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A COMPREHENSIVE REVIEW AND PROPOSED INVESTIGATION OF THE AGE, GROWTH, AND REPRODUCTIVE BIOLOGY OF BIGEYE TUNA IN THE PACIFIC OCEAN

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Executive Summary

The 3rd session of the Western and Central Pacific Fisheries Commission Scientific Committee recommended that a project on bigeye growth and reproductive biology be implemented to help reduce uncertainty in these parameters to improve the precision of stock assessments. The Fourth Regular Session of the Commission in December 2007 endorsed funding to prepare a comprehensive research plan on Pacific-wide bigeye growth and reproductive biology. This document articulates this plan. The review of information demonstrates considerable knowledge uncertainty in the WCPO with information from the central Pacific scant and an investigation of age, growth, and reproductive biology of bigeye is required. Existing information however supports the hypothesis that reproductive and growth parameters used in the current stock assessment models are strongly influenced by prevailing oceanography and variation in estimates can be expected both in longitudinal and latitudinal dimensions. Analysis of the sensitivity of the reproductive parameters used in stock assessment demonstrates that current knowledge uncertainty has influence on spawning biomass and biomass reference points and the F multiplier. Variation in growth rate was less influential. The research plan outlines important hypotheses, experimental design considerations, preferred methods, sampling strategy, expected timelines and projected budget (split by RFMO jurisdictions) for implementing a Pacific-wide study to reduce current reproductive and growth uncertainties for bigeye. The importance of collaboration and co-operation between all WCPFC members, participating territories, and co-operating non-member Countries will be critical to the effective implementation of the research plan. Options for fine and coarse scale resolution of data are presented. Implementation of the study will take four years after 2 year pilot study is completed. The pilot study is proposed for the EEZ's of Palau and Micronesia in Region 3 of the WCPO stock assessment model. A determination of sampling requirements for the broader Pacific-wide phase 2 of the study will occur at the completion of the pilot study.

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1.0 Introduction

1.1 Background

Bigeye tuna inhabit tropical and subtropical waters of the Pacific, Indian and Atlantic Oceans. In the Pacific ocean, bigeye are exploited between northern Japan (40°N) and the north island of New Zealand (40°S) in the west, and from 40°N to 30°S in the east, except near coastal waters of Central America between 5° and 20°N (Miyabe 1994, Hampton et al. 1998). Two approaches have been used for modelling the population dynamics of bigeye in the Pacific Ocean; a single Pacific–wide model (Hampton and Maunder 2005); and a two stock model, east and west of 150ºW (Anonymous 2008, Hampton et al. 2006). The existence of a single genetic stock is supported by the continuous distribution of catches of bigeye across the equatorial Pacific Ocean (Figure 1). Further, a number of movements >1,000 nautical miles have been observed from bigeye tagging programs (Figure 2, Anonymous 2008, Hampton and Williams 2005, Schaefer and Fuller 2005). This has included recoveries by longliners fishing in the EPO of bigeye tagged in the western Pacific. In addition, genetic work by Grewe and Hampton (1998) did not identify subdivisions of bigeye throughout the Pacific Ocean.

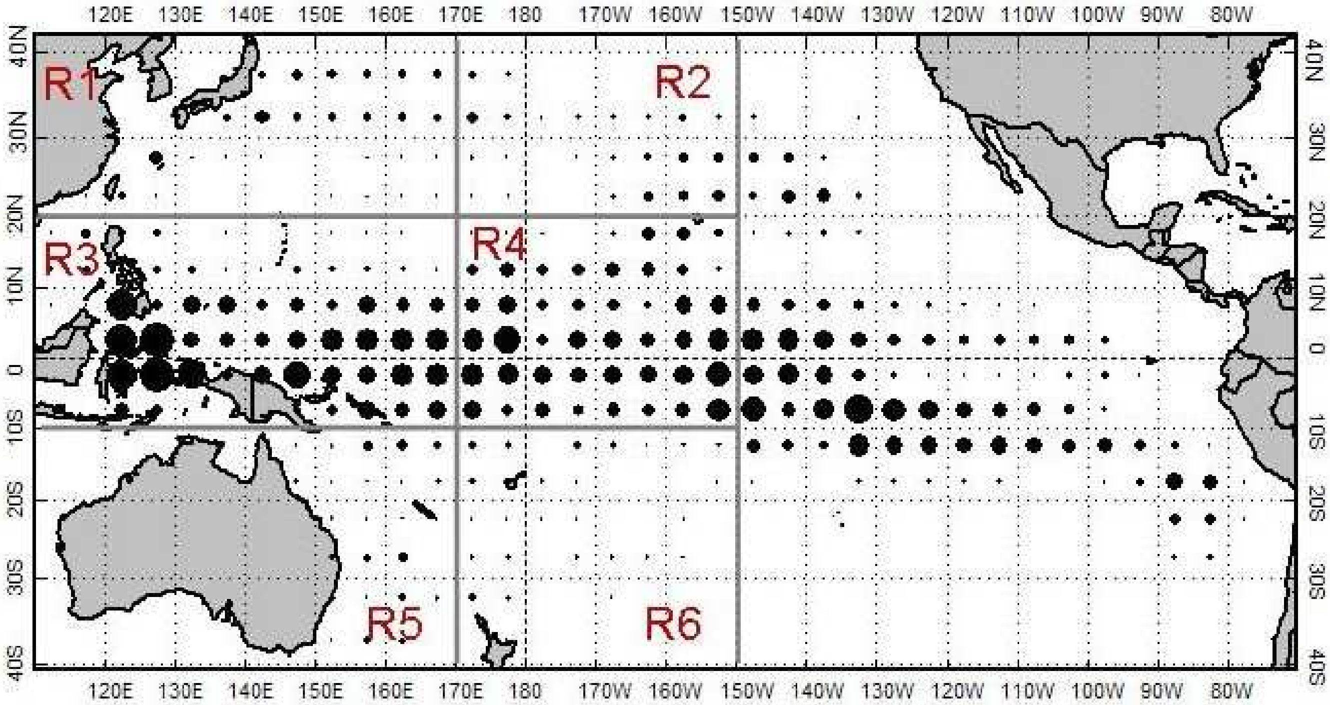


Figure 1. Distribution of total bigeye catches, 1990–2006. Source: SPC data. The six-region spatial stratification used in the 2006 MULTIFAN-CL analysis is also shown.

However, in addition to the practicalities of splitting the Pacific into a two-stock model aligned according to the jurisdiction of the fisheries management commissions, there is ecological support for modeling the regions separately. Archival tagging studies in the EPO have not identified long-distance movement between the WCPO and EPO, despite times at liberty of up to 446 and an individual’s movement path estimated to be 32,500 km (Schaefer and Fuller, 2002). No tagged bigeye moved more than 20º of longitude or 10º of latitude throughout the study, suggesting localised populations of bigeye (Schaefer and Fuller 2002), similar to the conclusion of Farley et al. (2006) for bigeye in the Coral Sea. Larvae were also reported as rare between 180º and 150°W suggesting that spawning may be limited in this central region.

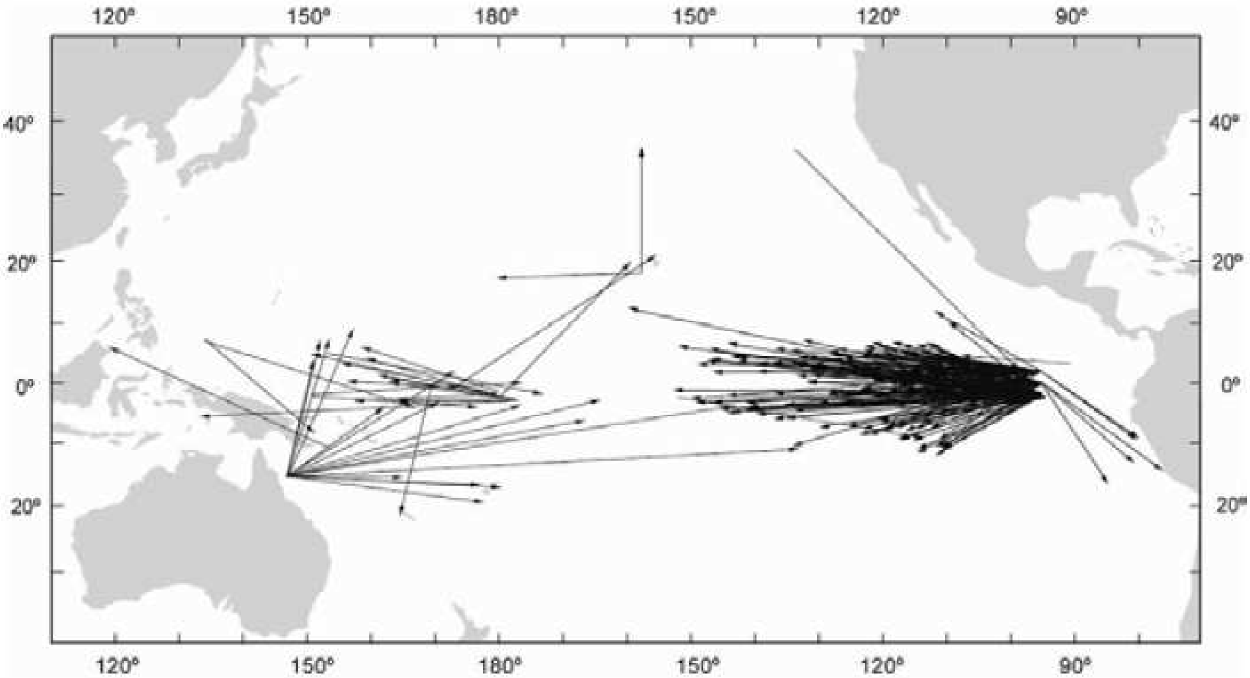


Figure 2. Long distance movement (greater than 1000 nm) of tagged bigeye in the Pacific Ocean. Source, Anonymous. (2008)

Since 2000, approximately 53–66% of total weights of WCPO catches of bigeye have been recorded by longline methods fisheries (Williams and Reid 2007). Most bigeye in longline catches are greater than 70 cm FL (Williams and Reid 2007) and are highly valuable. The purse-seine fishery in the WCPO also captures significant quantities of bigeye, accounting for 20–33% of annual bigeye catches since 2000 (Williams and Reid 2007), with almost all bigeye reported from sets associated with FADs or logs (Molony 2004). In contrast to longline catches, most bigeye in purse-seine catches are less than 70 cm FL (Figure 3). Other fisheries also record significant catches of bigeye. Fisheries of Indonesia and the Philippines reported annual catches of a similar magnitude to catches from the WCPO purse-seine fishery. The pole-and-line fishery of the WCPO reports very low catches of bigeye (less than 3% of total catches). Dependent on their length BET specimens can be easily identified using external diagnostic features including lateral markings, lengths and shapes of pectoral fins, and the second dorsal and anal fins (Schaefer 1999). Small bigeye (~50 cm FL) however can be confused with small yellowfin tuna, especially in purse-seine catches and potential for under-reporting of small bigeye has been raised (Lawson 2002, 2008).

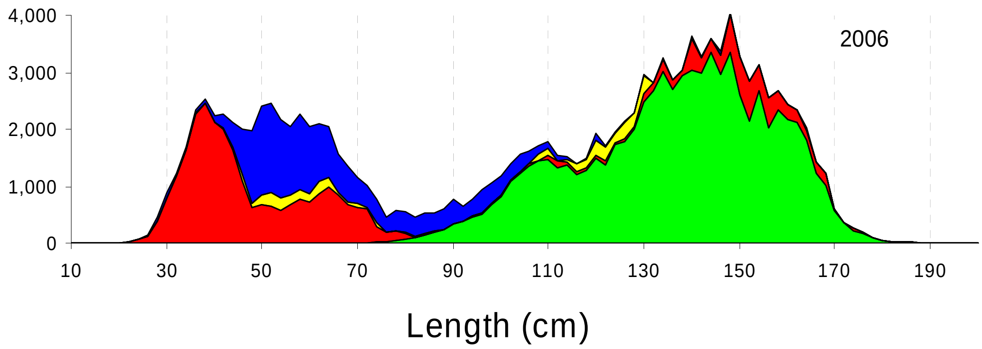


Figure 1. Annual catches of bigeye tuna in metric tonnes in the WCPO by 2 cm length class and fishery method, 2006. Source, Williams and Reid (2007). Fishery codes: green, longline; blue, purse-seine fisheries on associated schools (logs, FADs etc); yellow, purse-seine on unassociated schools (free schools); red, fisheries of Indonesia and the Philippines.

