

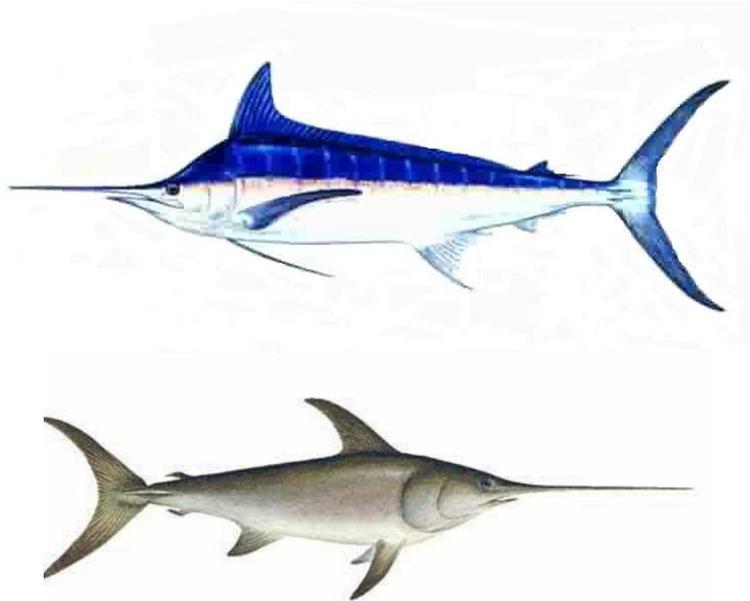


A sensitivity study of age-structured production model (ASPM) for striped marlin (*Kajikia audax*) in the western and central North Pacific Ocean

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Abstract

We evaluated the impacts of uncertainty of recruitment variation, size-at-age, maturity, natural mortality rate, steepness of stock–recruitment relationship on the population dynamics and management-related quantities for striped marlin (*Kajikia audax*) in the western and central North Pacific Ocean using an age-structured production model. The results suggest that annual recruitment variation is an important component of uncertainty to characterize temporal trend of population abundance. Incorporation of recruitment variation calls for a better fit to the assessment model. The virgin biomass and management reference points were found to be more sensitive to the uncertainty of natural mortality and steepness than other parameters such as age-at-length and maturity ogives.

1. Introduction

The striped marlin, *Kajikia audax*, is known as a migratory fish distributed in the Indo-Pacific Ocean between 45°N and 45°S (Nakamura, 1985). Striped marlin support important commercial and recreational fisheries throughout the Indian and Pacific Oceans (Ortega-Garcia et al., 2003; Bromhead et al., 2004; Kopf et al., 2005). They are caught mostly in the longline fisheries in the North Pacific Ocean (NPO). Lesser amounts of striped marlin are caught by recreational, gillnet and other fisheries.

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Pairwise microsatellite analyses revealed four groups: (1) Japan – Immature Hawaii – Southern California; (2) Mature Hawaii; (3) Mexico – Central America; and (4) Australia – New Zealand in the Pacific Ocean. No significant differentiation was found between groups 1 and 2 (McDowell and Graves, 2008; Purcell and Edmands, 2011). Therefore, two stocks of striped marlin separated at 140°W are assumed in NPO.

For the previous assessment of striped marlin in the NPO, a preliminary sensitivity examination of the stock synthesis 2 (SS2) to key assumptions was conducted based on a single-stock scenario by the striped marlin working group (SMWG) (Piner et al., 2007). The assessment was performed using two different starting periods (model started in 1952 and 1964 respectively). The results of all sensitivity runs indicated that striped marlin were at low population levels (i.e., decline 90%). Although the hyper-depletion of striped marlin has been argued by the SMWG, the decline of striped marlin catches likely implied a low population level. Another study evaluating the performance of age-structured models suggested that more biological information is necessary for further analysis (Wang et al., 2007).

Billfish stock assessments are often subject to large uncertainty in input data and life history parameters, which calls for incorporating uncertainty associated with the input parameter in a risk evaluation of the overexploitation. It is important to test models with data (Hilborn and Mangel, 1997). The objective of this study is to evaluate the population dynamics and quantities of management interest for striped marlin population in western and central North Pacific Ocean (WCNPO) using different input parameters based on an age-structured production model (ASPM; Punt, 1994; Restrepo, 1997).

