Stock Assessment and Future Projections of Blue Shark in the North Pacific Ocean by Bayesian Surplus Production Model using Revised Data[1]

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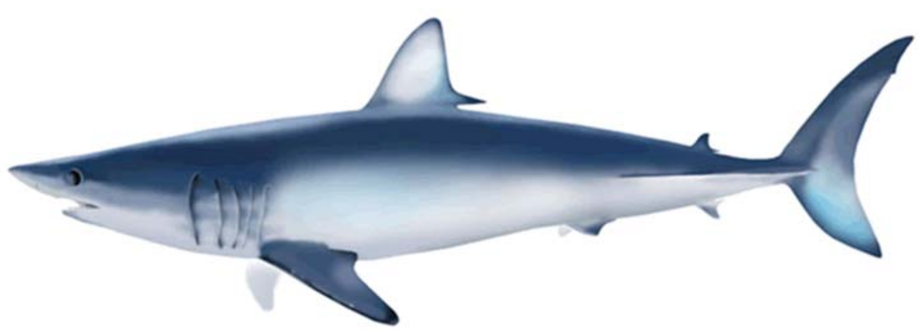

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Abstract

This working paper reports results of the revised stock assessment for north Pacific blue shark using a state-space Bayesian surplus production (BSP2) model. In this assessment, five CPUE indices, Japan offshore shallow longline CPUE for 1976 to 1993 (**JE**), Japan offshore and distant water logline CPUE for 1994 to 2010 (**JL**), Hawaii deep-set longline CPUE (**HW**), SPC longline CPUE (**SP**) and Taiwan large-scale longline CPUE (**TW**), were used to account for a full range of uncertainties associated with stock dynamics. Catch data for the assessment period, 1971-2011, were used. In this assessment, eight reference cases were set up, such that the model was fitted to either each of four indices alone (JL_Ref, HW_Ref, SP_Ref and TW_Ref) or the combination of one of the four with JE index (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref).

Model fits in posterior mode estimation were not good for HW, SP and TW CPUE indices regardless of using these indices alone or in combination with JE index, while model fits for both JE and JL indices were quite good. This is probably due to inconsistency of trends between catch and these three indices. Across all the eight reference cases examined, model convergences were all fairly well.

The four single-index cases (JL_Ref, HW_Ref, SP_Ref and TW_Ref) resulted in vague posterior distributions with long tails for key parameters and stock dynamics with almost no trend detected and extremely wide confidence limits. Thus, we concluded valuable that insight about the stock dynamics and status for north Pacific blue shark could hardly be drawn from results of JL_Ref, HW_Ref, SP_Ref and TW_Ref cases, and decided that only the other four cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) should be examined further in sensitivity analyses and future projections.

Although assessment results were different among JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref, with respect to median estimates, they generally produced similar stock status and future projections. i.e., the stock biomass of north Pacific blue shark was well above the biomass at maximum sustainable yield (B_{msy}), and the fishing rate in 2011 was well below F_{msy}. However, for reference cases and the related sensitivity runs for JEHW_Ref, JESP_Ref and JETW, 90% confidence intervals for B_{2011}/B_{msy} and F_{2011}/F_{msy} were considerably wide.

Under both status quo constant catch and F harvest policies, the median stock biomass of blue shark will remain stable and above B_{msy} level throughout the projection time horizon with high probabilities. Similarly, future median fishing mortality will remain well below F_{msy}.

Given the better model fit to the data and narrower confidence limits for key assessment parameter estimates, it can be considered that the result from JEJL_Ref case would be most plausible to represent the stock dynamics and status for north Pacific blue shark.

The results of this revised assessment using the BSP2 model mostly suggest optimistic stock status for north Pacific blue shark with respect to median estimates even though alternative choices of CPUE indices were used to account for a full range of uncertainties about stock dynamics. However, some uncertainties about stock status were still recognized in some reference cases and the related sensitivity runs. Considering this together with potential uncertainties associated with catch data estimates used, biological and demographic parameters, and model structures, a decisive final conclusion on stock status for north Pacific blue shark should be carefully drawn from examination and discussion of outcomes from multiple assessment approaches (i.e., BSP2 and SS assessment) in the ISC Shark Working Group.

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1. Introduction

The Western and Central Pacific Fisheries Commission (WCPFC) Scientific Committee Ninth Regular Session (SC9) reviewed and discussed results of the stock assessment using Bayesian surplus production (BSP) model for north Pacific blue shark conducted by the International Scientific Committee for tuna and tuna-like species in the North Pacific Ocean (ISC) Shark Working Group (SHARKWG) (ISC SHARKWG 2013b). In the discussion, concerns were raised about the assessment results using limited alternative CPUE indices only and a need to consider a full range of uncertainties in the data inputs was noted. Consequently, SC9 could not reach consensus on which CPUE indices best reflected changes in the relative abundance of north Pacific blue shark and recommended ISC SHARKWG that a revised assessment be presented to SC10 in 2014 (WCPFC 2013).

This working paper reports results of the revised stock assessment for north Pacific blue shark using the BSP model. In this revised assessment, five different CPUE indices were used to fit the model to account for a full range of uncertainties about stock dynamics associated with alternative index choices. These CPUE indices were reviewed and discussed in the ISC SHARKWG workshop in January 2014 (ISC SHARKWG 2014). For this revised assessment, standardizations of CPUE data were improved and catch estimates for Japanese and Taiwanese fleets were revised. Details of revisions of CPUE standardizations, CPUE indices and catch data are described in ISC SHARKWG (2014).

2. Data used

2.1.1 Catch data

Catch data were revised from those used in the 2013 stock assessment. Details of the data revision and agreements on the data were described in ISC SHARKWG (2014). Thorough general review and description of catch data for north Pacific blue shark can be found in the 2013 assessment report (ISC SHARKWG 2013b). The catch data used in this assessment were shown in Figure 1. These catch data were provided to member scientists in an MS-Excel formatted file named "Blue shark catch data updated through 2012 as of Jan 24 2014.xlsx" by the ISC SHARKWG chair (Suzanne Kohin, NMFS/SWFSC, La Jolla, CA. USA).

2.1.2 Standardized CPUE index data

In this stock assessment for north Pacific blue shark, five abundance indices, Japan offshore shallow longline CPUE for 1976 to 1993 (Japan early period, **JE**), Japan offshore and distant water logline CPUE for 1994 to 2010 (Japan late, **JL**), Hawaii deep-set longline CPUE (**HW**), SPC longline CPUE (**SP**) and Taiwan large-scale longline CPUE (**TW**), were used to account for a full range of uncertainties about stock dynamics (Table 1 and Figure 2). Detailed descriptions and characteristics of these indices can be found in ISC SHARKWG (2014). All the five CPUE indices were standardized through statistical modeling to estimate year trends of relative stock dynamics for the blue shark. The model was fitted to the index(ices) either by alone (JL, HW, SP or TW) or by the combination of each of the four with JE index (Table 1 and also see below).

3. Model Description

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3.1 Bayesian surplus production model

The ISC SHARKWG decided to use a Bayesian surplus production (BSP) model (ISC SHARKWG 2013a) and chose the BSP2 software developed for ICCAT (McAllister and Babcock 2006[1]). A state-space version of the BSP model that incorporates stochastic process error in the stock dynamics was used, thereby allowing a more thorough accounting of uncertainty in estimates of stock biomass, future projections, and deviations as compared to a deterministic BSP model (Stanley et al. 2012). BSP2 takes a Bayesian parameter estimation approach in which the posterior distribution of key parameters given data is obtained from the likelihood of the data and the prior distribution of the data using Bayes theorem (McAllister and Babcock 2006). Using the priors enables the model to incorporate existing information and expert judgments. BSP2 approximates the posterior distribution applying the Sampling Importance Resampling (SIR) algorithm. The software fits either a Schaefer or Fletcher/Schaefer production model to time-series of catch and indices of abundance (standardized CPUE indices) with CV (coefficient of variation). The Schafer surplus production model is expressed as (Prager 1994):

(1) $$\frac{dB_t}{dt} = rB_t - \frac{r}{K}B_t^2 - F_tB_t$$

where r is intrinsic rate of increase, K is carrying capacity, B_t is biomass at time t, and F_t is fishing mortality rate at time t. In the Schaefer model, the biomass that produces maximum sustainable yield (B_{msy}) is one half of K.

A generalized version of the model which allows B_{msy}/K to vary includes a shape parameter, n, as well as the additional parameter m (maximum sustainable yield, MSY) (Fletcher 1978):

(2) $$\frac{dB_t}{dt} = gm\frac{B_t}{K} - gm\left(\frac{B_t}{K}\right)^n - F_tB_t$$

where

(3) $$g = \frac{n^{n/n-1}}{n-1}$$

and the inflection point is

(4) $$\phi = \frac{B_{msy}}{K} = \left(\frac{1}{n}\right)^{1/n-1}.$$

At n=2, the inflection point occurs at 0.5K and this model is identical with the Schaefer model (Prager 2002). This model predicts near-infinite rates of surplus production per capita as abundance decreases to low levels when $n \le 1$ (i.e., $B_{msy}/K \le 1/e$) (Quinn and Deriso 1999, Prager 2002). BSP2 has been adapted to provide a more realistic production model by fitting a synthesis of the Fletcher and Schaefer models that can take on reasonable values of r at all inflection points (called the Fletcher-Schaefer model) (McAllister and Babcock 2006). For $n > 2$ the original Fletcher model as in Eq. 2 applies. For $n < 2$ and $B_t/B_{msy} > 1$ the Fletcher model also applies. For $n < 2$ and B_t/B_{msy}

[1] The current available software manual of the BSP model (McAllister and Babcock 2006) does not fully explain input parameters, model options and outputs for a state-space version of the BSP model, although it is still useful to learn how to run the software. The ISC Shark Working Group held a three-day workshop in Yokohama, Japan in November 2012 during which Dr. Murdoch McAllister demonstrated how to run the state-space BSP model software.

≤ 1 the functional Schaefer model as in Eq. 1 applies, where *K* is replaced with *h*=2∅*K*, and ∅ is from Eq. 4.

A state-space version of the BSP model that incorporates lognormal deviates from total annual stock biomass predictions as described in Stanley et al. (2012) was used:

$$(5) \qquad B_t = \left(B_{t-1} + rB_{t-1} - \tfrac{r}{K} B_{t-1}^2 - F_{t-1}B_{t-1}\right)\exp\left(\varepsilon_t - \tfrac{\sigma_p^2}{2}\right)$$

where the prior probability distribution for the process error term is given by $\varepsilon_t \sim Normal\left(0, \sigma_p^2\right)$.

3.2 Reference case specifications and input parameter settings

Data and initial conditions for eight reference cases are summarized in Table 1 along with the agreements at the January 2014 ISC SHARKWG meeting (ISC SHARKWG 2014). Biological and demographic assumptions made to setup the model were described in ISC SHARKWG (2013b), and are found in Table 1.

Although model setup was determined through SHARKWG consensus at the January 2014 meeting, the choice of one input parameter value was subsequently changed as a result of exploratory model tuning. It was determined that the standard deviation (SD) of 0.07 for stock dynamics process error gave better model fits to the data in posterior mode estimation by some preliminary BSP2 model runs conducted to examine the relationship between SD for the process error, CV(s) for CPUE index(ices) and model fits. Thus, SD for the process error was changed from the original choice of 0.05 to 0.07 in this assessment.

The ISC SHARKWG agreed to use five abundance indices (JE, JL, HW, SP and TW CPUE indices) for investigating a full range of uncertainty about stock dynamics of north Pacific blue shark (ISC SHARKWG 2014). In this assessment, we set up the eight reference cases that the model was fitted to either each of four indices (JL, HW, SP and TW) alone or the combination of one of the four with JE index (Table 1).

CV for each CPUE index was determined as follows. Assuming that the CV for each index was constant across years, the CV value was repeatedly adjusted (iterative reweighting) with an initial value of 0.20 until the ratio of the input CV to the empirical model fit (output) CV ranged approximately between 1.1-1.5, while SD of the process error for stock dynamics was fixed at 0.07, to account for uncertainty model parameters and allow for efficient important sampling (M. McAllister, pers. comm.).

As in the assessment in 2013 (ISC SHARKWG 2013b), the initial and terminal years of assessment were set to 1971 and 2011, respectively.

3.3 Specifications and parameter settings for sensitivity runs

Eighteen sensitivity runs based on alternative biological and demographic parameters were agreed at the 2014 January meeting (ISC SHARKWG 2014). These are summarized in Table 2. Alternative choices of 'low' and 'high' *r* prior mean were based on ranges considered biologically plausible from demographic analyses (Cortés 2002, Babcock and Cortés 2009, also see Kleiber et al. 2009 for choices for SD). Effects of lower and higher stock productivity values of the shape parameter on results were examined. As in the reference cases, different assumptions of B_{init}/K (*alpha.b0*) prior mean and SD were based upon expert opinion, after considering the work of

Ohshimo et al. (2014), Matsunaga et al. (2005), Ward and Myers (2005), and reported longline effort in the North Pacific Ocean since 1950. Details of these alternative choices for sensitivity runs were described in ISC SHARKWG (2013b).

It was concluded that meaningful insight about the stock dynamics and status for north Pacific blue shark could not be drawn with confidence from results of JL_Ref, HW_Ref, SP_Ref and TW_Ref cases after close examination on results of these four cases (see Results and Discussion section below), further investigations by sensitivity runs were conducted for the other four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) only.

3.4 Evaluation of alternative sensitivity runs with Bayes factors

Bayes factors (Kass and Raftery 1995) for the reference cases and for each of the corresponding sensitivity runs were calculated to compare the credibility of a model given the data. Bayes factors provide a basis for examining both the relative goodness of model fit to the data and the parsimony for each of the alternative models. Factor values are calculated as the ratio of the marginal probability of the data for one model to that of another model. The average value for the importance weights from a given model result was used as an approximation of the probability of the data given the model (Kass and Raftery 1995, Stanley et al. 2012). This is a numerically stable approximation for the data probability, given the model and approximations obtained through importance sampling. Bayes factors for sensitivity runs were compared to the related reference case. In general, Bayes factors need to differ substantially from 1.0 for inferences to be made from the analysis. However, even considerably small or large differences in the factors can be caused by random chance in the data and/or misspecification of probability models. Thus, intermediate ranges for relative Bayes factors such as between 0.001 and 100 must be carefully interpreted (Stanley et al. 2012). If the relative factor of one model to another is less than 0.01 or greater than 100, the model could be considered highly unlikely compared to the other.