Stock assessments of bigeye tuna have been routinely undertaken for the western and central Pacific Ocean (WCPO), eastern Pacific Ocean (EPO), and more recently Pacific-wide. The most recent assessment (Hampton et al. 2006) indicates that there is a high likelihood that the bigeye stock in the WCPO is experiencing overfishing. That is, the recent (2001–2004) levels of fishing mortality (effort) are greater than the levels estimated to obtain MSY. It is estimated that a 25% reduction in fishing mortality is required to reduce fishing mortality to the level estimated to achieve MSY. Although the bigeye stock in the WCPO is not currently overfished, there is a high risk that it could be moved into an overfished state if the current level of fishing mortality is maintained. The recent recruitment of bigeye in the WCPO is higher than the long-term average. If the recruitment declines to average levels (as has recently occurred in the EPO), a greater reduction in effort would be required to maintain fishing mortality at levels required to achieve MSY.

1.2 Synopsis of Current Knowledge

Size at Maturity

The methods used in the small number of studies of bigeye maturity vary from visual macroscopic examinations at sea (Farley et al. 2006) to more rigorous examinations using histological methods in the laboratory (Schaefer et al. 2005, Sun et al. 2006). Maturity of bigeye is most accurately indicated by the presence of hydrated oocytes in the ovarian lumen or microscopically observed post-ovulatory follicles of recent age or for the male, by a variety of visual observations of the testis (Nikaido et al. 1991). Macroscopic examination of the gonads is inadequate in many instances for determining the maturity status of female tunas and thus creates biases in deriving maturity schedules (Schaefer 2001). It is problematic to compare estimates of maturity for BET from various regions in the Pacific or elsewhere, if the same methodology has not been applied for estimation of maturity. However, available data appears to indicate there is spatial variability in the estimated lengths at 50% for females between the western and eastern Pacific Ocean (Table 1). There has been little sampling of fish from 140E to 150W and consequently the maturity schedule is unknown for this central region (Figure 3). It is worth noting that there has been no comprehensive study of bigeye maturity across the distribution of bigeye in the Pacific Ocean.

It is unclear whether maturation of tunas is best regarded as a function of length or age (Schaefer 2001), but in other fish species both can be important (Heino et al. 2002). Environment undoubtedly plays an important role as well. Sea surface temperatures are on average much lower in the EPO compared to the tropical WCPO that may depress maturity schedules of EPO residing bigeye, resulting in larger, older fish at L_{min}. It has been suggested that bigeye maturity, or the development into an active spawning condition may be more linked to surface layer sea temperatures above 26° C (Mohri 1998). Kume (1967) noted a correlation between mature but sexually inactive bigeye at SSTs below 23° to 24°C, which appears to represent a lower limit to bigeye spawning activity. The Coral Sea study (Farley et al. 2003, 2006) is the only study reviewed where the methods document that age, length and maturity information were collected from the same individuals, but their analysis does not examine the interaction between these three variables. At an individual level, maturation may be influenced by growth history (Morita and Fukuwaka 2006), body condition (Grift et al. 2007), population density and environmental conditions (Policansky 1983). In addition, average age and size at maturation may change through time due to selection pressure from fishing. Farley et al. (2006) also articulate that there is some evidence to suggest that bigeye maturity estimates vary depending on the depth that fish are sampled and consequently gear may be an important component of bias in estimates. This hypothesis is explained by mature fish moving to the surface to spawn when temperatures are ≥26°C where they are caught by surface fisheries, whereas less mature fish remain in the cooler and deeper waters where they are caught by deeper-set fisheries (Hisada 1973). However, we know from archival tag data that bigeye in all states of maturity are consistently shallow within the mixed layer at night and during the daytime even when bigeye are exhibiting their classical deep scattering layer foraging behavior they are required to make upward excursions into the mixed layer in order to thermoregulate (Brill et al. 1999, Schaefer and Fuller 2002, Evans et al. 2008). These observations do not support the hypothesis of Hisada (1973) as an explanation for the differences observed. Overall, the limited spatial and temporal coverage of studies to date has limited the ability to examine the influence of these effects on the bigeye maturation schedule.

Table 1 Estimates of maturity at length/age.

Study	Method	Location	Estimate
Farley et al. 2003, Farley et al. 2006	Macroscopic n = 635 ovaries	Australia (east coast)	L_{min}=80 cm FL L_{50}= 102.4 cm FL females (Age_{2+} = 80%; Age_{3+}= 20%) L_{50}= 86.6 cm FL males (Age_{1+}= 86%; Age_{2+}= 14%)
Nikaido et al. 1991 (Secondary citation used)	NA	11°-13°N, 163°-176°W	Most over 100 cm sexually mature
Kikawa 1962 (Secondary citation used)	NA	NA	Few sexually mature females < 100 cm
Kikawa 1953 (Secondary citation used)	NA	NA	L_{min}= 90-100 cm
Kikawa 1957, 1961 (Secondary citation used)	NA	NA	L_{min}= 101-105 cm FL male L_{min}= 91-95 cm FL female
Kume 1962	NA	NA	Running ripe Female 93 cm
Schaefer et al. 2005	Histological N = 683 ovaries	EPO	L_{min}=102 cm FL females (age 2+, Schaefer and Fuller 2006) L_{50}=135 cm FL females (age 3+, Schaefer and Fuller 2006)
Sun et al. 2006; Chi-Lu Sun unpubl. data	Histological n= 380 gonads	Philippines	L_{min}=99.7 cm FL females (age 3+, Sun et al. 2002) L_{50}=105 cm FL females (age 3+, Sun et al. 2002)
Yuen 1955 (Secondary citation used)		Marshall Is Line Is (Kiribati) Hawaiian Is	L_{min}= 90-100 cm FL

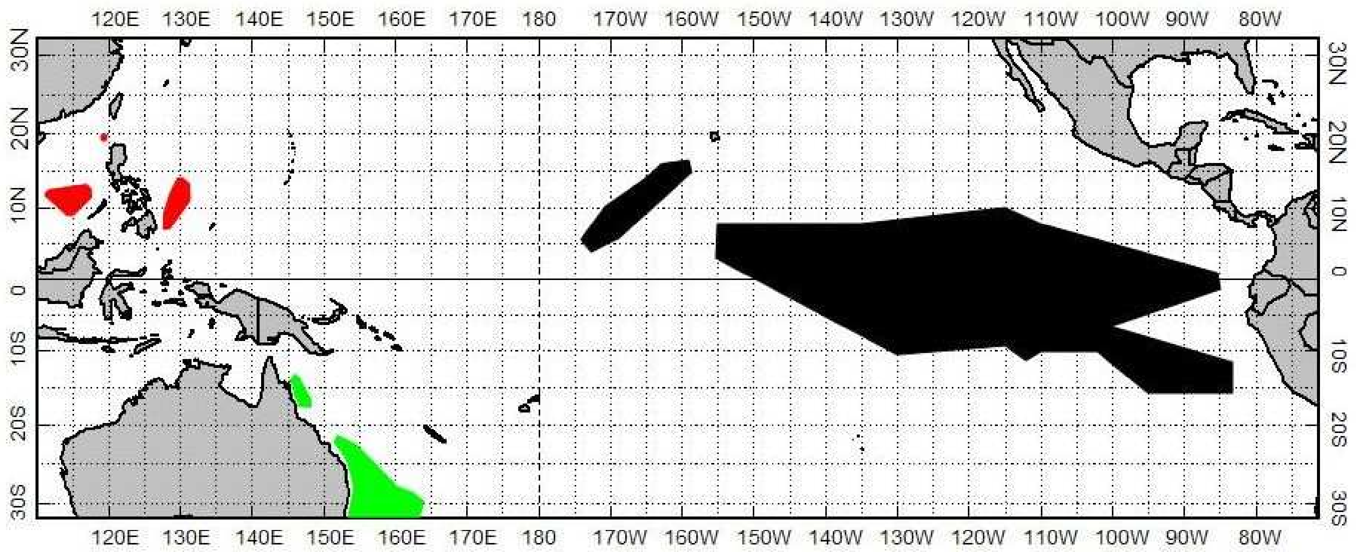


Figure 3. Location of recent studies on bigeye where reproductive parameters have been estimated; Schaefer et al. 2005 (black); Farley et al. 2006 (green); Sun et al. 2006 (red).

Spawning Area and Season

The consensus from published studies is bigeye spawn throughout the year in tropical regions (10°N - 10°S) and possibly only during summer months in sub-equatorial regions (Table 2). It can be assumed that bigeye spawning and larval development are common at SSTs above 26°C, but may occur in some regions with surface mixed layers of 23°-24°C and above.

Table 2 Estimates of spawning area and season.

Study	Method	Location	Estimate
Sun et al. 2006	Spawning Season - determined by monthly variations in the mean GSI, the average mean diameter of the oocytes at the most advanced stage, and the proportion of specimens in various ovarian maturing stages n=380 females	Philippines	Spawning occurred throughout the year with a peak season in February to September.
Farley et al. 2003 Farley et al. 2006	Microincremental otolith analysis and macroscopic maturity observations	Australia (east coast)	Spawning Season= Birth dates back calculated from otoliths for 36 fish were February to July. Mature females predominantly caught in Oct-Dec in 2000 and 2001 indicating this as a spawning period. Information and methods insufficient to determine if seasonal or continual spawning
Schaefer et al. 2005	Spawning season = postovulatory follicles or hydrated or migratory nucleus oocytes	EPO	Spawning Season = Continual spawning (15°N - 15°S; 105°W - 175°W). Spawning occurred from 24°C to 30°C. The percentages of females classified as spawning were higher at SSTs greater than 28°C.
Nikaido et al. 1991	Secondary citation used which did not provide method & location details		noted bigeye in active spawning condition in May - July
Yuen 1955	Ovary sampling Results were considered preliminary due to restricted sample sizes and periods	Marshall Is Line Is (Kiribati) Hawaiian Is Sampling period (Apr–Oct)	Spawning Season = Continual Spawning fpr equatorial samples. Two peak spawning periods observed: Jan-Feb and July-Oct. A large data set from the Hawaiian Islands revealed no bigeye tuna in spawning condition

Sex ratio

Information on sex ratio of bigeye by area in the published literature are incomplete and somewhat inconsistent (Figure 3) though there is general agreement that males are more abundant, particularly in the larger size classes (Table 3). Unpublished information collected through port and observer sampling has resolved some of these spatial coverage issues for the western and central Pacific Ocean (Hoyle et al. 2008). In addition to variation in sex ratio with size there is also evidence of spatial variation (Hoyle et al. 2008). Sex will be an important co-variate for analysis of other reproductive parameters used in stock assessment and consequently should be part of the meta-data collected when sampling other tissue from individuals.