2. Materials and methods

2.1 Data used

Data were originally compiled by the SMWG at the January 2011 meeting in

Honolulu, Hawaii and the May 2011 meeting in Taipei, Taiwan. In this study, the striped marlin in WCNPO is considered as a separated stock based on the two-stock scenario assumption (ISC, 2011). A total of 16 fisheries were identified and their catches were input into the model (**Fig. 1**). Generally, the catch peaked in 1970s at a level around 8000 mt, and then steadily declined to a level of 2500 mt in the end of the series. Eight time-series of standardized catch-per-unit-effort (CPUE) were used in the model. Each CPUE series is defined below: (1) Japanese Distant Water longline (Early) (JPN_DWLLearly, 1952 ~ 1974); (2) Japanese Distant Water longline (JPN_DWLL, 1975 ~ 2009); (3) Japanese Coastal Longline (JPN_CLL, 1994 ~ 2009); (4) Japanese drift net (Early) (JPN_DFT1, 1977 ~ 1993); (5) Japanese drift net (JPN_DFT2, 2001 ~ 2009); (6) Taiwanese longline (early) (TWN_EARLY, 1967 ~ 1993); (7) Taiwanese longline (TWN_LATE, 1995 ~ 2009); (8) Hawaiian longline (HW_LL, 1996 ~ 2009). Numbers-at-length data were available from ISC for 9 of the 16 fisheries.

2.2 Assessment Model

An age-structured production model similar to that of Punt (1994) and Restrepo (1997) is applied to the striped marlin in WCNPO. The growth and survival patterns were assumed to be the same for both sexes, thus the model is a single-sex model. The model assumes that recruitment is related to spawning stock biomass according to a Beverton-Holt stock-recruitment (S-R) relationship. For parsimony, no deviations of the S-R relationship were assumed in the base-case model. Because of the lack of length-frequency data for the other fleets (e.g., JPN_OLL, JPN_SQUID, TWN_OSLL, etc.), we used a fleet-aggregated selectivity to develop the ASPM and simplified the model structure. The combined size-composition of the catch from various fisheries was used to estimate the selectivity by applying the separable virtual population analysis (SVPA) (Pope and Shepherd, 1982), independently outside the ASPM. We assumed the vulnerability of a fish increases monotonically to an asymptote with increasing length by a logistic function. The parameter values were listed in Table 1.

2.3 Biological parameters

In the base model, the weight of a fish is calculated using the von Bertalanffy growth function and length-weight relationship based on the age and growth study of Sun et al. (2011a). Animals aged 15 and older are assigned to a plus-group ($\lambda = 15$). The maturity vector was based on a study of the striped marlin's reproductive biology by Sun et al. (2011b). The steepness (h) was fixed at 0.87 according to Brodziak (2011) and the natural mortality (M) was fixed at 0.38 for all ages according to Piner and Lee (2011). The values of input parameters for the ASPM model were listed in Table 1.

2.4 Sensitivity Runs

Sensitivity analyses are carried out to examine the influence of the base-case values assumed for some of the model parameters on the model outputs. For comparing the results among different runs, no recruitment variability is assumed in sensitivity tests. The parameters change from the base model in the tests of sensitivity was defined as follow:

- (1) The deviations about S-R relationship were assumed log-normally distributed ($\sigma = 0.4$) for the last thirty year (Scenario R var);
- (2) Different weight-at-age vectors using VBGF parameters from Melo-Barrera et al. (2003) ($L_\infty = 221$; $K = 0.23$; $t_0 = -1.6$) (scenario VBGF 2);
- (3) VBGF parameters from Skillman and Yong (1976) ($L_\infty = 277.4$; $K = 0.41$; $t_0 = -0.52$) (scenario VBGF 3);
- (4) A larger size-at-50% maturity of 202.6 LJFL from Kopf (2010) (scenario Mature 2);
- (5) $M = 0.2$ for all ages (Piner et al., 2007);
- (6) $M = 0.28$ for all ages;
- (7) $M = 0.48$ for all ages (Hinton and Bayliff, 2002);
- (8) $h = 0.6$ (Piner et al., 2007);

(9) $h = 0.7$;

(10) $h = 0.8$

The ASPM model outputs are evaluated using several key quantities of management interest as follows: (1) SSB, spawning stock biomass; (2) SSB/SSB_{MSY} , the ratio of spawning stock biomass to that at which MSY is achieved; (3) F , the exploitation rate; (4) F/F_{MSY} , ratio of exploitation rate to that at which MSY is achieved.

3. Results and discussion

3.1 Recruitment variation

The results of model-predicted catch-rates of eight fleets for the base-case model and the run included the recruitment deviation by changing from the base model were shown in **Fig. 2**. Generally, the model-predicted catch-rates are smoother than the observed (standardized) CPUE, and the stochastic model (with recruitment variation) presents a better fitting of CPUE data compared to the non-stochastic run. For example, the standardized CPUE of JPN_DFT1 showed an increasing trend between 1980 and 1990, but the predicted indices of the deterministic model show a slightly decreasing trend. The stochastic run presents a slight recover pattern of population abundance in the end of the series, compared to the deterministic run. However, both model-estimated catch-rates followed the trends of standardized catch-rate indices.

