat yield curve, the current effort levels are estimated to produce, under average conditions, catch that is only slightly less than AMSY. Future projections under the current effort levels and average recruitment indicate that the population will remain at approximately the same level over the next 5 years (Figure B-6). These simulations were carried out using the average recruitment for the 1975-2004 period. If they had been carried out using the average recruitment for the 1984-2004 period it is likely that the estimates of SBR and catches would be greater. Both the purse-seine and longline catches are expected to remain close to 2004 levels (Figure B-6).

AMSY has been stable during the assessment period (Figure B-7). This suggests that the overall pattern of selectivity has not varied a great deal through time. The overall level of fishing effort however has varied with respect to the AMSY multiplier.

The analysis indicates that strong cohorts entered the fishery in 1998-2000, and that these cohorts

increased the population biomass during 1999-2000. However, they have now moved through the population, so the biomass decreased during 2001-2004.

The overall average weights of yellowfin tuna that are caught have consistently been much less than the critical weight (about 35.2 kg), indicating that, from the yield-per-recruit standpoint, the yellowfin in the EPO are not harvested at the optimal size. There is substantial variability in the average weights of the yellowfin taken by the different fisheries, however. In general, the floating-object, unassociated, and pole-and-line fisheries capture younger, smaller fish than do the dolphin-associated and longline fisheries. The longline fisheries and the purse-seine sets in the southern area on yellowfin associated with dolphins capture older, larger yellowfin than do the coastal and northern dolphin-associated fisheries. The AMSY calculations indicate that the yield levels could be considerably increased if the fishing effort were diverted to the fisheries that catch yellowfin closest to the critical weight (longlining and purse-seine sets on yellowfin associated with dolphins, particularly in the southern area). This would also increase the SBR levels.

The impacts of the 2004 *Resolution for a Multi-Annual Program on the Conservation of Tuna in the eastern Pacific Ocean for 2004, 2005, and 2006* are predicted to result in slightly higher biomass and SBR than would otherwise have been the case.

A sensitivity analysis was carried out to estimate the effect of a stock-recruitment relationship. The results suggest that the model with a stock-recruitment relationship fits the data slightly better than the base case, but this result could also be explained by the regime shift, since spawning biomass is low during the period of low recruitment and high during the high recruitment. The results from the analysis with a stock-recruitment relationship are more pessimistic, suggesting that the effort level is greater than that which would produce the AMSY (Table B-1); however, the yield at this effort level is still only 6% less than AMSY. The biomass is estimated to have been less than the biomass that would produce the AMSY for most of the modeling period, except for most of the 2000-2002 period.

The assessment results are very similar to those from the previous assessments. The major differences occur, as expected, in the most recent years. The current assessment, and those for 2002, 2003 and 2004, indicate that the biomass increased in 2000, whereas the earlier assessments indicated a decline. In addition, SBR and the SBR corresponding to the AMSY has increased compared to the 2004 assessment because of changes in estimates of growth and current age-specific fishing mortality.

Summary

1. The results are similar to those of the previous five assessments, except that SBR at AMSY is similar only to those of the last three assessments.
2. The biomass is estimated to have declined very slightly in 2004.
3. There is uncertainty about recent and future recruitment and biomass levels.
4. The estimate of current SBR is less than that required to produce AMSY but its confidence intervals encompass the AMSY.
5. The current fishing mortality rates are above those required to produce AMSY.
6. The average weight of a yellowfin in the catch is much less than the critical weight, and increasing the average weight of the fish caught would substantially increase AMSY.
7. There have been two different productivity regimes, and the levels of AMSY and the biomass required to produce AMSY may differ between the regimes.
8. The results are sensitive to the assumption about the stock-recruitment relationship.

FIGURE TO BE UPDATED

FIGURE B-1. Total catches (retained catches plus discards) for the purse-seine fisheries, and retained catches for the pole-and-line fishery and longline fisheries, of yellowfin tuna in the eastern Pacific Ocean, used in the stock assessment. Purse-seine catches for 1975-1992 are based on unloading data. Longline catches for 1975-2003 are those reported to the IATTC by governments, and those for 2003 are predicted by the model based on 2003 effort levels and estimates of the biomass vulnerable to longlining in 2004.

FIGURA B-1. Capturas totales (capturas retenidas más descartes) de las pesquerías de cerco, y capturas retenidas de las pesquerías cañera y palangreras de atún aleta amarilla en el Océano Pacífico oriental, usadas en la evaluación de la población. Las capturas cerqueras de 1975-1992 se basan en datos de descargas. Las capturas palangreras de 1975-2002 son la reportadas a la CIAT por los gobiernos, y las de 2003 son predichas por el modelo con base en el nivel de esfuerzo de 2002 y estimaciones de la biomasa vulnerable a los palangres en 2003.

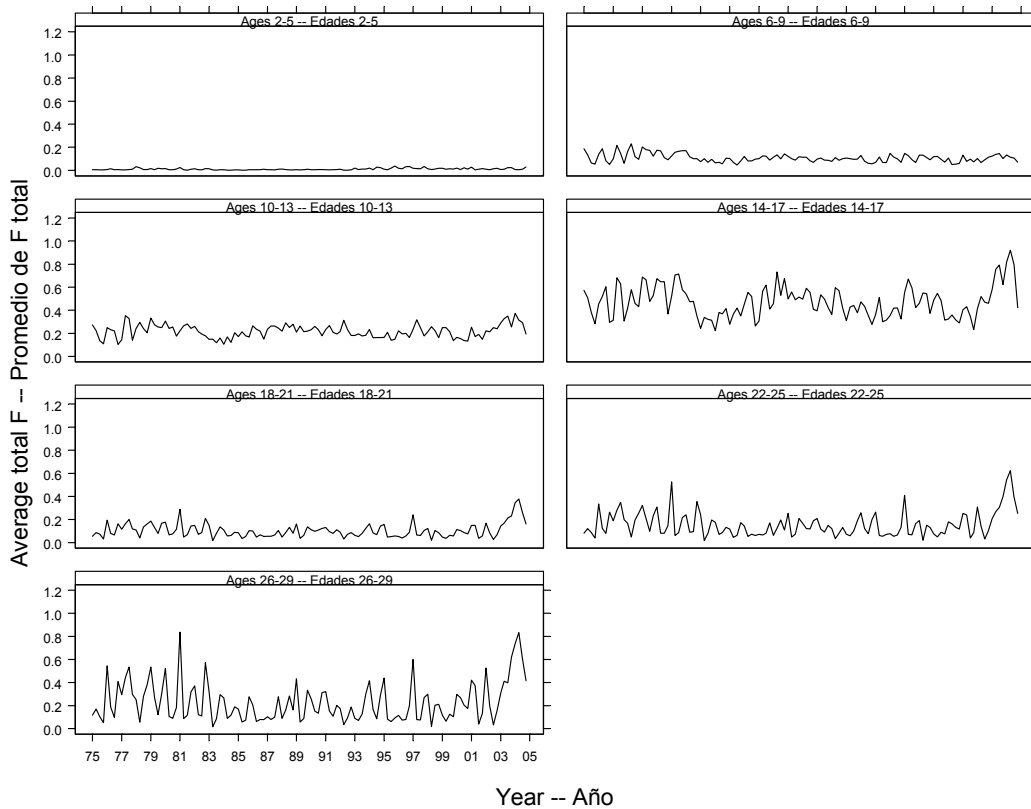


FIGURE B-2. Time series of average total quarterly fishing mortality of yellowfin tuna that have been recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish of the age range indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected fish that were 2-5 quarters old.

FIGURA B-2. Series de tiempo de la mortalidad por pesca trimestral total media de atún aleta amarilla reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de cuatro vectores trimestrales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior izquierdo es un promedio de las mortalidades por pesca que afectaron a los peces de entre 2 y 5 trimestres de edad.

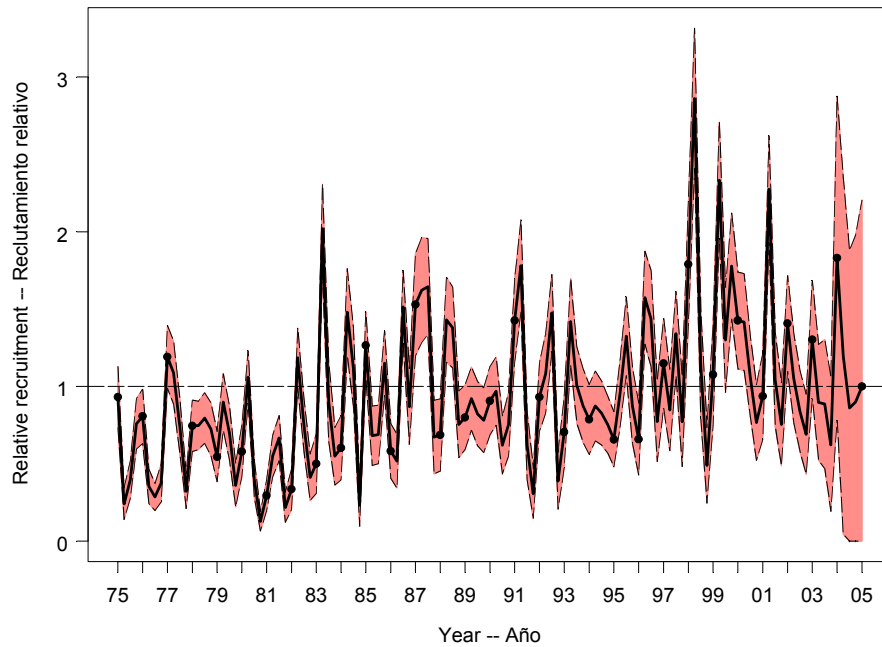
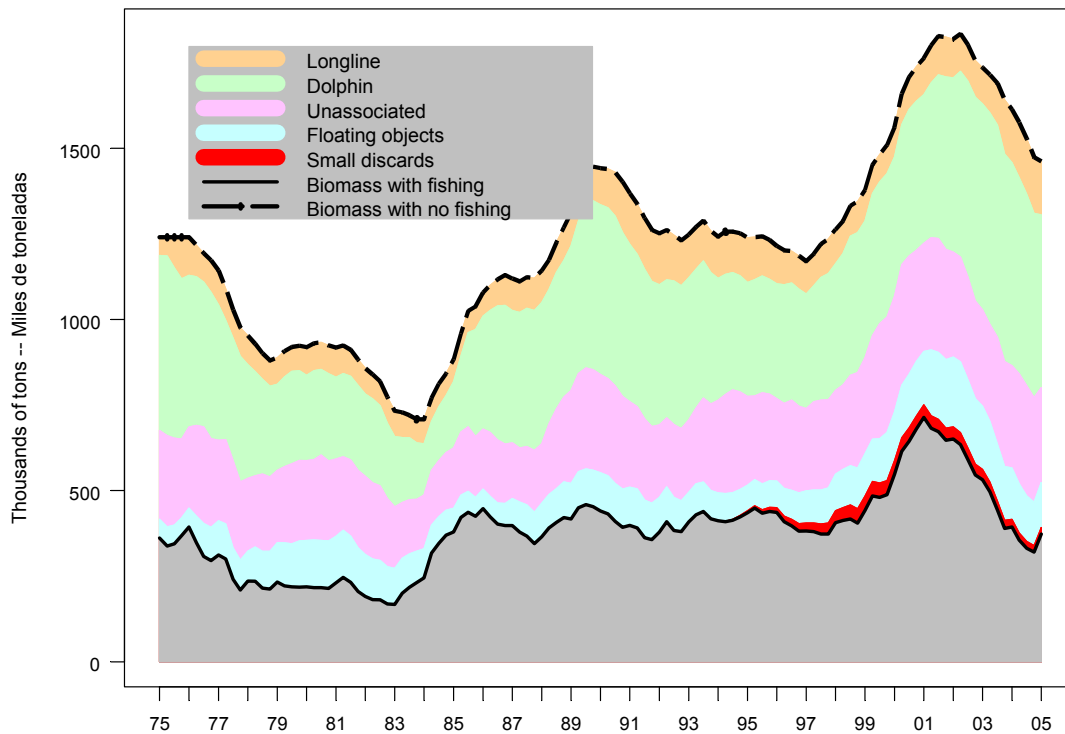


FIGURE B-3. Estimated recruitment of yellowfin tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the shaded area indicates the approximate 95% confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

FIGURA B-3. Reclutamiento estimado de atún aleta amarilla a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea gruesa ilustra las estimaciones de probabilidad máxima del reclutamiento, y el área sombreada indica los intervalos de confianza de 95% aproximados de esas estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.



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FIGURE B-4. Biomass trajectory of a simulated population of yellowfin tuna that was not exploited during 1975-2004 (dashed line) and that predicted by the stock assessment model (solid line). The different colored areas between the two lines represent the portion of the fishery impact attributed to each fishing method.

FIGURA B-4. Trayectoria de la biomasa de una población simulada de atún aleta amarilla no explotada durante 1975-2003 (línea de trazos) y la que predice el modelo de evaluación (línea sólida). Las áreas coloreadas entre las dos líneas representan la porción del impacto de la pesca atribuida a cada método de pesca.

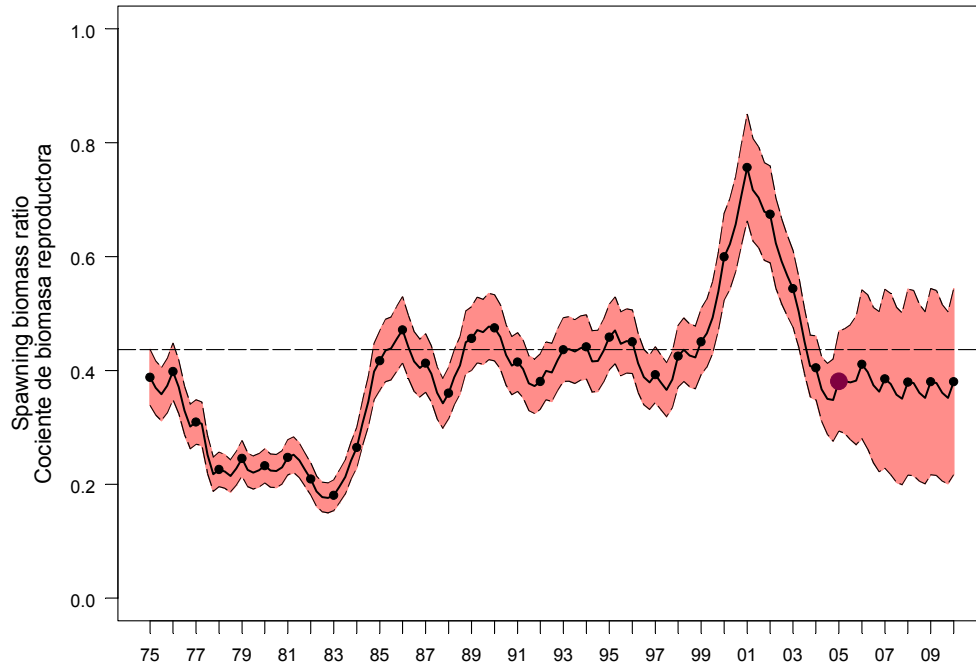


FIGURE B-5. Spawning biomass ratios (SBRs) for 1975-2004 and SBRs projected during 2005-2010 for yellowfin tuna in the EPO by the likelihood profile approximation method. The dashed horizontal line (at 0.44) identifies SBR_{AMSY} . The shaded area represents the 95% confidence limits of the estimates. The estimates after 2005 (the large dot) indicate the SBR predicted to occur if effort continues at the average of that observed in 2004, catchability (with effort deviates) continues at the average for 2002 and 2003, and average environmental conditions occur during the next 10 years.

FIGURA B-5. Cocientes de biomasa reproductora (SBR) para 1975-2003 y SBRs proyectados durante 2004-2009 para el atún aleta amarilla en el OPO por el método de aproximación de perfil de verosimilitud. La línea de trazos horizontal (en 0.38) identifica SBR_{RPMS} . El área sombreada representa los límites de confianza de 95% de las estimaciones. Las estimaciones a partir de 2004 (el punto grande) señalan el SBR predicho si el esfuerzo continúa en el nivel promedio de 2003, la capturabilidad (con desvíos de esfuerzo) continúa en el promedio de 2001 y 2002, y con condiciones ambientales promedio en los 10 próximos años.

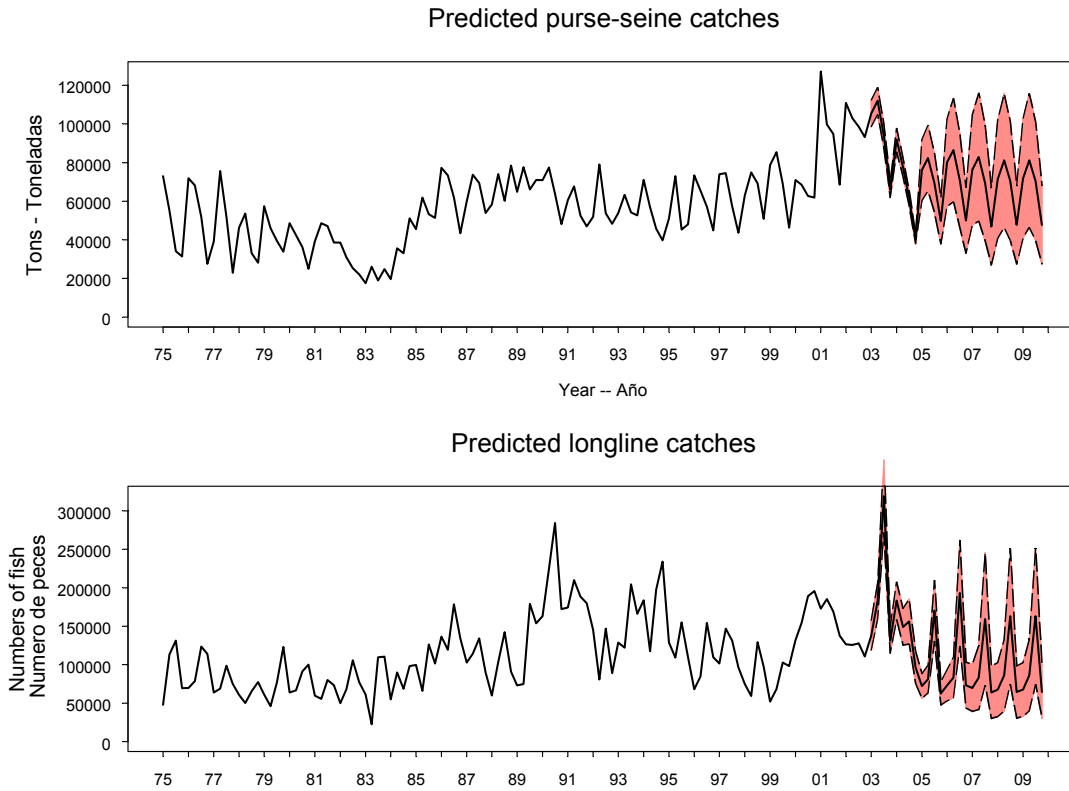


FIGURE B-6. Catches of yellowfin tuna during 1975-2004 and simulated catches of yellowfin tuna during 2005-2009 taken by the purse-seine and pole-and-line fleets (upper panel) and the longline fleet (lower panel), using the likelihood profile method. The shaded area represents the 95% confidence limits of the estimates.