3.5 Model without CPUE indices (Prior-only run)

Relative influence of priors and data on the marginal posterior distributions for key assessment parameters and stock dynamics of north Pacific blue shark was examined by running the reference case model without fitting to the CPUE indices (called prior-only run). In addition to the prior-only run using observed catch data, three prior-only runs using catch with very different trajectories and magnitudes (halving, doubling and reversed of catch) were also conducted to examine the influence of information contained in catch data on assessment results.

3.6 A range of uncertainties about stock dynamics and status investigated

In this stock assessment for north Pacific blue shark using the BSP2 model, we took a different approach to account for uncertainties about stock dynamics and status from a grid approach used in the assessment by the Stock Synthesis (SS) model. By setting the four reference cases using each of JL, HW, SP and TW indices and the other four cases fitting the model to each combination of these four indices with JE index together with the related sensitivity runs (Tables 1 and 2), a total of 80 runs (8 references + 4 references x 18 sensitivities) were conducted to investigate the full range of uncertainties associated with alternative CPUE indices and model input parameters. Further, the four prior-only runs (see above) were conducted to examine the relationship between data, priors and the model, and effects of priors on results (Table 2). For all these runs, we undertook a close and careful examination of model fit, model convergence and resultant key parameter estimates and stock dynamics/status.

3.7 Evaluation of model convergence

Model convergence was evaluated with BSP2 model software diagnostics (McAllister and Babcock 2006). In general, the joint posterior distribution is sufficiently well estimated when the maximum weight of any draw is less than approximately 0.5~1% (McAllister and Babcock 2006, M. McAllister pers. comm.), which is a measure of the relative influence of the highest weighted draw. Adequate precision is likely to be achieved after saving at least 20,000 samples, as samples are discarded if parameters exceed their specified bounds. The CV of weights should be relatively low, especially the CV of importance sample weights should be less than the CV of likelihood priors multiplied by priors for the same draw (McAllister et al. 2002).

3.8 Future projections

As stated previously, it was concluded that insights about the stock dynamics and status for north Pacific blue shark could not be confidently drawn from results of JL_Ref, HW_Ref, SP_Ref and TW_Ref cases by close examination on results of the four cases (see Results and Discussion section below), future projections were conducted for the other four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) only.

Future projections using seven harvest control policies (three levels of constant catch, three levels of constant F and F_{msy} policies) were conducted for the four reference cases. The three levels of constant catch assumed 46,690, 56,030, and 56,030 mt for all the four reference cases. The three levels of constant F assumed 0.0821, 0.0985 and 0.0657 for JEJL_Ref, 0.0675, 0.0810 and 0.0540 for JEHW_Ref, 0.0685, 0.0822 and 0.0548 for JESP_Ref, and 0.0798, 0.0958 and 0.0639 for JETW_Ref, respectively. These F values were calculated using estimates from results of each reference case. For both constant catch and F harvest policies, three levels of the policies correspond to the average of 2006-2010 catch or F (status quo), and 20% increases and 20% decreases from the average, respectively. Catch and F in 2011 were excluded from the averaging because the Japanese longline fleet was greatly affected by the Great East Japan Earthquake of March 2011 (major longline ports in the Tohoku area were destroyed), thus effort and catch subsequently decreased in 2011. For F_{msy} harvest policy, estimated values of F_{msy} for each simulation in each reference case were used. Time horizons of the projections were set at 5, 10, and 20 years from the terminal year (2011).

4. Results and Discussion

4.1 Eight reference cases

4.1.1 Model convergences of the eight reference cases

Available diagnostic statistics for model convergence of the eight reference cases from the BSP2 model software were checked to verify low posterior correlations (r and K), an adequate number of saved draws in importance sampling (>20,000 samples), a low maximum weight of any draw (< 1%), and that the CV of the weights of the importance draws was less than the CV of the likelihood times priors for the same draws (Tables A1 to A4). Although the CV of the weights was large, other

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statistics indicated that the joint posterior distribution was sufficiently estimated and it did not result in non-identifiability of parameters (M. McAllister, pers. comm.).

4.1.2 Model fits for the eight reference cases

Model fits to the standardized CPUE indices for the eight reference cases and the relevant residual plots were checked to verify whether reasonable results of posterior mode estimate were obtained (Figures 1A (a) to (h)). Model fits to the CPUE indices for JEJL_Ref and JL_Ref were quite good and there was no systematic pattern observed in the residual plots (Figures 1A (a) and (e)).

For other reference cases, model fits to the CPUE indices for HW_Ref, SP_Ref, TW_Ref and combinations with JE CPUE (JEHW_Ref, JESP_Ref, JETW_Ref) were not good while fits to that of JE were improved (Figures A1 (b), (c), (d), (f), (g) and (h)). There were also some systematic trends observed (positive to negative or vice versa) in residuals depending on particular cases, indicating some autocorrelation in the deviates. In the estimation process, we tried to obtain better model fits to CPUE data (of HW, SP and TW) for these six cases adjusting input values for the standard deviation (SD) of the process error for stock dynamics and total CVs for CPUE indices by iterating reweighting procedure. However, better fits (although it was just apparently better) to the CPUE data for these cases than the results presented in this paper were obtained only when unreasonable input settings were used. In other words, unacceptably lower or higher total CV magnitudes would need to be used when interatively reweighting CPUE indices to achieve better model fits. This resulted in too small or large of a ratio of the total CV input to the empirical model fit CV for some CPUE indices. In turn, this caused uncertainty in model parameter estimation and did not allow for reasonably efficient importance sampling (i.e., model convergence diminished or was never achieved). This is probably due to inconsistency between catch and CPUE (of HW, SP and TW) trends. Therefore, we considered that this was not model misspecification and concluded that the results presented in this paper were the best that could be obtained with these data.

4.1.3 Results of the eight reference cases

Stock assessment statistics and marginal posterior distributions for key parameters

Comparisons of stock assessment statistics (medians) for the eight reference cases are summarized in Table 3 and detailed statistics for each case are shown in Tables 4 to 11. Comparisons of marginal posterior distributions for key assessment statistics are plotted in Figures 3 and 4. Priors (for r and K) and marginal posterior distributions resulting from prior-only runs were also plotted in Figures 3 and 4.

Overall, the eight reference cases can be categorized by similarities of results of the assessment statistics into four groups as: JEJL_Ref; JEHW_Ref, JESP_Ref and JETW; JL_Ref; HW_Ref, SP_Ref and TW_Ref (Table 3 to 11 and Figure 3 and 4). Details of differences in each parameter estimate are explained below.

The posterior median estimate for r in JEJL_Ref case was the largest (0.41) of the eight cases (Table 3 and Figure 3 (a)). The medians for r in HW_Ref, SP_Ref and TW_Ref (0.34 to 0.35) were smaller than that in JEJL_Ref but larger than those in JEHW_Ref, JESP_Ref, JETW_Ref and JL_Ref (0.28 to 0.30). The posterior medians for r were slightly smaller than the posterior means in all reference cases except for JEJL_Ref, indicating some skewness to the right in the posterior distributions (Table 4 to 11, and Figure 3 (a) and 4 (a)). The r posterior distributions in all reference cases except for JEJL_Ref were quite similar in shape to the prior distribution and posterior

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distribution resulted from the prior-only run, implying that there was some new information contained in the data only used in JEJL_Ref case, which updated the distribution of *r* (Figures 3 (a) and 4 (a)).

The posterior median estimates for carrying capacity (K), the stock biomass at maximum sustainable yield, MSY (B_{msy}), the stock biomass in the initial year of assessment (B_{1971}) and the stock biomass in 2011 (B_{2011}) in JEJL_Ref case were smaller than those in other seven reference cases (Table 3). The posterior medians for these parameters were smaller than the posterior means in all eight reference cases (Tables 4 to 11). This indicates skewness to the right in the posterior distributions (Figures 3 and 4). The larger estimates of posterior mean, median and 90% confidence intervals for these parameters in JL_Ref, HW_Ref, SP_Ref and TW_Ref cases than those in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases resulted from this skewness and vagueness in the posterior distributions with considerably long fat tails (Figure 4).

The posterior median values for the maximum sustainable yield (MSY) in JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref and JL_Ref were estimated on the same order of magnitude (Table 3). Compared to this, the median estimates for this parameter in HW_Ref, SP_Ref and TW_Ref were much larger than and on a different order of magnitude from those in other five cases. The posterior mean values for MSY were more or less similar to the posterior medians in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases with respect to the order of magnitude, whereas the skewed and vague posterior distributions for MSY gave greater posterior means than medians in JL_Ref, HW_Ref, SP_Ref and TW_Ref cases (Table 4 to 11, and Figures 3 (b) and 4 (b)).

The posterior median estimates for the ratio of B_{2011}/B_{msy} ranged from approximately 1.5 to 2.0 across the eight reference cases (Table 3). The posterior mean values for this ratio were very similar to the posterior medians in all reference cases (Table 4 to 11).

The posterior medians for the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{msy}) were estimated ranging from 0.06 to 0.35 in the eight reference cases (Table 3). The small values of F_{2011}/F_{msy} in HW_Ref, SP_Ref and TW_Ref resulted from large estimates of B_{2011} compared to the catch in 2011. The estimates for F_{2011}/F_{msy} are considered underestimated compared to 'normal' years because the Great East Japan Earthquake and its tsunami attack affected base ports for Japanese longline fleet in 2011.

In JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases, although the marginal posterior distributions indicate moderate to high precision in the estimates for most key parameters, distributions for some parameters were skewed and had long tails (Figure 3). In contrast, the posterior distributions with skewed and very long fat tails in JL_Ref, HW_Ref, SP_Ref and TW_Ref cases show low precision in the estimates for the parameters although JL_Ref was somewhat different (Figure 4). Furthermore, the posterior distributions in HW_Ref, SP_Ref and TW_Ref were quite similar to those resulting from the prior-only run, meaning that the CPUE data used in these reference cases had no additional information beyond the priors.

Prior-only run analysis

Results from fitting to the data using only priors and a single year of each CPUE index (prior-only run) indicate that the CPUE indices are quite informative to the results, and the model is not overly influenced by priors in JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref and JL_Ref cases (Figure 3 and 4). Ranges of posterior distributions estimated from the prior-only run are still quite wide with long fat tails. This implies that the priors provide only vague information about most key parameters, and the results were driven primarily by the data (i.e., the priors are overly informative to the results). Similarities in shape of the posterior distributions between the prior-only, HW_Ref, SP_Ref and TW_Ref runs suggest that HW, SP and TW CPUE indices are informative only when these indices are incorporated in the model in combination with JE CPUE index (Figures 3 and 4).

The marginal posterior distributions for the key parameter resulting from prior-only runs using catch data that have very different trajectories and magnitude (reversed, doubling and halving of catch) were plotted in Figure 5. These plots for the posteriors show skewed and quite wide distributions with long fat tails, indicating that catch data also give vague information about the parameters and are not influential on the results.

Historical stock dynamics

The median estimate and 90% confidence limits for the historical stock dynamics in the eight reference cases and four prior-only runs are shown in Figure 6 and 7, respectively. Comparison of trends for the historical dynamics between the reference cases and prior-only runs was summarized in Figure 8.

Although there are some differences in trend and magnitude, fluctuation of patterns in the historical stock dynamics of north Pacific blue shark in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases were similar (Figures 6 (a) to (d) and Figure 8). Among the four cases, 90% confidence limits in JEJL_Ref case were noticeably narrower than those in the other three cases. The median stock biomass declined to a level below B_{msy} from the mid 1970s to the mid 1980s. Then, the stock subsequently increased after the late 1980s and by the early 1990s had recovered to a level above B_{msy}, and to the stock level similar to that of the mid 1970s. The blue shark biomass has been more or less stable since, indicating that total catches in recent years have been near replacement yield. The stock biomass dynamics in JL_Ref also showed somewhat a comparable trend to those in these four reference cases (Figure 6 (e) and Figure 8). However, the 90% confidence limits for the stock biomass in JL_Ref case were much broader than those in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref whereas the magnitude of the median stock biomass in JL_Ref was only slightly higher than those in the four reference cases.

Estimated median trajectories for the historical stock biomass in HW_Ref, SP_Ref and TW_Ref cases were much higher (approximately four times higher on average) than JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases (Figure 8). The same pattern was observed in the median trajectories for the stock biomass resulted from the four prior-only runs. The median trajectories for the stock biomass in the HW_Ref, SP_Ref and TW_Ref cases and prior-only runs did not show reductions of the stock biomass below B_{msy} during the mid and late 1980s which were observed in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases (Figures 6, 7 and 8). The median trajectories in these three reference cases and prior-only runs had rather monotonic trends with slight increases. Similar to JL_Ref case, the 90% confidence limits for the stock biomass in HW_Ref, SP_Ref and TW_Ref cases and prior-only runs were noticeably wider than those in JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref (Figures 6 and 7).

Considering these monotonic trends and extremely wide confidence intervals together with the vague marginal posteriors for key assessment parameters (discussed above) in JL_Ref, HW_Ref, SP_Ref and TW_Ref cases, the CPUE index data of JL, HW, SP and TW did not provide useful information about stock dynamics and status of north Pacific blue shark when these CPUE data were used alone in the model (i.e., not a combination with JE CPUE index). Therefore, meaningful insight about stock dynamics and status for the blue shark could not be drawn from assessment results of JL_Ref, HW_Ref, SP_Ref and TW_Ref cases.

Kobe plots

Degrees of stock depletion and overfishing for the eight reference cases were illustrated using the "Kobe plot" (Figure 9). Overall, resultant Kobe plots of the eight cases could be roughly divided into two groups by resemblance of trajectory pattern regarding to median estimates: JEJL_Ref, JEHE_Ref, JESP_Ref and JETW_Ref; JL_Ref, HW_Ref, SP_Ref and TW_Ref.