The time trajectory of spawning stock biomass for the base-case and the deterministic run were shown in **Fig. 3A**. Both models suggested that that spawning stock biomass declined from 1952 until the early 1960s. This reduction was due to the high catches of JPN_OTHER fisheries during this period (**Fig. 1**). The spawning stock biomass is estimated to be about 70% of the pristine state in mid 1960s. However, the spawning stock biomass seemed to decline in the 1970s, corresponding to the highest catches of striped marlin caught by the JPN_DFT fishery. There is a slight recovery from early 1980s corresponding to the high CPUE in JPN_DWLL and JPN_DFT1

and the catch reduction of JPN_DFT1. Thereafter, the spawning stock biomass continuously decline slowly to the end of time series for the deterministic model, but not for the stochastic model. The spawning stock biomass seemed to recover from early 1990s, but decline after the late 1990s, and then slightly increase in the recent years for the stochastic model.

Generally, the increases of the exploitation rate follow the decreasing pattern of the spawning stock biomass for both runs before early 1980s (**Fig. 3C**), thereafter the exploitation rate declined for the stochastic run. However, this is not found in the deterministic run. It should be noted that the estimated exploitation rate of both models seems to decrease in the recent years. However, the current exploitation rate exceeded the level to maintain MSY (F_{MSY}) for the deterministic run, but not found for the stochastic run (**Fig. 3D**).

A plot of the deterministic- and stochastic-based estimates of spawning stock biomass and exploitation rate do not show that they are at a similar level (**Fig. 3**), and suggested that the result is sensitive to recruitment variations. This clearly shows a lack of information about stock and recruitment of this species and more work needs to be done on the behavior of the stochastic recruitment.

3.2 Uncertainty of growth and size-at-maturity

The estimated spawning stock biomass varied with the uncertainty in growth parameters (**Fig. 3A**). The relationships of weight-at-age, age-at-maturity, and age-specific selectivity is not independent to the variation of growth. Therefore, the uncertainty of the growth parameter affected the estimation of spawning stock biomass. We found that the VBGF3 scenario has a larger estimate of virgin biomass. However, the SSB/SSB_{MSY} ratios among different growth variation scenarios are almost the same, compared to the result of the base-case scenario (**Fig. 3B**). This suggests that the SSB_{MSY} would vary with uncertainty of input growth parameters as well. For example, fish with a slow growth rate but larger maximum attainable size would have a larger estimate of SSB_{MSY} (the VBGF3 scenario).

The uncertainty of 50%-size-at-maturity has a larger impact on the estimation of spawning stock biomass as expected. A larger size-at-50% maturity would have a large estimated value of virgin biomass, thus the times-series of exploitation rate is not so high due to the large amount of exploitable biomass (**Fig. 3C**). However, the small values of SSB_{MSY} and F_{MSY} (**Fig. 3D**) were observed in this case, which suggests that fish of a population maturing at large size may have a high risk of over-exploitation.

The uncertainty of growth parameters would also impact on the estimation of current exploitation rate. For example, a relative high value of current exploitation rate (**Fig. 3C**) and small F_{MSY} (**Fig. 3D**) was suggested to the case that fish has a slow rate approaching to a small maximum attainable size (i.e., the VBGF2 scenario). Furthermore, we suggest that the uncertainty in growth parameter would have a larger impact on the exploitation rates after 1980s, compared to that in the earlier period (1950-1975). This may result from relatively low exploitable biomass in the late period, thus the variation of exploitation rate would be high.

3.3 Uncertainty of natural mortality and steepness

The estimated time-series spawning stock biomass and exploitation rate varied largely with the uncertainty of natural mortality and steepness. The sensitivity results show that increase productivity via M results in a smaller estimate of virgin biomass but less depleted population (**Figs. 4A**). The estimated values of SSB_{MSY} and F_{MSY} would be changed according to the fish productivity. For example, fish with a high mortality rate would have small SSB_{MSY} and high F_{MSY} values (**Fig. 4B and 4D**). The estimated exploitation rate is relative high due to the low level of exploitable biomass between 1975 and 2000 (**Fig. 4C**), but significantly decline in the end of the series (2000 ~ 2010). The F/F_{MSY} ratio was observed to be declined as well (**Fig. 4D**). Contrasting, less productive populations start from a larger initial size and end up more depleted.

For the uncertainty of steepness of stock-recruitment function, similar patterns of the SSB, exploitation rate and management-related quantities were shown in **Fig. 5**.