FIGURA B-6. Capturas de atún aleta amarilla durante 1975-2003 y capturas simuladas de aleta amarilla durante 2004-2008 por las flotas de cerco y de caña (recuadro superior) y la flota palangrera (recuadro inferior), usando el método de aproximación de perfil de verosimilitud. El área sombreada representa los intervalos de confianza de 95% estimados de las estimaciones.

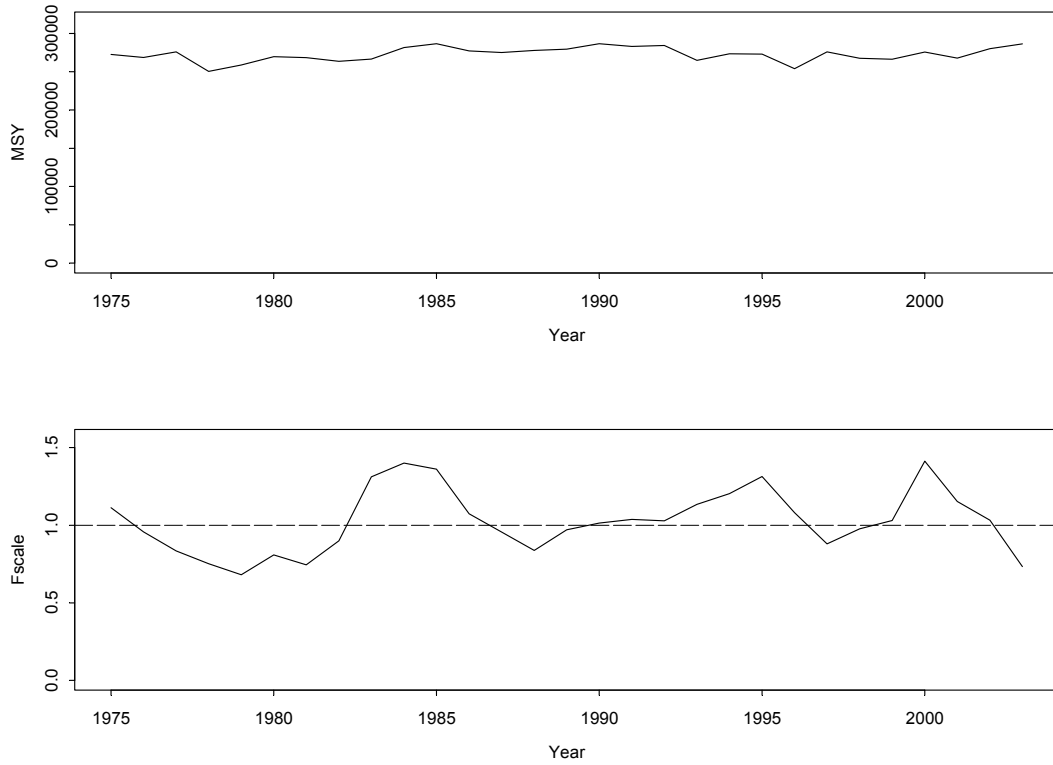


FIGURE B-7. AMSY (upper panel) and the amount that effort would need to be reduced to provide the AMSY (lower panel), estimated separately for each year using the average age-specific fishing mortality for each year.

TABLE B-1. AMSY and related quantities for the base case assessment and the stock-recruitment relationship sensitivity analysis ($h = 0.75$). All analyses are based on average fishing mortality for 2002 and 2003. B_{2004} , B_{AMSY} , and B_0 are the biomass of yellowfin 1.5+ years old at the start of 2005, at AMSY, and without fishing, respectively, and S_{2005} , S_{AMSY} , and S_0 are the female spawning biomass at the start of 2005, at AMSY, and without fishing, respectively. C_{2004} is the estimated total catch in 2004.

TABLA B-1. RMSP y cantidades relacionadas para la evaluación del caso base y el análisis de sensibilidad a la relación población-reclutamiento ($h = 0.75$). Todos los análisis se basan en la mortalidad por pesca media de 2001 y 2002. B_{2004} , B_{RMSP} , y B_0 son la biomasa de patudo de edad 1+ años al principio de 2004, en RMSP, y sin pesca, respectivamente, y S_{2004} , S_{RMSP} , y S_0 son la biomasa reproductora de hembras al principio de 2004, en RMSP, y sin pesca, respectivamente. C_{2003} es la captura total estimada en 2003.

		Base case Caso base	$h = 0.75$
AMSY–RMSP	(t)	284,707	306,775
$B_{\text{AMSY}} - B_{\text{RMSP}}$	(t)	419,598	531,276
$S_{\text{AMSY}} - S_{\text{RMSP}}$	(t)	8,144	10,141
$C_{2004}/\text{AMSY} - C_{2002}/\text{RMSP}$		1.04	0.97
$B_{2004}/B_{\text{AMSY}} - B_{2003}/B_{\text{RMSP}}$		0.89	0.72
$S_{2004}/S_{\text{AMSY}} - S_{2003}/S_{\text{RMSP}}$		0.87	0.71
$S_{\text{AMSY}}/S_{F=0} - S_{\text{RMSP}}/S_{F=0}$		0.44	0.45
F multiplier—Multiplicador de F		0.83	0.67

C. SKIPJACK TUNA

An age-structured catch-at-length analysis (A-SCALA) is used to assess skipjack tuna in the eastern Pacific Ocean (EPO). The analysis method is described in IATTC Bulletin, Vol. 22, No. 5, and readers are referred to that report for technical details. This method was used for the most recent assessment of skipjack tuna conducted in 2004, which included data up to and including 2003.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, fishing effort, and the size compositions of the catches of several different fisheries have been analyzed. The catches used in the assessment are presented in Figure C-1. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality, fishing mortality, and stock structure have also been made. The assessment is still considered preliminary because (1) it is not known whether catch per day of fishing for purse-seine fisheries is proportional to abundance, (2) it is possible that there is a population of large skipjack that is invulnerable to the fisheries, and (3) stock structure in relation to fish in the EPO and in the western and central Pacific is uncertain. However, results from sensitivity analyses for this assessment are more consistent than those of previous years.

The recruitment of skipjack tuna to the fisheries in the EPO is highly variable (Figure C-2). Fishing mortality (Figure C-3) is estimated to be about the same or less than the rate of natural mortality. These estimates of fishing mortality are supported by estimates from tagging data. Biomass fluctuates in response to variations in both recruitment and exploitation (Figure C-4). Estimates of absolute biomass are moderately sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries and the monotonic selectivity assumption, but the trends in biomass are not.

The analysis indicates that a group of relatively strong cohorts (but not as strong as those of 1998) entered the fishery in 2002-2003, and that these cohorts increased the biomass and catches during 2003. There is an indication that the most recent recruitments are average, which may lead to lower biomasses and catches. However, these estimates of low recruitment are based on limited information, and are therefore very uncertain.

There is considerable variation in spawning biomass ratio (ratio of the spawning biomass to that for the unfished stock; SBR) for skipjack tuna in the EPO (Figure C-5). In 2003 the SBR was at a high level (about 0.61). Estimates based on average maximum sustainable yield (AMSY) and yield-per-recruit indicate that maximum yields are achieved with infinite fishing mortality because the critical weight is less than the average weight at recruitment to the fishery. However, this is uncertain because of uncertainties in the estimates of natural mortality and growth. Estimates of SBR are not sensitive to weights given to the information about abundance in the catch and effort data for the floating-object fisheries and the monotonic selectivity assumption.

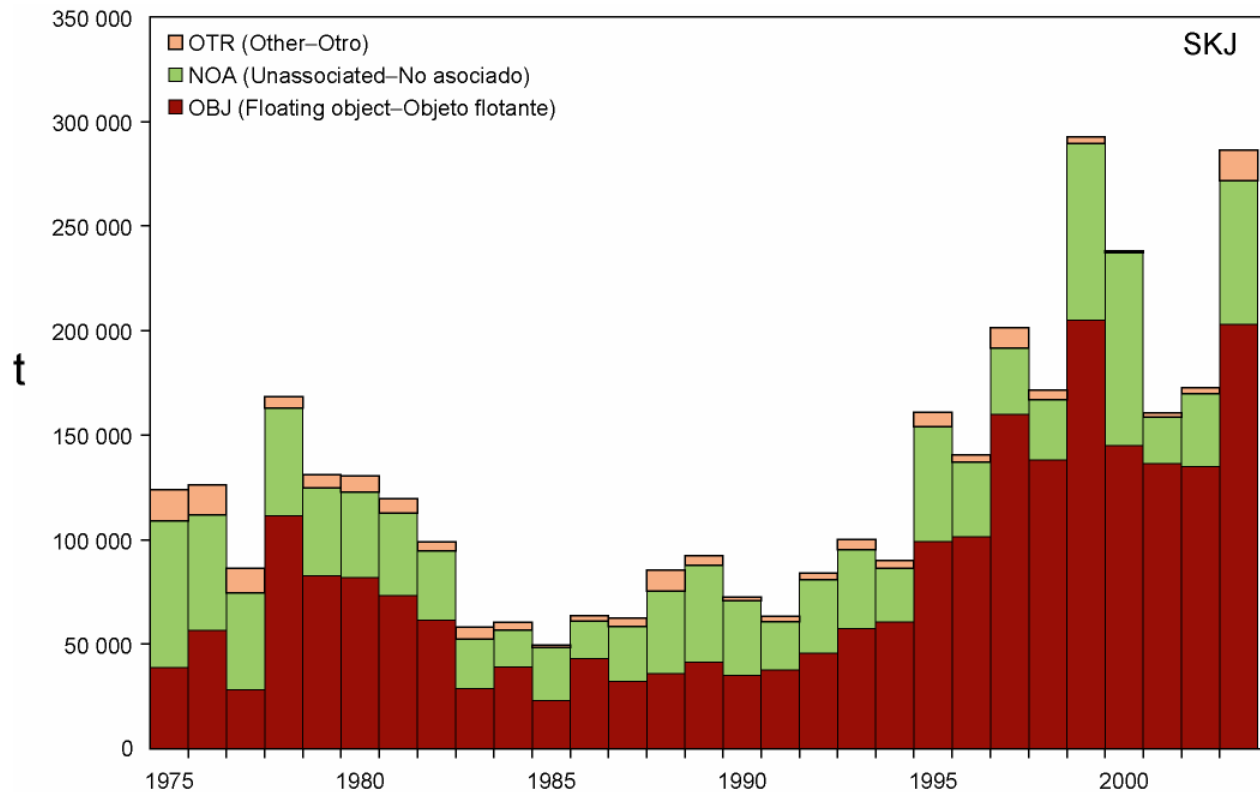


FIGURE C-1. Total catches (retained catches plus discards) for the purse-seine fisheries on floating objects and unassociated schools, and for other fisheries combined, of skipjack tuna in the eastern Pacific Ocean, 1975-2003, used in the stock assessment. Purse-seine catches are based on unloading data.

FIGURA C-1. Capturas totales (capturas retenidas más descartes) de las pesquerías de cerco sobre objetos flotantes y cardúmenes no asociados, y de las demás pesquerías combinadas, de atún barrilete en el Océano Pacífico oriental, 1975-2003, usadas en la evaluación de la población. Las capturas cerqueras se basan en datos de descargas.

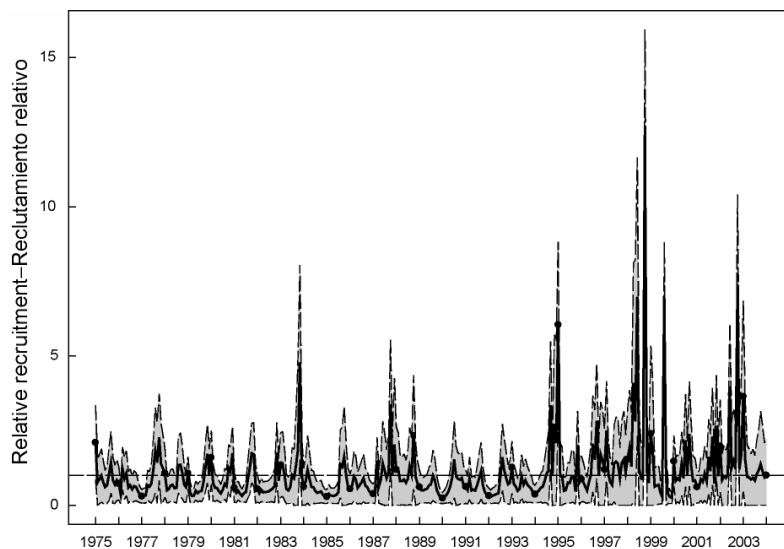


FIGURE C-2. Estimated recruitment of skipjack tuna to the fisheries of the EPO. The estimates are scaled so that the average recruitment is equal to 1.0. The solid line illustrates the maximum-likelihood estimates of recruitment, and the shaded area the 95% confidence intervals. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a monthly basis, there are 12 estimates of recruitment for each year.

FIGURA C-2. Reclutamiento estimado de atún barrilete a las pesquerías del OPO. Se escalan las estimaciones para que el reclutamiento medio equivalga a 1,0. La línea sólida ilustra las estimaciones de reclutamiento de probabilidad máxima, y el área sombreada los intervalos de confianza de 95%. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por meses, hay 12 estimaciones de reclutamiento para cada año.

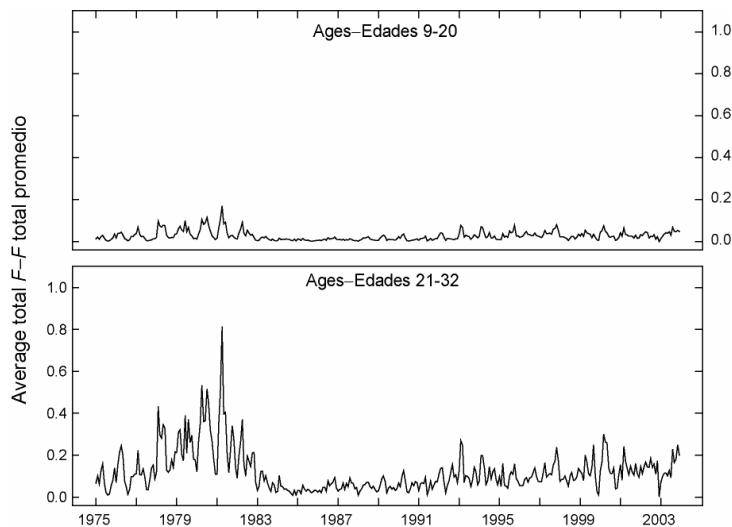


FIGURE C-3. Time series of average total monthly fishing mortality of skipjack tuna recruited to the fisheries of the EPO. Each panel illustrates an average of 12 monthly fishing mortality vectors that affected fish of the age range indicated in the title of each panel. For example, the trend illustrated in the upper panel is an average of the fishing mortalities that affected fish that were 9-20 months old.

FIGURA C-3. Series de tiempo de la mortalidad por pesca mensual total media de atún barrilete reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de 12 vectores mensuales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior es un promedio de las mortalidades por pesca que afectaron a los peces de entre 9 y 20 meses de edad.

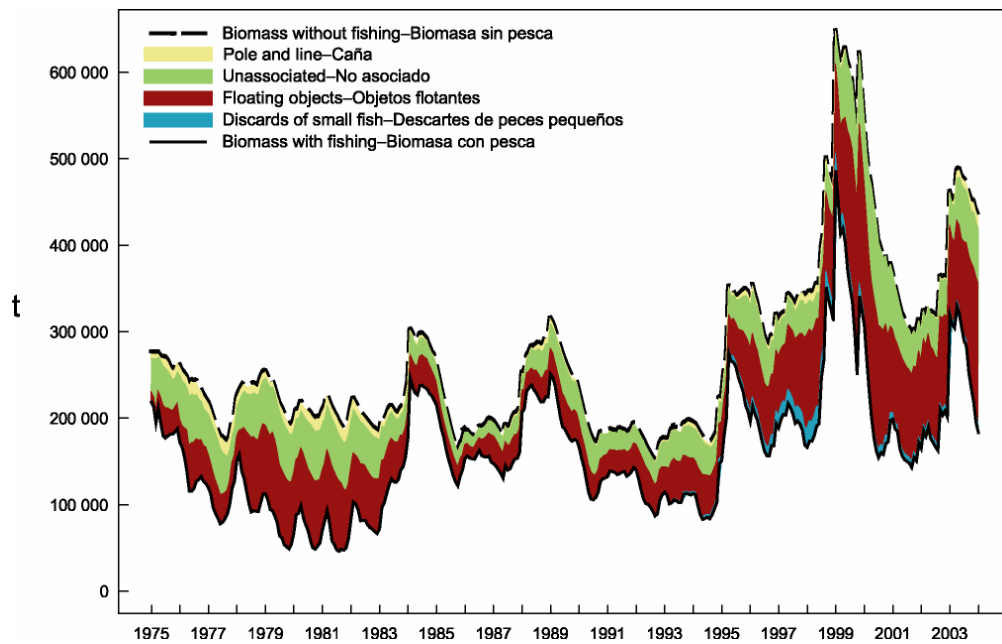


FIGURE C-4. Biomass trajectory of a simulated population of skipjack tuna that was not exploited during 1975-2003 (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the fishery impact attributed to each fishing method.

FIGURA C-4. Trayectoria de la biomasa de una población simulada de atún barrilete no explotada durante 1975-2003 (línea de trazos) y la que predice el modelo de evaluación (línea sólida). Las áreas sombreadas entre las dos líneas representan la porción del impacto de la pesca atribuida a cada método de pesca.