Fecundity

Batch fecundity rather than annual fecundity is estimated for bigeye as they spawn numerous times in a season or year and their potential annual fecundity exceeds the number of oocytes within the ovaries at any given time (Hunter et al. 1985). Batch fecundity can only be estimated in bigeye at the final stages of oocyte maturation (migratory nucleus and hydrated oocytes) when there is a distinct break in the distribution of oocytes from which batch fecundities can be derived (Schaefer 2001). Estimates of batch fecundity through other methods are likely to be upwardly biased (Schaefer 2001). In addition to these methodology issues, there is likely to be only a short period of time when ovaries can be sampled from bigeye when migratory nucleus and hydrated oocytes are found. In yellowfin, this was from late afternoon until immediately prior to spawning (Schaefer 2001). Bigeye spawning has been estimated to occur between 1900 h and 0400 h (Schaefer et al. 2005), which in most situations would preclude the use of purse-seine samples in batch fecundity estimates.

In the Pacific Ocean batch fecundity estimates are limited to 3 published studies that have applied appropriate methods (Table 4). There is a large discrepancy between estimates from the Philippines area (Sun et al. 2006) and the EPO (Schaefer et al. 2005) with oocytes per gram of body weight higher in the Philippines than that reported for the EPO. The variance reported in these studies however is high and it is plausible that there is no difference in batch fecundities. Nikaido (1991) estimated batch fecundity from a few western Pacific Ocean samples that were similar to those for few from EPO. No information is reported in the published literature for the central Pacific region.

Table 3 Estimates of sex ratio.

Study	Method	Location	Male:female ratio
Sun et al. 2004 Sun et al. 2006	Gonad examination n=888 female= 380(85-174 cm FL) male =508 (88-174 cm FL)	Philippines (Taiwanese longline)	146 + cm FL males predominant
Farley et al. 2003	gonads n=1376	Australia (east coast)	Coral Sea = males predominant (1.24:1) Qld/NSW = no bias detected
Schaefer et al. 2005	Gonads n=1986 (purse seine) n=124 (longline)	EPO	Males predominant in 80-84.9 cm FL; 90-94.9 cm FL; 115-119.9 cm FL; 130-134.9 cm FL increments

Table 4 Estimates of batch fecundity.

Study	Method	Location	Estimate
Sun et al. 2006	Gravimetric n=129 females	Philippines	Batch fecundity = No. migratory-nucleus stage oocytes $BF=8.815x10^{-4}FL^{4.419}$ and $BF=6.153x10^{3}W^{1.543}$ where BF = batch fecundity in number of oocytes; FL = fork length in centimeters; and W= body weight in kilograms.
Nikaido et al. 1991		11°- 13°N, 163°- 176°W	batch fecundities 1M-5M/ spawn for fish 120 to 180 cm 31 oocytes per gram of body weight
Schaefer et al. 2005	Gravimetric n=7 females	EPO	Batch fecundity = No. migratory-nucleus stage oocytes Mean = 23.7 oocytes per gram of body weight (95% CI = 14.1 to 33.3). Length to Batch fecundity relationship (126 cm FL=622718; 128 cm FL=925019; 130 cm FL=834438; 136 cm FL=884841; 142 cm FL=1776074; 145 cm FL=2965049; 148 cm FL=2152076)

Spawning frequency

Spawning frequency is estimated as the mean interval between sequential spawning events (Schaefer 2001). Methods to estimate spawning frequency require the examination of ovaries for the presence of postovulatory follicles after spawning. The age and longevity of postovulatory follicles has been validated for bigeye by Schaefer et al. (2005). The fraction of mature females in a population spawning per day can be estimated and this then converted to a spawning frequency. Two studies have estimated spawning fraction in the Pacific Ocean (Table 5) with both studies indicating in equatorial waters that daily spawning occurs once a female starts spawning.

Table 5 Estimates of Spawning fraction.

Study	Method	Location	Estimate
Sun et al. 2006	Spawning fraction - based on the presence of postovulatory follicles in histological examinations of ripe fish n=380 females	Philippines	Spawning fraction=0.75 and mean spawning interval of 1.34 days if total females (n=237) are included Spawning fraction =0.95and mean spawning interval of 1.05 days if only ripe females (n=186)
Schaefer et al. 2005	Spawning season = presence of postovulatory follicles Spawning fraction - based on the presence of postovulatory follicles in histological examinations of ripe fish	EPO	Spawning fraction = 0.39 and mean spawning interval of 2.6 d if total females (n = 198) are included. Spawning fraction = 0.78 and mean spawning interval of 1.3 d if total females (n = 102) are included.

Age & Growth

Maximum age of bigeye is not known, but tag recapture data provides empirical evidence that bigeye tuna can live to at least 12+ years of age. Recently, large bigeye tuna have been aged using a combination of daily and annular marks at 13 to 16 years of age (Farley et al. 2006). A significant proportion of bigeye survive until approximately eight years of age (Hampton et al. 2006). Age and growth of bigeye has been inferred from modal progression of length (Kume and Joseph 1966) and/or weight frequencies (Kikkawa and Cushing 2001), dorsal spines (Sun et al. 2001), otoliths (Lehodey et al. 1999, Leroy 2001, Farley et al. 2006, Schaefer and Fuller 2006), and in conjunction with tagging data (Hampton et al. 1998, Lehodey et al. 1999, Schaefer and Fuller 2006).

Bigeye grow rapidly, reaching approximately 56 cm FL at one year of age (Schaefer and Fuller 2006) and 80 cm FL within 1.5 (Hampton et al. 1998) to 2 years of age (Kikkawa and Cushing 2001), with linear growth until fish reach 50–100 cm FL (Hampton et al. 2006). Males and females grow at approximately the same rate up to 150 cm FL (Table 6), with males displaying slightly faster growth rates than females beyond this size, although statistical differences are not detected (Schaefer and Fuller 2006). The faster growth rates of large males may be due to the increased demands of reproduction for large females. VBGF statistics estimated for the various (length at age) datasets are provided in Table 6.

Recent age studies have validated daily micro-increments to age 3 (Farley et al. 2006) and age 4 (Schaefer and Fuller 2006). The variance in lengths at age from these validated studies indicates that model progression of length or weight is not reliable beyond the first year. No validation has occurred for the dorsal spine method. Tagging data in conjunction with yearly increment analysis of for older fish has provided some validation for the ageing of older individuals.

1.3 Stock Assessment Sensitivities

Current WCPO Stock Assessment Model

The WCPO stock assessment currently models bigeye over 6 regions (Figure 1). The regions' boundaries are predominantly determined by the fit of the CPUE and length frequency data. The same reproductive and growth parameterisations are applied to each region, because information is insufficient to add spatial structure to these parameters. The current stock assessment indicates that the fishing mortality exceeds F_{msy}, and that the biomass is approaching MSY (Langley et al. 2008). Sensitivity analyses demonstrate that the model is strongly influenced by precision in CPUE and length frequency data (Langley et al. 2008, Hoyle et al. 2008). Further examination demonstrates that the model is also influenced by the structural assumptions associated with estimating the reproductive and growth parameters (see Hoyle and Nicol 2008 for details). This analysis examined the influence of alternative estimates of natural mortality, fecundity at length, spawning fraction at length and alternative maturity schedules. The effect of an alternative growth curve, and an alternative steepness assumption, were also assessed. Alternative estimates for all reproductive and growth parameters and natural mortality influenced the spawning biomass reference points ($SB_{current}/SB_{msy}$ and $SB_{current}/SB_0$) typically by more than 10% and influenced biomass (B/B_{msy}) and the $F_{multiplier}$ reference points by between 1 % and 5 % (Table 7). The results support the need for further investment in knowledge acquisition to reduce the current level of uncertainty.

Table 6. VB derived parameters from otoliths/spine aged fish

Study	Method	Location	VB estimates
Sun et al. (2001)	Dorsal spine ageing n=	Phillipines	Male/female difference not detected L_∞ = 208.7 K= 0.2011 T_0 = -0.9906
Farley et al. (2003) Farley et al. (2006)	Otolith with validation n= (Coral Sea) n= (Sth Qld/NSW)	Australia (east coast)	Male/female difference not detected Coral Sea: L_∞ = 158.37, K= 0.327, T_0 = -1.26 Sth Qld/NSW: L_∞ = 168.57, K = 0.279, T_0 =- 1.41
Lehodey et al. (1999)	Otolith with tagging validation n=	Recovered from RTTP tagged. French Polynesia	60-100 cm most uncertainty for growth. L_∞ = 228.59 K= 0.226 T_0 = -0.425
Schaefer and Fuller 2006	Otolith with validation n= 254 recaptured with OTC mark n=205 tag returns; n=372 otoliths only	EPO	Male/female difference not detected Good correlation between otoliths and tag age. Study did not sample 5+ L_∞ = 400.3 K= 0.108 T_0 = -0.398

Table 7. Results from sensitivity analysis of reproductive and growth parameters to the 2008 base case model (with revised estimates of sex-ratio and natural mortality)

Parameter	SR Steepness = 0.957				SR Steepness = 0.7			
	F_{MULT}	$\frac{B}{B_{MSY}}$	$\frac{SB_{CURR}}{SB_{MSY}}$	$\frac{SB_{CURR}}{SB_0}$	F_{MULT}	$\frac{B}{B_{MSY}}$	$\frac{SB_{CURR}}{SB_{MSY}}$	$\frac{SB_{CURR}}{SB_0}$
BASE CASE (2008)								
+ Maturity (Sun 2006)	↑3%	↑2%	↑12%	↑41%	↑11%	↑8%	↑28%	↑42%
Combinations								
+ Maturity + Fecundity (Sun unpubl)	↑2%	↑1%	↑8%	↑22%	↑6%	↑4%	↑17%	↑23%
+ Maturity + Spawn.fract (Sun 2006)	↑3%	↑2%	↑11%	↑37%	↑10%	↑7%	↑26%	↑38%
+ Maturity + Fecundity + Spawn. fract								
Maturity = (Sun 2006, unpubl)	↑2%	↑1%	↑7%	↑19%	↑5%	↑4%	↑15%	↑19%
Maturity = EPO model (age)	0	0	0	0	0	0	0	0
Maturity = EPO model (length)	0	0	↓1%	↓4%	↓1%	↓1%	↓3%	↓5%
+ Maturity + Fecundity + Spawn. fract + Alterantive Growth (WCPO 2006 Final growth curve)	↑2%	↑1%	↑7%	↑19%	↑5%	↑4%	↑15%	↑19%

Current EPO Stock Assessment Model

The bigeye tuna stock in the eastern Pacific Ocean (EPO) is evaluated using a Stock Synthesis II (Methot 2005) assessment application (Aires-da-Silva and Maunder 2008). SS2 is a general size based, age-structured, integrated (fitted to many different types of data) statistical model. The bigeye application fits to indices of abundance based on CPUE and to length-frequency data. Recent stock assessments for bigeye indicated that MSY-related reference points are likely to have been exceeded and that conservation measures are needed (Aires-da-Silva and Maunder 2008; IATTC 2008a). In particular, it is estimated that the spawning stock biomass is depleted to 17% of the virgin biomass, which is about 10% less than the level corresponding to the MSY (Aires-da-Silva and Maunder 2008). Sensitivity analyses have shown that the assessment results can be influenced by changes in data (CPUE and length frequencies) and structural assumptions on biological processes, mainly growth and natural mortality of the young fish (Aires-da-Silva and Maunder 2007, 2008; IATTCb).

Further examination supports that the model is also influenced by the structural assumptions associated with estimating the reproductive and growth parameters (see Annex 1 for details). In general, the alternative M schedules evaluated resulted in percent changes below 10%, in absolute value, for $SB_{current}/SB_{MSY}$, $SB_{current}/SB_0$ and $F_{multiplier}$ (runs 1-4, h=1 and h=0.75). Higher percent changes (between 15-30%, approximately) were recorded for the two extreme M cases. Changes of the maturity schedule had a substantial impact (e.g., up to ~40% change) on spawning biomass (SB) related quantities (SB_{MSY} and SB_{MSY}/SB_0). Changes were much smaller for $SB_{current}/SB_{MSY}$ (<8 %). With respect to $F_{multiplier}$, changes were not observed when no stock recruitment relationship was assumed, but they became detectable (up to ~10 %) a stock recruitment steepness of 0.75. Noticeable changes were found for the current depletion estimate of the stock $SB_{current}/SB_0$ (up to ~14%). Higher percent changes (up to ~130 %) were recorded for the extreme case when no stock recruitment relationship was assumed. No effect of different fecundity relationships were detected except for SB_{MSY} and $Catch_{current}/MSY$.