When the steepness parameter approaches its theoretical maximum value of 1.0, the small spawning stock biomass (or exploitable biomass) and high exploitation rates are observed. However, the high value of h means the stock-recruitment curve can yield recruits at very low spawning biomass, therefore the estimated exploitation rate tends to decline with year when the exploitable biomass is increasing and the observed catch is decreasing for the recent years. The high h may lead to F_{MSY} and SSB_{MSY} values that are relative high and low, respectively. Productivity for the striped marlin stock is unlikely to be at such an extremes (very high productivity $h = 0.99$ or very low productivity $h = 0.6$). It is unsuitable to assume constant recruitment when spawning biomass reaches extremely low levels. We also found the estimated trend of the spawning stock biomass and exploitation rate would change upward or downward by the uncertainty of natural mortality (assumed M not varied between years) and steepness, but the estimates of that would change inter-annually by the recruitment deviation (**Figs. 4B and 5B**).

This paper focused on a range of assessments based on different assumptions and input parameters to show the sensitivity of results to model assumptions. However, all the sensitivity runs indicate that the exploitable biomass declined by around 90% of the pristine state. A similar result was also suggested by the previous SS2 sensitivity runs for a single striped marlin stock in NPO (Piner et al., 2007). It is recommended that future studies explore the models that have flexibility to fully incorporate biological information and the uncertainties associated with biological inputs.

References

- Brodziak, J. 2011. Probable values of stock-recruitment steepness for north Pacific striped marlin. ISC/11/BILLWG-2/11.
- Bromhead, D., Pepperell, J., Wise, B., and Finlay, J. 2004. Striped marlin: Biology and fisheries. Bureau of Rural Sciences, Canberra. 260 pp.
- Hilborn, R., and Mangel, M. 1997. The ecological detective: confronting models with data, Princeton University Press, Princeton, New Jersey, USA.

- Hinton, M. G., and Bayliff, W. H. 2002. Status of striped Marlin in the Eastern Pacific Ocean in 2011 and outlook for 2002. SCTB15 WP. BBRG-1.
- ISC 2011. Report of the billfish working group workshop. BILLWG-2, International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean. 24 May- June 2011. Taipei, Taiwan.
- Kopf, R. K., Davie, P. S., and Holdsworth, J. C. 2005. Size trends and population characteristics of striped marlin, *Tetrapturus audax* caught in the New Zealand recreational fishery. N.Z. J. Mar. Freshwat. Res., 39: 1145-1156.
- Kopf, R. K., Pepperell, J., and Davie, P. S. 2009. A preliminary report on age, growth, and reproductive dynamics of striped marlin (*Kajikia audax*) in the southwest Pacific Ocean. WCPFC-SC5/BI-WP-01.
- McDowell, J. R., and Graves, J. E. 2008. Population structure of striped marlin (*Kajikia audax*) in the Pacific Ocean based on analysis of microsatellite and mitochondrial DNA. Can. J. Fish. Aquat. Sci., 65: 1307-1320.
- Melo-Barrera, F. N., Felix-Uraga, R., and Quinonez-Velazquez, C. 2003. Growth and length-weight relationship of the striped marlin, *Tetrapturus audax* (Pisces: Istiophoridae), in Cabo San Lucas, Baja California Sur, Mexico. Cienc. Mar., 29: 305-313.
- Ortega-Garcia, S., Klett-Traulsen, A., and Ponce-Diaz, G. 2003. Analysis of sportfishing catch rates of striped marlin (*Tetrapturus audax*) at Cabo San Lucas, Baja California Sur, Mexico, and their relation to sea surface temperature. Mar. Freshwater Res., 54: 483-488.
- Piner, K., Conser, R., DiNardo, G., and Brodziak, J. 2007. SS2 Sensitivity Runs for Striped Marlin Assessment WG 2007. ISC/07/MARLIN&SWOWG-1/02.
- Piner, K., and Lee, H. H. 2011. Correction to meta-analysis of striped marlin natural mortality. ISC/11/BILLWG-2/08.
- Pope, J. G., and Shepherd, J. G. 1982. A simple method for the consistent interpretation of catch-at-age data. J. Cons. int. Explor. Mer, 40: 176-184.
- Punt, A. E. 1994. Assessments of the stocks of Cape hakes, *Merluccius* spp. off South Africa. S. Afr. J. Mar. Sci., 14: 159-186.