For the first group (JEJL_Ref, JEHE_Ref, JESP_Ref and JETW_Ref), the stock biomass of north Pacific blue shark was well above the biomass at the maximum sustainable yield (B_{msy}), and the fishing rate well below that at F_{msy} in 1971 (Figures 9 (a) to (d)). The historical trajectories of stock status revealed that north Pacific blue shark had experienced some levels of depletion and overfishing in previous years showing that the trajectories moved through the orange (overfishing), red (overfished and overfishing) and yellow (overfished) zones in sequence in the Kobe plots. In recent years including 2011, the stock condition returned into the Kobe green zone and stock biomass has remained above B_{msy} with fishing mortality below F_{msy}. Only the 90% confidence limits for B/B_{msy} in 2011 in JEHW_Ref and JESP_Ref extended to the yellow zone (Figures 9 (b) and (c)).

The historical trajectories of stock status for the second group (JL_Ref, HW_Ref, SP_Ref and TW_Ref) stayed within the green zone in the assessment period of 1971 to 2011 (Figures 9 (e) to (h)). Although there were some transitions of the stock status observed in JL_Ref, the stock status almost did not change during the assessment period in these four reference cases. This is not surprising given the monotonic trends for the historical stock dynamics in the four cases discussed above.

4.2 Sensitivity analyses

Again, because stock dynamics resulting from JL_Ref, HW_Ref, SP_Ref and TW_Ref cases are equivocal, sensitivity analyses were further conducted for JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref only.

4.2.1 Model convergences of the eight reference cases

Similar to the eight reference case, available diagnostics for model convergence from BSP2 was checked to verify low posterior correlations (r and K) for all sensitivity run results, an adequate number of draws in importance sampling were saved (>20,000 samples), all draws had a low maximum weight (< 1%), and the CV of the weights of the importance draws were less than the CV of the likelihood times the priors for the same draws (Tables A1 to A4).

4.2.2 Model fits for the eight reference cases

Model fits to the standardized CPUE indices and the relevant residual plots for all sensitivity runs (corresponded to the four reference cases of JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) in posterior mode estimation were examined in the same way as the reference cases explained in section 4.1.2. Although there were slight differences in residual patterns between each reference case and related sensitivity run results, the overall patterns for sensitivity runs were similar (figures not shown) to that of the reference case (Figures 1A (a) to (d)).

4.2.3 Results of sensitivity runs

Although there were some differences in parameter estimates found between each of the four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) and some corresponding sensitivity runs, overall the sensitivity analyses did not reveal substantially different stock status compared to the reference cases (Tables 12 to 15, and Figures 10 and 11). With respect to median estimates, all of the sensitivity runs indicated that the stock biomass of north Pacific blue shark in 2011 is above B_{msy} (estimates of B_{2011}/B_{msy}) and 2011 fishing mortality rate is below F_{msy} (estimates of F_{2011}/F_{msy}). However, estimates of B_{2011}/B_{msy} and F_{2011}/F_{msy} were highly uncertain in some sensitivity runs for JEHW_Ref, JESP_Ref and JETW_Ref cases (Figures 11 (b) to (d)). As mentioned before, the exploitation rate in 2011 was probably underestimated because the Japanese longline effort was affected by the 2011 Great East Japan Earthquake.

The differences in sensitivities to alternative input choices varied depending on a combination of a reference case and the related sensitivity runs examined. Details of differences in each parameter estimate between the reference cases and sensitivity runs are explained and discussed below.

Surplus production function, B_{msy}/K (Shape parameter n)

Results were relatively sensitive to the choice of B_{msy}/K (runs **_R34Sh03[2] and **_R34Sh06 in Tables 12 to 15, and Figure 10; also see r versus B_{msy}/K grids results in Table 12 to 15). Posterior median values for B_{2011}/B_{msy} increased when B_{msy}/K was decreased from 0.6 to 0.3. This difference in B_{2011}/B_{msy} represented the largest range observed among all sensitivity runs in which only one input assumption was changed. Median estimates of the ratio of the 2011 fishing mortality to that at MSY (F_{2011}/F_{msy}) were slightly sensitive to changes in B_{msy}/K. The estimates of current stock biomass (B_{2011}) and biomass at MSY (B_{msy}) were scaled up and down when B_{msy}/K was set to 0.3 and 0.6, respectively.

r prior mean

Results were modestly sensitive to the run where the r prior mean was set at a biologically plausible minimum value of 0.14 (runs **_R14A08[3] in Tables 12 to 15, and Figure 10; also see r versus B_{init}/K grids results in Table 12 to 15). Posterior medians for B_{2011}/B_{msy} in the four reference cases were greater than those in the corresponding sensitivity runs. Median values for F_{2011}/F_{msy} in the reference cases were almost the same as those in the sensitivity runs except for JEHW_Ref. In addition, the estimates of current stock biomass (B_{2011}) and biomass at MSY (B_{msy}) were scaled up and down when the r prior mean was set to biological minimum and maximum values, respectively.

The posterior medians for r in the sensitivity runs were estimated lower than in the corresponding reference cases when the r prior mean was set at biologically plausible minimum value of 0.14 (see estimates indicated by run identifiers which contain "R14" in Table 12 to 15). However, in the JEJL_Ref case this does not indicate the data contain information that supports

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[2] A symbol "**" represents identifiers for combinations of the CPUE indices described in Table 1 such as "JEJL_R34Sh03" or "JEHW_R14Sh06."

[3] A symbol "**" represents identifiers for combinations of the CPUE indices described in Table 1 such as "JEJL_R14A08" or "JEHW_R43A08."

such a lower *r* value because the sensitivity run with a more diffuse *r* prior resulted in a similar posterior median for *r* to the reference, suggesting that the data supported larger *r* values (JEJL_Rsd07 in Table 12). As discussed below, a Bayes factor comparison also indicates that the model run using the biological minimum *r* prior resulted in worse fits to the data than the reference case (Table 16, see below).

Unlike JEJL case, although estimated medians were not so low as the biological minimum value, the data used in JEHW, JESP and JETW cases somewhat support lower *r* values than those in the reference cases. This is apparent from the median estimates for *r* in the sensitivity runs with a more diffuse *r* prior (JEHW_Rsd07, JESP_Rsd07 and JETW_Rsd07 in Tables 13 to 15, respectively). Further, Bayes factors also imply that the data favor (although not strongly) lower values of *r* in JEHW, JESP and JETW cases (Table 16, see below). However, it is also worthwhile to note here that the estimates for stock status parameters had wide confidence intervals, thus indicating high uncertainty about stock status.

Other sensitivity runs

Estimated medians for all other sensitivity runs were similar to the corresponding reference cases with respect to stock status parameters (Tables 12 to 15, and Figures 10 and 11). Thus, it can be concluded that the results were insensitive to these alternative assumptions in terms of medians. However, 90% confidence limits for some sensitivity runs were broader than in the references, especially for JEHW, JESP and JETW cases.

Historical stock dynamics for sensitivity runs

Although the historical stock dynamics for north Pacific blue shark fluctuated, depending on the reference cases and the corresponding sensitivity runs examined, comparison of median trajectories of the stock dynamics between the reference case and all the sensitivity runs exhibited that overall patterns of the dynamics for the sensitivity runs were similar to the reference case and the only noticeable differences were levels of stock biomass (Figure 10). The highest biomass level was estimated when *r* prior mean was set to a biologically plausible minimum value of 0.14 and B_{msy}/K was 0.3 (**_R14Sh03) while the lowest level resulted from the sensitivity run with *r* set to biologically maximum of 0.43 and B_{msy}/K equal to 0.6 (**_R43Sh06). Generally, the consistency of sensitivity analyses supports the stock status and relative historical stock dynamics represented by each reference case.

4.2.4 Bayes factor evaluation

Table 16 summarizes comparisons of Bayes factors for the alternative sensitivity runs corresponded to the four reference cases. As a whole, none of the Bayes factors indicated that any of the alternative sensitivity runs could be viewed as much less or more likely than the corresponding reference case. However, some differences in Bayes factor were detected for some sensitivity runs as follows.

The sensitivity run assuming a lower B_{msy}/K of 0.3 in JEJL case (JEJL_R34Sh03) had a Bayes factor of 0.92, indicating that the reference case showed a better fit to the data than with the lower alternative B_{msy}/K value, whereas in other three cases, the lower B_{msy}/K alternative runs resulted in Bayes factors which were greater than those in the corresponding reference cases (1.80 for

JEHW_R34Sh03, 1.75 for JESP_R34Sh03 and 1.69 for JETW_R34Sh03), indicating that the reference cases gave slightly worse fits than the lower alternatives for B_{msy}/K. This was consistent with the sensitivity run using a biologically plausible minimum for *r* prior mean (0.14) in JEJL case (JEJL_R14A08) and resulting in a Bayes factor of 0.38, showing that the reference case gave a better fit to the data than with the lower alternative, while in the other three cases the same lower alternative runs for *r* prior mean produced larger Bayes factors than those in the references (1.72 for JEHW_R14A08, 1.17 for JESP_R14A08 and 1.09 for JETW_R14A08), suggesting a slightly worse fit of the reference cases than the lower alternative *r* prior.

This tendency towards better fits associated with higher productivity alternatives in JEJL case and better fits for lower productivity alternatives in JEHW, JESP and JETW cases is also consistent with differences in Bayes factors for alternative assumptions of B_{init}/K, (i.e., a relatively highly productive stock does not need larger initial biomass compared to catch whereas a low productive stock needs a higher B_{init}/K ratio). The assumption of B_{init}/K prior mean set at 0.5 produced a Bayes factor of 1.10 in JEJL case (JEJL_R34A05), indicating that this alternative provided a slightly better fit to the data than the reference case. In contrast, the sensitivity runs using B_{init}/K prior mean of 1.0 had higher Bayes factors than the reference cases in JEHW, JESP and JETW (1.16, 1.18 and 1.11, respectively), showing slightly better fits to the data than the reference.

The differences in Bayes factor explained above did not affect the relative trends of stock dynamics and stock status with respect to median estimates (Figures 10 and 11).

4.3 Future projections

As discussed above, having concluded that meaningful insights about north Pacific blue shark stock dynamics could not be confidently derived from assessment results of JL_Ref, HW_Ref, SP_Ref and TW_Ref cases, future projections were conducted only for JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref.

Figures 12 and 13 respectively illustrate comparisons of median future projected stock dynamics and catch trends for north Pacific blue shark under seven different harvest policies using the four reference case models: status quo, +20% and -20% constant catch, status quo, +20% and -20% constant fishing mortality rate (*F*) and F_{msy} (*F* at MSY) harvest rules. Status quo catch and *F* rules were based on the average catch and *F* over the recent 5 years of 2006 to 2010. Information for management decision was summarized in Tables 17 to 20.

With respect to median estimates, future projected dynamics of stock biomass and catch for blue shark had very similar patterns in all JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref cases while there were some differences observed in the magnitudes of stock biomass and catch (Figures 12 and 13). Under the status quo policy, the median stock biomass of blue shark will remain stable. This was expected because the current catch level was estimated at near replacement yield. Even under +20% constant catch and constant *F* harvest policies, the blue shark stock will stay above the biomass at maximum sustainable yield, B_{msy}, throughout the projection time horizon with a probability higher than 85% (Tables 17 to 20). Similarly, future median fishing mortality will remain well below F_{msy}. A status quo constant *F* policy will produce approximately 50,000 mt to 60,000 mt catch over the projection years depending upon the reference case.

5. Conclusions

The outcomes of the stock assessments and future projections of north Pacific blue shark using a state-space Bayesian surplus production (BSP2) model with revised catch and CPUE data were summarized as follows:

- Model fits in posterior mode estimation for Hawaii (HW), SPC (SP) and Taiwan (TW) longline CPUE indices regardless of using these indices alone or in combination with Japan early period (JE) longline index in the model were not good, while model fits for both JE and Japan late period (JL) longline indices were. Model fits for HW, SP and TW could not be improved by altering input settings for total CVs for indices and the standard deviation of process error for stock dynamics within a reasonable range of value. This is probably due to inconsistency between catch and the three indices. Across all the eight reference cases examined (JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref, JL_Ref, HW_Ref, SP_Ref and TW_Ref), model convergences were acceptable.
- The four single-index cases (JL_Ref, HW_Ref, SP_Ref and TW_Ref) resulted in uninformative marginal posterior distributions with long fat tails for key parameters and stock dynamics with almost no trend detected and extremely wide confidence limits. Thus, insight about the stock dynamics and status for north Pacific blue shark could not be inferred with confidence from results of JL_Ref, HW_Ref, SP_Ref and TW_Ref cases. As a result only the other four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref) were examined further in sensitivity analyses and future projections.
- Although assessment results were different in detail among the four reference cases (JEJL_Ref, JEHW_Ref, JESP_Ref and JETW_Ref), with respect to median estimates, they generally produced similar stock status and future projections. i.e., the stock biomass of north Pacific blue shark was well above the biomass at the maximum sustainable yield (B_{msy}), and the fishing rate well below that at F_{msy} in 2011. However, for reference cases and the related sensitivity runs for JEHW_Ref, JESP_Ref and JETW, 90% confidence intervals for B_{2011}/B_{msy} and F_{2011}/F_{msy} were wide.
- Under both status quo constant catch and F harvest policies, the median stock biomass of blue shark will remain stable and above B_{msy} level throughout the projection time horizon with high probabilities. Similarly, future median fishing mortality will remain well below F_{msy}.
- Conclusions drawn from this assessment above were not substantially different from those of the assessment conducted last year (2013b).
- Given the better model fit to the data and narrower confidence limits for key assessment parameter estimates, it can be considered that the result from JEJL_Ref case would be most appropriate to represent the stock dynamics and status for north Pacific blue shark.
- The median estimates from the results of this revised assessment suggest an optimistic stock status for north Pacific blue shark with respect to commonly used reference points, even across alternative choices of CPUE to account for a full range of uncertainties about stock dynamics. However, some uncertainties about stock status are still recognized in some reference cases and the related sensitivity runs. Considering this together with potential uncertainties associated with catch data estimates used, biological and demographic parameters, and model structures, final conclusions on stock status for north Pacific blue shark should be carefully drawn from examination and discussion of outcomes from multiple assessment approaches (i.e., BSP2 and SS assessment) in SHARKWG.