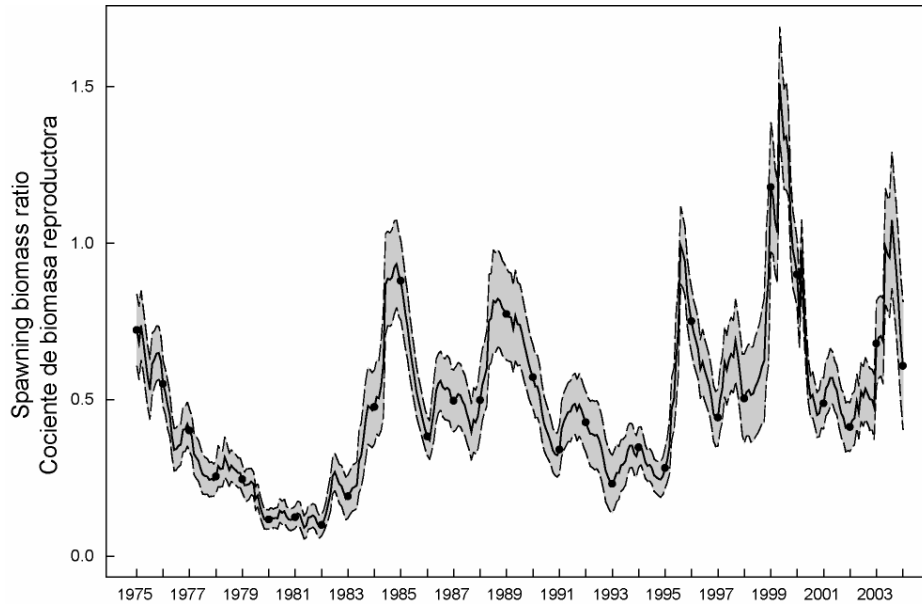


FIGURE C-5. Estimated time series of spawning biomass ratios (SBRs) for skipjack tuna in the EPO, from the monotonic selectivity assessment. The shaded area represents the 95% confidence limits of the estimates.

FIGURA C-5. Series de tiempo estimadas de los cocientes de biomasa reproductora (SBR) de atún barrilete en el OPO, de la evaluación de selectividad monotónica. El área sombreada representa los intervalos de confianza de 95% de las estimaciones.

D. BIGEYE TUNA

An age-structured catch-at-length analysis, A-SCALA, was used to assess bigeye tuna in the eastern Pacific Ocean (EPO). The analysis method is described in IATTC Bulletin, Vol. 22, No. 5, and readers are referred to that report for technical details. The stock assessment details are available on the [IATTC web site](http://www.iattc.org), www.iattc.org. The assessment reported here is based on the assumption that there is a single stock in the eastern Pacific Ocean. Its results are consistent with results of other analyses of bigeye tuna on a Pacific-wide basis.

Several inputs into this assessment differ from that for 2003. New results from recent age and growth studies have been incorporated. Catch and length-frequency data for the surface fisheries have been updated to include new data for 2004 and revised data for 2000-2003. Effort data for the surface fisheries have been updated to include new data for 2004 and revised data for 1975-2003. Monthly reporting of catch data for the longline fishery provided, at the time of the assessment, complete 2004 catch data for Japan and the Republic of Korea and partial catch for the other nations. Catch data for the Japanese longline fisheries have been updated for 1999-2002 and new data for 2003 added. Catch data for the longline fisheries of Chinese Taipei have been updated to include new data for 2002. Catch data for the longline fisheries of the Peoples Republic of China have been updated to include new data for 2003 and revised data for 2001 and 2002. Longline catch-at-length data for 2001-2002 have been updated and new data for 2003 added. Longline effort data based on statistical habitat-based standardization of catch per unit of effort have been updated to include data for 2002, and raw catch and effort data were used to extend the time series to the second quarter of 2004. The catches are shown in Figure D-1.

A sensitivity analyses was performed that investigated including a stock-recruitment relationship in the assessment.

There have been important changes in the amounts of fishing mortality caused by the fisheries that catch bigeye tuna in the EPO. On average, the fishing mortality of bigeye less than about 18 quarters old has increased substantially since 1993, and that of fish more than about 18 quarters old has increased slightly (Figure D-2). The increase in average fishing mortality on the younger fish was caused by the expansion of the fisheries that catch bigeye in association with floating objects.

There are several important features in the estimated time series of bigeye recruitment (Figure D-3). First, estimates of recruitment before 1993 are very uncertain, as the floating-object fisheries, which catch small bigeye, were not operating. There was a period of above-average recruitment in 1994-1998, followed by a period of below-average recruitment in 1999-2000. The recruitments were above average in 2001 and 2002. The most recent recruitment is very uncertain, due to the fact that recently-recruited bigeye are represented in only a few length-frequency data sets. The extended period of relatively large recruitments in 1995 to 1998 coincided with the expansion of the fisheries that catch bigeye in association with floating objects.

Fishing has reduced the total biomass of bigeye present in the EPO, and it is predicted that it will be near its lowest level by the end of 2005 (Figure D-4). There has been an accelerated decline in biomass since the peak in 2000. Analysis of the levels of fishing mortality associated with each fishery indicates that, since the expansion of the purse-seine fishing on floating objects in the early to mid-1990s, the purse-seine fishery has had a much greater impact on the stock than has the longline fishery.

The estimates of recruitment and biomass were only moderately sensitive to the steepness of the stock-recruitment relationship. The relationship between recruitment and the environmental index used in previous assessments was found to be not significant, and therefore was not used in the analysis.

At the beginning of 2005, the spawning biomass of bigeye tuna in the EPO (Figure D-5; large dot) was declining from a recent high level. At that time the spawning biomass ratio (the ratio of current spawning biomass to biomass of spawners in the absence of fishing mortality; SBR) was about 0.13, about 41%

less than the level corresponding to the average maximum sustainable yield (SBR_{AMSY}), with lower and upper confidence limits (± 2 standard deviations) of about 0.08 and 0.18. The estimate of the upper confidence bound is less than the estimate of SBR_{AMSY} (0.21). Previous assessments had predicted that the spawning biomass would decline below the SBR_{AMSY} level.

Estimates of the average SBR projected to occur during 2005-2010 indicate that the SBR is likely to remain below the level corresponding to the AMSY for many years unless fishing mortality is greatly reduced or recruitment is greater than average levels for a number of years (Figure D-5).

The average weight of fish in the catch of all fisheries combined has been substantially below the critical weight (about 63.3 kg) since 1993, suggesting that the recent age-specific pattern of fishing mortality is not satisfactory from a yield-per-recruit perspective.

In the base case assessment, recent catches are estimated to have been about 5% above the AMSY (Table D-1). If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the level of fishing effort corresponding to the AMSY is about 57% of the current level of effort. Decreasing the effort to 57% of its present level would increase the long-term average yield by about 11% and would increase the spawning potential of the stock by about 69%. The AMSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that for the longline fishery that operates south of 15°N because it catches larger individuals, which are close to the critical size. Before the expansion of the floating-object fishery that started in 1993, AMSY was greater than the current AMSY and the fishing mortality was less than that corresponding to AMSY (Figure D.7).

All analyses considered suggest that at the start of 2005 the spawning biomass was below the level corresponding to the AMSY (Table D-1). AMSY and the fishing mortality (F) multiplier are sensitive to how the assessment model is parameterized, the data that are included in the assessment, and the periods assumed to represent average fishing mortality, but under all scenarios considered, fishing mortality is well above the level corresponding to the AMSY.

The effects of the 2004 Resolution for a Multi-Annual Program on the Conservation of Tuna in the Eastern Pacific Ocean for 2004, 2005 and 2006 are estimated to be insufficient to allow the stock to rebuild. If the effort is reduced to levels that support AMSY, the stock will rebuild to SBR_{AMSY} within the 5-year projection period.

Summary:

1. Current fishing mortality levels are greater than those corresponding to the AMSY.
2. As a consequence, if fishing effort is not reduced, total biomass and spawning biomass will remain around the lowest levels observed during the period modelled (1975-2005).
3. The current status and future projections are considerably more pessimistic if a stock-recruitment relationship ($h = 0.75$) exists.
4. These conclusions are robust to the alternative model and data formulations considered in this and previous analyses.

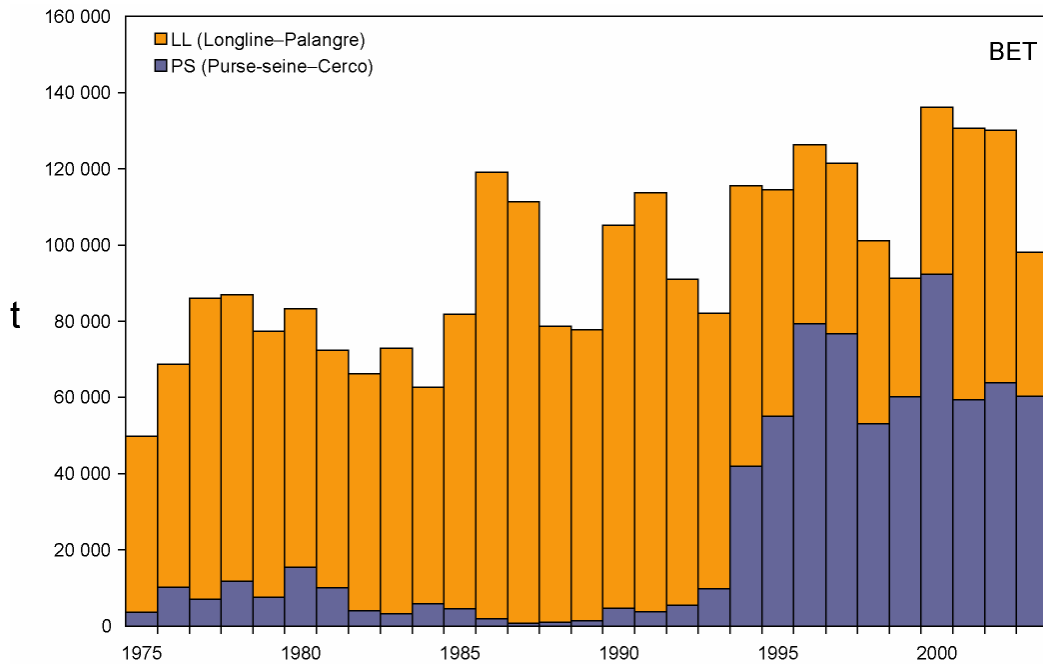


FIGURE D-1. Total catches (retained catches plus discards) for the purse-seine fisheries, and retained catches for the longline fisheries, of bigeye tuna in the eastern Pacific Ocean, 1975-2004, used in the stock assessment. Purse-seine catches for 1975-1992 are based on unloading data, those for 1993-1999 on unloading data adjusted to account for mis-identification, and those for 2000-2004 on species composition sampling. Longline catches for 1975-2002 are those reported to the IATTC by governments, and those for 2003 are predicted by the model based on 2002 effort levels and estimates of the biomass vulnerable to longlining in 2003.

FIGURA D-1. Capturas totales (capturas retenidas más descartes) de las pesquerías de cerco y capturas retenidas de las pesquerías palangreras de atún patudo en el Océano Pacífico oriental, 1975-2004, usadas en la evaluación de la población. Las capturas cerqueras de 1975-1992 se basan en datos de descargas, las de 1993-1999 en datos de descargas ajustados para tomar en cuenta identificaciones incorrectas, y las de 2000-2004 en el muestreo de composición por especies. Las capturas palangreras de 1975-2002 son la reportadas a la CIAT por los gobiernos, y las de 2003 son predichas por el modelo con base en el nivel de esfuerzo de 2002 y estimaciones de la biomasa vulnerable a los palangres en 2003.

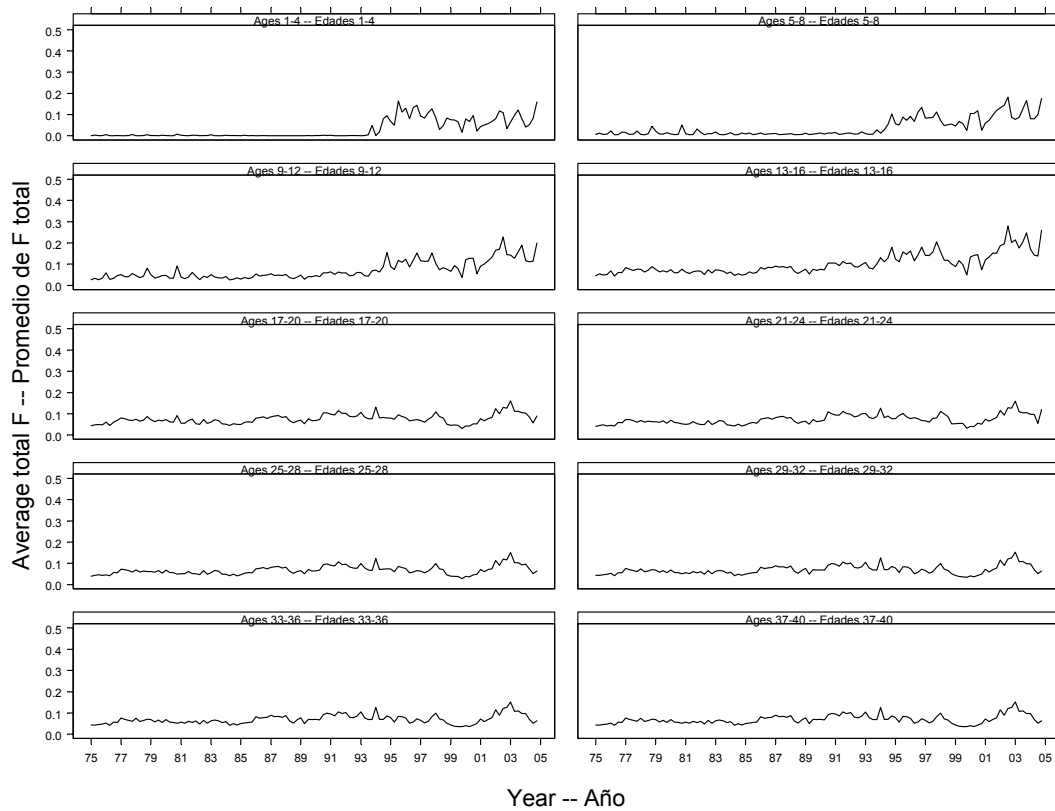


FIGURE D-2. Time series of average total quarterly fishing mortality on bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates an average of four quarterly fishing mortality vectors that affected the fish in the range of ages indicated in the title of each panel. For example, the trend illustrated in the upper-left panel is an average of the fishing mortalities that affected fish that were 1-4 quarters old.

FIGURA D-2. Series de tiempo de la mortalidad por pesca trimestral total media de atún patudo reclutado a las pesquerías del OPO. Cada recuadro ilustra un promedio de cuatro vectores trimestrales de mortalidad por pesca que afectaron los peces de la edad indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior izquierdo es un promedio de las mortalidades por pesca que afectaron a peces de entre 1-4 trimestres de edad.

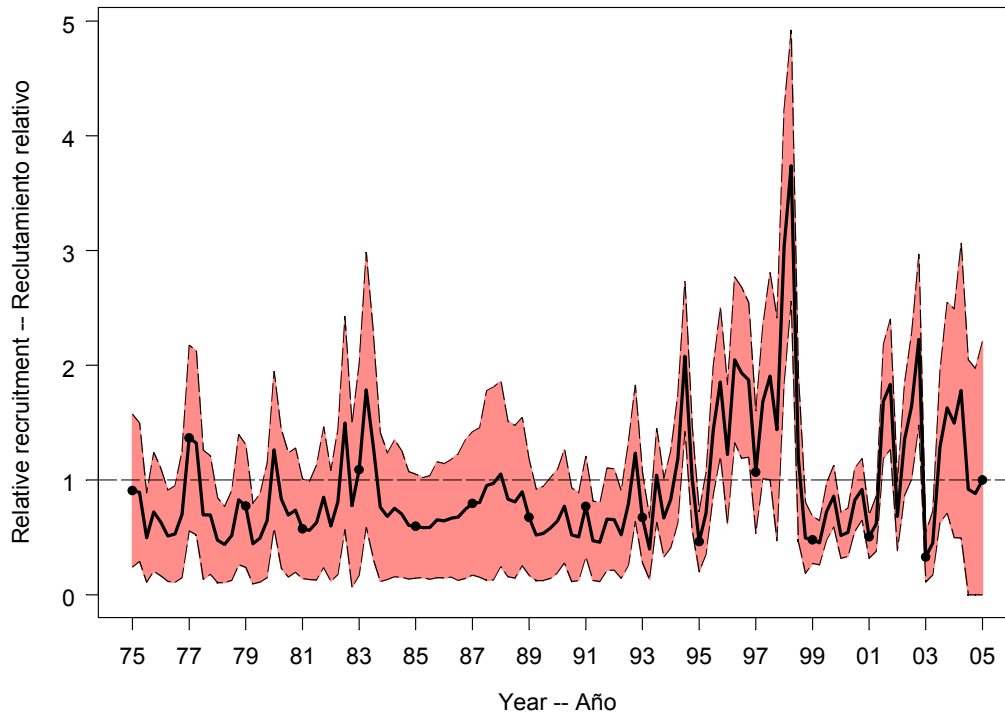


FIGURE D-3. Estimated recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The bold line illustrates the maximum likelihood estimates of recruitment, and the shaded areas indicates the approximate 95% confidence intervals around those estimates. The labels on the time axis are drawn at the start of each year, but, since the assessment model represents time on a quarterly basis, there are four estimates of recruitment for each year.

FIGURA D-3. Reclutamiento estimado de atún patudo a las pesquerías del OPO. Se escalan las estimaciones para que la estimación de reclutamiento virgen equivalga a 1,0. La línea gruesa ilustra las estimaciones de reclutamiento de verosimilitud máxima, y el área sombreada indica los intervalos de confianza de 95% aproximados de esas estimaciones. Se dibujan las leyendas en el eje de tiempo al principio de cada año, pero, ya que el modelo de evaluación representa el tiempo por trimestres, hay cuatro estimaciones de reclutamiento para cada año.