- Purcell, C., and Edmands, S. 2011. Resolving the genetic structure of striped marlin, *Kajikia audax*, in the Pacific Ocean through spatial and temporal sampling of adult and immature fish. *Can. J. Fish. Aquat. Sci.*, 68: 1861-1875.
- Restrepo, V. R. 1997. An implementation of the age-structured production model with application to West Atlantic bluefin tuna fisheries. *Col. Vol. Sci. Pap. ICCAT*, 46(2): 348-353.
- Ricard, D., and Basson, M. 2002. Application of an age-structured production model (ASPM) to the Indian Ocean bigeye tuna (*Thunnus obesus*) resource. *IOTC Proc*, 5: 189-202.
- Skillman, R. A., and Yong, M. Y. Y. 1976. von Bertalanffy growth-curves for striped marlin, *Tetrapturus audax*, and blue marlin, *Makaira nigricans*, in central north Pacific Ocean. *Fish. Bull.*, 74: 553-566.
- Sun, C. L., Chang, S. Y., Chang, Y. J., and Yeh, S. Z. 2011a. Reproductive biology of female striped marlin (*Kajikia audax*) in the waters off Taiwan (preliminary). *ISC/11/BILLWG-1/09*.
- Sun, C. L., Hsu, W. S., Su, N. J., Yeh, S. Z., Chang, Y. J., and Chiang, W. C. 2011b. Age and growth of striped marlin (*Kajikia audax*) in the waters off Taiwan: A revision. *ISC/11/BILLWG-2/07*.
- Wang, S. P., Sun, C. L., Yeh, S. Z., DiNardo, G., Chiang, W. C., and Chang, S. K. 2007. Examination of the performance of age-structured model for striped marlin in the North Pacific. *ISC/07/MARLIN&SWOWG-1/14*.

Table 1. List of parameters and models for developing ASPM (base-case) for the striped marlin in the western and central North Pacific Ocean.

Description	Parameter symbol	Parameter value	Source
Size-at-age	$LJFL_t$ (cm)	$LJFL_t = 243.44 \times (1 - e^{-0.04(1+2.05)(t+0.4)})$	Sun et al. (2011a)
Length-weight relationship	a and b	$a = 0.000005$ $b = 3.16$	Sun et al. (2011a)
Natural mortality	M (year ⁻¹)	0.38	ISC 2011
Age-at-maturity	P_{LJFL}	$P_{LJFL} = 1 / 1 + \exp\left(-\ln 19 \frac{LJFL - 178.98}{235.96 - 178.98}\right)$	Sun et al. (2011b)
Plus-group	λ	15	ISC 2011
Fleet-aggregated selectivity	S_{LJFL}	$S_{LJFL} = 1 / 1 + \exp\left(-\ln 19 \frac{LJFL - 128}{151 - 128}\right)$	derived from SVPA
Steepness	h	0.87	ISC 2011