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Table 1. Reference case specifications, key input parameter choices and case identifiers.

Specifications/Parameters	Value	Description/comments
K	Uniform distribution on log(K)	Range: [100, 20000] x 1000 MT The minimum value was determined based upon a value approximately similar to the historical largest catch.
r prior	mean=0.34, SD=0.5 Lognormal distribution	Based on Cortés (2002) and Kleiber et al. (2009)
B_{init}/K (*alpha.b0*) prior	mean=0.8, SD=0.5 Lognormal distribution	The prior was developed, by expert opinion, after considering the work of Oshimo et al. (ISC/14/SHARKWG-1/04), Matsunaga et al. (2005), Ward and Myers (2005), and reported longline effort in the North Pacific Ocean since 1950. *init* (initial year of assessment) = 1971
Surplus production function	B_{msy}/K=0.47	Fletcher-Schaefer model, corresponded to shape parameter of n=1.71
Process error of stock dynamics	SD=0.07	The value of process error of stock dynamics was determined considering balance between this value and CV(s) for CPUE index(ices) to obtain reasonable model fits
Catch		Total dead removals estimated by WG members (for details, see prior assessment report and ISC SHARKWG
Standardized CPUE index		For details, see ISC SHARKWG (2014). Each CPUE index is referred in this WP by abbreviated identifiers below.
	Japanese offshore shallow longline (Hokkaido and Tohoku fleets) for 1976-1993 (Early period)	**JE**
	Japanese offshore and distant water longline (Hokkaido and Tohoku fleets) for 1994-2010 (Late period)	**JL**
	Hawaii Deep-set longline (2000-2012)	**HW**
	SPC longline (1993-2009)	**SP**
	Taiwan large longline (2004-2012)	**TW**
Reference case identifier		In this assessment, the CPUE indices above were treated equally and eight reference cases were examined using the following index (ices). Each reference case is referred by case identifiers in the left column.
	JEJL_Ref	A combination of JE and JL indices
	JEHW_Ref	A combination of JE and HW indices
	JESP_Ref	A combination of JE and SP indices
	JETW_Ref	A combination of JE and TW indices
	JL_Ref	JL index only
	HW_Ref	HW index only
	SP_Ref	SP index only
	TW_Ref	TW index only
CV's for CPUE index	0.100 for JE and 0.074 for JL	JEJL_Ref
	0.097 for JE and 0.315 for HW	JEHW_Ref
	0.095 for JE and 0.385 for SP	JESP_Ref
	0.150 for JE and 0.640 for TW	JETW_Ref
	0.084 for JL	JL_Ref
	0.3288 for HW	HW_Ref
	0.340 for SP	SP_Ref
	0.680 for TW	TW_Ref
		Considering that total CV for CPUE index is treated as the square root of ((observation error CV)^2+(process error CV)^2) in the BSP2 software and the observation error CV for index is quite small, the total CV is dominated by the process error CV for index. To set the total CV for CPUE index properly, inputted CV for index was repeatedly adjusted (iterative reweighting) with an initial value of 0.20 until the ratio of inputted CV to outputted CV got roughly equal to 1.1-1.5 assuming that the CV for index is constant across years, while SD of the process error for the biomass dynamics equation is fixed at 0.05 (M. McAllister, pers. comm.).

[1]Working document submitted to the ISC Shark Working Group Workshop, 03-10 June 2014, National Taiwan Ocean University, Keelung, Taiwan
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Table 2. Specifications and key parameter settings for sensitivity runs and prior-only runs.

Category description	Run ID [*1]	Run description/comments
B_{msy}/K (shape parameter n)	**_R34SH03 **_R34SH06	B_{msy}/K = 0.3 (n = 0.68) B_{msy}/K = 0.6 (n = 3.39)
r prior mean	**_R14A08 **_R43A08	mean = 0.14 (from Babcock and Cortés 2009) mean = 0.43 (from Cortés 2002)
r prior SD	**_Rsd03 **_Rsd07	SD = 0.3 SD = 0.7
B_{init}/K (*alpha.b0*) prior mean	**_R34A05 **_R34A10	mean = 0.5 mean = 1.0
B_{init}/K (*alpha.b0*) prior SD	**_Asd07 **_Asd09	SD = 0.7 SD = 0.9
r versus B_{init}/K grids	**_R14A05 **_R43A05 **_R14A10 **_R43A10	r prior mean = 0.14, B_{init}/K prior mean = 0.5 r prior mean = 0.43, B_{init}/K prior mean = 0.5 r prior mean = 0.14, B_{init}/K prior mean = 1.0 r prior mean = 0.43, B_{init}/K prior mean = 1.0 These sensitivity runs allow grid comparison to examine interactions of r [0.14, 0.34(reference), 0.43] and B_{init}/K [0.5, 0.8(Reference), 1.0] along with **_R34A05 **_R34A10, **_Ref, **_R14A08 and **_R43A08 sensitivity runs above.
r versus B_{msy}/K (shape parameter n) grids	**_R14Sh03 **_R43Sh03 **_R14Sh06 **_R43Sh06	r prior mean = 0.14, B_{msy}/K = 0.3 (n = 0.68) r prior mean = 0.43, B_{msy}/K = 0.3 (n = 0.68) r prior mean = 0.14, B_{msy}/K = 0.6 (n = 3.34) r prior mean = 0.43, B_{msy}/K = 0.6 (n = 3.39) These sensitivity runs allow grid comparison to examine interactions of r [0.14, 0.34(reference), 0.43] and B_{msy}/K [0.3, 0.47(reference), 0.6] (n[0.68, 1.71, 3.39]) along with **_R34Sh03, **_R34Sh06, **_Ref, **_R14A08 (Bmsy/K=0.47) and **_R43A08 (Bmsy/K=0.47) sensitivity runs above.
Prior-only runs	Ponly_obscat Ponly_hlfcat Ponly_dblcat Ponly_rvscat	with observed catch with halving catch with doubling catch with reversed catch

Footnote *1: "**" represents identifiers for CPUE index or combinations of the indices described in Table 1
e.g., for a combination of JE and JL, the run identifier is like JEJL_R14A08.

Table 3. Comparison of model results of the eight reference cases – medians (drawn from the posterior distributions) of important biological parameters and reference points.

Variable	Median							
	JEJL_Ref	JEHW_Ref	JESP_Ref	JETW_Ref	JL_Ref	HW_Ref	SP_Ref	TW_Ref
r	0.41	0.29	0.29	0.30	0.28	0.34	0.34	0.35
K ('000 MT)	806	1129	1141	1088	1633	4021	4368	4148
MSY ('000 MT)	76	76	77	75	98	303	325	321
B_{msy} ('000 MT)	379	531	536	512	767	1890	2053	1950
B_{1971} ('000 MT)	556	982	994	877	1104	2975	3259	3090
B_{2011} ('000 MT)	622	720	754	783	1332	3563	3961	3932
B_{2011}/B_{msy}	1.65	1.51	1.52	1.63	1.82	1.91	1.89	1.98
B_{2011}/B_{1971}	1.15	0.77	0.78	0.91	1.22	1.17	1.17	1.22
B_{2011}/K	0.82	0.75	0.76	0.81	0.91	0.96	0.95	0.99
F_{msy} (ratio)	0.20	0.14	0.14	0.15	0.14	0.17	0.17	0.18
F_{2011} (ratio)	0.07	0.06	0.05	0.05	0.03	0.01	0.01	0.01
F_{2011}/F_{msy}	0.32	0.35	0.34	0.33	0.22	0.07	0.07	0.06

Table 4. **JEJL_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.41	0.14	0.33	0.20	0.41	0.65
K ('000 MT)	955	597	0.63	491	806	1884
MSY ('000 MT)	79	19	0.24	65	76	98
B_{msy} ('000 MT)	449	281	0.63	231	379	886
B_{1971} ('000 MT)	735	773	1.05	253	556	1657
B_{2011} ('000 MT)	744	542	0.73	373	622	1459
B_{2011}/B_{msy}	1.65	0.25	0.15	1.24	1.65	2.08
B_{2011}/B_{1971}	1.21	0.43	0.35	0.68	1.15	2.05
B_{2011}/K	0.78	0.12	0.15	0.62	0.82	1.04
F_{msy} (ratio)	0.20	0.07	0.33	0.10	0.20	0.33
F_{2011} (ratio)	0.07	0.02	0.37	0.03	0.07	0.11
F_{2011}/F_{msy}	0.33	0.07	0.23	0.22	0.32	0.45

Table 5. **JEHW_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.31	0.14	0.46	0.12	0.29	0.58
K ('000 MT)	1586	1700	1.07	558	1129	4121
MSY ('000 MT)	90	71	0.79	53	76	165
B_{msy} ('000 MT)	746	799	1.07	262	531	1937
B_{1971} ('000 MT)	1796	2521	1.40	338	982	5486
B_{2011} ('000 MT)	1151	1517	1.32	374	720	3401
B_{2011}/B_{msy}	1.48	0.36	0.24	0.80	1.51	2.04
B_{2011}/B_{1971}	0.83	0.36	0.43	0.37	0.77	1.52
B_{2011}/K	0.70	0.17	0.24	0.40	0.75	1.02
F_{msy} (ratio)	0.15	0.07	0.46	0.06	0.14	0.29
F_{2011} (ratio)	0.06	0.03	0.51	0.01	0.06	0.11
F_{2011}/F_{msy}	0.41	0.29	0.70	0.13	0.35	0.91

Table 6. **JESP_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.31	0.13	0.43	0.13	0.29	0.57
K ('000 MT)	1610	1738	1.08	572	1141	4121
MSY ('000 MT)	92	63	0.68	57	77	176
B_{msy} ('000 MT)	757	817	1.08	269	536	1937
B_{1971} ('000 MT)	1783	2433	1.37	354	994	5169
B_{2011} ('000 MT)	1205	1597	1.33	381	754	3409
B_{2011}/B_{msy}	1.52	0.36	0.24	0.92	1.52	2.13
B_{2011}/B_{1971}	0.85	0.35	0.42	0.41	0.78	1.53
B_{2011}/K	0.71	0.17	0.24	0.46	0.76	1.06
F_{msy} (ratio)	0.16	0.07	0.43	0.07	0.14	0.29
F_{2011} (ratio)	0.06	0.03	0.51	0.01	0.05	0.11
F_{2011}/F_{msy}	0.38	0.21	0.55	0.12	0.34	0.73

[1]Working document submitted to the ISC Shark Working Group Workshop, 03-10 June 2014, National Taiwan Ocean University, Keelung, Taiwan
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Table 7. **JETW_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.32	0.13	0.42	0.14	0.30	0.56
K ('000 MT)	1538	1720	1.12	565	1088	3911
MSY ('000 MT)	93	78	0.85	58	75	170
B_{msy} ('000 MT)	723	808	1.12	266	512	1838
B_{1971} ('000 MT)	1595	2322	1.46	338	877	4750
B_{2011} ('000 MT)	1235	1707	1.38	405	783	3557
B_{2011}/B_{msy}	1.62	0.33	0.21	1.06	1.63	2.15
B_{2011}/B_{1971}	0.99	0.44	0.44	0.47	0.91	1.79
B_{2011}/K	0.76	0.16	0.21	0.53	0.81	1.07
F_{msy} (ratio)	0.16	0.07	0.42	0.07	0.15	0.28
F_{2011} (ratio)	0.05	0.03	0.50	0.01	0.05	0.10
F_{2011}/F_{msy}	0.35	0.18	0.50	0.12	0.33	0.62

Table 8. **JL_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.31	0.13	0.43	0.14	0.28	0.55
K ('000 MT)	3281	3962	1.21	593	1633	12645
MSY ('000 MT)	188	226	1.20	64	98	627
B_{msy} ('000 MT)	1542	1862	1.21	279	767	5943
B_{1971} ('000 MT)	2256	2814	1.25	355	1104	8678
B_{2011} ('000 MT)	3104	4188	1.35	444	1332	12746
B_{2011}/B_{msy}	1.83	0.35	0.19	1.28	1.82	2.41
B_{2011}/B_{1971}	1.41	0.75	0.53	0.60	1.22	2.83
B_{2011}/K	0.86	0.17	0.19	0.64	0.91	1.21
F_{msy} (ratio)	0.15	0.07	0.43	0.07	0.14	0.28
F_{2011} (ratio)	0.04	0.03	0.79	0.00	0.03	0.09
F_{2011}/F_{msy}	0.23	0.14	0.63	0.03	0.22	0.46

Table 9. **HW_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.38	0.18	0.47	0.15	0.34	0.73
K ('000 MT)	5855	4998	0.85	884	4021	16731
MSY ('000 MT)	495	519	1.05	73	303	1543
B_{msy} ('000 MT)	2752	2349	0.85	415	1890	7864
B_{1971} ('000 MT)	4370	4080	0.93	582	2975	12927
B_{2011} ('000 MT)	5415	4906	0.91	584	3563	15799
B_{2011}/B_{msy}	1.87	0.35	0.19	1.29	1.91	2.35
B_{2011}/B_{1971}	1.29	0.60	0.47	0.57	1.17	2.44
B_{2011}/K	0.88	0.17	0.19	0.65	0.96	1.18
F_{msy} (ratio)	0.19	0.09	0.47	0.08	0.17	0.36
F_{2011} (ratio)	0.02	0.03	1.54	0.00	0.01	0.07
F_{2011}/F_{msy}	0.14	0.31	2.17	0.01	0.07	0.40

Table 10. **SP_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.37	0.17	0.46	0.15	0.34	0.69
K ('000 MT)	6168	5099	0.83	934	4368	16844
MSY ('000 MT)	509	517	1.02	77	325	1552
B_{msy} ('000 MT)	2899	2396	0.83	439	2053	7917
B_{1971} ('000 MT)	4593	4192	0.91	584	3259	13675
B_{2011} ('000 MT)	5658	4969	0.88	624	3961	16155
B_{2011}/B_{msy}	1.87	0.36	0.19	1.29	1.89	2.41
B_{2011}/B_{1971}	1.30	0.62	0.48	0.59	1.17	2.44
B_{2011}/K	0.88	0.17	0.19	0.64	0.95	1.20
F_{msy} (ratio)	0.18	0.08	0.46	0.08	0.17	0.35
F_{2011} (ratio)	0.02	0.03	1.68	0.00	0.01	0.06
F_{2011}/F_{msy}	0.13	0.38	2.84	0.01	0.07	0.37

Table 11. **TW_Ref** case model results - mean, standard deviation, and coefficient of variation, median and 90% confidence intervals (drawn from the posterior distributions) of important biological parameters and reference points.– medians of important biological parameters and reference points.