1.4 A Pacific-wide bigeye tuna growth and reproductive biology programme

The vision that is articulated in this document is that of a Pacific wide study to examine the age, growth, and reproductive biology of bigeye. The quality of information on biological parameters of bigeye such as growth, maturity, spawning locations, sex ratios, fecundity, and size and age based estimates of reproductive characteristics that is used in stock assessments of bigeye tuna in the Pacific Ocean is variable (Miyabe and Bayliff 1998, Western Pacific Regional Fishery Management Council 2005, Schaefer 2001). The consensus of these reviews is that a broad scale investigation of bigeye maturity and reproductive parameters using histological methodology is required, particularly for the Western and Central Pacific Ocean. The disparity in results by area also suggests that studies need to be carried out on an ocean basis and results from one area should be used with caution in other areas.

The 3rd session of the Western and Central Pacific Fisheries Commission Scientific Committee recommended that a project on bigeye growth and reproductive biology be implemented to help reduce uncertainty in these parameters to improve the precision of the stock assessments. The Fourth Regular Session of the Commission in December 2007 endorsed funding for 2008 to prepare a comprehensive research plan on Pacific-wide bigeye growth and reproductive biology. This document articulates this plan. The main body of funded activity presented is for a regional project focused on the equatorial and sub-equatorial WCPO and EPO.

2.0 Goal and Objectives

The goal of the 'Pacific-wide Bigeye Growth and Reproductive Biology Study is to improve stock assessment and management of bigeye tuna in the Pacific Ocean. The specific objectives are:

1. To obtain data that will contribute to, and reduce uncertainty in, the maturity schedule used in stock assessment models, over the equatorial and sub-equatorial range of bigeye.
2. To obtain comprehensive information on the growth rate of bigeye and the spatial and seasonal variation expected in this rate.
3. To obtain information on bigeye fecundity, and the influence of age and size on batch fecundity, at a resolution suitable for use in stock assessment models.
4. To obtain information on the spatial and seasonal variation in spawning frequency and location, at a resolution suitable for use in stock assessment models.

Objectives, activities, outputs, outcomes and assumptions are summarised in a logical frame-work format in Table 8. Examples of specific management questions or issues that will be addressed by the project are given in Table 9.

3.0 Data collection

3.1 Hypothesis

The main hypothesis of the 'Pacific-wide Bigeye Growth and Reproductive Biology Programme' is:

> Reproductive and growth parameters (maturation, spawning fraction & area, seasonality, fecundity, rate of growth) of bigeye in the Pacific Ocean vary spatially in association with prevailing oceanographic conditions.

<u>Sub-hypotheses include:</u>

1 The estimated maturation schedule for bigeye varies with ocean productivity (latitude and longitude as surrogate measures).

2 Spawning fraction and area is positively influenced by the volume of water > 26°C.

3 The estimated rate of growth for bigeye varies with ocean productivity (latitude and longitude as surrogate measures).

4 Batch fecundity is influenced by age, length, and rate of growth.

3.2 Design & Analysis Considerations

To test these hypotheses and to facilitate comparison with previous studies (Schaefer et al. 2005, Farley et al. 2006, Schaefer and Fuller 2006, Sun et al. 2006) the following biological material and capture data will be required from each individual sampled:

* Gonad samples (for sexing, maturation, atresia and spawning frequency determination);
* Whole hydrated ovary sampling (for batch fecundity)
* Sagittal otoliths and the first spinoform ray of the first dorsal fin (for age determination);
* Fork length of fish (nearest cm);
* Weight of fish (nearest g);
* Capture location (longitude and latitude);
* Capture time;
* Vessel name and flag;
* Port sampler or observer sampled;
* Fishing method and set information (eg. hook/net depth);
* Sea surface temperature (SST) when available.

To facilitate comparison with the study of Schaefer et al. 2005 in the EPO, individuals should be sampled for each 10 cm length interval from 80 to 150+ cm in the WCPO. This regime should sample across the full range of maturity states for females.

In the EPO, reproductive parameters including the maturity schedule have been estimated recently, and within the area from which most of the catch occurs. The only apparent shortfall in the reproductive parameter estimates (Schaefer et al. 2005) was a shortage of samples collected for batch fecundity estimates. Consequently in the EPO individuals equal to or greater than 100 cm FL only need to be considered for sampling in each EPO strata and those should be obtained only from longline vessels.

A spatially stratified block design is the most statistically robust option for testing these hypotheses. Blocking by longitude, latitude and size with individuals within these blocks randomly sampled is recommended and provides data tailored for incorporation into stock models. To maximise opportunities for comparison with existing information (Schaefer et al. 2005, Sun et al. 2006) two options are proposed for spatial blocking: (1) a fine scale design where blocking applies at a 32° longitude × 10° latitude (Figure 4a); and (2) a coarser scale design where blocking occurs at a at a 32° longitude × 20° latitude (Figure 4b). Response terms, fixed effects and random effects for this design are detailed in Table 10. The coarser scale blocking would result in restricted interpretation of the effects of environmental variation on reproduction and growth parameters. The results of a pilot study (see section 3.7) should be used to determine whether the fine or coarse scale blocking satisfy the data needs of the stock assessment models.

In addition, as spawning is assumed seasonal in sub-equatorial regions, occurring during periods when sea surface temperatures (SST) are > 24°C, a temporal block of quarter should be included to estimate this effect. Sampling at SST < 24°C would be of limited value as determining maturity state and fecundity is not reliable. Consequently sampling would only need to occur in quarters when SST exceeds 24°C. This design would result in 480 strata for the WCPO and 120 for the EPO when applying the fine scale design and 256 strata for the WCPO and 106 for the EPO when applying the coarse scale design (Table 11). The blocking design at the fine scale would allow for inclusion of Longhurst (1998) oceanographic zones as a fixed effect in the analysis. To avoid bias associated with sampling from tuna schools the set details should be included in the analytical model used.

Expert opinion recommends that at least 6 individuals be sampled per block to ensure adequate statistical power. However power analysis to confirm this recommendation is warranted. This analysis should use existing bigeye, data collected from the proposed pilot study (see section 3.7) and where necessary data borrowed from yellowfin.

Table 8. Logical framework table – objectives, activities, outputs, outcomes and assumptions.

<table>
<tr><th colspan="5">Goal: To improve stock assessment and management of bigeye tuna in the Pacific Ocean.</th></tr>
<tr><th>Objectives</th><th>Activities</th><th>Outputs</th><th>Outcomes</th><th>Assumptions</th></tr>
<tr><td>1. To obtain data that will contribute to, and reduce uncertainty in the maturity schedule over the equatorial range of bigeye</td><td>Reproductive material collected through port and observer, fishing company sampling; Histological examination of gonads, data analysis & modeling</td><td>Maturity ogive (incl. length & age) provided for stock assessment models with estimates of regional variability.</td><td rowspan="4">More accurate & precise estimates of stock status, recent fishing impacts; assessment of management alternatives based on improved scientific information; Improved science-based plans for management of tuna fisheries at the national level</td><td rowspan="4">Obtaining reproductive material as successful as previous large-scale projects;
Industry & Governments cooperate in the collection of biological samples;
Regional/national observer programmes can be used to collect biological material;
Regional and national tuna fisheries management authorities take appropriate actions on the basis of new information</td></tr>
<tr><td>2. To obtain comprehensive information on the growth rate of bigeye and the spatial and seasonal variation expected in this rate.</td><td>Biological material suitable for ageing (otoliths and spines) collected through port and observer, fishing company sampling; Laboratory examination of otoliths/spines, data analysis & modeling</td><td>Length-age-growth data for reproductive analysis and stock assessment models with estimates of regional variability.</td></tr>
<tr><td>3. To obtain information on bigeye fecundity and the influence of age and size</td><td>Collection of hydrated ovaries through port and observer, fishing company sampling; Laboratory examination of ovaries, data analysis & modeling</td><td>Length-age-fecundity relationship provided for reproductive analysis and stock assessment models with estimates of regional variability.</td></tr>
<tr><td>4. To obtain information on the spatial and seasonal variation in spawning frequency and location.</td><td>Reproductive material collected through port and observer, fishing company sampling; Histological examination of gonads, data analysis & modeling</td><td>Estimation of spawning fraction and season for reproductive analysis and stock assessment models with estimates of regional variability.</td></tr>
</table>

Table 9. Examples of important management issues addressed by research plan.

Management issue	Current scientific resources	The role of this study in resolving issue	Relevant WCPFC Convention text
1. To obtain comprehensive information on the growth rate of bigeye and the spatial and seasonal variation expected in this rate.	Spatial coverage of equatorial sub region adequate and demonstrates disparity in results indicating that environmental conditions influence estimates. Data is insufficient to test for influence of environmental influences	Study will provide structured sampling in space and time allowing for hypotheses about environmental influences to be tested. The analysis will provide the age data necessary for the comprehensive estimation of bigeye reproductive parameters used in stock assessments.	The collection of reproductive and growth data will be integral to the WCPFC achieving the following management measures and performance indicators. **5.** Conservation and Management measures that support long-term sustainability & optimum utilisation of highly migratory fish stocks in the Convention Area are adopted on the basis of the best scientific information available (Articles 5a,b,g,h, 12.1 and 12.2). P.I. The information, advice and recommendations to the Commission by the SC in accordance with the research plan recommended to the Commission constitute the best scientific information available (Article 12.2a). **7.** Impacts on target stocks, non-target species and species belonging to the same ecosystem or dependent upon or associated with target species managed effectively by the Commission (Article 5 a and d). PI. The capability of the SC to assess the impacts of fishing, other human activities and environmental factors on target stocks, non-target species and species belonging to the same ecosystem or dependent upon or associated with target species (Article 5d).
2. Are there spatial differences in maturation that would warrant explicit sub-regional structure being included in stock assessment and management?	Two studies from the Western Pacific and one study from the Eastern Pacific strongly indicate spatial variance in the maturation ogive for bigeye tuna. No information exists for the Central Pacific. No comprehensive data set to test the ecological drivers of this variance.	First Pacific-wide study of maturation, resolving the current low spatial coverage of information thereby providing clear information on the structural assumptions of the stock assessment models. Study will include the effects of age and length for maturation thereby improving precision of year and sub-regional effects in stock assessments.	
3. Does variance in growth and environmental conditions influence batch fecundity at length that would warrant explicit sub-regional structure being included in stock assessment and management?	Current batch fecundity estimates lack precision and a single study from the western Pacific only has modeled the influence of length and weight on batch fecundity. No data on relationship between age and fecundity.	A Pacific-wide study of batch fecundity would resolve the current low spatial coverage of information. Study will include the effects of age and length for fecundity thereby improving precision of year and sub-regional effects in stock assessments.	
4. Does spatial and seasonal variation in spawning fraction and location necessitate explicit sub-regional structure being included in stock assessment and management?	Spawning fraction for western and eastern Pacific adequately estimated. Limited information for sub-equatorial area. No information for central Pacific. Available information suggests continuous spawning season in equatorial areas and seasonal spawning in sub-equatorial regions.	A Pacific-wide study would resolve the current low spatial coverage of information, particularly in the sub-equatorial and central Pacific areas.	