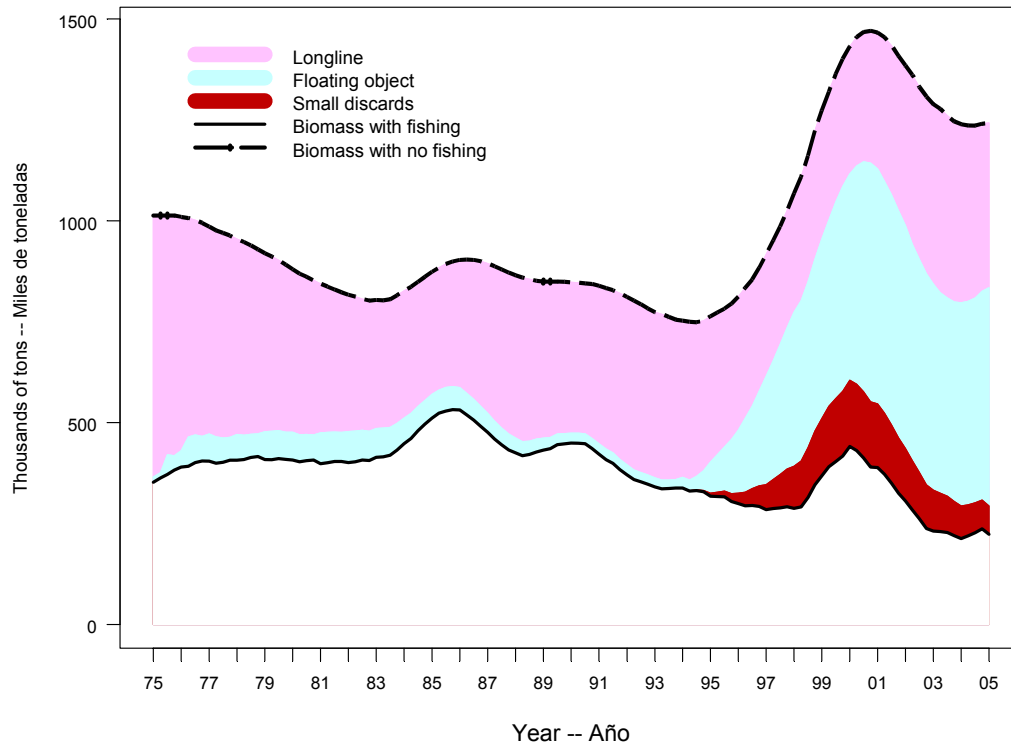


FIGURE D-4. Biomass trajectory of a simulated population of bigeye tuna that was not exploited during 1975-2004 (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the fishery impact attributed to each fishing method.

FIGURA D-4. Trayectoria de la biomasa de una población simulada de atún patudo no explotada durante 1975-2004 (línea de trazos) y la que predice el modelo de evaluación (línea sólida). Las áreas sombreadas entre las dos líneas señalan la porción del impacto de la pesca atribuida a cada método de pesca.

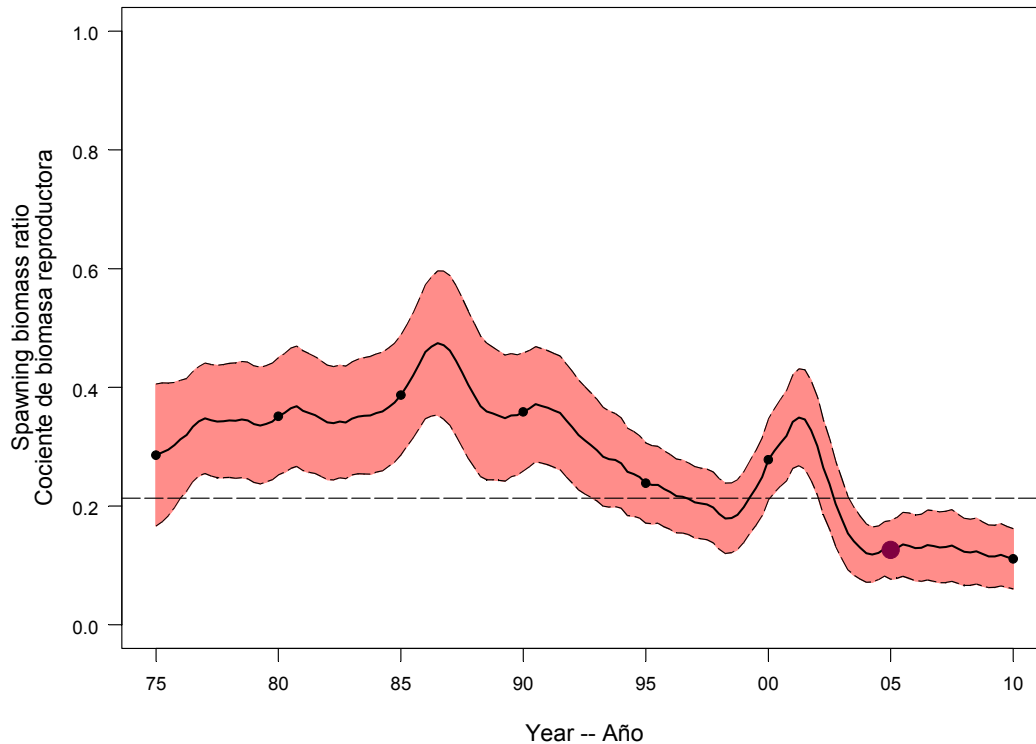


FIGURE D-5. Estimated time series of spawning biomass ratios (SBRs) for bigeye tuna in the EPO. The dashed horizontal line (at about 0.21) identifies the SBR at AMSY. The solid line illustrates the maximum likelihood estimates, and the shaded areas are 95% confidence intervals around those estimates. The estimates after 2005 (the large dot) indicate the SBR predicted to occur if effort continues at the average of that observed in 2004, catchability (with effort deviates) continues at the average for 2002 and 2003 (except for the northern longline fishery, for which the data for 2001-2002 are used), and average environmental conditions occur during the next 5 years.

FIGURA D-5. Serie de tiempo estimada de los cocientes de biomasa reproductora (SBR) para el atún patudo en el OPO. La línea de trazos horizontal (en aproximadamente 0.21) identifica el SBR en RMSP. La línea sólida ilustra las estimaciones de verosimilitud máxima, y el área sombreada representa los intervalos de confianza de 95% alrededor de esas estimaciones. Las estimaciones a partir de 2005 (el punto grande) señalan el the SBR predicho si el esfuerzo continúa en el nivel observado en 2004, la capturabilidad (con desvíos de esfuerzo) continúa en el promedio de 2002 y 2003 (con excepción de la pesquería palangre del norte, para la cual se utiliza los datos de 2001-2002), y con condiciones ambientales promedio en los 5 próximos años.

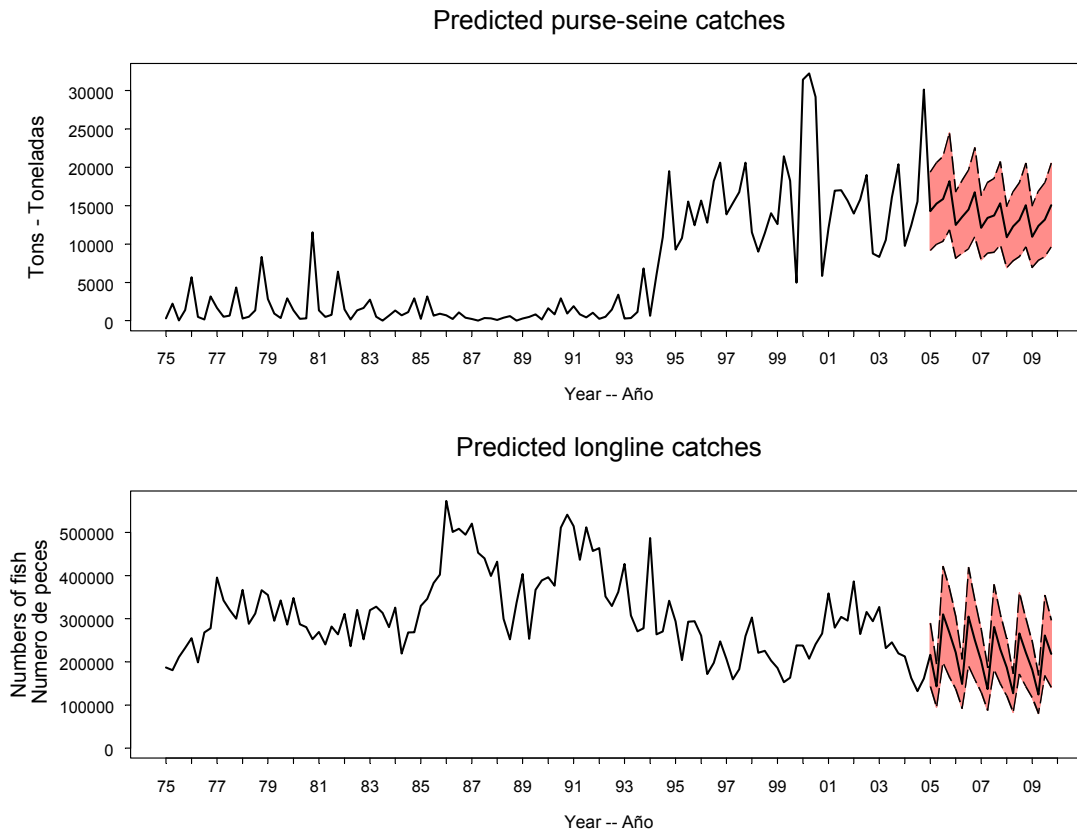


FIGURE D-6. Predicted quarterly catches of bigeye for the purse-seine and pole-and-line (upper panel) and longline (lower panel) fisheries, based on average effort for 2004 and average catchability for 2002 and 2003 (except for the northern longline fishery, for which the data for 2001-2002 are used). The shaded areas represent 95% confidence intervals for the predictions of future catches. Note that the vertical scales of the panels are different.

FIGURA D-6. Capturas trimestrales predichas de atún patudo para las pesquerías de cerco y de caña (recuadro superior) y palangreras (recuadro inferior), basadas en el esfuerzo promedio de 2004 y la capturabilidad promedio de 2002 y 2003 (con excepción de la pesquería palangre del sur, para la cual se utiliza los datos de 2001-2002). Las zonas sombreadas representan intervalos de confianza de 95% para las predicciones de capturas futuras. Nótese que las escalas verticales de los recuadros son diferentes.

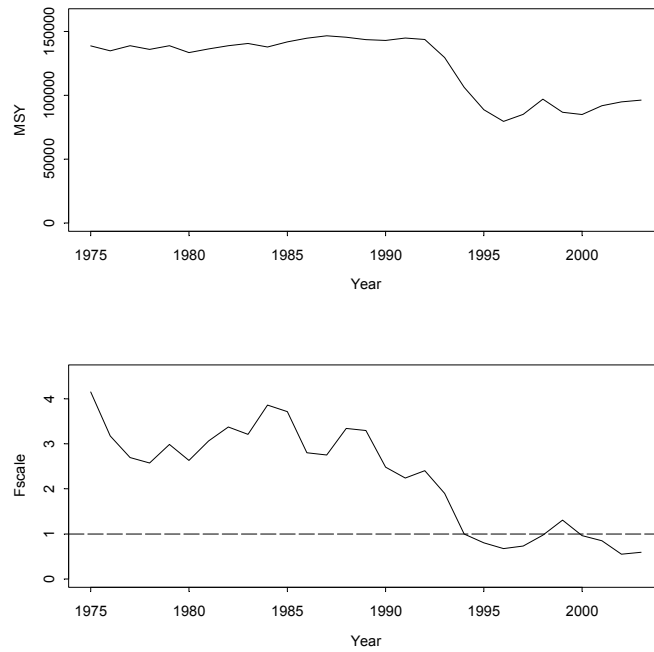


FIGURE D-7. AMSY (upper panel) and the amount that the effort would need to be scaled in that year to support AMSY (lower panel) estimated separately for each year using the average age-specific fishing mortality for each year.

FIGURA D-7. RMSP (recuadro superior) y la cantidad que el esfuerzo

TABLE D-1. Estimates of the AMSY and its associated quantities for the base case assessment and sensitivity analyses. All analyses are based on average fishing mortality for 2002 and 2003. B_{recent} , B_{AMSY} , and B_0 are the biomass of bigeye 1+ years old at the start of 2005, at AMSY, and without fishing, respectively, and S_{recent} , S_{AMSY} , and S_0 are the female spawning biomass at the start of 2005, at AMSY, and without fishing, respectively. C_{recent} is the estimated total catch in 2004.

TABLA D-1. Estimaciones del RMSP y sus valores asociados para la evaluación del caso base y los análisis de sensibilidad. Todos los análisis se basan en la mortalidad por pesca media de 2002 y 2003. B_{recent} , B_{RMSP} , y B_0 son la biomasa de patudo de edad 1+ años al principio de 2005, en RMSP, y sin pesca, respectivamente, y S_{recent} , S_{RMSP} , y S_0 son la biomasa reproductora de hembras al principio de 2005, en RMSP, y sin pesca, respectivamente. C_{recent} es la captura total estimada en 2004

	Base case	Steepness = 0.75
	Caso base	Inclinación = 0.75
AMSY—RMSP	95572	91270
$B_{\text{AMSY}}—B_{\text{RMSP}}$	292504	462975
$S_{\text{AMSY}}—S_{\text{RMSP}}$	482	879
$B_{\text{AMSY}}/B_0—B_{\text{RMSP}}/B_0$	0.29	0.36
$S_{\text{AMSY}}/S_0—S_{\text{RMSP}}/S_0$	0.21	0.30
$C_{\text{recent}}/\text{AMSY}—C_{\text{recent}}/\text{RMSP}$	1.05	1.13
$B_{\text{recent}}/B_{\text{AMSY}}—B_{\text{recent}}/B_{\text{RMSP}}$	0.76	0.54
$S_{\text{recent}}/S_{\text{AMSY}}—S_{\text{recent}}/S_{\text{RMSP}}$	0.59	0.41
F multiplier—Multiplicador de F	0.57	0.41

E. PACIFIC BLUEFIN TUNA

Tagging studies have shown that there is exchange of Pacific bluefin between the eastern and western Pacific Ocean. Larval, postlarval, and early juvenile bluefin have been caught in the western Pacific Ocean (WPO), but not the eastern Pacific Ocean (EPO), so it is likely that there is a single stock of bluefin in the Pacific Ocean.

Most of the catches of bluefin in the EPO are taken by purse seiners. Nearly all of the purse-seine catch is made west of Baja California and California, within about 100 nautical miles of the coast, between about 23°N and 35°N. In recent years a considerable portion of the purse-seine catch of bluefin has been transported to holding pens, where the fish are held for fattening and later sale as sashimi-grade fish. Lesser amounts of bluefin are caught by recreational, gillnet, and longline gear. Bluefin have been caught during every month of the year, but most of the fish are taken during May through October.

Bluefin are exploited by various gears in the WPO from Taiwan to Hokkaido. Age-0 fish about 15 to 30 cm in length are caught by trolling during July-October south of Shikoku Island and south of Shizuoka Prefecture. During November-April age-0 fish about 35 to 60 cm in length are taken by trolling south and west of Kyushu Island. Age-1 and older fish are caught by purse seining, mostly during May-September, between about 30°-42°N and 140°-152°E. Bluefin of various sizes are also caught by traps, gillnets, and other gear, especially in the Sea of Japan. Small amounts of bluefin are also caught near the southeastern coast of Japan by longlining.

The high-seas longline fisheries are directed mainly at tropical tunas, albacore, and billfishes, but small amounts of Pacific bluefin are caught by these fisheries. Small amounts of bluefin are also caught by Japanese pole-and-line vessels on the high seas.

Tagging studies, conducted with conventional and archival tags, have revealed a great deal of information about the life history of bluefin. As stated above, it appears that spawning occurs only in the WPO. Some fish apparently remain their entire lives in the WPO, while others migrate to the EPO. These migrations begin mostly, or perhaps entirely, during the first and second years of life. The first- and second-year migrants are exposed to various fisheries before beginning their journey to the EPO. The migrants, after crossing the ocean, are exposed to commercial and recreational fisheries off California and Baja California. Eventually, the survivors return to the WPO.

Bluefin are most often found in the EPO in waters where the sea-surface temperatures (SSTs) are between 17° and 23°C. Fish 15 to 31 cm in length are found in the WPO in waters where the SSTs are between 24° and 29°C. The survival of larval and early juvenile bluefin is undoubtedly strongly influenced by the environment. Conditions in the WPO probably influence the portions of the juvenile fish there that move to the EPO, and also the timing of these movements. Likewise, conditions in the EPO probably influence the timing of the return of the juvenile fish to the WPO.

Various indices of abundance of bluefin in the EPO have been calculated, but none of these is entirely satisfactory. The IATTC has calculated "habitat" and "bluefin-vessel" indices for the EPO routinely for several years.

A preliminary cohort analysis has indicated that the biomass of the spawning stock was relatively high during the 1960s, decreased during the 1970s and 1980s, and then increased during the 1990s. The recruitment was estimated to be highly variable, with four or five strong cohorts produced during the 1960-1998 period.

The total catches of bluefin have fluctuated considerably during the last 50 years (Figure E-1). The presence of consecutive years of above-average catches (mid-1950s to mid-1960s) and below-average catches (early 1980s to early 1990s) could be due to consecutive years of above-average and below-average recruitment. The results of yield-per-recruit and cohort analyses indicate that greater catches could be obtained if the catches of age-0 and age-1 fish were reduced or eliminated.

Spawner-recruit analyses do not indicate that the recruitment of Pacific bluefin could be increased by permitting more fish to spawn.