Variable	Mean	SD	CV	5th Percentile	Median	95th Percentile
r	0.39	0.18	0.47	0.15	0.35	0.74
K ('000 MT)	5964	5055	0.85	810	4148	16570
MSY ('000 MT)	515	527	1.02	73	321	1611
B_{msy} ('000 MT)	2803	2376	0.85	381	1950	7788
B_{1971} ('000 MT)	4402	4119	0.94	528	3090	13267
B_{2011} ('000 MT)	5761	5149	0.89	606	3932	16380
B_{2011}/B_{msy}	1.97	0.32	0.16	1.43	1.98	2.45
B_{2011}/B_{1971}	1.37	0.64	0.47	0.65	1.22	2.59
B_{2011}/K	0.92	0.15	0.16	0.71	0.99	1.22
F_{msy} (ratio)	0.19	0.09	0.47	0.08	0.18	0.37
F_{2011} (ratio)	0.02	0.02	1.16	0.00	0.01	0.07
F_{2011}/F_{msy}	0.12	0.16	1.39	0.01	0.06	0.37

Table 12. Comparison of medians and 90% credibility intervals drawn from the posterior distributions for five parameters in **JEJL** reference and sensitivity cases. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs.

Run ID	r			B_{msy} ('000 MT)			B_{2011} ('000 MT)			B_{2011}/B_{msy}			F_{2011}/F_{msy}		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
JEJL_Ref	0.20	0.41	0.65	231	379	886	373	622	1459	1.24	1.65	2.08	0.22	0.32	0.45
	B_{msy}/K (shape parameter n)														
JEJL_R34Sh03	0.14	0.43	0.75	199	373	2618	423	798	8479	1.54	2.23	3.72	0.07	0.23	0.38
JEJL_R34Sh06	0.18	0.30	0.45	251	388	630	350	539	1004	1.17	1.43	1.69	0.28	0.36	0.46
	r prior mean														
JEJL_R14A08	0.07	0.19	0.46	333	820	3917	512	1313	8929	1.09	1.60	2.30	0.10	0.31	0.54
JEJL_R43A08	0.24	0.45	0.70	218	344	683	356	563	1149	1.27	1.67	2.05	0.24	0.32	0.44
	r prior SD														
JEJL_Rsd03	0.24	0.39	0.58	260	398	728	411	649	1377	1.27	1.65	2.11	0.21	0.32	0.46
JEJL_Rsd07	0.09	0.39	0.70	222	398	2243	354	626	3517	1.20	1.67	2.21	0.21	0.32	0.47
	B_{1971}/K (alpha.b0) prior mean														
JEJL_R34A05	0.22	0.44	0.71	222	353	730	340	565	1110	1.23	1.63	2.10	0.24	0.32	0.45
JEJL_R34A10	0.19	0.41	0.64	236	376	965	374	621	1762	1.31	1.69	2.15	0.20	0.31	0.45
	B_{1971}/K (alpha.b0) prior SD														
JEJL_Asd07	0.21	0.41	0.70	224	370	854	358	608	1471	1.29	1.65	2.15	0.22	0.32	0.44
JEJL_Asd09	0.19	0.41	0.73	215	371	843	338	604	1575	1.27	1.65	2.15	0.22	0.33	0.44
	r versus B_{init}/K (alpha.b0) grids														
JEJL_R14A05	0.07	0.20	0.45	331	818	3484	503	1209	5404	0.94	1.52	2.11	0.13	0.33	0.62
JEJL_R43A05	0.26	0.49	0.76	202	321	592	316	511	987	1.25	1.65	2.11	0.24	0.32	0.45
JEJL_R14A10	0.07	0.19	0.45	332	826	3995	541	1361	8854	1.17	1.67	2.43	0.09	0.30	0.53
JEJL_R43A10	0.23	0.45	0.71	215	336	705	360	548	1274	1.28	1.69	2.08	0.22	0.32	0.45
	r versus B_{msy}/K (shape parameter n) grids														
JEJL_R14Sh03	0.07	0.19	0.46	334	883	3400	615	1792	10756	1.25	2.18	3.78	0.06	0.24	0.49
JEJL_R43Sh03	0.19	0.49	0.80	189	323	1248	394	685	3318	1.54	2.24	3.35	0.08	0.24	0.38
JEJL_R14Sh06	0.06	0.18	0.33	316	619	2858	466	862	3976	1.08	1.43	1.78	0.19	0.35	0.51
JEJL_R43Sh06	0.19	0.32	0.47	244	350	579	347	483	871	1.15	1.41	1.67	0.29	0.36	0.47

Table 13. Comparison of medians and 90% credibility intervals drawn from the posterior distributions for five parameters in **JEHW** reference and sensitivity cases. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs.

Run ID	r			B_{msy} ('000 MT)			B_{2011} ('000 MT)			B_{2011}/B_{msy}			F_{2011}/F_{msy}		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
JEHW_Ref	0.12	0.29	0.58	262	531	1937	374	720	3401	0.80	1.51	2.04	0.13	0.35	0.91
	B_{msy}/K (shape parameter n)														
JEHW_R34Sh03	0.14	0.31	0.62	262	540	2326	431	1019	6567	1.06	2.08	3.16	0.04	0.24	0.75
JEHW_R34Sh06	0.13	0.29	0.52	215	388	839	298	522	1109	0.98	1.39	1.66	0.28	0.37	0.64
	r prior mean														
JEHW_R14A08	0.06	0.13	0.30	468	1052	4141	386	1192	6825	0.44	1.31	2.03	0.11	0.45	2.10
JEHW_R43A08	0.15	0.34	0.64	241	440	1273	353	641	2086	0.98	1.54	2.01	0.17	0.34	0.69
	r prior SD														
JEHW_Rsd03	0.20	0.32	0.52	288	470	1114	383	685	1942	0.97	1.53	2.01	0.16	0.34	0.67
JEHW_Rsd07	0.07	0.23	0.59	261	650	2666	357	757	4390	0.49	1.45	2.01	0.13	0.37	1.77
	B_{1971}/K (*alpha.b0*) prior mean														
JEHW_R34A05	0.12	0.32	0.63	244	469	1260	355	646	1753	0.73	1.48	1.96	0.22	0.36	0.94
JEHW_R34A10	0.12	0.27	0.54	276	564	2365	382	774	4344	0.85	1.52	2.07	0.11	0.34	0.90
	B_{1971}/K (*alpha.b0*) prior SD														
JEHW_Asd07	0.13	0.28	0.57	267	541	1868	380	748	3337	0.83	1.52	2.04	0.13	0.35	0.90
JEHW_Asd09	0.11	0.28	0.59	262	551	2050	378	764	3866	0.80	1.54	2.03	0.13	0.34	0.95
	r versus B_{init}/K (*alpha.b0*) grids														
JEHW_R14A05	0.06	0.13	0.31	458	982	3275	340	983	4339	0.30	1.10	1.84	0.17	0.58	2.46
JEHW_R43A05	0.13	0.38	0.68	224	396	1036	348	567	1267	0.67	1.54	1.97	0.23	0.35	1.08
JEHW_R14A10	0.06	0.13	0.29	505	1111	4296	438	1374	7530	0.52	1.38	2.07	0.09	0.41	1.83
JEHW_R43A10	0.15	0.32	0.62	243	469	1776	364	670	2978	1.00	1.55	2.03	0.13	0.34	0.70
	r versus B_{msy}/K(shape parameter n) grids														
JEHW_R14Sh03	0.06	0.14	0.33	431	885	3067	416	1339	7614	0.59	1.67	3.11	0.07	0.40	1.79
JEHW_R43Sh03	0.17	0.37	0.70	234	468	2143	421	929	6218	1.21	2.14	3.16	0.04	0.22	0.60
JEHW_R14Sh06	0.05	0.11	0.28	383	901	3248	342	869	4386	0.35	1.16	1.64	0.17	0.48	2.16
JEHW_R43Sh06	0.16	0.33	0.57	203	335	709	281	458	931	1.09	1.41	1.66	0.28	0.36	0.54

[1]Working document submitted to the ISC Shark Working Group Workshop, 03-10 June 2014, National Taiwan Ocean University, Keelung, Taiwan
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Table 14. Comparison of medians and 90% credibility intervals drawn from the posterior distributions for five parameters in **JESP** reference and sensitivity cases. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs.

Run ID	r			B_{msy} ('000 MT)			B_{2011} ('000 MT)			B_{2011}/B_{msy}			F_{2011}/F_{msy}		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
JESP_Ref	0.13	0.29	0.57	269	536	1937	381	754	3409	0.92	1.52	2.13	0.12	0.34	0.73
	B_{msy}/K (shape parameter n)														
JESP_R34Sh03	0.15	0.33	0.63	257	525	2424	442	1038	6930	1.17	2.12	3.32	0.04	0.22	0.59
JESP_R34Sh06	0.13	0.29	0.51	222	389	841	307	527	1096	0.98	1.39	1.70	0.28	0.37	0.59
	r prior mean														
JESP_R14A08	0.06	0.14	0.30	473	1099	4498	507	1407	8019	0.66	1.42	2.21	0.09	0.37	1.21
JESP_R43A08	0.17	0.34	0.62	243	446	1351	360	657	2387	1.02	1.54	2.09	0.16	0.34	0.61
	r prior SD														
JESP_Rsd03	0.20	0.32	0.50	298	478	1166	402	709	2049	1.01	1.54	2.11	0.16	0.34	0.60
JESP_Rsd07	0.08	0.25	0.57	268	620	3075	385	839	5145	0.81	1.49	2.13	0.11	0.35	0.92
	B_{1971}/K (*alpha.b0*) prior mean														
JESP_R34A05	0.14	0.32	0.61	251	469	1252	361	670	1952	0.88	1.50	2.06	0.19	0.35	0.75
JESP_R34A10	0.13	0.28	0.55	279	561	2396	397	800	4459	0.97	1.54	2.15	0.10	0.33	0.69
	B_{1971}/K (*alpha.b0*) prior SD														
JESP_Asd07	0.14	0.29	0.57	268	540	2470	383	775	4712	0.95	1.54	2.15	0.10	0.33	0.70
JESP_Asd09	0.13	0.28	0.56	273	541	1985	396	780	3444	0.96	1.54	2.12	0.12	0.33	0.69
	r versus B_{init}/K (*alpha.b0*) grids														
JESP_R14A05	0.06	0.14	0.34	440	1029	3929	437	1100	5814	0.43	1.22	2.01	0.12	0.48	1.61
JESP_R43A05	0.17	0.38	0.67	227	393	967	343	587	1437	0.98	1.53	2.05	0.22	0.34	0.64
JESP_R14A10	0.06	0.14	0.30	492	1125	4624	543	1565	8335	0.76	1.47	2.24	0.08	0.35	1.13
JESP_R43A10	0.16	0.33	0.61	250	465	1743	365	693	2989	1.02	1.55	2.13	0.13	0.33	0.62
	r versus B_{msy}/K (shape parameter n) grids														
JESP_R14Sh03	0.06	0.15	0.35	438	955	3474	558	1691	8854	0.82	1.86	3.34	0.06	0.31	1.13
JESP_R43Sh03	0.19	0.40	0.70	232	454	2087	421	910	5733	1.28	2.14	3.27	0.04	0.22	0.50
JESP_R14Sh06	0.05	0.12	0.29	382	851	3488	417	946	4754	0.59	1.23	1.71	0.17	0.43	1.23
JESP_R43Sh06	0.16	0.32	0.55	208	345	688	288	473	922	1.06	1.41	1.70	0.28	0.36	0.54

[1]Working document submitted to the ISC Shark Working Group Workshop, 03-10 June 2014, National Taiwan Ocean University, Keelung, Taiwan
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Table 15. Comparison of medians and 90% credibility intervals drawn from the posterior distributions for five parameters in **JETW** reference and sensitivity cases. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs.

Run ID	r			B_{msy} ('000 MT)			B_{2011} ('000 MT)			B_{2011}/B_{msy}			F_{2011}/F_{msy}		
	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%	5%	Median	95%
JETW_Ref	0.14	0.30	0.56	266	512	1838	405	783	3557	1.06	1.63	2.15	0.12	0.33	0.62
	B_{msy}/K (shape parameter n)														
JETW_R34Sh03	0.16	0.34	0.63	247	489	2226	474	1041	6786	1.34	2.30	3.42	0.04	0.22	0.51
JETW_R34Sh06	0.13	0.27	0.50	228	407	908	323	567	1267	1.07	1.43	1.70	0.27	0.36	0.55
	r prior mean														
JETW_R14A08	0.07	0.15	0.31	472	1076	4532	558	1479	8747	0.73	1.53	2.26	0.08	0.35	1.07
JETW_R43A08	0.17	0.34	0.63	245	438	1294	388	694	2451	1.15	1.65	2.13	0.15	0.32	0.55
	r prior SD														
JETW_Rsd03	0.20	0.32	0.50	295	467	1221	434	746	2351	1.16	1.65	2.17	0.13	0.32	0.55
JETW_Rsd07	0.09	0.27	0.57	266	581	2805	409	861	4990	0.96	1.63	2.20	0.10	0.33	0.73
	B_{1971}/K (*alpha.b0*) prior mean														
JETW_R34A05	0.15	0.32	0.60	255	479	1254	400	730	2003	0.99	1.61	2.08	0.20	0.33	0.62
JETW_R34A10	0.14	0.29	0.55	273	524	2223	417	814	4419	1.09	1.66	2.19	0.10	0.32	0.60
	B_{1971}/K (*alpha.b0*) prior SD														
JETW_Asd07	0.14	0.29	0.57	267	517	1956	418	796	3681	1.08	1.64	2.17	0.12	0.32	0.59
JETW_Asd09	0.14	0.29	0.56	273	535	1942	414	828	3538	1.06	1.65	2.21	0.12	0.32	0.60
	r versus B_{init}/K (*alpha.b0*) grids														
JETW_R14A05	0.06	0.15	0.32	443	1016	3652	512	1216	5666	0.52	1.35	2.07	0.13	0.41	1.26
JETW_R43A05	0.18	0.37	0.67	228	404	946	373	641	1511	1.14	1.64	2.08	0.22	0.32	0.53
JETW_R14A10	0.07	0.14	0.30	482	1104	4423	554	1634	8921	0.78	1.57	2.35	0.08	0.34	1.08
JETW_R43A10	0.17	0.33	0.61	248	453	1604	394	719	3053	1.18	1.66	2.17	0.12	0.32	0.53
	r versus B_{msy}/K(shape parameter n) grids														
JETW_R14Sh03	0.07	0.16	0.35	420	952	3556	585	1756	9816	0.91	2.00	3.53	0.05	0.28	0.99
JETW_R43Sh03	0.20	0.40	0.72	223	421	1837	442	913	5658	1.43	2.33	3.39	0.04	0.21	0.46
JETW_R14Sh06	0.05	0.13	0.27	395	823	3316	468	1017	4663	0.67	1.34	1.74	0.16	0.40	0.97
JETW_R43Sh06	0.15	0.31	0.58	199	356	730	281	504	1048	1.15	1.44	1.69	0.28	0.36	0.50

Table 16. Comparison of Bayes factors for alternative sensitivity runs of the four cases (JEJL, JEHW, JESP, JETW). Bayes factors reflect the ratio of the probability of the blue shark stock assessment data based on a sensitivity run to the probability of the data obtained from the reference case.