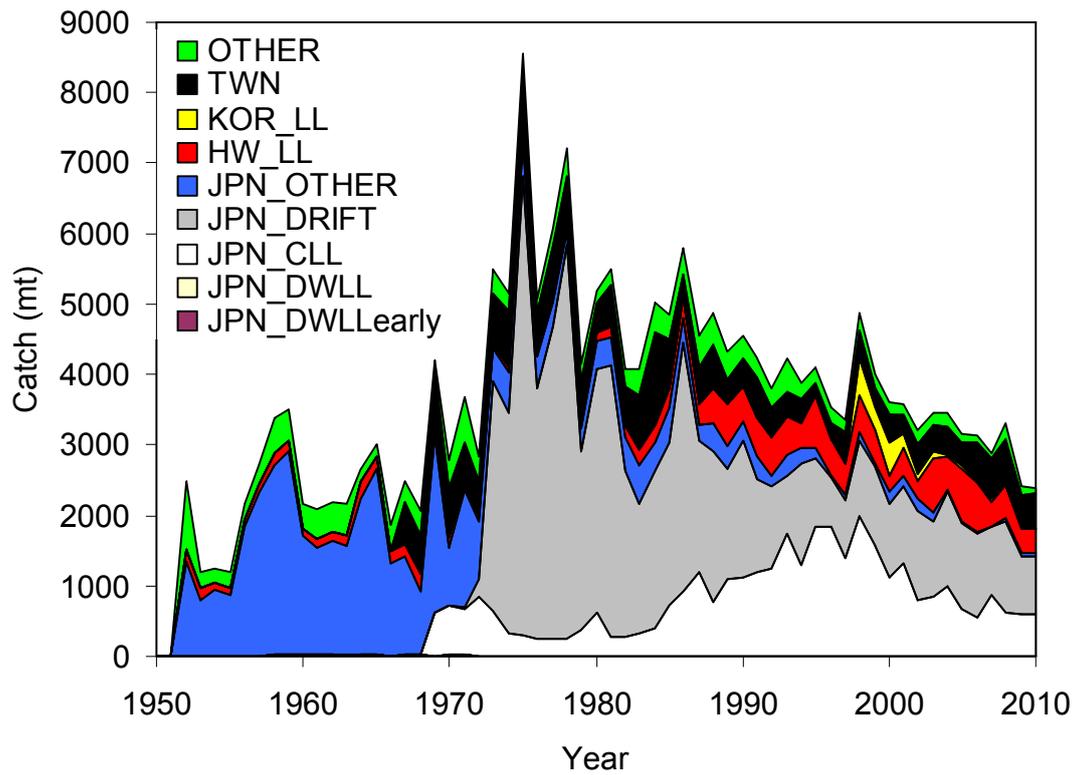


Figure 1. Annual catches (1952-2009) of striped marlin by fleet in the western and central North Pacific Ocean. JPN_DWLLearly: Japanese distant-water longline early (1952 ~ 1974) ; JPN_DWLL: Japanese distant-water longline (1975 ~ 2010); JPN_CLL: Japanese coastal longline; JPN_DFT: Japanese driftnet; JPN_OTHER: Japanese other fisheries; HW_LL: Hawaiian longline; KOR_LL: Korea longline fisheries; TWN: Taiwanese fisheries (longline, offshore longline, and coastal fisheries combined); OTHER: other fisheries.

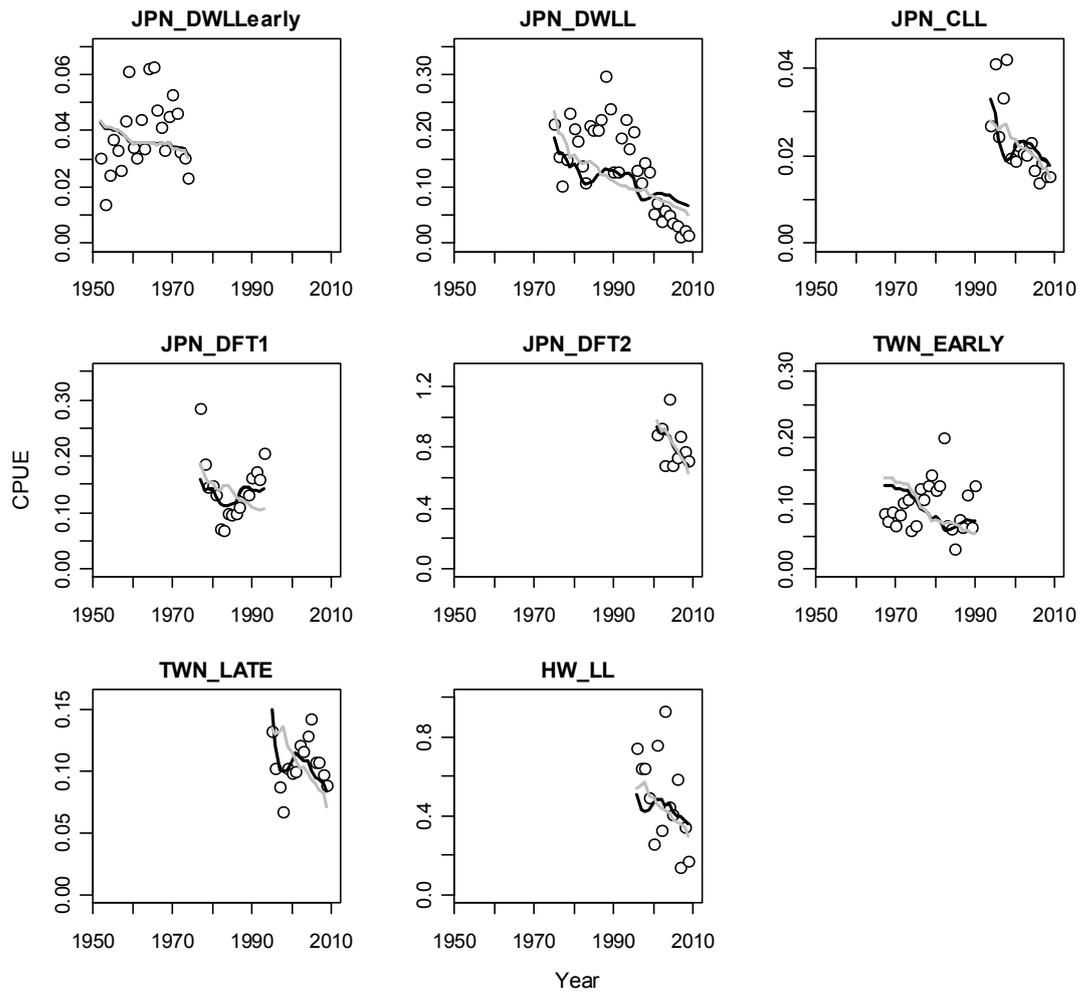


Figure 2. Observed (circle) and model-predicted CPUEs of the bases-case (gray line) and the run without the recruitment deviation (black line) for the striped marlin in the western and central North Pacific Ocean