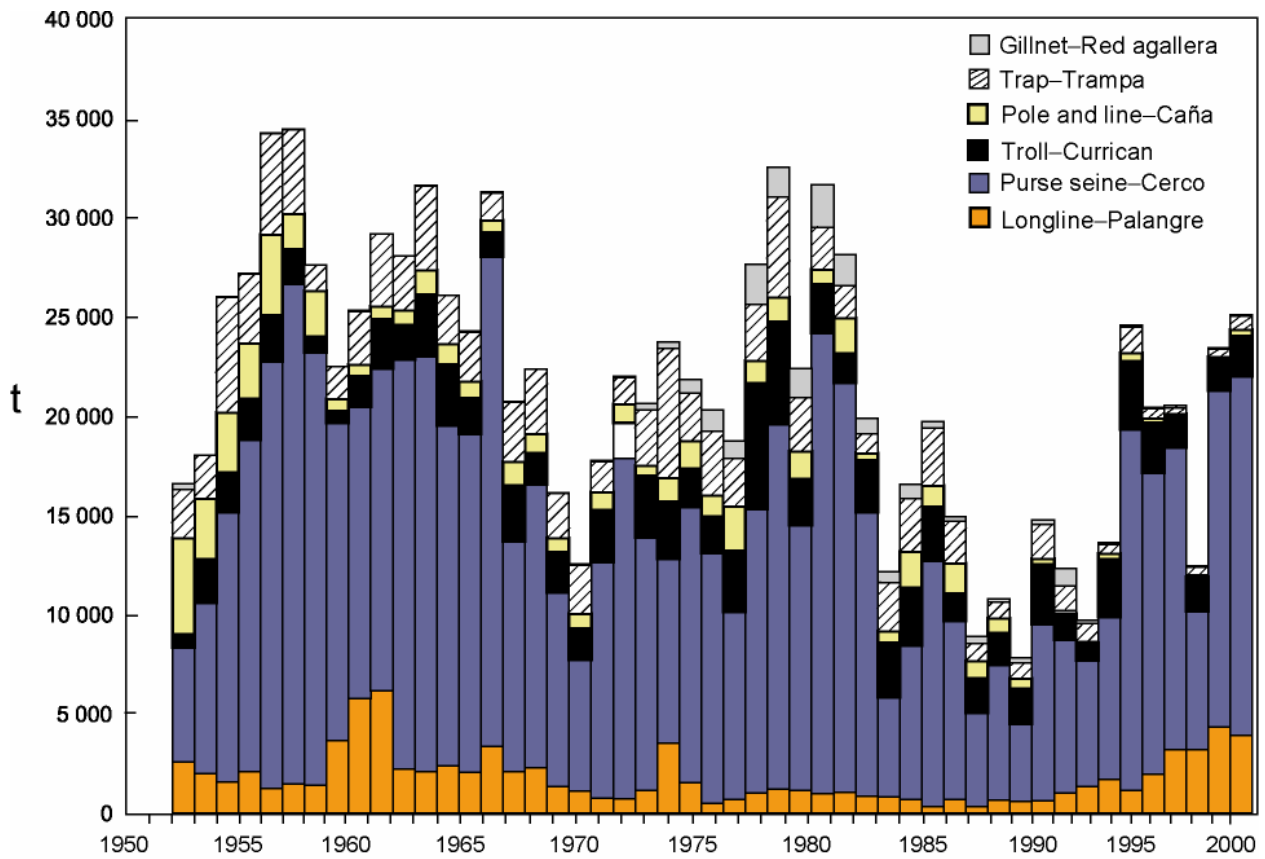


FIGURE E-1. Retained catches of Pacific bluefin, 1952-2000.
FIGURA E-1. Capturas retenidas de aleta azul del Pacífico, 1952-2000.

F. ALBACORE TUNA

Most scientists who have studied albacore in the Pacific Ocean have concluded that there are two stocks, one occurring in the northern hemisphere and the other in the southern hemisphere. Albacore are caught by longliners in most of the North and South Pacific, but not often between about 10°N and 5°S, by trollers in the eastern and central North Pacific and the central South Pacific, and by pole-and-line vessels in the western North Pacific. In the North Pacific about 62% of the fish are taken in surface fisheries that catch smaller, younger albacore, whereas only about 10% of the albacore caught in the South Pacific are taken by surface gears. Total annual catches of albacore from the North Pacific peaked in 1976 at about 125,000 t, and then declined. Catches recovered during the 1990s, and reached 121,500 t in 1999 (Figure F-1a). In the South Pacific, annual catches have ranged between about 25,000 and 55,000 t during the period since 1980 (Figure F-1b).

The juveniles and adults are caught mostly in the Kuroshio Current, the North Pacific Transition Zone, and the California Current in the North Pacific and the Subtropical Convergence Zone in the South Pacific, but spawning occurs in tropical and subtropical waters, centering around 20°N and 20°S latitude. North Pacific albacore are believed to spawn between March and July in the western and central Pacific.

The movements of North Pacific albacore are strongly influenced by oceanic conditions, and migrating albacore tend to concentrate along oceanic fronts in the North Pacific Transition Zone. The great majority are caught in waters between 15° and 19.5° C. Details of the migration remain unclear, but juvenile fish (2- to 5-year-olds) are believed to move into the eastern Pacific in the spring and early summer, returning to the western and central Pacific, perhaps annually, in the late fall and winter, and tending to remain there as they mature. It has been hypothesized that there are two subgroups of North Pacific albacore, separated at 40°N in the EPO, with the northern subgroup more likely to migrate to the western and central Pacific Ocean.

Less is known about the movements of albacore in the South Pacific Ocean. The juveniles move southward from the tropics when they are about 35 cm long, and then eastward along the Subtropical Convergence Zone to about 130°W. When the fish approach maturity they return to the tropics, where they spawn. Recoveries of tagged fish released in areas east of 155°W were usually made at locations to the east and north of the release site, whereas those of fish released west of 155°W were usually made at locations to the west and north of the release site.

New age-structured stock assessments were presented for the South and North Pacific stocks of albacore in 2003 and 2004, respectively.

The South Pacific assessment, carried out with MULTIFAN-CL by the Secretariat for the Pacific Community, incorporated catch and effort, length-frequency, and tagging data. The stock was estimated to be well above the level that would produce the average maximum sustainable yield (AMSY), and that yield would continue to increase with further increases in effort, though the extent to which yield could increase sustainably is not well determined. Although the recent recruitments are estimated to be slightly below average, there currently appears to be no need to restrict the fisheries for albacore in the South Pacific Ocean.

Virtual population analyses of the North Pacific stock of albacore were carried out during the 19th North Pacific Albacore Workshop in 2004. The estimated 2004 biomass, 438,000 t, was about 25% greater than that estimated for 1975, the first year of the period modeled. The estimated recruitments since 1990 have generally been greater than those of the 1980s, and the catches per unit effort for most of the surface fisheries have increased in recent years. However, longline catch rates have declined since the mid-1990s. The Workshop estimated low (0.43) and high (0.68) levels for fishing mortality (F) at full recruitment, and noted that if rates of F continue at assumed levels, it is unlikely that the spawning stock biomass (SSB) will rebuild to SSB_{MSY} levels within a 5-year time period.

The 2005 meeting of the International Scientific Committee gave the following advice:

“Future SSB can be maintained at or above the minimum ‘observed’ SSB (43,000 t in 1977) with F’s slightly higher than the current F range. However, the lowest ‘observed’ SSB estimates all occurred in late 1970’s and may be the least reliable estimates of SSB. A more robust SSB threshold could be based on the lower 10th or 25th percentile of ‘observed’ SSB. If so done, current F should maintain SSB at or above the 10th percentile threshold but a modest reduction from current F may be needed to maintain SSB at or above the 25th percentile threshold.”

We consider the higher level for current fishing mortality (0.68) to be more likely, based on the methods used to calculate the estimates. Furthermore, even the high estimate may be too low, given the retrospective bias shown by the model. Current fishing mortality of 0.68 implies an equilibrium spawning stock biomass at 17% of unfished levels. Projections assuming fishing mortality of 0.68, under low and high scenarios of future recruitment, suggest that the biomass may decline if current levels of fishing mortality persist.

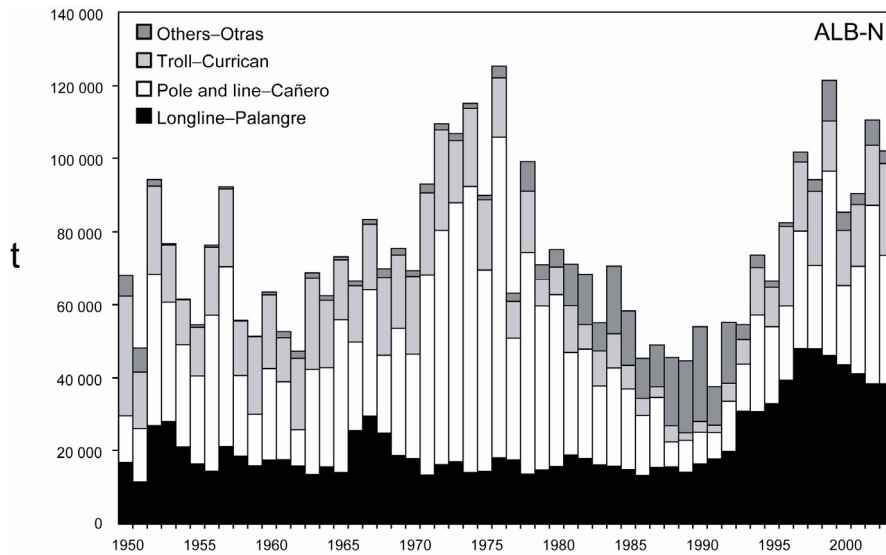


FIGURE F-1a. Retained catches of North Pacific albacore, 1950-2003.

FIGURA F-1a. Capturas retenidas de albacora del Pacífico norte, 1950-2003.

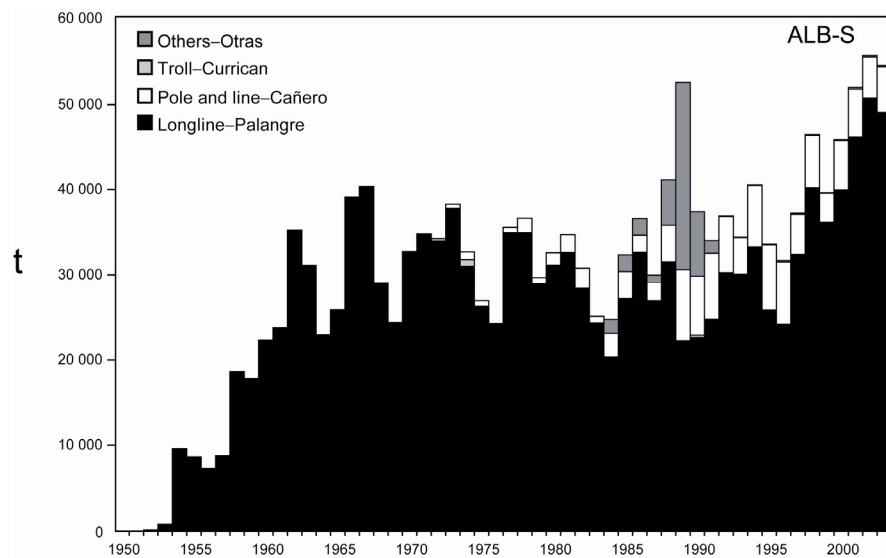


FIGURE F-1b. Retained catches of South Pacific albacore, 1950-2003.

FIGURA F-1b. Capturas retenidas de albacora del Pacífico sur, 1950-2003.

G. SWORDFISH

Swordfish (*Xiphias gladius*) occur throughout the Pacific Ocean between about 50°N and 50°S. They are caught mostly by the longline fisheries of Far East and Western Hemisphere nations. Lesser amounts are taken by gillnet and harpoon fisheries. They are seldom caught by recreational fishermen. During the most recent three-year period the greatest catches in the EPO have been taken by vessels of Spain, Chile, and Japan, which together harvested about 72% of the total swordfish catch taken in the region. Of these three, Spain and Chile have fisheries that target swordfish, while swordfish taken in the Japanese fishery are incidental catches in a fishery that predominately targets bigeye tuna. Other States with fisheries known to target swordfish are Mexico and the United States.

Swordfish reach maturity at about 5 to 6 years of age, when they are about 150 to 170 cm in length. They probably spawn more than once per season. Unequal sex ratios occur frequently. For fish greater than 170 cm in length, the proportion of females increases with increasing length.

Only fragmentary data are available on the movements of swordfish. They tend to inhabit waters further below the surface during the day than at night.

Swordfish tend to inhabit frontal zones. Several of these occur in the eastern Pacific Ocean (EPO), including areas off California and Baja California, off Ecuador, Peru, and Chile, and in the equatorial Pacific. Swordfish tolerate temperatures of about 5° to 27°C, but their optimum range is about 18° to 22°C. Swordfish larvae have been found only at temperatures exceeding 24°C.

It is considered, based on fisheries data, that there are two stocks of swordfish in the EPO, one with its center of distribution in the southeastern Pacific Ocean, and another with its center of distribution off California and Baja California. As well, there may be movement of a northwestern Pacific stock of swordfish into the EPO at various times. Results of genetic studies specifically undertaken to help resolve the question of stock structure are expected to be completed within the next few months.

Results of preliminary modeling with MULTIFAN-CL of a North Pacific swordfish stock in areas north of 10°N and west of 135°W indicate that in recent years the biomass level has been stable and well above 50% of the unexploited levels of stock biomass, implying that swordfish are not overexploited at current levels of fishing effort.

The standardized catch rates (CPUEs) of longline fisheries in the northern and southern regions of the EPO and trends in relative abundance obtained from them do not indicate declining abundances. Attempts to fit production models to the data failed to produce estimates of management parameters, such as average maximum sustained yield, under reasonable assumptions of natural mortality rates, due to lack of contrast in the trends. This lack of contrast suggests that the fisheries that have been taking swordfish in these regions have not been of a magnitude sufficient to cause significant responses in the populations. Based on these considerations, and the historically stable catches, it appears that swordfish are not overfished in the northern and southern regions of the EPO.

However, there have been increases in operations of and catches (Figure G-1) from fisheries that are targeting swordfish, particularly those gillnet and longline fisheries previously noted, and the stocks should be monitored closely for changes in trends in catch and catch rates. The average annual catch during 1998-2002 for the northern region has been about 4,800 t, and for the southern region about 9,100 t. It should be noted that catches in the southern region have doubled during this period, reaching 13,300 t in 2002, which exceeded the previously-recorded high catch of 12,400 t reported in 1991. At some point it would be a normal expectation that high levels of catch maintained over a period of time will result in reductions in CPUE.

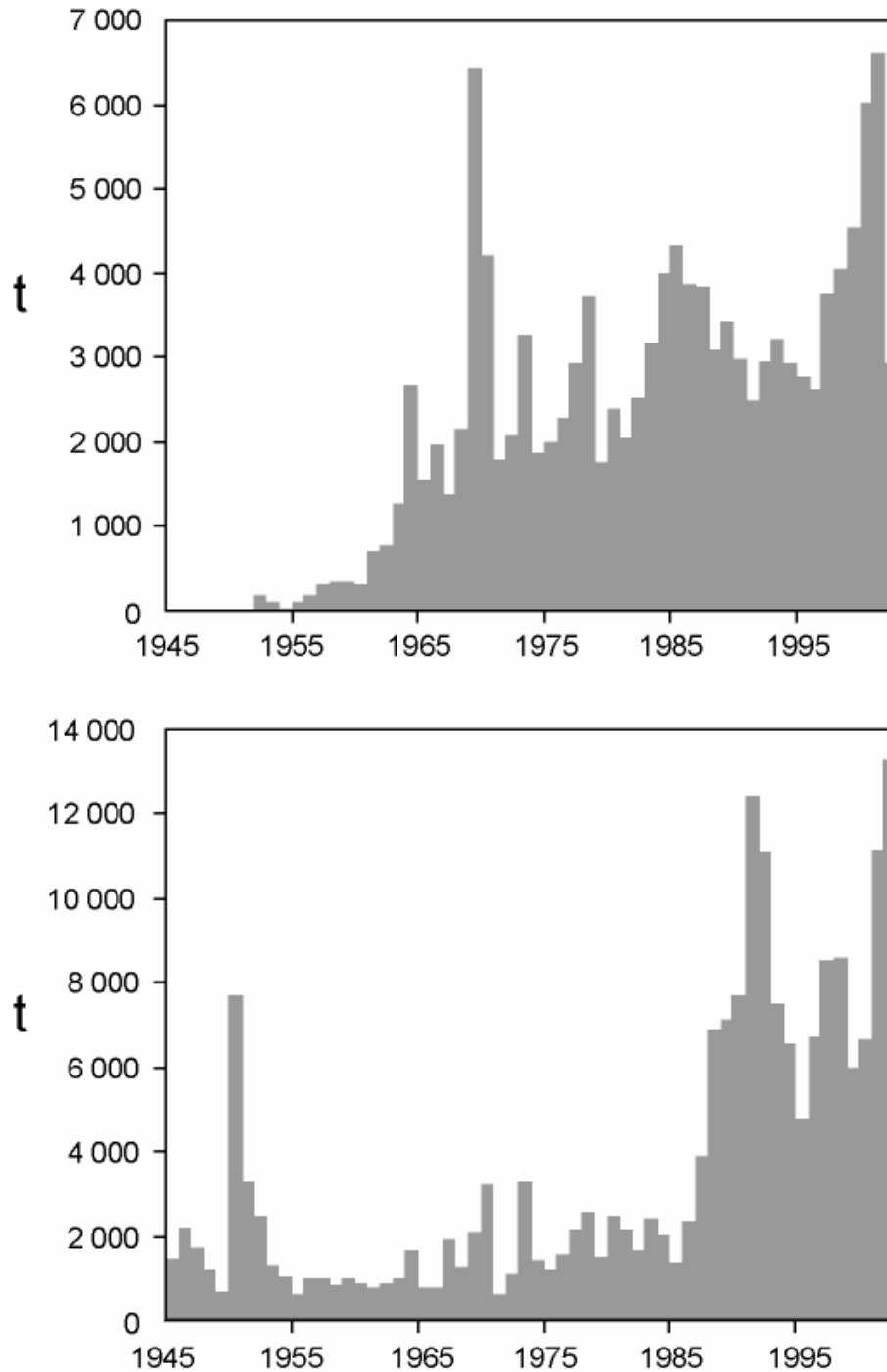


FIGURE G-1. Retained catches of swordfish in the northern (upper panel) and southern (lower panel) region of the eastern Pacific Ocean, 1945-2002.

FIGURA G-1. Capturas retenidas de pez espada en la región norte (recuadro superior) y sur (recuadro inferior) del Océano Pacífico oriental, 1945-2002.

H. BLUE MARLIN

The best knowledge currently available indicates that blue marlin (*Makaira nigricans*) constitutes a single world-wide species and that there is a single stock of blue marlin in the Pacific Ocean. For this reason, statistics on catches (Figure H-1) are compiled, and analyses of stock status are made, for the entire Pacific Ocean, even though it is important to know how catches in the eastern Pacific Ocean (Figure H-2) vary over time.

Blue marlin are taken by longline vessels of many nations that fish for tunas and billfishes between about 50°N and 50°S. Lesser amounts are taken by recreational fisheries and by various commercial surface fisheries.

Small numbers of blue marlin have been tagged, mostly by recreational fishermen, with conventional tags. A few of these fish have been recaptured long distances from the locations of release. In addition, blue marlin have been tagged with acoustic tags and their activities monitored for short periods.

Blue marlin usually inhabit regions where the sea-surface temperatures (SSTs) are greater than 24°C, and they spend about 90% of their time at depths in which the temperatures are within 1° to 2° of the SSTs.

The Deriso-Schnute delay-difference population dynamics model, a form of production model, was used to assess the status of the blue marlin stock in the Pacific Ocean. Data for the estimated annual total retained catches for 1951-1997 and standardized catch rates developed from catch and nominal fishing effort data for the Japanese longline fishery for 1955-1997 were used. It was concluded that the levels of biomass and fishing effort were near those required to maintain the average maximum sustainable yield (AMSY).