Category description	Run ID *1	Run description	Bayes factor by run case			
			JEJL	JEHW	JESP	JETW
B_{msy}/K (shape parameter n)	**_Ref	B_{msy}/K = 0.47 (n = 1.71)	1.00	1.00	1.00	1.00
	**_R34Sh03	B_{msy}/K = 0.30 (n = 0.68)	0.92	1.80	1.75	1.69
	**_R34Sh06	B_{msy}/K = 0.60 (n = 3.39)	0.63	0.42	0.44	0.40
r prior mean	**_Ref	mean = 0.34	1.00	1.00	1.00	1.00
	**_R14A08	mean = 0.14	0.38	1.72	1.17	1.09
	**_R43A08	mean = 0.43	1.08	0.88	0.88	0.88
r prior SD	**_Ref	SD = 0.5	1.00	1.00	1.00	1.00
	**_Rsd03	SD = 0.3	1.07	0.92	1.00	1.06
	**_Rsd07	SD = 0.7	1.17	1.37	1.02	0.96
B_{init}/K (*alpha.b0*) prior mean	**_Ref	mean = 0.8	1.00	1.00	1.00	1.00
	**_R34A05	mean = 0.5	1.10	0.66	0.59	0.72
	**_R34A10	mean = 1.0	0.93	1.16	1.18	1.11
B_{init}/K (*alpha.b0*) prior SD	**_Ref	SD = 0.5	1.00	1.00	1.00	1.00
	**_Asd07	SD = 0.7	0.97	1.02	0.93	1.00
	**_Asd09	SD = 0.9	1.05	1.10	0.86	1.00

Footnote *1: "**" represents identifiers for CPUE index or combinations of the indices described in Table 1
e.g., for a combination of JE and JL, the run identifier is like JEJL_R14A08.

Table 17. Decision table based on results of future projections for **JEJL_Ref** case.

Run ID	HCR	Total C_{2011}	B_{2011}/B_{msy}	F_{2011}/F_{msy}	Total C_{2016}	B_{2016}/B_{msy}	$P(B_{2016}>B_{msy})$	F_{2016}/F_{msy}	Total C_{2021}	B_{2021}/B_{msy}	$P(B_{2021}>B_{msy})$	F_{2021}/F_{msy}	Total C_{2031}	B_{2031}/B_{msy}	$P(B_{2031}>B_{msy})$	F_{2031}/F_{msy}
JEJL_Ref	Status quo	40.51	1.65	0.32	46.69	1.64	0.99	0.37	46.69	1.64	0.98	0.37	46.69	1.65	0.98	0.37
	+20%	40.51	1.65	0.32	56.03	1.56	0.98	0.47	56.03	1.54	0.96	0.48	56.03	1.51	0.95	0.48
	-20%	40.51	1.65	0.32	37.35	1.72	1.00	0.28	37.35	1.74	0.99	0.28	37.35	1.77	1.00	0.28
	$F_{2006\text{-}2010}$	40.51	1.65	0.32	50.43	1.64	0.98	0.37	49.29	1.60	0.98	0.37	49.57	1.59	0.97	0.37
	+20%	40.51	1.65	0.32	57.88	1.56	0.97	0.37	56.01	1.51	0.93	0.37	55.07	1.50	0.94	0.37
	-20%	40.51	1.65	0.32	42.27	1.71	0.98	0.37	41.72	1.69	0.99	0.37	42.01	1.67	0.98	0.37
	F_{msy}	40.51	1.65	0.32	88.47	1.13	0.76	1.03	79.25	1.03	0.59	1.01	76.08	0.98	0.45	1.00

Table 18. Decision table based on results of future projections for **JEHW_Ref** case.

Run ID	HCR	Total C_{2011}	B_{2011}/B_{msy}	F_{2011}/F_{msy}	Total C_{2016}	B_{2016}/B_{msy}	$P(B_{2016}>B_{msy})$	F_{2016}/F_{msy}	Total C_{2021}	B_{2021}/B_{msy}	$P(B_{2021}>B_{msy})$	F_{2021}/F_{msy}	Total C_{2031}	B_{2031}/B_{msy}	$P(B_{2031}>B_{msy})$	F_{2031}/F_{msy}
JEHW_Ref	Status quo	40.51	1.51	0.35	46.69	1.57	0.91	0.39	46.69	1.60	0.90	0.38	46.69	1.61	0.90	0.37
	+20%	40.51	1.51	0.35	56.03	1.50	0.88	0.49	56.03	1.49	0.86	0.48	56.03	1.48	0.83	0.47
	-20%	40.51	1.51	0.35	37.35	1.64	0.92	0.30	37.35	1.69	0.93	0.28	37.35	1.72	0.94	0.28
	$F_{2006\text{-}2010}$	40.51	1.51	0.35	50.26	1.54	0.90	0.39	50.14	1.53	0.89	0.38	50.36	1.52	0.88	0.37
	+20%	40.51	1.51	0.35	57.92	1.47	0.89	0.39	56.82	1.44	0.85	0.38	56.29	1.42	0.82	0.37
	-20%	40.51	1.51	0.35	41.81	1.61	0.92	0.39	42.51	1.62	0.92	0.38	43.74	1.62	0.92	0.37
	F_{msy}	40.51	1.51	0.35	88.58	1.13	0.72	1.03	80.27	1.03	0.56	1.01	75.80	0.98	0.47	1.00

Table 19. Decision table based on results of future projections for **JESP_Ref** case.

Run ID	HCR	Total C_{2011}	B_{2011}/B_{msy}	F_{2011}/F_{msy}	Total C_{2016}	B_{2016}/B_{msy}	$P(B_{2016}>B_{msy})$	F_{2016}/F_{msy}	Total C_{2021}	B_{2021}/B_{msy}	$P(B_{2021}>B_{msy})$	F_{2021}/F_{msy}	Total C_{2031}	B_{2031}/B_{msy}	$P(B_{2031}>B_{msy})$	F_{2031}/F_{msy}
JESP_Ref	Status quo	40.51	1.52	0.34	46.69	1.59	0.92	0.38	46.69	1.61	0.93	0.37	46.69	1.64	0.93	0.36
	+20%	40.51	1.52	0.34	56.03	1.52	0.90	0.47	56.03	1.51	0.88	0.47	56.03	1.51	0.87	0.46
	-20%	40.51	1.52	0.34	37.35	1.66	0.94	0.29	37.35	1.71	0.96	0.28	37.35	1.74	0.96	0.27
	$F_{2006\text{-}2010}$	40.51	1.52	0.34	52.71	1.55	0.92	0.38	52.90	1.53	0.92	0.37	53.05	1.53	0.90	0.36
	+20%	40.51	1.52	0.34	60.76	1.48	0.90	0.38	59.62	1.44	0.88	0.37	59.02	1.43	0.84	0.36
	-20%	40.51	1.52	0.34	43.86	1.62	0.94	0.38	44.88	1.62	0.94	0.37	45.72	1.63	0.94	0.36
	F_{msy}	40.51	1.52	0.34	90.88	1.14	0.74	1.03	81.98	1.04	0.58	1.01	77.92	0.99	0.48	1.00

Table 20. Decision table based on results of future projections for **JETW_Ref** case.

Run ID	HCR	Total C_{2011}	B_{2011}/B_{msy}	F_{2011}/F_{msy}	Total C_{2016}	B_{2016}/B_{msy}	$P(B_{2016}>B_{msy})$	F_{2016}/F_{msy}	Total C_{2021}	B_{2021}/B_{msy}	$P(B_{2021}>B_{msy})$	F_{2021}/F_{msy}	Total C_{2031}	B_{2031}/B_{msy}	$P(B_{2031}>B_{msy})$	F_{2031}/F_{msy}
JETW_Ref	Status quo	40.51	1.63	0.33	46.69	1.64	0.95	0.37	46.69	1.64	0.95	0.37	46.69	1.64	0.95	0.37
	+20%	40.51	1.63	0.33	56.03	1.56	0.93	0.47	56.03	1.54	0.92	0.48	56.03	1.51	0.89	0.48
	-20%	40.51	1.63	0.33	37.35	1.70	0.97	0.29	37.35	1.74	0.97	0.28	37.35	1.74	0.98	0.28
	$F_{2006\text{-}2010}$	40.51	1.63	0.33	59.52	1.53	0.94	0.37	58.08	1.49	0.92	0.37	56.82	1.46	0.88	0.37
	+20%	40.51	1.63	0.33	68.12	1.45	0.91	0.37	64.71	1.38	0.86	0.37	62.27	1.35	0.81	0.37
	-20%	40.51	1.63	0.33	49.98	1.61	0.96	0.37	50.02	1.60	0.95	0.37	49.48	1.58	0.94	0.37
	F_{msy}	40.51	1.63	0.33	90.95	1.17	0.78	1.04	81.48	1.06	0.61	1.01	76.34	0.99	0.49	1.00

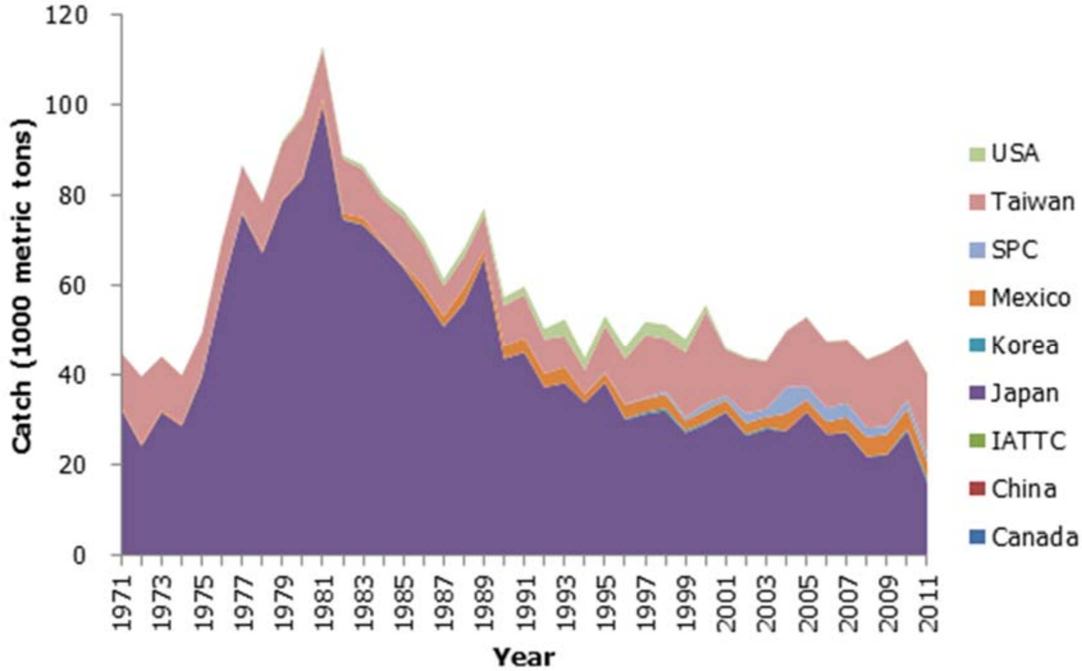

Figure 1. Total catch of blue sharks (*Prionace glauca*) in the North Pacific Ocean from 1971-2011 across all data sources, broken down by nation when possible, or source of fishery data.

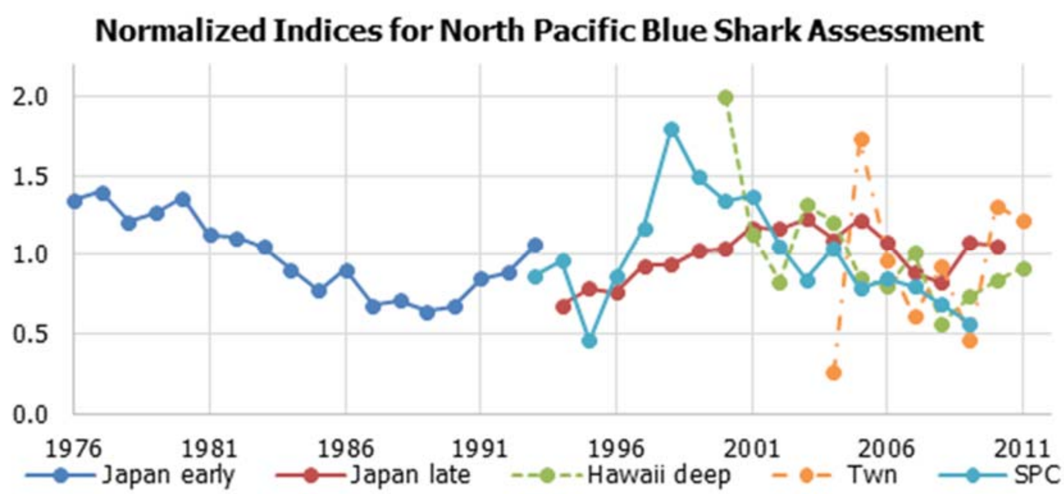

Figure 2. Standardized CPUE indices used in the North Pacific Ocean blue shark (*Prionace glauca*) stock assessment.