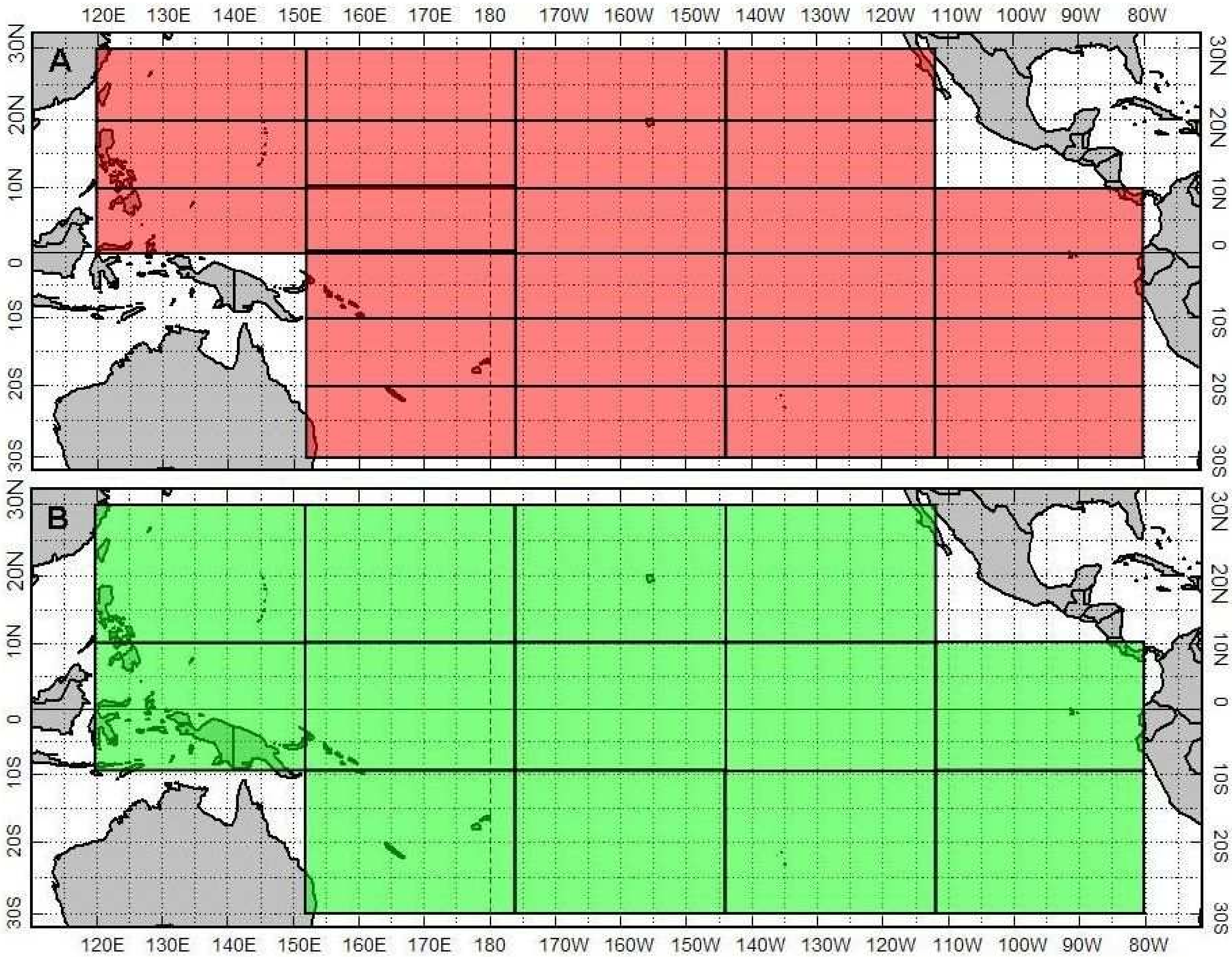


Figure 4 Proposed blocking designs for the collection of samples for the study on bigeye reproductive and growth biology. (A) Fine scale resolution; (B) Coarse scale resolution

Table 10. Response terms, fixed effects, covariates and random effects proposed for the analysis of the data collected for the study of bigeye reproductive and growth biology.

Response Terms	Growth rate, Maturation, Spawning fraction, Fecundity
Fixed Effects	Quarter
Covariates	Length, Age, Latitude, Longitude, SST
Random Effects	block, capture method (Purse Seine, Hand Line or longline), set (depth)

Table 11. Number of strata and samples proposed for the blocking design for the study on bigeye reproductive and growth biology.

Strata	Fine Scale		Coarse Scale	
	WCPO (120E-150W)	EPO (150W-80W	WCPO (120E-150W)	EPO (150W-80W
Longitude	3	2	3	2
Latitude	6	6	3	3
Quarter	4	4	4	4
Size class	8	6	8	6
Strata not sampled due to land mass	96	64	32	32
Strata not sampled due to SST <24°C in sub-equatorial areas	16	104	0	6
Total strata	**480**	**120**	**256**	**106**
Individual sampled	6	6	6	6
Total fish sampled	**2784**	**720**	**1536**	**636**

3.3 Collection of Reproductive and Ageing samples

Gonads, sagittal otoliths and the first spinoform ray of the first dorsal fin should be collected. Gonads should be stored in 10% buffered formalin prior to laboratory examination. Otoliths should be extracted, dried and stored in appropriate vials. In circumstances where fish heads are required for presentation of fish at market, drill extraction methods exist for sagittal otoliths (Farley 2002). Extracted dorsal spines will be stored frozen if they cannot be cleaned at the time of the sampling.

The experimental design proposed for reproductive parameters does not include sampling individuals in the 30 to 80 cm FL as the existing information strongly indicates that these will be immature females. However, Lehodey et al. (1999) identify this range as being the most uncertain for length at age determination and additional sampling of these individuals is proposed. As these individuals are rarely captured by long-line gear, sampling should be prioritised to the purse-seine fisheries in the blocks within 10 N – 10 S Latitude (Figure 4a, 4b). Six-samples per 10 cm bin range is also recommended for these size classes with each of the strata identified. In the EPO, the age at size, and growth estimates (Schaefer and Fuller 2006) over the size range of 30 to 150 cm were based on daily increment counts on otoliths. Given the high precision is this methods additional sampling in the 30 to 80 cm FL range is not a priority for the EPO.

3.4 Analytical methods for reproductive and ageing parameters

Histological methods (Schaefer et al. 2005, Sun et al. 2006) should be applied to determine sex, maturity state and spawning status. Batch fecundity should be estimated using the hydrated oocyte method (Schaefer et al. 2005, Sun et al. 2006).

Preparation and ageing of otoliths should follow the methods outlined in Farley et al. (2006) and Schaefer et al. (2006). Consideration should be given to alternatives to multiple readings by multiple individuals (Ashley Williams pers. comm). For dorsal spines the methods should follow those outlined in Sun et al. (2001). Where feasible this project should co-ordinate with the tag recovery officer of the Pacific Tuna Tagging Programme to collect samples from tagged bigeye which will aid in the validation of age estimates.

3.5 Sampling Opportunities

Port and observer sampling is likely to be the most efficient method for the collection of biological material necessary to implement this research plan. An examination of the length data collected by these port and observer programmes, from both purse-seine and longline fisheries, over the last 5 years (Figure 5), indicates that an adequate representation of the size range can be sampled from these fisheries across the spatial area of the WCPO. This will require that strong collaborative links are established with the existing port and observer sampling programmes. The previous study on bigeye reproductive biology in the EPO which included some longline caught fish, relied upon samples collected by a Japanese longline research vessel. This proposal anticipates that similar arrangements will also need to occur. The failure to collect an adequate number of samples will be the biggest risk to the project and success of the study depends upon the cooperation and commitment of the fishing industries, longline vessels, their governments scientists, and observers, to devote the manpower and effort to obtain samples. To minimise the risk of failure, it is recommended that a sampling coordinator is appointed to organise the sampling with the national observer and port sampler programmes, to provide training and to insure of the appropriate spatial and temporal coverage of the sampling and of the quality of the data and samples collected. It is also recommended that a fee per sample for collection of material and data be provided to the port samplers and observers. Rates paid for stomach sampling as part of the current Oceanic Fisheries Management (GEF funded) project being implemented in the WCPO is USD1 per sample. As this design requires both reproductive material and otoliths to be sampled a fee of USD2 per sample is recommended.

Both the EPO and WCPO stock assessment models are female only. Consequently, this project will have greatest application through the improved precision and understanding of female growth and reproductive biology. There is sufficient information to demonstrate that sex ratio of bigeye in the Pacific Ocean varies in relation to size and spatial location of the fish and is male biased (Hoyle et al. 2008). There is reduced reliability of sex determination when macroscopic techniques are used for fish < 50 cm (Kurt Schaefer pers. Comm.). To avoid the potential for insufficient sampling the numbers per fish size are outlined in Table 12.

When possible the study should incorporate country initiated reproductive and age/growth studies into its design and data collection schedule.

Table 12. Number of fish per size class that is recommended to be sampled by port samplers and observers

Size	Number samples per strata	Commentary
80-90	6 fish (WCPO only)	Macroscopic examination possible onboard fishing vessels
90-100	6 fish (WCPO only)	
100-110	6 fish	
110-120	6 fish	
120-130	6 fish	
130-140	6 fish	
140-150	6 fish	
>150	6 fish	
30-80 cm additional otolith sampling (WCPO only)		
30-40	12 fish	Macroscopic examination unreliable, approximate 50:50 sex ratio, double number of samples recommended
40-50	12 fish	
50-60	6 fish	Macroscopic examination possible onboard fishing vessels
60-70	6 fish	
70-80	6 fish	

Purse-seine

Lawson (2008) examined the distribution of unloadings by port and month, and notes that for most ports, purse-seine visits have been sporadic, except for six ports for which visits have been regular (Honiara, Majuro, Pago Pago, Pohnpei, Rabaul and Yaizu). The areas fished by vessels visiting the six ports are shown to be representative (Table 13). Priority flags to sample are Honiara (Korea 62 %, Taiwan 13 %, Papua New

Guinea 12 %, Vanuatu 6 %); Majuro (Taiwan 35%, Republic of the Marshall Islands 20%, Papua New Guinea 12 %, Vanuatu, 11 %, Korea 10%), Pago Pago (Unites States 85%, New Zealand 10%), Pohnpei (Taiwan 49%, Korea 17%, Papua New Guinea 16 %, Federated States of Micronesia 8%, China 7%), Rabaul (Korea 31 %, Taiwan 29 %, Papua New Guinea 28 %) and Yaizu (Japan 99 %).

Longline

The longline fisheries will be largely restricted to observer sampling where fish are pre-processed before arrival at port. Table 14 identifies the level of effort and primary flags for each 30°Longitude and 10° Latitude cell. Observer sampling of United States flagged vessels in 180°-150°W, 30°N-10°N area; Korean, Taiwan and Japan in the 180°-150°W, 10°N-10°S area; and American Samoa, Taiwan, French Polynesia, Western Samoa and Cook Island flagged vessels in the 180°-150°W, 10°S-30°S would be priorities. In the longitudinal zone of 150°E-180°, sampling from Japanese, Taiwan and Korean flagged vessels in the 30°N-10°N area; Japanese, Korean, Chinese, Taiwanese flagged vessels in the 10°N-10°S area; and Fijian, Taiwanese, Chinese, Vanuatu, Australian, New Caledonian flagged vessels in the 10°S-30°S would be priorities. In the longitudinal zone of 120°E-150°E, sampling from Taiwanese flagged vessels in the 30°N-10°N area; Taiwanese, Philippines, Indonesian flagged vessels in the 10°N-10°S area; and Papua New Guinean and Australian flagged vessels in the 10°S-20°S would be priorities.

3.6 Data Sharing and Intellectual Property

The intellectual property for this study should reside jointly with the project consultants and the WCPFC and IATTC. The intellectual property agreement between the parties should provide right for the fisheries commissions to obtain raw and laboratory processed data and analysed results and provide this information to consultants or service providers undertaking analysis for these commissions that may require reproductive and growth biology information. The agreement should also provide rights for scientific publication of the project to reside with the project consultants for a period of 3 years after the completion of the project, after which the rights reside with the WCPFC and IATTC.