A more recent analysis, using MULTIFAN-CL, was conducted to assess the blue marlin stocks in the Pacific Ocean and to evaluate the efficacy of habitat-based standardization of longline effort. There is considerable uncertainty regarding the levels of fishing effort that would produce the AMSY. However, it was determined that blue marlin in the Pacific Ocean are close to fully exploited, *i.e.* that the population is near the top of the yield curve. It was also found that standardization of effort, using a habitat-based model, allowed estimation of parameters within reasonable bounds and with reduced confidence intervals about the estimates.

The fisheries in the EPO have historically captured about 10 to 18% of the total harvest of blue marlin from the Pacific Ocean, with captures in the most recent 5-year period averaging about 10% of the total harvest.

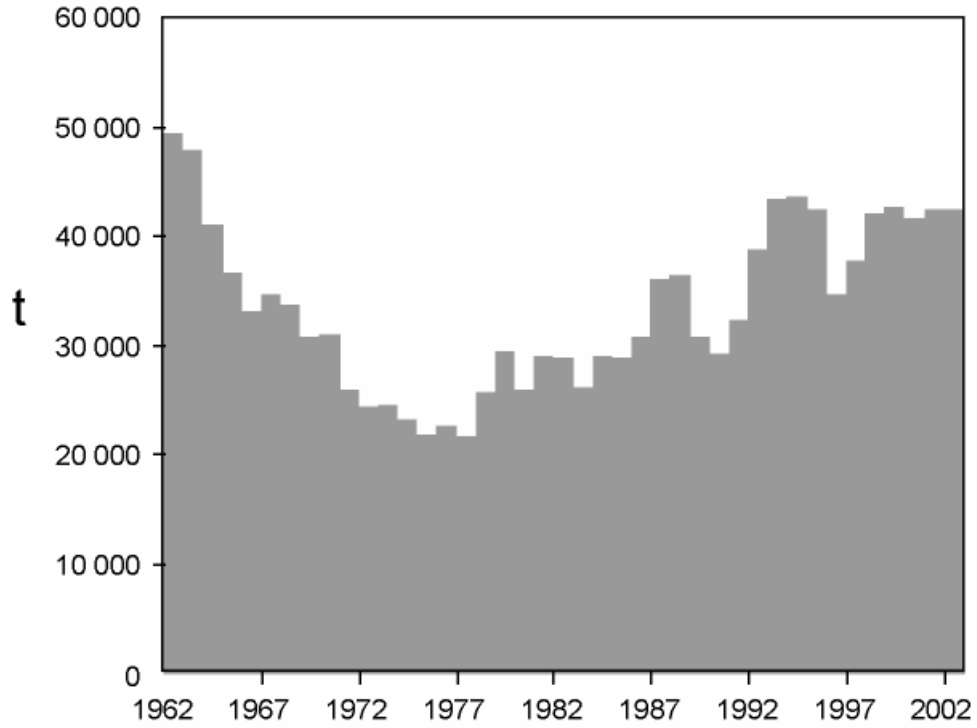


FIGURE H-1. Retained catches of blue marlin in the Pacific Ocean, 1962-2002.

FIGURA H-1. Capturas retenidas de marlín azul en el Océano Pacífico, 1962-2002.

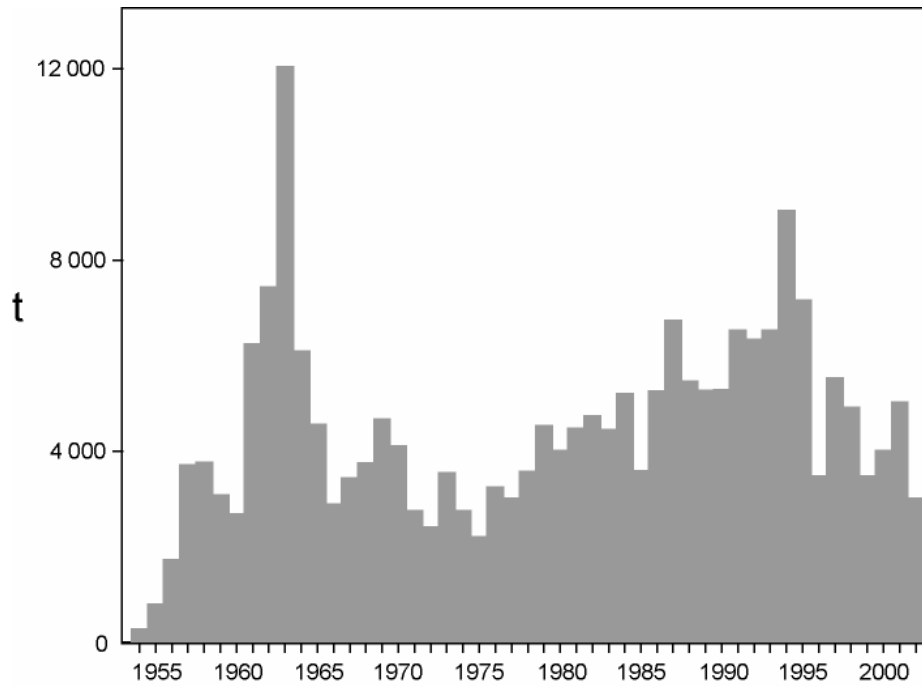


FIGURE H-2. Retained catches of blue marlin in the eastern Pacific Ocean, 1954-2002.

FIGURA H-2. Capturas retenidas de marlín azul en el Océano Pacífico oriental, 1954-2002.

I. STRIPED MARLIN

Striped marlin (*Tetrapturus audax*) occur throughout the Pacific Ocean between about 45°N and 45°S. They are caught mostly by the longline fisheries of Far East and Western Hemisphere nations. Lesser amounts are caught by recreational, gillnet, and other fisheries. During recent years the greatest catches (Figure I-1) in the eastern Pacific Ocean (EPO) have been taken by fisheries of Costa Rica, Japan, and the Republic of Korea.

Striped marlin reach maturity when they are about 140 cm long, and spawning occurs in widely-scattered areas of the Pacific Ocean.

The stock structure of striped marlin in the Pacific Ocean is not well known. There are indications that there is only limited exchange of striped marlin between the EPO and the central and western Pacific Ocean, so it is considered in this report that examinations of local depletions and independent assessments of the striped marlin of the EPO are meaningful. An analysis of trends in catch rates in subareas suggest that the fish in the EPO consist of one stock. Genetic studies have suggested that there are separate populations in the eastern and western South Pacific and that there may be a separate populations with centers of distribution in the regions proximate to Hawaii in the north-central Pacific and to Ecuador and to Mexico in the EPO. However, preliminary results of more recent analyses suggest that the fish in the Ecuador and Mexico region are from a single population.

Few tagging data are available for striped marlin. Most recaptures of tagged fish released off the tip of the Baja California peninsula have been made in the general area of release, but some have been recaptured around the Revillagigedo Islands, a few around Hawaii, and one near Norfolk Island.

Such being the case, the conclusions reached for a single-stock model, chosen on the basis of trends in catch rates, should be considered tentative, and efforts should be undertaken to resolve the question of stock structure of striped marlin in the EPO. To this end, a collaborative study to investigate the stock structure and status of striped marlin in the Pacific has been undertaken.

Standardized catch rates were obtained from a general linear model and from the statistical habitat-based standardization method. Analyses of stock status made using two production models, taking into account the time period when billfish were targeted by longline fishing in the EPO, were considered the most plausible. A Pella-Tomlinson model yielded estimates of the average maximum sustained yield (AMSY) in the range of 3,700 to 4,100 t, with a current biomass to be about 47% of the unfished biomass. The current biomass is estimated to be greater than the biomass that would produce the AMSY. An analysis, using the Deriso-Schnute delay-difference model, yielded estimates of AMSY in the range of 8,700 to 9,200 t, with current biomass greater than that needed to produce the AMSY and about 70% of the size of the unexploited biomass.

Landings and standardized fishing effort for striped marlin decreased in the EPO from 1990-1991 through 1998, and this decline has continued, with annual catches during 2000 to 2002 between about 1,500 and 2,200 t, levels that are well below estimated AMSY harvest levels. This may result in a continued increase in the biomass of the stock in the EPO.

The stock(s) of striped marlin in the EPO are apparently in good condition, with current and near-term anticipated fishing effort less than that required to produce the AMSY.

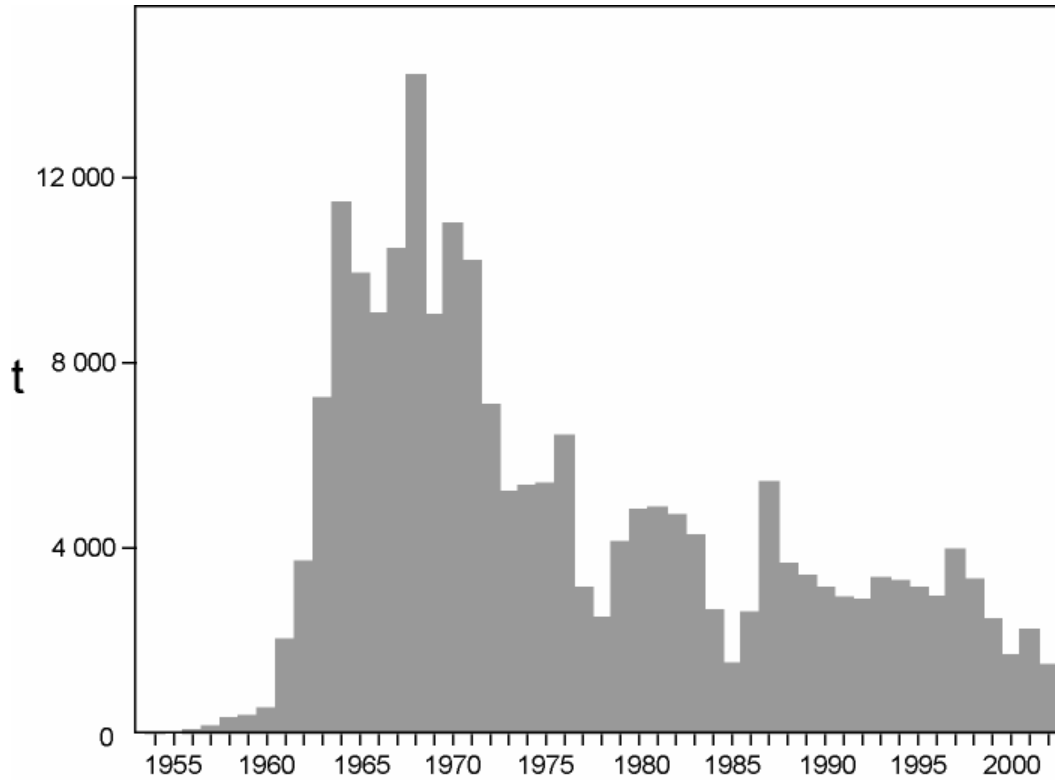


FIGURE I-1. Retained catches of striped marlin in the eastern Pacific Ocean, 1954-2002.

FIGURA I-1. Capturas retenidas de marlín rayado en el Océano Pacífico oriental, 1954-2002.

J. ECOSYSTEM CONSIDERATIONS

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1. INTRODUCTION

The FAO Code of Conduct for Responsible Fisheries provides that management of fisheries should ensure the conservation not only of target species, but also of the other species belonging to the same ecosystem. In 2001, the Reykjavik Declaration on Responsible Fisheries in the Ecosystem elaborated this standard with a commitment to incorporate an ecosystem approach into fisheries management.

The IATTC has taken account of ecosystem issues in many of its decisions, but until recently has not focused its attention on the entire ecosystem in which the target species, the tunas and billfishes, reside. This section provides a coherent view, summarizing what is known about the direct impact of the fisheries upon various species and species groups of the ecosystem, and reviews what is known about the environment and about other species that are not directly impacted by the fisheries. The purpose is to provide the Commission the opportunity to consider the ecosystem as a whole as part of its consideration of the status of the tuna and billfish stocks and management measures.

This review does not suggest objectives for the incorporation of ecosystem considerations into the management of tuna or billfish fisheries, nor any new management measures. Rather, its prime purpose is to offer the Commission the opportunity to ensure that ecosystem considerations are clearly part of its agenda.

It is important to remember that the view that we have of the ecosystem is based on the recent past; we have no information about the ecosystem before exploitation began. Also, the environment is subject to change on a variety of time scales, including the well-known El Niño fluctuations and more recently recognized longer-term changes, such as the Pacific Decadal Oscillation and other climate changes.

In addition to reporting the catches of the principal species of tunas and billfishes, the staff has reported the bycatches of other species that are normally discarded. In this section, data on these bycatches are presented in the context of the effect of the fishery on the ecosystem. Unfortunately, while relatively good information is available for the tunas and billfishes, information for the entire fishery is not available. The information is comprehensive for large (carrying capacity greater than 363 t) purse seiners that carry observers under the Agreement on the International Dolphin Conservation Program (AIDCP), and information on retained catches is also reported for other purse seiners, pole-and-line vessels, and much of the longline fleet. Some information is available on sharks that are retained by parts of the longline fleet. Information on bycatches and discards is also available for Class-6 and for some smaller purse seiners. There is yet little information available on bycatches and discards for other fishing vessels.

2. THE IMPACT OF CATCHES**2.1. Single-species assessments**

This section provides a summary of current information on the effect of the tuna fisheries on stocks of single species in the eastern Pacific Ocean (EPO). It focuses on the current biomass of each stock

considered, compared to what it might have been in the absence of a fishery. The intention is to show how the fishery may have altered the components of the ecosystem, rather than the detailed assessments, which can be found in other sections of this report and in other Commission documents. The section below frequently refers to comparisons with the unexploited stock size. The unexploited stock size normally must be estimated, and here is the stock size that would be produced in the absence of a fishery with the average recruitment observed during the period in which the stock was assessed. There are no direct measurements of the unexploited stock size, and, in any case, it would have varied from year to year.

2.1.1. Tunas

2.1.1.a Yellowfin

Since 1984 the yellowfin stock has been close to or above the level that would provide the average maximum sustainable yield. To meet this objective, the spawning stock size must be kept above 44% of its unexploited size with the current mix of fishing methods. One estimate of the effect of this reduced stock size is that the predation by yellowfin on other parts of the ecosystem is reduced to about 30% of what it was in the absence of a fishery.

2.1.1.b Skipjack

Skipjack assessments are far less certain than those for yellowfin and bigeye, in part because the fishery in the EPO does not appear to be having much impact on the stock. However, it appears that fluctuations in recruitment cause large variations in stock size. In 2003, the biomass was estimated to be about 60% of what it would have been in the absence of a fishery and under average conditions.

2.1.1.c Bigeye

Up to 1993 bigeye were taken mostly by longline fishing. The stock size in 1993 is estimated to have been 30% of its unexploited size. After 1993, purse seining for tunas associated with fish-aggregating devices (FADs) took significant quantities of small and medium-sized bigeye. Currently, after several years of poor recruitment and excessive levels of fishing mortality, the stock size is estimated to be at about 13% of its unexploited size. The biomass estimated for 2005 is near the lowest since 1975, the first year included in the model.

2.1.1.d Albacore

It is generally considered that there are two stocks of albacore in the Pacific Ocean, one in the North Pacific and the other in the South Pacific. A new assessment for South Pacific albacore, done by the Secretariat of the Pacific Community in 2003, showed that the South Pacific stock is at about 60% of its unexploited size. A new assessment by the North Pacific Albacore Workshop in 2004 indicated the North Pacific stock to be at about 45% of its unexploited size.

2.1.2. Billfishes

2.1.2.a Swordfish

The variations in standardized catch per unit of effort of swordfish in the northern and southern EPO show no trend, suggesting that catches to date have not affected the stocks significantly, though recent catches have been near record levels.

2.1.2.b Blue marlin

Recent stock assessments of blue marlin suggest that the current stock size is between 50% and 90% of the unexploited stock size.

2.1.2.c Striped marlin

A recent stock assessment of striped marlin suggests that the current stock size is about 50 to 70% of the

unexploited stock size.

2.1.2.d Black marlin, sailfish, and shortbill spearfish

No recent formal stock assessments have been made for these species, although there are some data presented in the IATTC Bulletin series published jointly by scientists of the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan and the IATTC that show trends in catches, effort, and catches per unit of effort.

2.2. Marine mammals

Marine mammals, especially spotted dolphins, spinner dolphins, and common dolphins, are frequently found associated with yellowfin tuna in the size range of about 10 to 40 kg in the EPO. Purse-seine fishermen have found that their catches of yellowfin in the EPO can be maximized by setting their nets around herds of dolphins and the associated schools of tunas, and then releasing the dolphins while retaining the tunas. The incidental mortality of dolphins in this operation was high during the early years of the fishery, but after the late 1980s it decreased precipitously. The mortalities of dolphins in the fishery in 2004 and published estimates of the abundances of the various stocks are shown in Table J-1.

Studies of the association of tunas with dolphins have been an important component of the staff's long-term approach to understanding key interactions in the ecosystem. The extent to which yellowfin tuna and dolphins compete for resources, or whether either or both of them benefits from the interaction, remain critical pieces of information, given the large biomasses of both groups and their high rates of prey consumption. Populations of dolphins involved in the purse-seine fishery were reduced from their unexploited levels during the 1960s and 1970s, and there is now some evidence of a slow recovery.

During 2003, scientists of the U.S. National Marine Fisheries Service (NMFS) conducted the latest in a series of research cruises under the *Stenella* Abundance Research Project (STAR). The primary objective of the multi-year study is to investigate trends in population size of the dolphins that have been taken as incidental catch by the purse-seine fishery in the EPO. During STAR 2003, data on cetacean distribution, herd size, and herd composition were collected aboard two research vessels, *David Starr Jordan* and *McArthur II*, to estimate dolphin abundance. These data are currently being analyzed.

Scientists of the NMFS have made estimates of the abundances of several other species of marine mammals based on data from research cruises made between 1986 and 2000 in the EPO. The STAR 2003 cruises will provide further estimates of abundance of these mammals. Of the species not significantly affected by the tuna fishery, short-finned pilot whales and three stocks of common dolphins showed increasing trends in abundance during that 15-year period. The apparent increased abundance of these mammals may have caused a decrease in the carrying capacity of the EPO for other predators that overlap in diet, including spotted dolphins. Bryde's whales also increased in estimated abundance, but there is very little diet overlap between these baleen whales and the upper-level predators impacted by the fisheries. Striped dolphins showed no clear trend in estimated abundance over time, and the estimates of abundance of sperm whales tended to decrease in recent years.

Some marine mammals are adversely affected by reduced food availability during El Niño events, especially in coastal ecosystems. Examples that have been documented include dolphins, pinnipeds and Bryde's whales off Peru, and pinnipeds around the Galapagos Islands. Large whales are able to move in response to changes in prey productivity and distribution.