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(a)

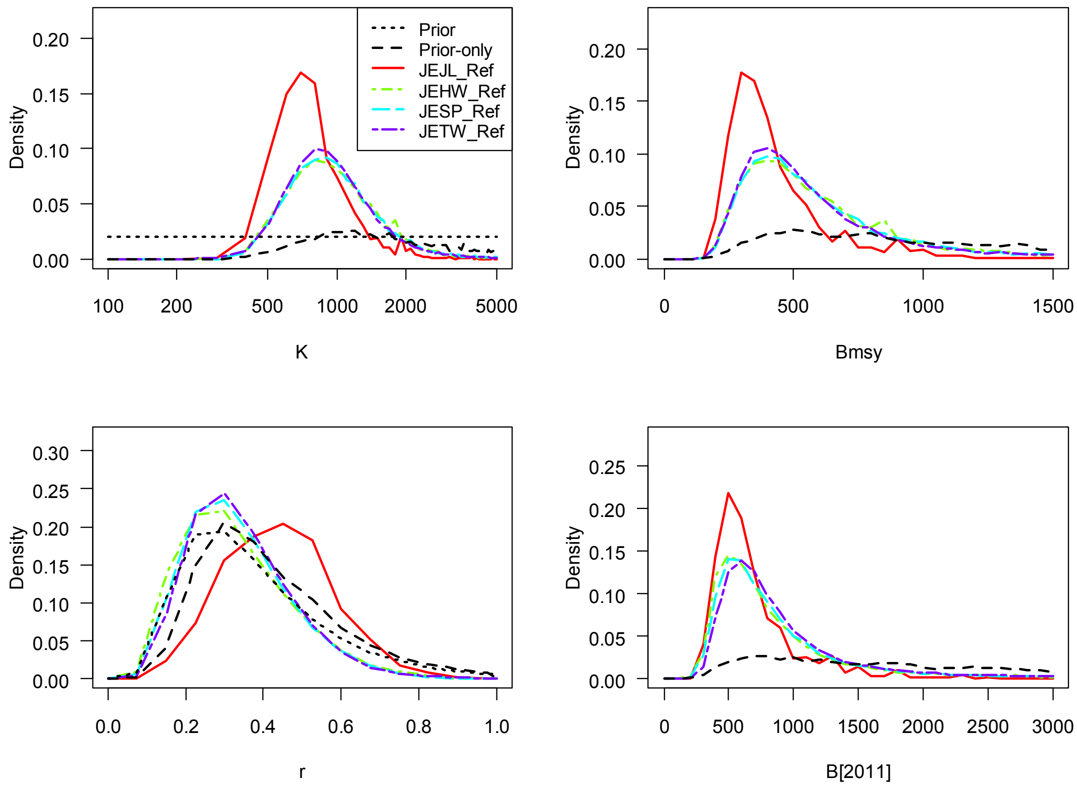

Figure 3. Comparison of marginal posterior distributions for the four reference cases (**JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref**). (a) Four panels correspond to carrying capacity (*K*), stock biomass (B_{msy}) at maximum sustainable yield (MSY), the maximum intrinsic rate of natural increase (*r*) and stock biomass in 2011. Note that the horizontal axis of the top left panel for *K* is log-scaled.

(b)

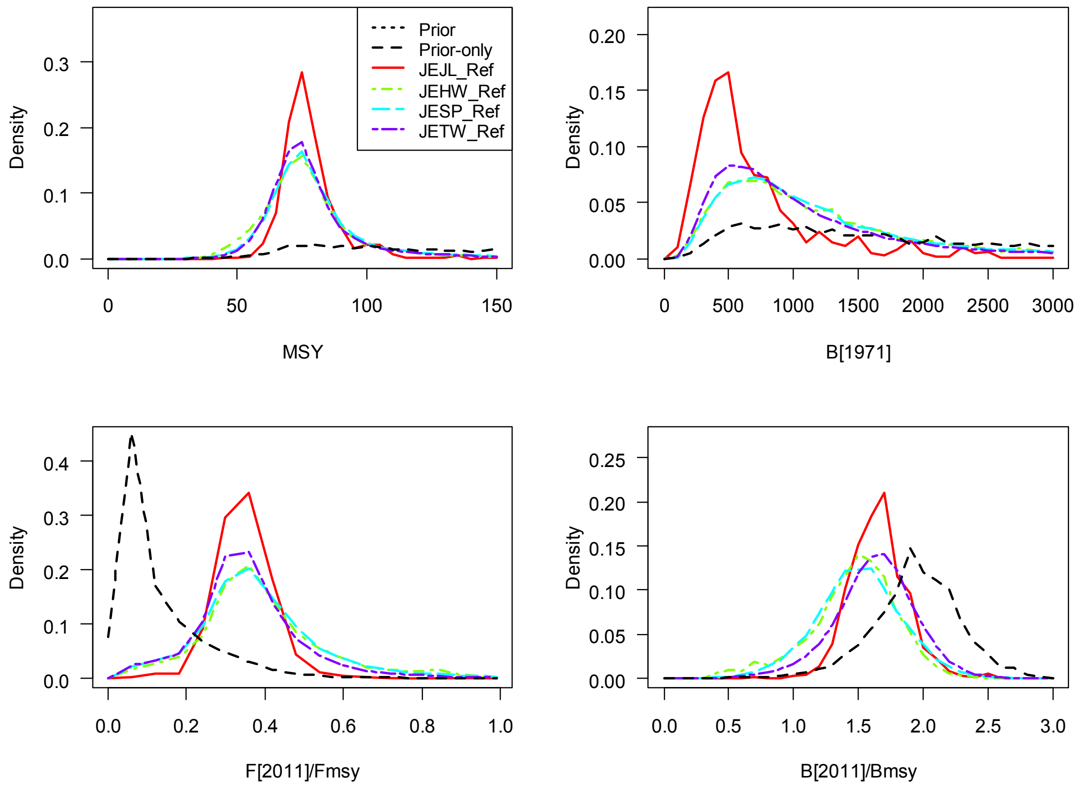

Figure 3 (cont'd). Comparison of marginal posterior distributions for the four reference cases (**JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref**). (b) Four panels correspond to maximum sustainable yield (MSY), stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{msy}) and the ratio of stock biomass in 2011 to that at MSY (B_{2011}/B_{msy}).

(a)

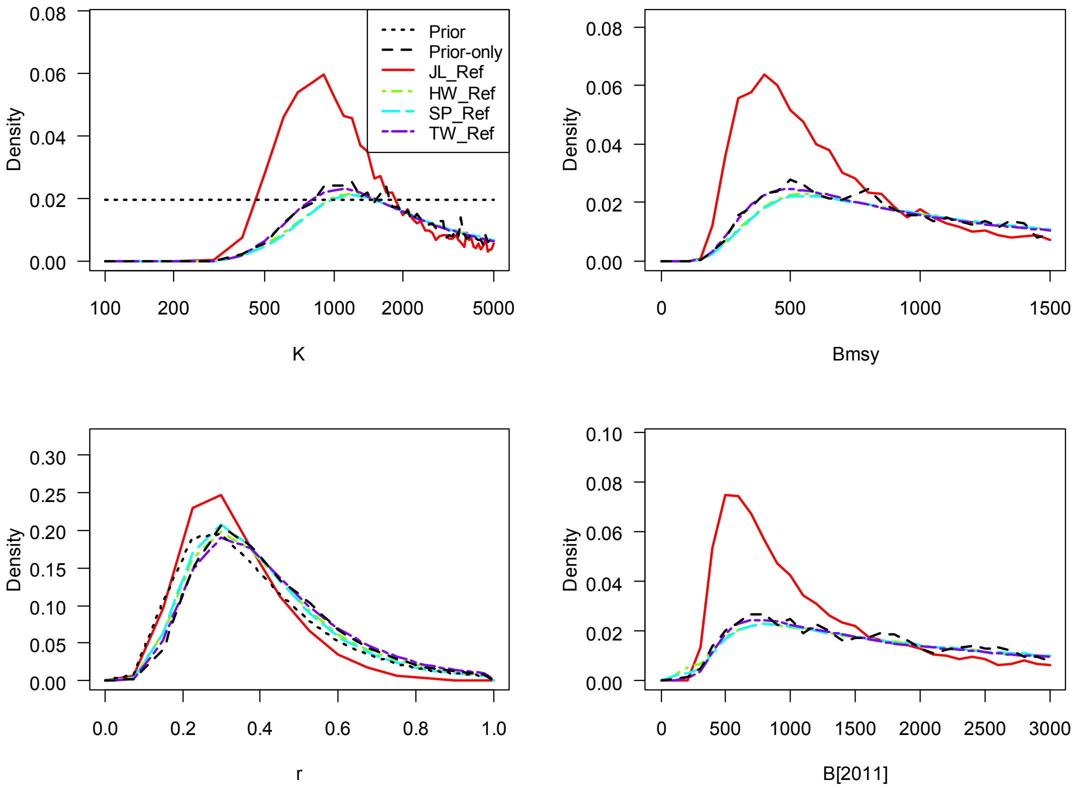

Figure 4. Comparison of marginal posterior distributions for the four reference cases (**JL_Ref, HW_Ref, SP_Ref, TW_Ref**). (a) Four panels correspond to carrying capacity (*K*), stock biomass (B_{msy}) at maximum sustainable yield (MSY), the maximum intrinsic rate of natural increase (*r*) and stock biomass in 2011. Note that the horizontal axis of the top left panel for *K* is log-scaled.

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(b)

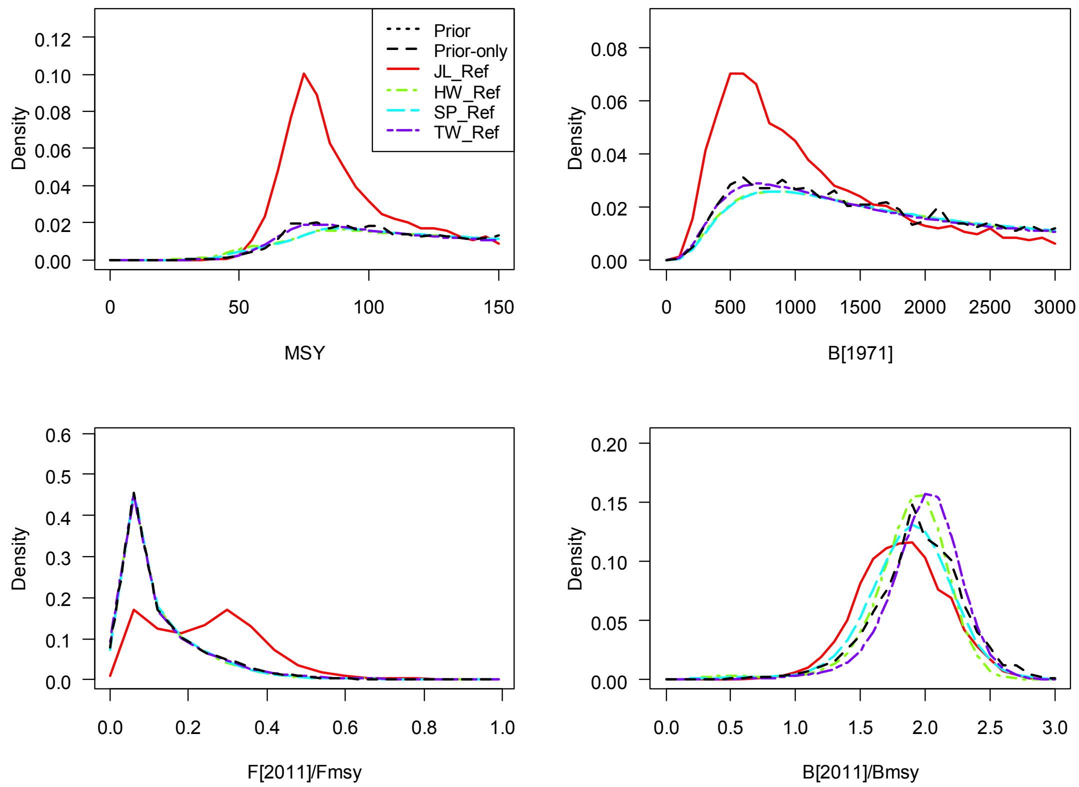

Figure 4 (cont'd). Comparison of marginal posterior distributions for the four reference cases (**JL_Ref, HW_Ref, SP_Ref, TW_Ref**). (b) Four panels correspond to maximum sustainable yield (MSY), stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{msy}) and the ratio of stock biomass in 2011 to that at MSY (B_{2011}/B_{msy}).