The collection of biological samples is often the most time consuming and logistically difficult component of this type of study. Consequently the specimens collected in this study are likely to be useable for other studies into the future. The WCPFC and IATTC should give considerations to the establishment a specimen store to house the samples after completion of this project.

3.7 Pilot study

To determine the sampling requirements for each strata of the Pacific wide study and the feasibility of sampling from longline and purse-seine vessels a pilot study is proposed. This should occur over a 2 year period. Region 3 is the priority of the WCPO stock model and it is preferable that the pilot study occurs in this area to immediately satisfy some of the data needs of the stock assessments for bigeye. Fish caught from the Palau and Micronesia EEZ's are on average larger in size than the other areas with region 3. The stock assessment model currently assumes that these are older fish with higher reproductive output. The fish could also be younger but faster growing individuals. Undertaking the pilot study in this area would resolve this issue in addition to providing the information necessary to determine the sampling requirements of the Pacific-wide study. Six individuals per strata are required for the Palau EEZ and the Micronesia EEZ for this pilot study. As both EEZ's are located in the WCPO warmpool, there is little expectation of seasonal variability in reproduction and sampling in a single season only would be required for this pilot study. This would equate to 78 samples from each EEZ.

4.0 Time line and Budget

The total duration of the Pacific wide study as foreseen in this research plan is 4 years with collection of biological material expected to be completed within 30 months. A detailed calendar of activities is provided in Table 15, a budget summary in Table 16, and detailed budget for the fine scale sampling in Table 17 and coarse-scale sampling in Table 18. The coarse sampling block design would result in a 12% saving in costs. The exact timing of activities depends on the availability of funding and the selection of suitable researcher(s) to implement the research plan. It is worth noting that the largest uncertainty in budget is associated with daily increment analysis of otoliths for ageing. IATTC estimates of USD100 per otolith have been used, however a quote of USD30 per otolith was also received. This quote however was not by someone who had undertaken daily increment analysis of bigeye previously and was considered inappropriate for costing the project. However it does suggest that the overall budget could be reduced by up to 15% (fine scale) and 11% (coarse scale). The pilot study should determine if the price of the otolith sampling.

A calendar of activities for the pilot study is provided in Table 19 and budget in Table 20.

5.0 Institutional Arrangements

The project should be jointly managed by the WCPFC and the IATTC through the formation of a Steering Committee. The Steering Committee will consult on various planning and implementation issues, and will report the progress of the project to the Scientific Committee of the WCPFC and the Working Group on Stock Assessment of the IATTC at their annual sessions during the course of the project. The executives of both the WCPFC and IATTC should facilitate, when necessary, the cooperation of Countries for the provision of samples. The Steering Committee should comprise as a minimum:

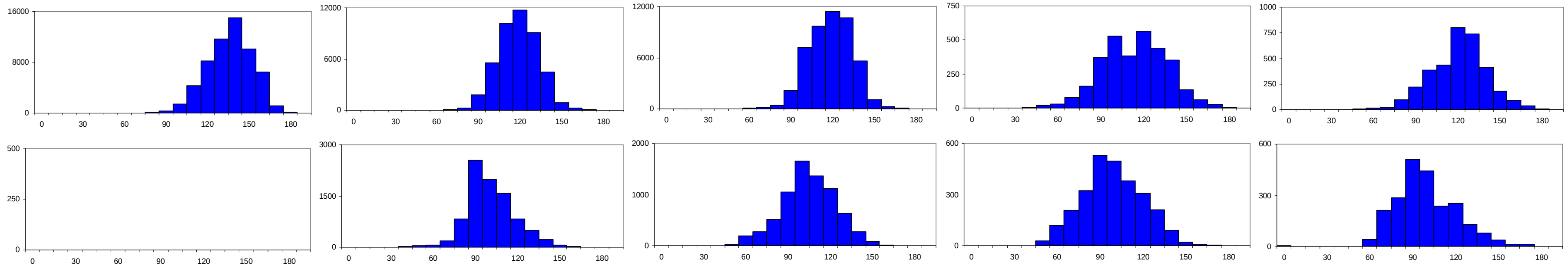
- WCPFC secretariat representation (Science Manager or representative)
- IATTC representation (Science Manager or representative)
- WCPFC Science provider representative (eg. SPC-OFP scientist)
- IATTC Science provider representative (eg. Kurt Schaefer)
- WCPFC Science Committee- Biology Specialist Working Group representative
- WCPFC Science Committee- Stock Assessment Specialist Working Group representative
- Project consultant(s)

Day-to-day management and implementation of the project will be vested in the project consultant.

120°-140°E 140°-180°E 180°E-180° 180°-180°W 180°-
140°W

0-10°N

0-10°S

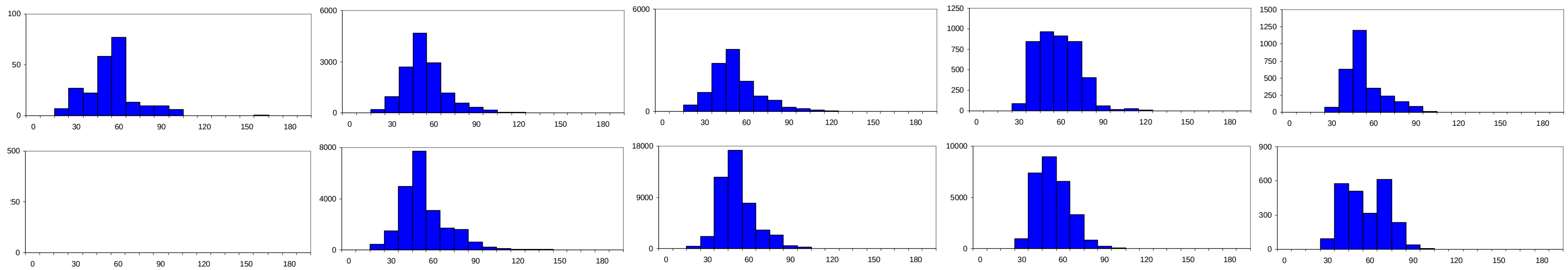


LONGLINE

120°-140°E 140°-180°E 180°E-180° 180°-180°W 180°-
140°W

0-10°N

0-10°S



PURSE SEINE

Figure 5 Length frequency graphs for each of the lat/long blocks

Table 13 Percent Effort (number of sets) for purse seine according to submitted logsheets by qrt and lat/long

Honiara	Longitude											
	120-150				150-180				180-150			
Latitude	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
30-20	0	0	0	0	0	0	0	0	0	0	0	0
20-10	0	0	0	0	**9**	**1**	0	**4**	0	0	0	0
10-0	**1**	0	0	0	**33**	**3**	**9**	**34**	0	0	0	**1**
0-10	**1**	0	0	0	**1**	0	**1**	**3**	0	0	0	0
10-20	0	0	0	0	0	0	0	0	0	0	0	0
20-30	0	0	0	0	0	0	0	0	0	0	0	0

Majuro	Longitude											
	120-150				150-180				180-150			
Latitude	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	**7**	**10**	**17**	**15**	0	**1**	**1**	**1**
	0	0	0	0	**4**	**17**	**14**	**7**	0	**1**	**3**	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0

Pago Pago	Longitude											
	120-150				150-180				180-150			
Latitude	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
30-20	0	0	0	0	0	0	0	0	0	0	0	0
20-10	0	0	0	0	**1**	0	0	0	0	0	0	0
10-0	**1**	**1**	0	0	**13**	**12**	**12**	**11**	**6**	**9**	**11**	**10**
0-10	0	**2**	0	0	**1**	**3**	**1**	**1**	0	0	**3**	**1**
10-20	0	0	0	0	0	0	0	0	0	0	0	0
20-30	0	0	0	0	0	0	0	0	0	0	0	0

Pohnpei	Longitude											
	120-150				150-180				180-150			
Latitude	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	1	**1**	**1**	**1**	**14**	**11**	**11**	**14**	0	0	0	0
	2	**2**	**1**	0	**9**	**12**	**14**	**5**	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0

Rabaul	Longitude											
	120-150				150-180				180-150			
Latitude	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
30-20	0	0	0	0	0	0	0	0	0	0	0	0
20-10	0	0	0	0	0	0	0	0	0	0	0	0
10-0	**3**	**2**	**1**	**3**	**22**	**13**	**5**	**23**	0	0	0	0
0-10	**4**	**2**	**2**	**1**	**5**	**3**	**4**	**4**	0	0	0	0
10-20	0	0	0	0	0	0	0	0	0	0	0	0
20-30	0	0	0	0	0	0	0	0	0	0	0	0

Yaizu	Longitude											
	120-150				150-180				180-150			
Latitude	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	**1**	0	**1**	**8**	**3**	**7**	**13**	0	0	0	0
	4	**12**	**4**	**2**	**10**	**14**	**12**	**8**	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0

Table 14 Longline effort by lat/long and primary flags

	120-150								150-180								180-150							
	% Effort				Flag				% Effort				Flag				% Effort				Flag			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
30-20	3	7	10	2	TW	TW	TW	TW	3	1	<1	1	JP TW VU	JP	JP	JP	4	1	2	5	US JP TW	US	US	US
20-10	1	10	4	3	TW JP	TW	TW	TW	2	2	1	2	JP KR TW	JP KR	JP	JP	6	6	2	3	US JP KR	US JP KR	US	US
10-0	17	14	18	26	TW PH IN	TW PH IN	TW PH IN	TW PH IN	13	9	10	11	JP CN TW KR	JP CN TW	CN JP CN TW	CN JP CN TW KR	10	6	4	6	KR TW JP	KR TW JP	KR TW JP	KR TW JP
0-10	7	6	5	7	IN	IN	IN	IN	4	5	9	5	KR JP TW	KR JP TW	KR JP TW	KR JP TW	7	8	9	7	KR TW	KR TW	KR TW	KR TW
10-20	<1	<1	<1	<1	PG AU	PG AU	PG AU	PG AU	12	12	7	12	FJ TW CN VU	FJ TW CN VU KR	FJ TW CN VU	FJ TW CN VU	5	5	5	6	AS FJ PF WS TW	AS PF WS TW	AS PF WS	AS PF WS
20-30									4	4	9	3	AU FJ NC	AU NC TW	AU NC TW	AU FJ NC	1	2	6	1	TO TW FJ CK	TO TW CK VU	CK TO TW VU	CK TO FJ CK PF

Table 15 Timeline of Pacific wide activities

Activity/Milestone	Year 1				Year 2				Year 3				Year 4			
Selection of Research provider(s)	X															
Project Commencement			X													
Arrange port and observer sampling			X	X	X	X	X	X	X	X	X	X				
Power Analysis		X														
Collection of biological material			X	X	X	X	X	X	X	X	X	X				
Laboratory analysis						X	X	X	X	X	X	X	X			
Data analysis									X	X	X	X	X	X		
SC reporting			X				X				X				X	
Final project report														X		

Table 16 Budget summary for Pacific-wide study (thousand USD)

Year	WCPO		EPO	
	Fine scale	**Coarse Scale**	**Fine scale**	**Coarse Scale**
Year 1	62	62	61	61
Year 2	336	236	174	169
Year 3	485	350	266	260
Year 4	160	129	108	106
Total	**1043**	**777**	**609**	**596**

Table 17 Detailed budget (thousand USD) for the fine scale Pacific wide sampling, processing, analyses, and reporting on bigeye age, growth, and reproductive biology.