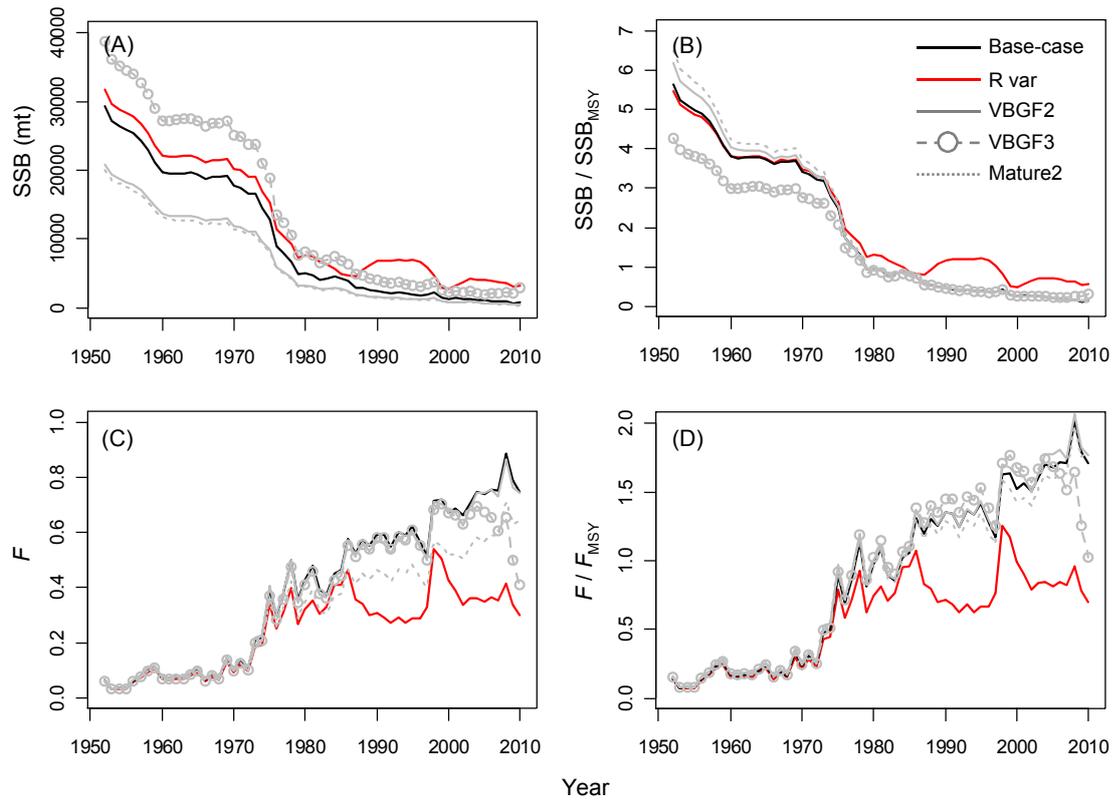


Figure 3. Time trajectories of the SSB (A); SSB / SSB_{MSY} (B); F (C); and F / F_{MSY} (D) by different growth and maturation parameters for the striped marlin in the western and central North Pacific Ocean.