2.3. Sea turtles

Sea turtles are caught on longlines when they take the bait on hooks, are snagged accidentally by hooks, or are entangled in the lines. Estimates of incidental mortality of turtles due to longline and gillnet fishing are few. It was reported that 166 leatherback and 6,000 other turtle species, mostly olive Ridley, were incidentally caught by Japan's longline fishery in the EPO during 2000 (4th meeting IATTC Working Group on Bycatch). Of these, 25 and 3,000, respectively, were dead. The mortality rates due to

longlining in the EPO are likely to be similar for other fleets targeting bigeye tuna, and possibly greater for those that set lines at shallower depths for albacore and swordfish. About 23 million of the 200 million hooks set each year in the EPO by distant-water longline vessels target swordfish with shallow longlines. In addition, there is a sizeable fleet of local longline vessels that fish for tunas and billfishes in the EPO.

Sea turtles are occasionally caught in purse seines in the EPO tuna fishery. Most interactions occur when the turtles associate with floating objects (for the most part FADs), and are captured when the object is encircled. In other cases, nets set around unassociated schools of tunas or schools associated with dolphins may capture sea turtles that happen to be at that location. The olive Ridley turtle is, by far, the species of sea turtle taken most often by purse seiners. It is followed by the black or green sea turtles, and, very occasionally, by the loggerhead and hawksbill turtles. Only one leatherback mortality has been recorded during the 10 years that IATTC observers have been recording this information. Some of the turtles are unidentified because they were too far from the vessel or it was too dark for the observer to identify them. Sea turtles, at times, become entangled in the webbing under FADs and drown. In some cases, they are entangled by the fishing gear and may be injured or killed. The estimated average annual mortalities of turtles caused by Class-6 purse-seine vessels during 1993-2003 were as follows: **TABLE TO BE UPDATED FOR 2004**

	Set type		
	Floating object	Unassociated	Dolphin
Olive Ridley	47.8	18.3	10.7
Black or eastern Pacific green	5.8	3.9	0.7
Loggerhead	0.6	1.2	0.1
Hawksbill	0.6	0.2	0.2
Leatherback	0.1	0.0	0.0
Unidentified	22.0	10.3	4.4
Total	76.8	33.8	16.1
Average number of sets	4,479	4,941	9,320

The mortalities of sea turtles due to purse seining for tunas are probably less than those due to other types of human activity, which include exploitation of eggs and adults, beach development, pollution, entanglement in and ingestion of marine debris, and impacts of other fisheries.

The populations of olive Ridley, black, and loggerhead turtles are designated as endangered, and those of the hawksbill and leatherback turtles as critically endangered, by the International Union for the Conservation of Nature.

2.4. Sharks and other large fishes

Sharks and other large fishes are taken by both purse-seine and longline vessels. Silky sharks are the most commonly-caught species of shark in the purse-seine fishery. Preliminary estimates of indices of relative abundance of large silky sharks based on the purse-seine data show a decreasing trend over the 1993-2003 period for each of the three types of purse-seine sets. It is not known whether this decreasing trend is due to the fisheries, changes in the environment (perhaps associated with the 1997-1998 El Niño), or other processes. The trend does not appear to be due to changes in the density of floating objects.

A stock assessment for blue sharks in the North Pacific has been conducted by the NMFS Honolulu Laboratory and the NRIFSF in Shimizu, Japan. Preliminary results provided a range of plausible values for maximum sustainable yield (MSY) of 1.8 to nearly 4 times the current catch of blue shark per year. This work indicates that under the 2001 fishing regime in the North Pacific, the blue shark population appears to be in no danger of collapse.

The average annual discards (in numbers) of sharks and other large fishes in the EPO during 1993-2004 (other than those discussed above) by large (carrying capacity greater than 363 t) purse-seine vessels are

as follows: **TABLE TO BE UPDATED FOR 2004**

	Set type		
	Floating object	Unassociated	Dolphin
Dorado	523,537	10,349	328
Wahoo	259,204	1,067	378
Rainbow runner and yellowtail	101,921	18,298	1,206
Sharks	37,011	6,957	3,930
Rays	239	3,250	796
Billfishes	1,921	1,107	946
Other large fishes	16,525	20,091	26

Apart from the assessments of billfishes, summarized in Sections G-I of this report, and blue shark there are no stock assessments available for these species in the EPO, and hence the impact of the bycatches on the stocks is unknown.

The catch rates of species other than tunas in the purse-seine fishery are different for each type of set. With a few exceptions, the bycatch rates are greatest in sets on floating objects, followed by unassociated sets and, at a much lower level, dolphin sets. Dolphin bycatch rates are greatest for dolphin sets, followed by unassociated sets and, at a much lower level, floating-object sets. The bycatch rates of sailfish, manta rays, and stingrays are greatest in unassociated sets, followed by dolphin sets and then floating-object sets. Because of these differences, it is necessary to follow the changes in frequency of the different types of sets to interpret the changes in bycatch figures. The estimated numbers of purse-seine sets of each type in the EPO during 1987-2004 are shown in Table A-6.

3. OTHER ECOSYSTEM COMPONENTS

3.1. Seabirds

There are approximately 100 species of seabirds in the tropical EPO. Some seabirds associate with subsurface predators, such as fishes (especially tunas) and marine mammals. Subsurface predators often drive prey to the surface to trap them against the air-water interface, where the prey become available to the birds. Most species of seabirds take prey within a half meter of the sea surface or in the air (flyingfishes and flying squid). In addition to driving the prey to the surface, subsurface predators make prey available to the birds by injuring or disorienting the prey and by leaving scraps after feeding on large prey. Feeding opportunities for some seabird species are dependent on the presence of tuna schools feeding at the surface.

Seabirds are affected by the variability of the ocean environment. During the 1982-1983 El Niño, seabird populations throughout the tropical and northeastern Pacific Ocean experienced breeding failures and mass mortalities, or migrated elsewhere in search of food. Some species, however, are apparently not affected by El Niño events. In general, seabirds that forage in upwelling areas of the tropical EPO and Peru Current suffer reproductive failures and mortalities due to food shortage during El Niño events, while seabirds that forage in areas less affected by El Niño may be relatively unaffected.

According to the *Report of the Scientific Research Program under the U.S. International Dolphin Conservation Program Act*, prepared by the NMFS in September 2002, there were no significant temporal trends in abundance estimates over the 1986-2000 period for any species of seabird, except for a downward trend for the Tahiti petrel, in the tropical EPO.

Some seabirds are susceptible to being caught on baited hooks in the pelagic longline fisheries. Data on the bycatch of black-footed albatross by the U.S. pelagic longline fishery in the central North Pacific Ocean have been analyzed, but comparable data for the longline fisheries in the EPO were not available. The IATTC is currently investigating the population status, while considering the effects of fisheries bycatch, of the black-footed albatross in the entire North Pacific.

3.2. Forage

The forage taxa occupying the middle trophic levels in the EPO are obviously an important component of the ecosystem, providing a link between primary production at the base of the food web and the upper-trophic-level predators, such as tunas and billfishes. The indirect effects of environmental variability are transmitted to the upper trophic levels through the forage taxa. Very little is known, however, about fluctuations in abundance of the large variety of prey species in the EPO. Scientists from the NMFS have recorded data on the distributions and abundances of common prey groups, including lanternfishes, flyingfishes, and some squids, in the tropical EPO during 1986-1990 and 1998-2000. Mean abundance estimates for all fish taxa, and to a lesser extent for squids, increased from 1986 through 1990. Estimates were low again in 1998, and then increased through 2000. Their interpretation of this pattern was that El Niño events in 1986-1987 and 1997-1998 had negative effects on these prey populations. More data on these taxa were collected during the NMFS STAR 2003 cruises, and are currently being analyzed.

Some small fishes, many of which are forage for the larger predators, are incidentally caught by purse-seine vessels in the EPO. Frigate and bullet tunas (*Auxis* spp.), for example, are a common prey of many of the animals that occupy the upper trophic levels in the tropical EPO. In the tropical EPO ecosystem model (Section 6), *Auxis* spp. comprise 10% or more of the diet of eight predator categories. Small quantities of frigate and bullet tunas are captured by purse-seine vessels on the high seas and by local artisanal fisheries in some coastal regions of Central and South America. The vast majority of *Auxis* spp. captured by tuna purse-seine vessels is discarded at sea. The estimated annual discards of small fishes on fishing trips of Class-6 purse-seine vessels with observers onboard in the EPO during 1993-2004 were as follows: **TABLE TO BE UPDATED FOR 2004**

	Units	Set type		
		Floating object	Unassociated	Dolphin
Triggerfishes and filefishes	numbers	719,287	5,102	3,453
Other small fishes	numbers	664,047	58,424	26,558
Frigate and bullet tunas (<i>Auxis</i> spp.)	metric tons	1,284.4	235.3	40.8

3.3. Larval fishes and plankton

Larval fishes have been collected by Manta (surface) net tows in the EPO for many years by personnel of the NMFS Southwest Fisheries Science Center. Of the 178 species identified, 17 taxa were found to be most likely to show the effects of environmental change. The occurrence, abundance, and distribution of these key taxa revealed no consistent temporal trends.

The phytoplankton and zooplankton populations in the tropical EPO are variable. For example, chlorophyll concentrations on the sea surface (an indicator of phytoplankton blooms) and the abundance of copepods were markedly reduced during the El Niño of 1982-1983, especially west of 120°W. Similarly, surface concentrations of chlorophyll decreased during the 1986-1987 El Niño and increased during the 1988 La Niña due to changes in nutrient availability.

The species and size composition of zooplankton is often more variable than zooplankton biomass. When water temperatures increase, warm-water species often replace cold-water species at particular locations. The relative abundance of small-sized copepods off northern Chile, for example, increased during the 1997-1998 El Niño, while the zooplankton biomass did not change.

4. TROPHIC INTERACTIONS

Tunas and billfishes are wide-ranging, generalist predators with high energy requirements, and as such, are key components of pelagic ecosystems. Ecological relationships among large pelagic predators, and between them and animals at lower trophic levels, are not well understood. Given the need to evaluate the implications of fishing activities on the underlying ecosystems, it is essential to acquire a reliable understanding of the trophic structure in open-ocean ecosystems, and the natural variability forced by the

environment.

Knowledge of the trophic ecology of predator fishes has historically derived from diet studies. Tunas that feed inshore utilize different prey than those caught offshore. For example, yellowfin and skipjack caught off Baja California feed heavily on red crabs (*Pleuroncodes planipes*). The most-common prey item for yellowfin tuna caught by purse-seine offshore are frigate tunas (*Auxis* spp.), squids and argonauts (cephalopods), and flyingfishes and other epipelagic fishes. Bigeye tuna feed at greater depths than yellowfin and skipjack, and utilize primarily cephalopods and mesopelagic fishes. The most important prey of skipjack are euphausiid crustaceans. Recently, diet studies have become focused on understanding resource partitioning among the predator communities, comprising tunas, sharks, billfishes, dorado (*Coryphaena* spp.), wahoo (*Acanthocybium solandri*), rainbow runner (*Elagatis bipinnulata*), and others, captured by purse-seine. In general, considerable resource partitioning occurs among the components of these communities. Diet overlap is greater for yellowfin caught in sets associated with dolphins than for yellowfin caught in other types of sets, due primarily to *Auxis* spp. being a common prey.

Stomach contents, however, provide only a relative snapshot of the most recent meal at the time of day an animal is captured, and under the conditions required for its capture. A more-recent method utilizes stable isotopes of carbon and nitrogen to investigate trophic relations. Stable carbon and nitrogen isotopes integrate information on all components of the diet into the animal's tissues, providing a recent history of trophic interactions and information on the structure and dynamics of ecological communities. This technology is now being applied in the pelagic EPO, and preliminary results suggest that potentially important components of the food web may not be represented in diet analyses of the principal predators.

5. PHYSICAL ENVIRONMENT¹

Environmental conditions affect marine ecosystems, the dynamics and catchability of tuna and billfish stocks, and the operations of the fishermen. Tunas and billfishes are pelagic fishes during all stages of their lives, and the physical factors that affect the tropical and sub-tropical Pacific Ocean can have important effects on their distribution and abundance. Environmental conditions are thought to cause considerable variability in the recruitment of tunas and billfishes. Stock assessments by the IATTC have often included the assumption that oceanographic conditions might influence recruitment in the EPO.

Different types of climate perturbations may impact fisheries differently. It is thought that the shallow thermocline in the EPO contributes to the success of purse-seine fishing for tunas, perhaps by acting as a thermal barrier to schools of small tunas, keeping them near the sea surface. When the thermocline is deep, however, as during an El Niño event, tunas seem to be less vulnerable to capture and catch rates have declined. Warm sea-surface temperatures (SSTs) can also cause these mobile fishes to move to more favorable habitat.

The ocean environment varies on a variety of time scales, from seasonal to interannual, decadal, and longer (e.g. climate phases or regimes). The dominant source of variability in the upper layers of the EPO is often called the El Niño-Southern Oscillation (ENSO). The ENSO is an irregular fluctuation involving the entire tropical Pacific Ocean and global atmosphere. It results in variations of the winds, rainfall, thermocline depth, circulation, biological productivity, and in the feeding and reproduction of fishes, birds, and marine mammals. El Niño events occur interannually at 2- to 7-year periods, and are characterized by weak trade winds, a deep thermocline, and abnormally high SSTs in the equatorial EPO. El Niño's opposite phase, often called La Niña, is characterized by strong trade winds, a shallow thermocline, and low SSTs. Research has documented a connection between ENSO and the rate of

¹ Much of the information in this section is from Fiedler, P.C. 2002. Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability. Mar. Ecol. Prog. Ser. 244: 265-283.

primary production, phytoplankton biomass, and phytoplankton species composition. Upwelling of nutrient-rich subsurface water is reduced during El Niño episodes, leading to a marked reduction in primary and secondary production. ENSO also directly affects animals at middle and upper trophic levels. Researchers have concluded that the 1982-1983 El Niño, for example, deepened the thermocline and nutricline, decreased primary production, reduced zooplankton abundance, and ultimately reduced the growth rates, reproductive successes, and survival of various birds, mammals, and fishes in the EPO. In general, however, the ocean inhabitants recover within a short time because their life histories are adapted to respond to a variable habitat.

Variability on a decadal scale (*i.e.* 10 to 30 years) also affects the EPO. In the late 1970s in the North Pacific, there was a major shift in physical and biological states. This climate shift was also detected in the tropical EPO, by small increases in SSTs, weakening of the trade winds, and a moderate change in surface chlorophyll levels. Some researchers have reported another major shift in the North Pacific in 1989. Climate-induced variability in the ocean has often been described in terms of “regimes” characterized by relatively stable means and patterns in the physical and biological variables. Analyses by the IATTC have indicated that the yellowfin tuna population in the EPO has experienced two different recruitment regimes (1975-1984 and 1985-present). The yellowfin population has been in a high-recruitment regime, which produced greater biomass levels, for approximately the last 16 years. The increased recruitment is thought to be due to a shift to a higher productivity regime in the Pacific Ocean. Decadal fluctuations in upwelling and water transport occur simultaneous to the higher-frequency ENSO pattern and have basin-wide effects on SSTs and thermocline slope that are similar to those caused by ENSO, but on longer time scales.

Environmental variability in the tropical EPO is manifested differently in different regions in which tunas are caught. For example, SST anomalies in the tropical EPO warm pool (5° to 20°N, east of 120°W) have been about one-half the magnitude and several months later than those in the equatorial Pacific NIÑO3 area (5°S to 5°N, 90° to 150°W).

6. AGGREGATE INDICATORS

Recognition of the consequences of fishing for marine ecosystems has stimulated much research in recent years. Researchers ask how the use of performance measures and reference points might be expanded to help meet the objectives of ecosystem-based fisheries management. Whereas reference points to date have been used primarily for single-species management of target species, applying performance measures and reference points to non-target species is believed to be a tractable first step. Current examples include incidental mortality limits for dolphins in the EPO purse-seine fishery under the AIDCP. Another area of interest is whether useful performance indicators based on ecosystem-level properties might be developed. Several ecosystem metrics or indicators, including community size structure, diversity indices, species richness and evenness, overlap indices, catch trophic spectra, relative abundance of an indicator species or group, and numerous environmental indicators, have been proposed. Whereas there is general agreement that multiple system-level indicators should be used, there is concern over whether there is sufficient practical knowledge of the dynamics of such metrics and whether a theoretical basis for identifying precautionary or limit reference points based on ecosystem properties exists. Ecosystem-level metrics are not yet commonly used for managing fisheries.

Food web diagrams are useful for representing the structure and flows of ecosystems. Trophic levels (TLs) are used in food-web ecology to characterize the functional role of organisms and to facilitate estimates of energy or mass flow through communities. A simplified food-web diagram, with approximate TLs, of the pelagic tropical EPO is shown in Figure J-1. Toothed whales (average TL 5.2), large squid predators (large bigeye tuna and swordfish, average TL 5.2) and sharks (average TL 5.0) are top-level predators. Other tunas, large piscivores, dolphins, and seabirds occupy slightly lower TLs. Smaller epipelagic fishes (*e.g.* *Auxis* spp. and flyingfishes), cephalopods, and mesopelagic fishes are the principal forage of many of the upper-level predators in the ecosystem. Small fishes and crustaceans prey

on two zooplankton groups, and the herbivorous microzooplankton (TL = 2) feed on the producers, phytoplankton and bacteria (TL = 1).

In exploited pelagic ecosystems, fisheries that target large piscivorous fishes act as the ecosystem's apex predators. Over time, fishing can cause the overall size composition of the catch to decline, and, in general, TLs of smaller organisms are lower than those of larger organisms. The mean trophic level of the organisms taken by a fishery is a potentially useful metric of ecosystem change and sustainability because it integrates an array of biological information about the components of the system. There has been increasing attention to analyzing the mean TL of fisheries catches and discards since a study demonstrated that, according to FAO landings statistics, the mean TL of the fishes and invertebrates landed globally had declined from 1950 to 1994. Some ecosystems, however, have changed in the other direction, from low TL communities to higher TL communities. Given the potential utility of this approach, TLs were estimated for a time series of annual catches and discards from 1993 to 2004 for three purse-seine fishing modes and the pole-and-line fishery in the EPO. The estimates were made by applying the TLs from the EPO ecosystem model (see Section 7), weighted by the catch data by fishery and year for all model groups from the IATTC tuna, bycatch, and discard data bases. The TLs of the summed catches of all purse-seine and pole-and-line fisheries were fairly constant from year to year (Figure J-2: Average PS+LP). The TL of the floating-object sets varied more than those of the other fisheries, due to the interannual variability in the sizes of the tunas caught and the species compositions of the bycatches in those sets.