Item	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
	WCPO	**EPO**	**WCPO**	**EPO**	**WCPO**	**EPO**	**WCPO**	**EPO**
Salaries								
Sampling coordinator (CROP Level I)	33	32	65	65	65	65		
Fecundity & Maturation analysis (USD30 sample)			32	8	43	11	11	3
Otolith/spine analysis (USD100 sample)			108	27	144	36	36	9
30-80 cm FL otolith/spine analysis(USD100 sample)			35		50		10	
Data analysis					36	36	40	40
Report writing					32	32	32	32
Operating								
Transportation cost of biological samples	5	5	20	20	20	20		
Reward payment	1	1	2	1	2	1		
Travel (sampling co-ordination)	10	10	20	20	20	20		
Travel (SC Committee)			5	5	5	5	5	5
Miscellaneous costs	5	5	5	5	5	5	5	5
Project Sub Total	**54**	**53**	**292**	**151**	**422**	**231**	**139**	**94**
Organisational overheads *assumed @15%	8	8	44	23	63	35	21	14
Total	**62**	**61**	**336**	**174**	**485**	**266**	**160**	**108**

Table 18 Detailed budget (thousand USD) for the coarse scale Pacific wide sampling, processing, analyses, and reporting on bigeye age, growth, and reproductive biology.

Item	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
	WCPO	**EPO**	**WCPO**	**EPO**	**WCPO**	**EPO**	**WCPO**	**EPO**
Salaries								
Sampling coordinator (CROP Level I)	33	32	65	65	65	65		
Fecundity & Maturation analysis (USD30 sample)			17	7	23	10	6	2
Otolith/spine analysis (USD100 sample)			57	24	77	32	19	8
30-80 cm FL otolith/spine analysis(USD100 sample)			15		20		5	
Data analysis					36	36	40	40
Report writing					32	32	32	32
Operating								
Transportation cost of biological samples	5	5	20	20	20	20		
Reward payment	1	1	1	1	1	1		
Travel (sampling co-ordination)	10	10	20	20	20	20		
Travel (SC Committee)			5	5	5	5	5	5
Miscellaneous costs	5	5	5	5	5	5	5	5
Project Sub Total	**54**	**53**	**205**	**147**	**304**	**226**	**112**	**92**
Organisational overheads *assumed @15%	8	8	31	22	46	34	17	14
Total	**62**	**61**	**236**	**169**	**350**	**260**	**129**	**106**

Table 19 Timeline of Pilot study activities

Activity/Milestone	2008				2009				2010			
SC4 endorsement			X									
WCPFC approval				X								
Selection of Research Coordinator					X							
Negotiate sampling arrangements and obtain endorsement/support					X							
Arrange port and observer sampling						X						
Collection of biological material							X	X	X			
Laboratory analysis								X	X	X		
Data analysis								X	X	X		
Power Analysis for Phase 2									X	X		
SC reporting											X	
Pilot study report and recommendations										X	X	

Table 20 Budget for the Pilot Study. Note: Institutional overheads of consulting organisation are not included in this estimated budget.

Item	2009	2010	Total
Project coordination	8000	6000	**14000**
Histology (USD30)	4680	0	**4680**
Otoliths (USD100)	15600	0	**15600**
Reward payments	312	0	**312**
Data analysis	0	6000	**6000**
Power Analysis	0	6000	**6000**
Pilot report and recommendations	0	6000	**6000**
SC reporting	0	5000	**5000**
Miscellaneous costs	1000		**1000**
Total	**29592**	**29000**	**58592**

8.0 Recommendations

The reduction of uncertainty in knowledge about bigeye reproductive and growth biology is a high priority issue identified by the Scientific Committee of the WCPFC (Summary Report, Scientific Committee, Third Regular Session, WCPFC). To reduce this uncertainty and to tailor data to the needs of existing stock models a Pacific wide study is required. This will require the implementation of an extensive biological sampling program that will be reliant upon obtaining samples from longline and purse seine fisheries by observers at sea. Port sampling will be possible when samples have reliable location information for the collection of otoliths for ageing.

To implement the research plan a 2 phase program is proposed:

1. Phase 1 comprises implementation of a pilot study over a 2 year period to determine the sampling needs and methodology of a Pacific wide study. It is recommended that this occurs in the EEZ's of Palau and Micronesia. The size

distribution of fish caught from these areas is influential in the WCPO stock model. In addition to project planning, the age-growth information should be used to update the stock model for these areas.
2. Phase 2 of the research plan will comprise the Pacific wide component. This will provide information to spatially model the variance in reproduction and growth in currently used stock models (Multifan-CL, Stock Synthesis, SEAPODYM). The Scientific Committee endorse this high priority research and encourage the WCPFC secretariat to pursue funding opportunities for this work.
3. All Nations involved in purse seine and longline fisheries in the WCPO cooperate in implementation of both Phase 1 and Phase 2.
4. Where possible associate national programs undertaken by CMM's within the implementation of Phase 2. This will require the application of the same methods as described in this document.

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ANNEX 1. Report on EPO Sensitivity Analysis

Sensitivity of Eastern Pacific Ocean bigeye tuna stock assessment to alternative biological assumptions

July 2008

A summary report prepared for a proposal to "A comprehensive review and proposed investigation of the age, growth, and reproductive of bigeye tuna in the Pacific Ocean"

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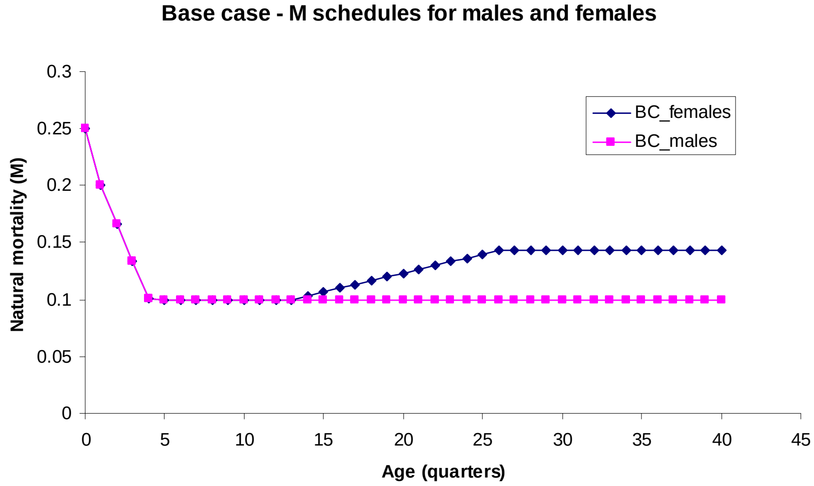
Introduction

The bigeye tuna stock in the eastern Pacific Ocean (EPO) is evaluated using a Stock Synthesis II (Methot 2005) assessment application (Aires-da-Silva and Maunder 2008). SS2 is a general size based, age-structured, integrated (fitted to many different types of data) statistical model. The bigeye application fits to indices of abundance based on CPUE and to length-frequency data. Recent stock assessments for bigeye indicated that MSY-related reference points are likely to have been exceeded and that conservation measures are needed (Aires-da-Silva and Maunder 2008; IATTC 2008a). In particular, it is estimated that the spawning stock biomass is depleted to 17% of the virgin biomass, which is about 10% less than the level corresponding to the MSY (Aires-da-Silva and Maunder 2008). Sensitivity analyses have shown that the assessment results can be influenced by changes in data (CPUE and length frequencies) and structural assumptions on biological processes, mainly growth and natural mortality of the young fish (Aires-da-Silva and Maunder 2007, 2008; IATTCb).

Additional sensitivity analyses were conducted in this study to evaluate the impact on the assessment results from alternative biological assumptions (natural mortality, maturity schedule, and fecundity at weight). The three sensitivities described below were run for two assumptions about the steepness (h) parameter of the stock-recruitment relationship: 1) that there is no relationship between stock and recruitment (h=1, the assumption of the base case model), and 2) a steepness of 0.75 (the alternative assumption in the EPO assessment). A description of the settings for each sensitivity analysis is shown in Table 21.

Natural mortality (M) schedule for females

A sensitivity analysis was conducted to investigate the influence of alternative schedules of natural mortality (M) for the maturing and mature female segments of the bigeye stock. Several studies have documented that while the sex ratios observed on the catch of small tuna are balanced, the catches of large tuna are dominated by males (Kume and Joseph 1966; Miyabe 2003). One possible explanation for this observation is that the increased spawning costs for female tuna results in higher natural mortality for females. The EPO SS2 assessment uses a sex-specific model and natural mortality schedules are provided for each sex separately (Figure 6.a.). A total of six alternative mortality schedules for females were considered in this sensitivity (Figure 6.b.). The different schedules attempt to capture a broad range of M for maturing sizes (10-25 quarters of age; curves M1 to M4) and low (curve M5) to high (curve M6) levels of M for mature fish.



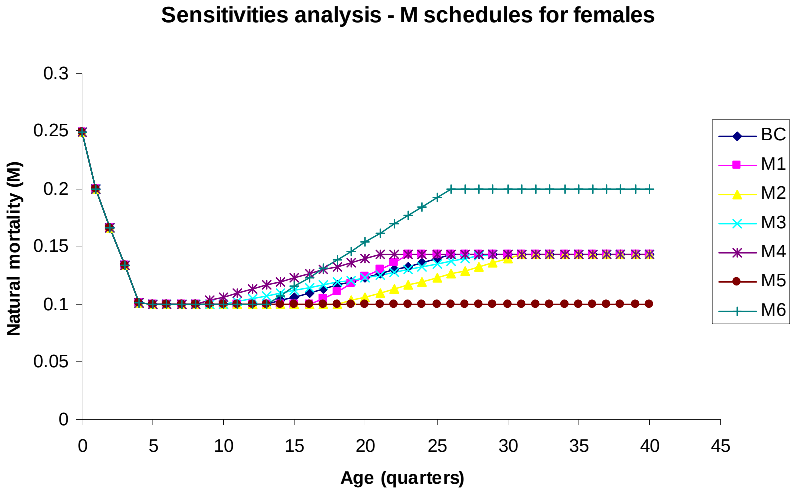


Figure 6. Natural mortality (M) schedules assumed in the EPO bigeye assessment. a) M curves for males and females assumed in the base case assessment. b) alternative maturity schedules for females assumed in the sensitivity analysis.

The management quantities of interest derived from the base case assessment (Aires da Silva and Maunder 2008) and the sensitivity analyses are presented in Table 22 for the two assumptions made about the steepness parameter (*h* = 1 and 0.75). The percent change of the management quantities obtained from the sensitivities analyses with respect to the 2008 stock assessment model (two cases of *h*) are shown on Table 23.

In general, the alternative M schedules resulted in percent changes below 10%, in absolute value, for SB_{CURR}/SB_{MSY}, SB_{CURR}/SB_0 and F_{MULT} (runs 1-4, *h*=1 and *h*=0.75). Sensitivities 1 and 3 had little impact (< 2%) on these quantities (*h*=1 and *h*=0.75). Higher percent changes (between 15-30%, approximately) were recorded for the two extreme M cases (runs 5 and 6).

Maturity schedule for females

A sensitivity analysis was made to evaluate the effect of different maturity schedules for females. An age-at-maturity ogive is specified in the EPO's bigeye model (Schaefer et al. 2005). Six alternative age-at-maturity schedules were obtained by manipulating the shape of the Richard's curve (Figure 7). The different schedules attempt to cover a broad parameter space around the inflection of the curve assumed in the base case model (curves 1-4) and one extreme case (curve 5).

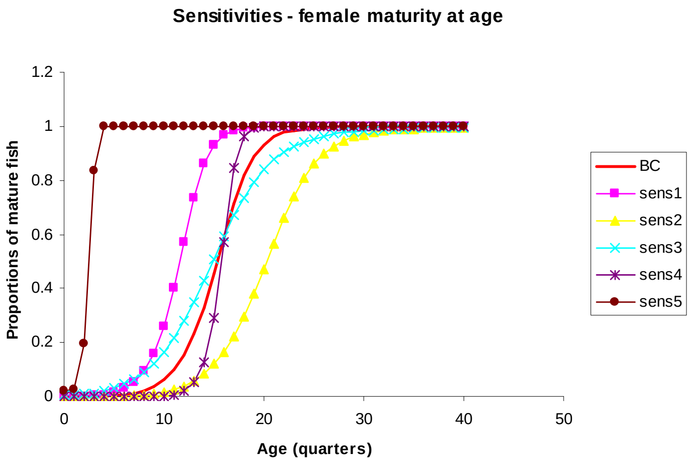


Figure 7. Maturity schedules for females assumed in the sensitivity analysis. The maturity ogive assumed in the base case model (derived from Schaefer et al., 2005) is also shown.