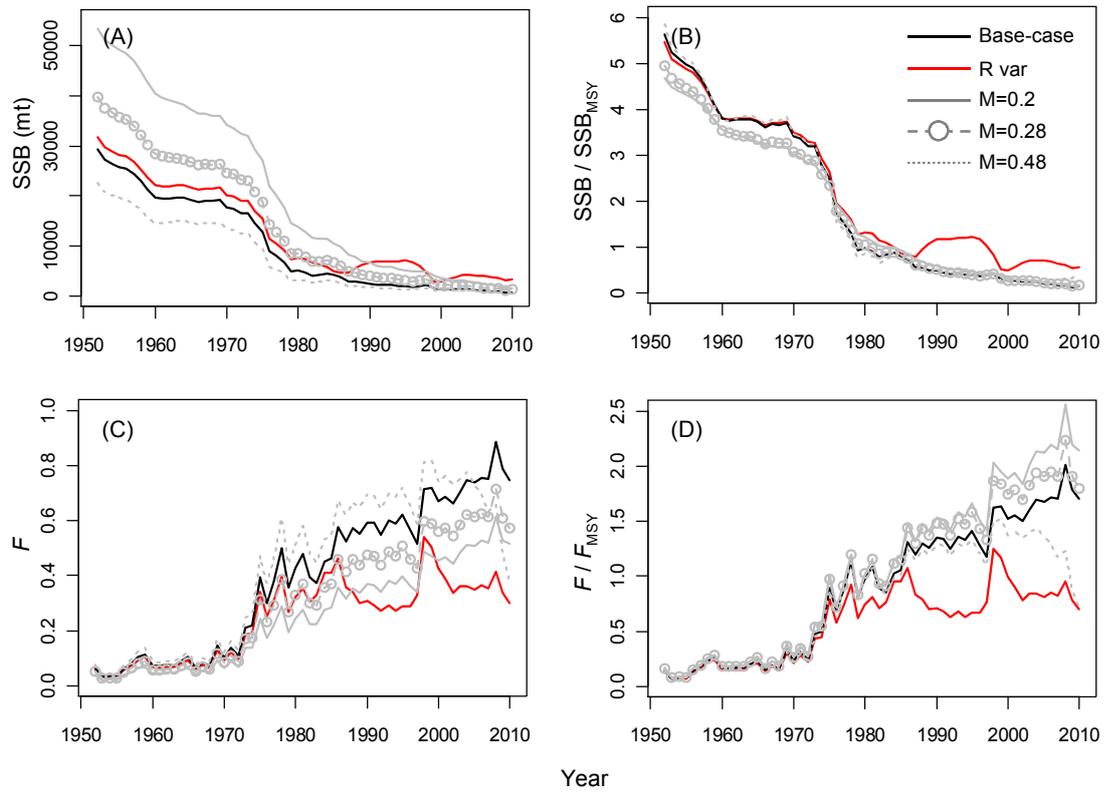


Figure 4. Time trajectories of the SSB (A); SSB / SSB_{MSY} (B); F (C); and F / F_{MSY} (D) by different natural mortality for the striped marlin in the western and central North Pacific Ocean.

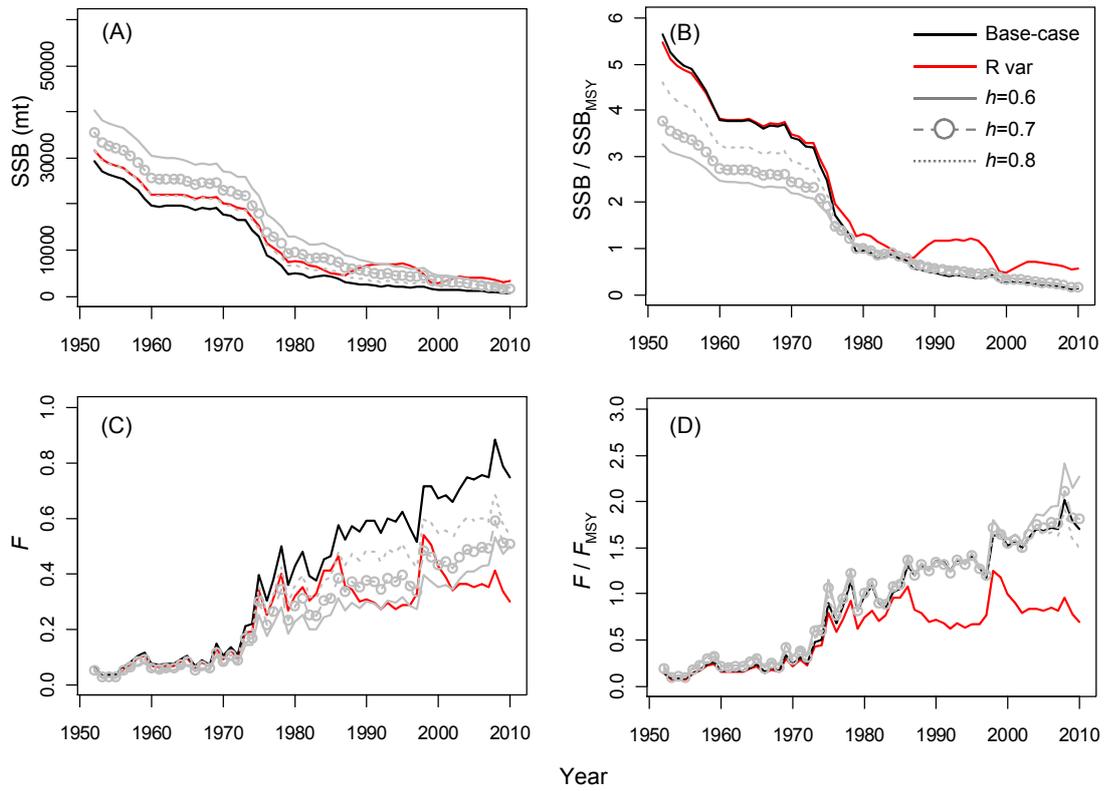


Figure 5. Time trajectories of the SSB (A); SSB / SSB_{MSY} (B); F (C); and F / F_{MSY} (D) by different values of steepness for the striped marlin in the western and central North Pacific Ocean.