TLs were also estimated separately for the time series of retained and discarded catches by year for the purse-seine fishery from 1993 to 2004 (Figure J-3). The TLs of the retained catches were quite stable from year to year, while the TLs of the discarded catches varied considerably. The greatest variation occurred for sets on unassociated fish. A low TL of the discarded catches by sets on unassociated fish in 1998 was due to increased bycatches of rays, which feed on plankton and other small animals that occupy low TLs. From 1998 to 2001, the discarded catches of rays gradually declined and those of large sharks increased, resulting in a gradually increasing TL of the discarded catches over that interval. To a lesser degree, the average TLs of the discarded catches of sets on floating objects also increased from 1998 to 2001. That increase was due primarily to increasing bycatches of large wahoo and small dorado.

7. ECOSYSTEM MODELING

It is clear that the different components of an ecosystem interact. The best way to describe the relationships and explore their effects is through ecosystem modeling. Our understanding of this complex maze of connections is at an early stage, and, consequently, the current ecosystem models are most useful as descriptive devices for exploring the effects of a mix of hypotheses and established connections among the ecosystem components. Ecosystem models must be compromises between simplistic representations on the one hand and unmanageable complexity on the other.

The IATTC staff has developed a model of the pelagic ecosystem in the tropical EPO (IATTC Bulletin, Vol. 22, No. 3) to explore how fishing and climate variation might affect the animals at middle and upper trophic levels. The ecosystem model has 38 components, including the principal exploited species (*e.g.* tunas), functional groups (*e.g.* sharks and flyingfishes), and sensitive species (*e.g.* sea turtles). Some taxa are further separated into size categories (*e.g.* large and small marlins). The model has finer taxonomic resolution at the upper trophic levels, but most of the system's biomass is contained in the middle and lower trophic levels. Fisheries landings and discards were estimated for five fishing "gears," pole-and-line, longline, dolphin sets by purse seiners, floating-object sets by purse seiners, and sets on unassociated schools by purse seiners. The model focuses on the pelagic regions; localized, coastal ecosystems are not adequately described by the model.

Most of the information describing inter-specific interactions in the model comes from a joint IATTC-NMFS project, which included studies of the food habits of co-occurring yellowfin, skipjack, and bigeye tuna, dolphins, pelagic sharks, billfishes, dorado, wahoo, rainbow runner, and others. The impetus of the

project was to contribute to the understanding of the tuna-dolphin association, and a community-level sampling design was adopted.

The ecosystem model has been used to evaluate the possible effects of variability in bottom-up forcing by the environment on the middle and upper trophic levels of the pelagic ecosystem. Predetermined time series of producer biomasses were put into the model as proxies for changes in primary production that have been documented during El Niño and La Niña events, and the dynamics of the remaining components of the ecosystem were simulated. The model was also used to evaluate the relative contributions of fishing and the environment in shaping ecosystem structure in the tropical pelagic EPO. This was done by using the model to predict which components of the ecosystem might be susceptible to top-down effects of fishing, given the apparent importance of environmental variability in structuring the ecosystem. In general, animals with relatively low turnover rates were influenced more by fishing than by the environment, and animals with relatively high turnover rates more by the environment than by fishing.

8. ACTIONS BY THE IATTC AND AIDCP ADDRESSING ECOSYSTEM CONSIDERATIONS

Both the IATTC and the AIDCP have objectives that address the incorporation of ecosystem considerations into the management of the tuna fisheries in the EPO. Actions taken in the past include:

8.1. Dolphins

- a. For many years, the impact of the fishery on the dolphin populations has been assessed, and programs to reduce or eliminate that impact have met with considerable success.
- b. The incidental mortality of each stock of dolphins has been limited to levels that are insignificant relative to stock sizes.
- c. Studies to determine why tunas associate with dolphins have been carried out.

8.2. Sea turtles

- a. A data base on all sea turtle sightings, captures, and mortalities reported by observers has been compiled.
- b. At its 70th meeting in June 2003, the IATTC adopted a Recommendation on Sea Turtles, which contemplates “the development of a three-year program that could include mitigation of sea turtle bycatch, biological research on sea turtles, improvement of fishing gears, industry education and other techniques to improve sea turtle conservation.” In January 2004, the Working Group on Bycatch drew up a detailed program that includes all these elements and urges all nations with vessels fishing for tunas in the EPO to provide the IATTC with information on interactions with sea turtles in the EPO, including both incidental and direct catches and other impacts on sea turtle populations. A resolution on a three-year program to mitigate the impact of tuna fishing on sea turtles was adopted by the 72nd meeting of the IATTC in June 2004. The resolution includes requirements for data collection, mitigation measures, industry education, capacity building and reporting.
- c. A resolution on releasing and handling of sea turtles captured in purse seines was adopted.
- d. A resolution on netting attached underwater to FADs was adopted.
- e. A resolution prohibiting disposing of plastic containers and other debris at sea was adopted.
- f. In response to a request made by the Subsecretaria de Recursos Pesqueros of Ecuador, the IATTC began a program, supported by the World Wildlife Fund and the U.S. to mitigate the incidental capture of sea turtles, to reduce the mortality of sea turtles due to longline fishing, and to compare the catch rates of tunas, billfishes, and dorado using circle and J hooks of two sizes. Circle hooks, compared to the J hooks currently used in the longline fishery, do not hook as many turtles, and

the chance of serious injury to the sea turtles that bite the hooks is reduced because they are wider and they tend to hook the lower jaw, rather than the more dangerous deep hookings in the esophagus and other areas, which are more common with the J hooks. Improved procedures and instruments to release hooked and entangled sea turtles have also been disseminated to the longline fleets of the region. In 2004, observers recorded data on more than 60 fishing trips of the vessels that are testing the different hooks. In addition, workshops and presentations were conducted by IATTC staff and others in Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Panama, and Peru.

8.3. Other species

- a. A resolution on live release of sharks, rays, billfishes, dorado, and other non-target species was adopted.
- b. A resolution directing the Director to seek funds for reduction of incidental mortality of juvenile tunas, for developing techniques and equipment to facilitate release of billfishes, sharks, and rays from the deck or the net, and to carry out experiments to determine the survival rates of released billfishes, sharks, and rays was adopted.

8.4. All species

- a. Data on the bycatches by Class-6 purse-seine vessels are being collected, and governments are urged to provide bycatch information from other vessels.
- b. Data on the spatial distributions of the bycatches and the bycatch/catch ratios have been collected for analyses of policy options to reduce bycatches.
- c. Information to evaluate measures to reduce the bycatches, such as closures, effort limits, *etc.*, has been collected.
- d. Assessments of habitat preferences and the effect of environmental changes have been made.

9. FUTURE DEVELOPMENTS

It is unlikely, in the near future at least, that there will be stock assessments for most of the bycatch species. In lieu of formal assessments, it may be possible to develop indices to assess trends in the status of these species. The IATTC staff's experience with dolphins suggests that the task is not trivial if relatively high precision is required.

An array of measures has been proposed to study changes in ecosystem properties. This could include studies of average trophic level, size spectra, dominance, diversity, *etc.*, to describe the ecosystem in an aggregate way.

The distributions of the fisheries for tunas and billfishes in the EPO are such that several regions with different ecological characteristics may be included. Within them, water masses, oceanographic or topographic features, influences from the continent, *etc.*, may generate heterogeneity that affects the distributions of the different species and their relative abundances in the catches. It would be desirable to increase our understanding of these ecological strata so that they can be used in our analyses.

It is important to continue studies of the ecosystems in the EPO. The power to resolve issues related to fisheries and the ecosystem will increase with the number of habitat variables, taxa and trophic levels studied and with longer time series of data.

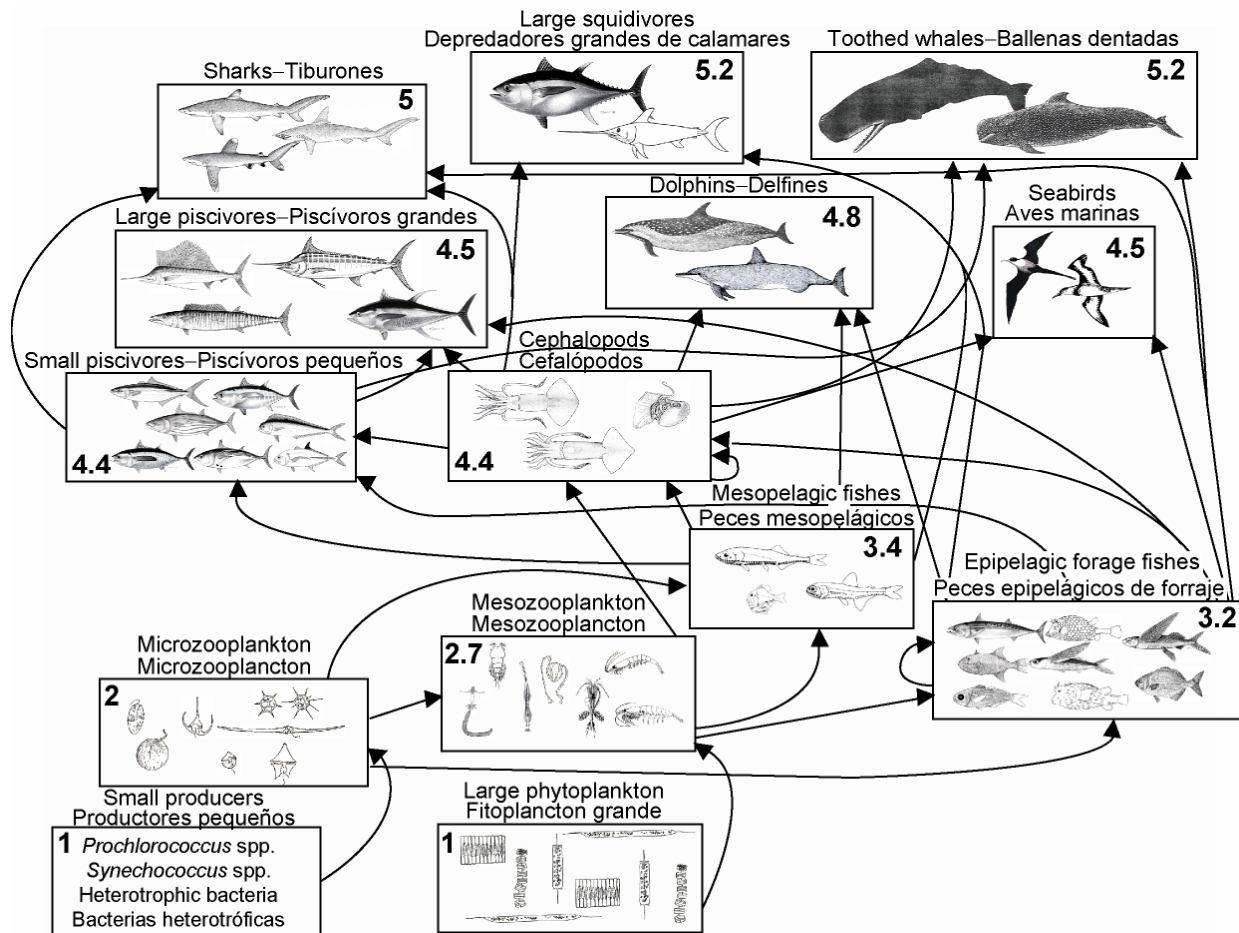


FIGURE J-1. Simplified food-web diagram of the pelagic ecosystem in the tropical eastern Pacific Ocean. The numbers inside the boxes indicate the approximate trophic levels of each group.

FIGURA J-1. Diagrama simplificado de la red trófica del ecosistema pelágico en el Océano Pacífico oriental tropical. Los números en los recuadros indican el nivel trófico aproximado de cada grupo.

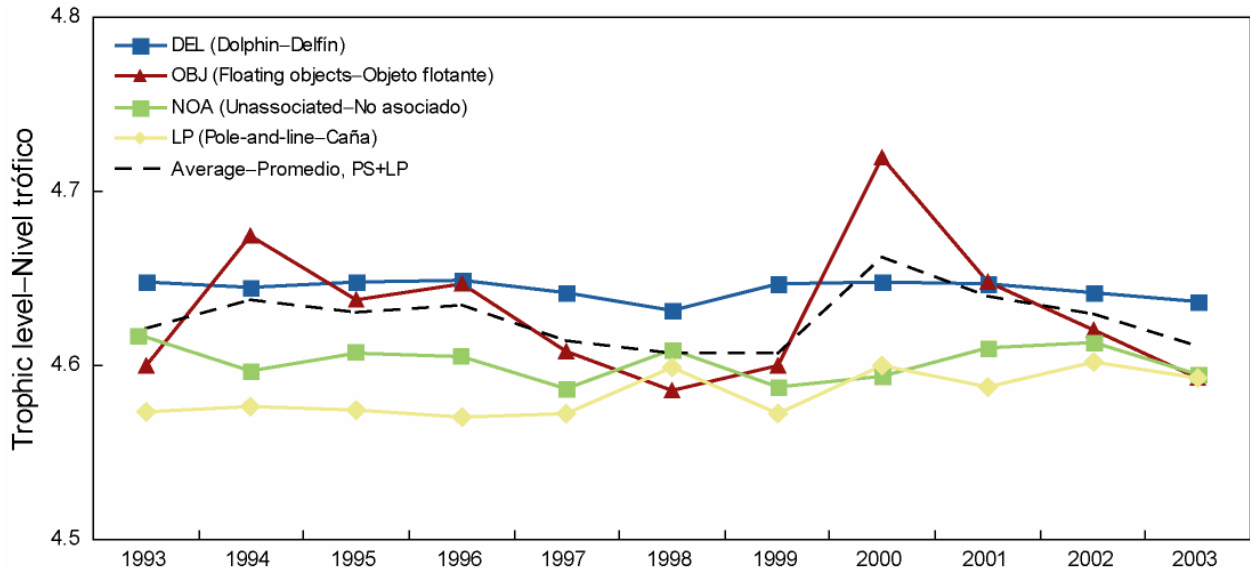


FIGURE J-2. FIGURE TO BE UPDATED FOR 2004 Yearly trophic level estimates of the catches (retained and discarded) by the purse-seine and pole-and-line fisheries in the tropical eastern Pacific Ocean.
FIGURA J-2. Estimaciones anuales del nivel trófico de las capturas (retenidas y descartadas) de las pesquerías cerquera y cañera en el Océano Pacífico oriental tropical.

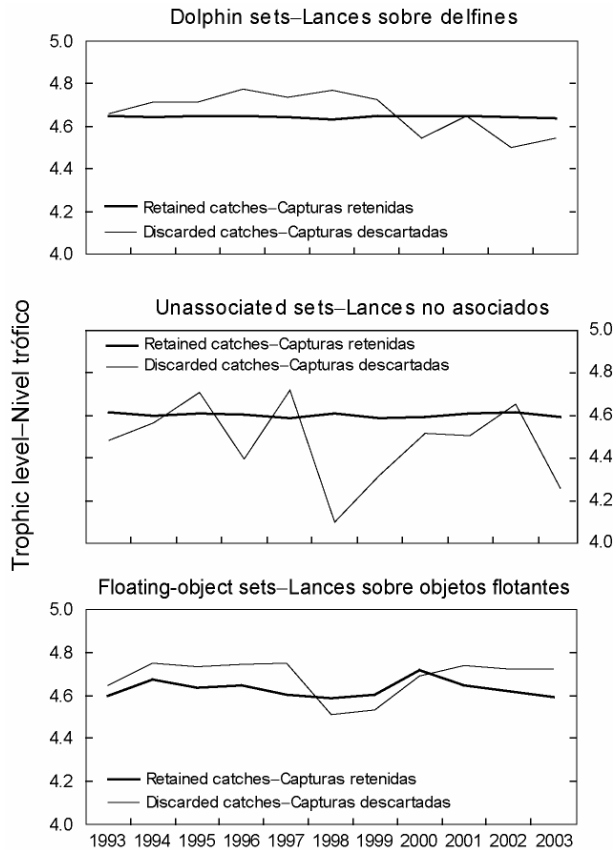


FIGURE J-3. FIGURE TO BE UPDATED FOR 2004 Trophic level estimates of the retained catches and discarded catches by purse-seine fishing modes in the tropical eastern Pacific Ocean.
FIGURA J-3. Estimaciones del nivel trófico de las capturas retenidas y descartadas por modalidad de pesca cerquera en el Océano Pacífico oriental tropical.

TABLE J-1. TABLE TO BE UPDATED FOR 2004 Preliminary estimates of mortalities of dolphins in 2004, population abundance pooled for 1986-1990 (from Report of the International Whaling Commission, 43: 477-493), and relative mortality (with approximate 95% confidence intervals), by stock. **TABLA J-1.** Estimaciones preliminares de la mortalidad incidental de delfines en 2004, la abundancia de poblaciones agrupadas para 1986-1990 (del Informe de la Comisión Ballenera Internacional, 43: 477-493), y la mortalidad relativa (con intervalos de confianza de 95% aproximados), por población..

Species and stock	Incidental mortality	Population abundance	Relative mortality (%)
Especie y población	Mortalidad incidental	Abundancia de la población	Mortalidad relativa (%)
Offshore spotted dolphin—Delfín manchado de altamar			
Northeastern—Nororiental	281	730,900	0.04 (0.030, 0.050)
Western/southern—Occidental y sureño	333	1,298,400	0.03 (0.020, 0.037)
Spinner dolphin—Delfín tornillo			
Eastern—Oriental	287	631,800	0.05 (0.028, 0.069)
Whitebelly—Panza blanca	169	1,019,300	0.02 (0.010, 0.022)
Common dolphin—Delfín común			
Northern—Norteño	133	476,300	0.03 (0.016, 0.060)
Central	140	406,100	0.03 (0.018, 0.068)
Southern—Sureño	99	2,210,900	<0.01 (0.003, 0.007)
Other dolphins—Otros delfines ¹	59	2,802,300	<0.01 (0.001, 0.002)
Total	1,501	9,576,000	0.02 (0.014, 0.018)

¹ "Other dolphins" includes the following species and stocks, whose observed mortalities were as follows: striped dolphins (*Stenella coeruleoalba*), 11; bottlenose dolphins (*Tursiops truncatus*), 4; shortfin pilot whale (*Globicephala macrorhynchus*), 2; coastal spotted dolphins, 15; and unidentified dolphins, 27.

¹ "Otros delfines" incluye las siguientes especies y poblaciones, con las mortalidades observadas correspondientes: delfín listado (*Stenella coeruleoalba*), 11; tonina (*Tursiops truncatus*), 4; ballena piloto (*Globicephala macrorhynchus*), 2; delfín manchado costero, 15; y delfines no identificados, 27.