As expected, changes of the maturity schedule had a substantial impact (e.g., ~40% change for cases 1 and 2, *h*=1) on spawning biomass (SB) related quantities (SB_{MSY} and SB_{MSY}/SB_0). Changes were much smaller for SB_{CURR}/S_{MSY} (<4% and <8 for *h*=1 and 0.75, respectively, for cases 1-4). With respect to F_{mult}, changes were not observed when no stock recruitment relationship was assumed (*h*=1), but they became detectable (<10%) for h=0.75. Noticeable changes were found for the current depletion estimate of the stock SB_{CURR}/SB_0 (<14% and <10% for h=1 and 0.75, respectively, for cases 1-4). Higher percent changes (up to around 130% and 70%) were recorded for the extreme case (run 5) when h was assumed at 1 and 0.75, respectively.

Fecundity at weight

A sensitivity analysis was conducted to investigate the effect of different assumptions about fecundity at weight. In SS2, fecundity is manipulated through the parameters of an assumed linear relationship between number of eggs and body weight. The slope parameter (b) of this relationship defines the rate of increase of fecundity as a function of weight. The EPO's base case model takes the standard assumption of b=1. Two alternative values were investigated (b=0.5 and b=1.5, cases 1 and 3, respectively). Except for SB_{MSY}, the alternative assumptions had no detectable effect on the management quantities. However, these runs assumed the natural mortality and maturity schedules as defined in the 2008 assessment. Further sensitivities should be explored.

Table 21. Description of the settings for the sensitivity analyses. Each sensitivity was run for two assumptions about the steepness (*h*) parameter of the stock-recruitment relationship (*h*=1 and *h* =0.75).

Model	M@age schedulle	Maturity@age schedulle	Fecundity@length
BASE CASE (BC) -			
2008 assessment	sex-specific (see Fig. 1a)	mat@age derived from Schaeffer et al. (1995)	proportional to weight b = 1 (slope of eggs/gram rel.)
Sensitivity 1 -			
M schedulle (females)	5 alternative shedulles of mat@age		
sens 1	see Fig. 1b	same as in BC	same as in BC
sens 2	"	"	"
sens 3	"	"	"
sens 4	"	"	"
sens 5	"	"	"
sens 6	"	"	"
Sensitivity 2 -			
Maturity schedule (females)		5 alternative shedulles of mat@age	
sens 1	same as in BC	see Fig. 2	same as in BC
sens 2	"	see Fig. 2	"
sens 3	"	see Fig. 2	"
sens 4	"	see Fig. 2	"
sens 5	"	see Fig. 2	"
Sensitivity 3 -			
Fecundity at weight			proportional to weight
sens 1	same as in BC	same as in BC	b = 0.5
sens 2	"	"	b = 1.5

Table 22. Management quantities derived from the base case model and three sensitivity analyses: natural mortality (M) and maturity schedules for females, and fecundity. Two assumptions were investigated about the steepness (*h*) parameter of the stock recruitment relationship (*h*=1 and *h*=0.75). See text for description of sensitivities.

Management		SR steepness = 1							SR steepness = 0.75					
		Sensitivity runs							Sensitivity runs					
quantities	BC 2008	1	2	3	4	5	6	2008	1	2	3	4	5	6
Sensitivity 1 - Natural mortality (M) schedule for females														
MSY	81,350	81,266	80,044	81,433	82,619	78,179	85,093	78,150	78,036	78,135	78,327	78,778	80,808	79,002
B_{MSY}	287,912	288,797	288,386	286,239	283,083	287,650	291,899	500,357	501,304	511,374	498,645	487,871	553,651	479,908
SB_{MSY}	59,626	60,639	64,296	58,085	52,174	69,360	51,857	118,154	119,854	130,635	115,640	102,691	157,181	95,118
B_{MSY}/B_0	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.34	0.34	0.34	0.34	0.34	0.35	0.34
SB_{MSY}/SB_0	0.19	0.19	0.19	0.19	0.19	0.18	0.20	0.30	0.30	0.30	0.30	0.30	0.29	0.30
C_{CURR}/MSY	1.08	1.08	1.10	1.08	1.06	1.12	1.03	1.12	1.13	1.13	1.12	1.11	1.09	1.11
B_{CURR}/B_{MSY}	1.15	1.15	1.08	1.15	1.20	0.93	1.32	0.74	0.74	0.68	0.74	0.77	0.55	0.88
SB_{CURR}/S_{MSY}	0.90	0.90	0.83	0.90	0.94	0.66	1.09	0.56	0.56	0.51	0.55	0.58	0.39	0.69
F_{MULT}	0.82	0.82	0.78	0.82	0.85	0.69	0.94	0.57	0.57	0.54	0.57	0.59	0.48	0.65
SB_{CURR}/SB_0	0.17	0.18	0.16	0.17	0.18	0.12	0.22	0.17	0.17	0.15	0.16	0.17	0.11	0.21
Sensitivity 2 - Maturity schedule for females														
MSY	81,350	81,350	81,350	81,350	81,350	81,350	-	78,150	77,219	79,717	77,770	78,643	76,735	-
B_{MSY}	287,912	287,912	287,912	287,912	287,912	287,912	-	500,357	472,311	536,345	488,353	511,677	421,653	-
SB_{MSY}	59,626	84,219	35,202	63,205	55,754	136,922	-	118,154	149,595	79,885	119,296	115,404	197,774	-
B_{MSY}/B_0	0.26	0.26	0.26	0.26	0.26	0.26	-	0.34	0.34	0.35	0.34	0.35	0.32	-
SB_{MSY}/SB_0	0.19	0.22	0.17	0.20	0.19	0.27	-	0.30	0.31	0.29	0.30	0.29	0.33	-
C_{CURR}/MSY	1.08	1.08	1.08	1.08	1.08	1.08	-	1.12	1.14	1.10	1.13	1.12	1.14	-
B_{CURR}/B_{MSY}	1.15	1.15	1.15	1.15	1.15	1.15	-	0.74	0.76	0.71	0.75	0.73	0.82	-
SB_{CURR}/S_{MSY}	0.90	0.91	0.89	0.93	0.91	1.17	-	0.56	0.59	0.52	0.58	0.55	0.85	-
F_{MULT}	0.82	0.82	0.82	0.82	0.82	0.82	-	0.57	0.58	0.56	0.57	0.57	0.61	-
SB_{CURR}/SB_0	0.17	0.20	0.15	0.19	0.17	0.32	-	0.17	0.18	0.15	0.17	0.16	0.28	-
Sensitivity 3 -Fecundity (eggs per weight relationship)														
MSY	81,350	81,350	81,350	-	-	-	-	78,150	78,150	78,150	-	-	-	-
B_{MSY}	287,912	287,912	287,912	-	-	-	-	500,357	500,357	500,357	-	-	-	-
SB_{MSY}	59,626	29,813	89,440	-	-	-	-	118,154	59,077	177,232	-	-	-	-
B_{MSY}/B_0	0.26	0.26	0.26	-	-	-	-	0.34	0.34	0.34	-	-	-	-
SB_{MSY}/SB_0	0.19	0.19	0.19	-	-	-	-	0.30	0.30	0.30	-	-	-	-
C_{CURR}/MSY	1.08	1.08	1.08	-	-	-	-	1.12	1.12	1.12	-	-	-	-
B_{CURR}/B_{MSY}	1.15	1.15	1.15	-	-	-	-	0.74	0.74	0.74	-	-	-	-
SB_{CURR}/S_{MSY}	0.90	0.90	0.90	-	-	-	-	0.56	0.56	0.56	-	-	-	-
F_{MULT}	0.82	0.82	0.82	-	-	-	-	0.57	0.57	0.57	-	-	-	-
SB_{CURR}/SB_0	0.17	0.17	0.17	-	-	-	-	0.17	0.17	0.17	-	-	-	-

Table 23. Percent change of management quantities obtained from the sensitivities analyses with respect to the base case model results (for each of the two cases of *h*, respectively). Absolute percent changes bigger than 5% are bolded.

Management quantities	SR steepness = 1 Sensitivity runs 1	2	3	4	5	6	SR steepness = 0.75 Sensitivity runs 1	2	3	4	5	6
Sensitivity 1 - Natural mortality (M) schedule for females												
MSY	0	-2	0	2	-4	5	0	0	0	1	3	1
B_{MSY}	0	0	-1	-2	0	1	0	2	0	-2	**11**	-4
SB_{MSY}	2	**8**	-3	**-12**	**16**	**-13**	1	**11**	-2	**-13**	**33**	**-19**
B_{MSY}/B_0	0	0	0	0	1	-1	0	0	0	0	1	-1
SB_{MSY}/SB_0	0	-1	0	0	**-5**	4	0	0	0	0	-2	2
C_{CURR}/MSY	0	2	0	-2	4	-4	0	0	0	-1	-3	-1
B_{CURR}/B_{MSY}	0	**-6**	0	4	**-19**	**15**	0	**-7**	0	5	**-25**	**19**
SB_{CURR}/S_{MSY}	0	**-8**	0	5	**-27**	**20**	0	**-8**	-1	4	**-29**	**23**
F_{MULT}	0	**-5**	0	4	**-16**	**14**	0	-5	0	3	**-16**	**14**
SB_{CURR}/SB_0	0	**-8**	-1	4	**-31**	**25**	0	**-8**	-1	4	**-31**	**25**
Sensitivity 2 - Maturity schedule for females												
MSY	0	0	0	0	0	-	-1	2	0	1	-2	-
B_{MSY}	0	0	0	0	0	-	**-6**	**7**	-2	2	**-16**	-
SB_{MSY}	**41**	**-41**	**6**	**-6**	**130**	-	**27**	**-32**	1	-2	**67**	-
B_{MSY}/B_0	0	0	0	0	0	-	-2	2	-1	1	**-7**	-
SB_{MSY}/SB_0	**11**	**-12**	5	-4	**40**	-	4	-4	1	-1	**13**	-
C_{CURR}/MSY	0	0	0	0	0	-	1	-2	0	-1	2	-
B_{CURR}/B_{MSY}	0	0	0	0	0	-	4	-4	1	-1	**12**	-
SB_{CURR}/S_{MSY}	1	-2	3	1	**29**	-	**6**	**-7**	4	-1	**52**	-
F_{MULT}	0	0	0	0	0	-	2	-1	1	0	**7**	-
SB_{CURR}/SB_0	**12**	**-13**	**8**	-3	**80**	-	**10**	**-10**	**6**	-2	**71**	-
Sensitivity 3 - Fecundity (eggs per weight relationship)												
MSY	0	0	-	-	-	-	0	0	-	-	-	-
B_{MSY}	0	0	-	-	-	-	0	0	-	-	-	-
SB_{MSY}	**-50**	**50**	-	-	-	-	**-50**	**50**	-	-	-	-
B_{MSY}/B_0	0	0	-	-	-	-	0	0	-	-	-	-
SB_{MSY}/SB_0	0	0	-	-	-	-	0	0	-	-	-	-
C_{CURR}/MSY	0	0	-	-	-	-	0	0	-	-	-	-
B_{CURR}/B_{MSY}	0	0	-	-	-	-	0	0	-	-	-	-
SB_{CURR}/S_{MSY}	0	0	-	-	-	-	0	0	-	-	-	-
F_{MULT}	0	0	-	-	-	-	0	0	-	-	-	-
SB_{CURR}/SB_0	0	0	-	-	-	-	0	0	-	-	-	-