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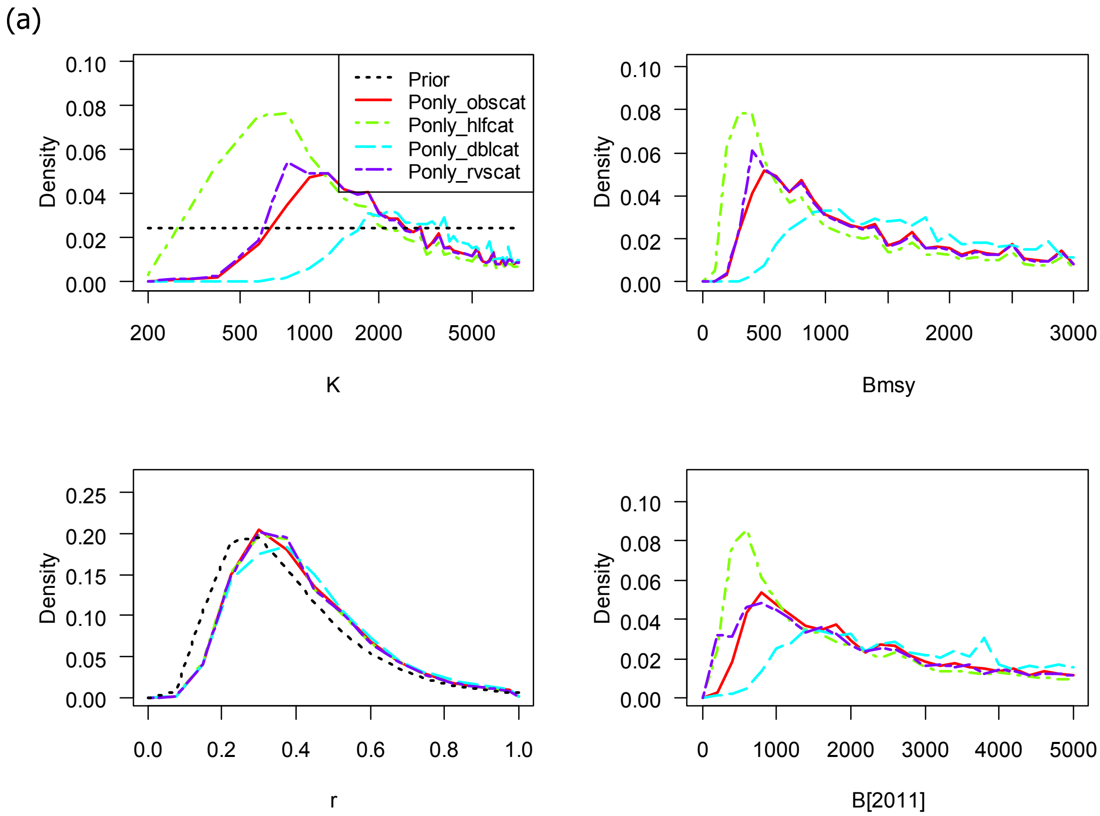


Figure 5. Comparison of marginal posterior distributions for four prior-only runs using different catch trajectories (**Ponly_obscat, Ponly_hlfcat, Ponly_dblcat, Ponly_rvscat**). (a) Four panels correspond to carrying capacity (*K*), stock biomass (B_{msy}) at maximum sustainable yield (MSY), the maximum intrinsic rate of natural increase (*r*) and stock biomass in 2011. Note that the horizontal axis of the top left panel for *K* is log-scaled.

(b)

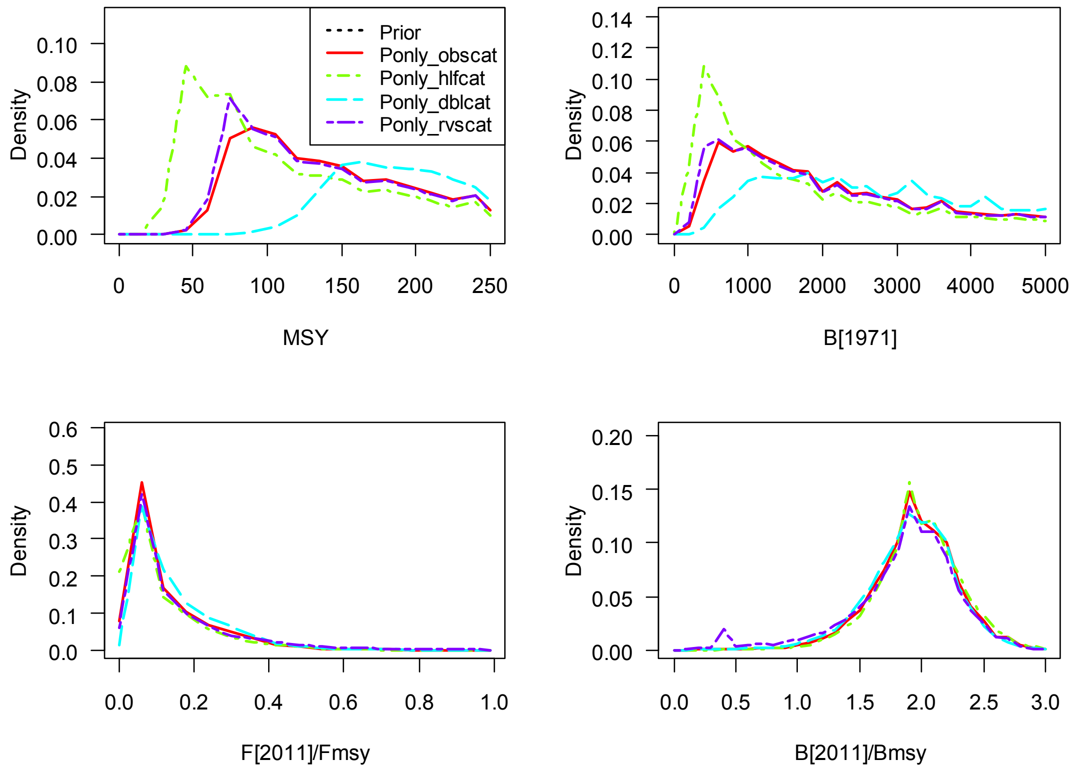
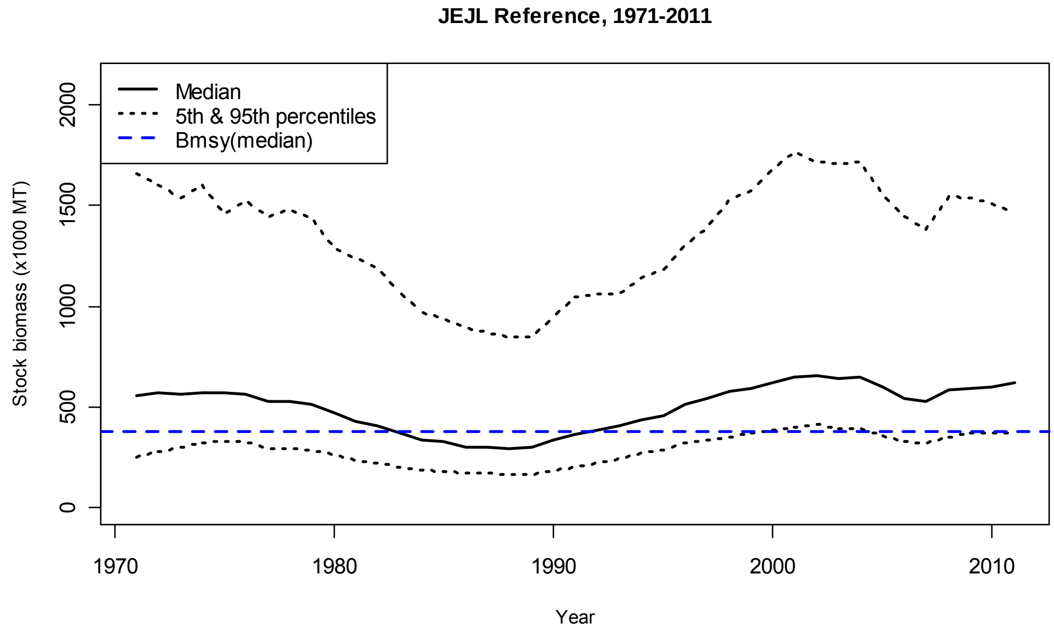


Figure 5 (cont'd). Comparison of marginal posterior distributions for four prior-only runs using different catch trajectories (**Ponly_obscat, Ponly_hlfcat, Ponly_dblcat, Ponly_rvscat**). (b) Four panels correspond to maximum sustainable yield (MSY), stock biomass in 1971, the ratio of fishing mortality rate in 2011 to that at MSY (F_{2011}/F_{msy}) and the ratio of stock biomass in 2011 to that at MSY (B_{2011}/B_{msy}).

(a)



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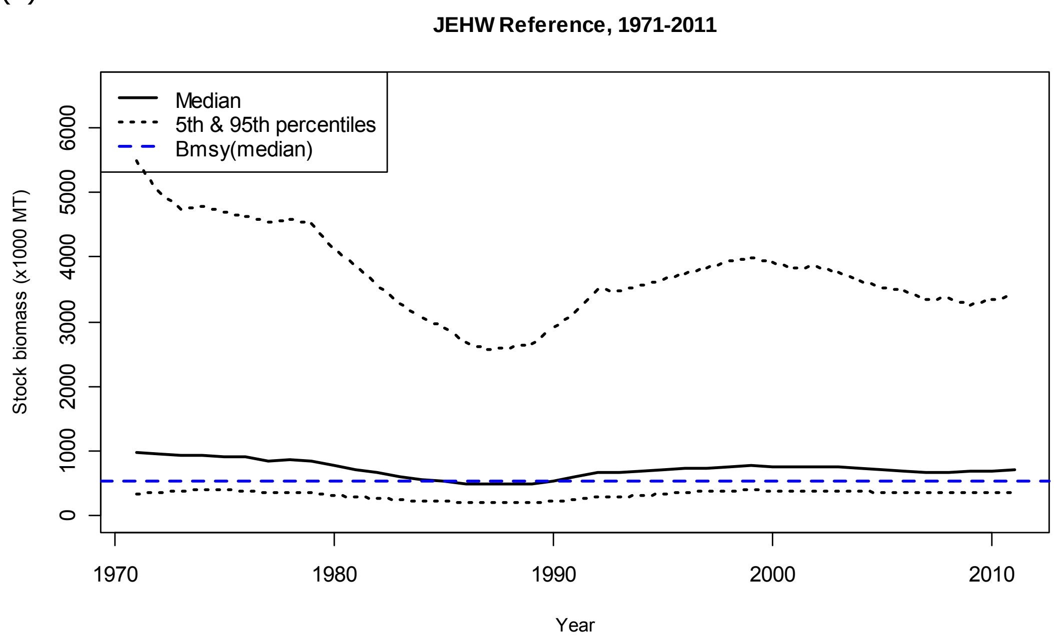

Figure 6. Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{msy}). (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

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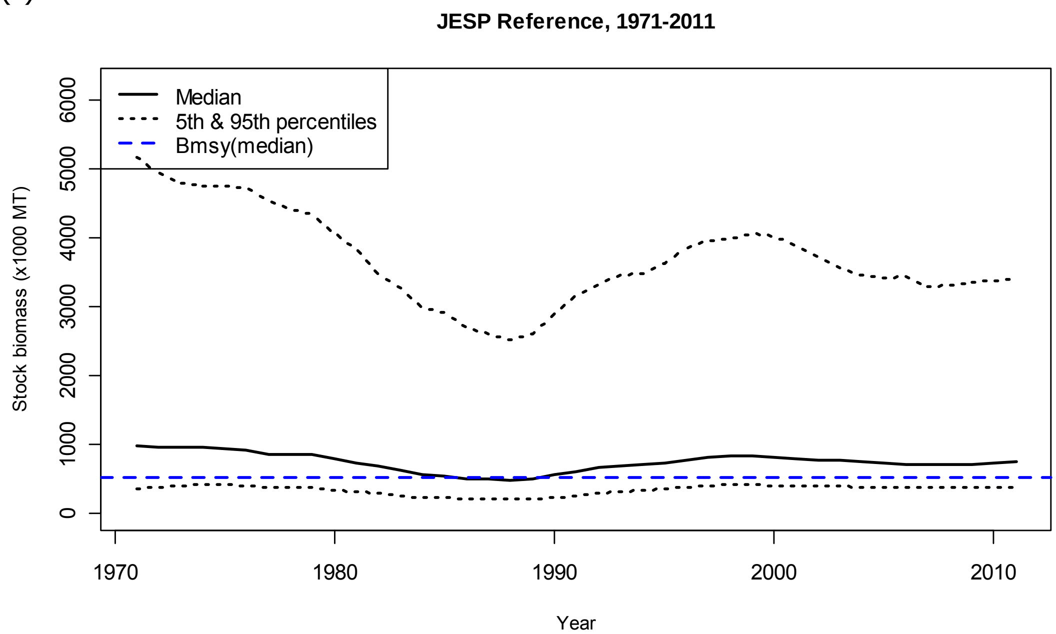
(c)



(d)

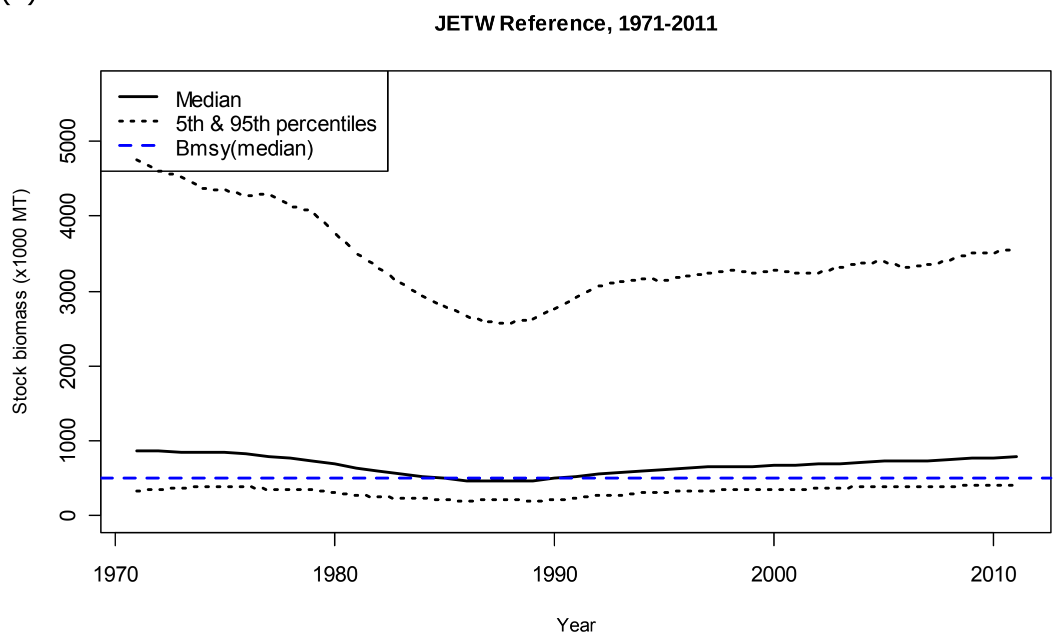
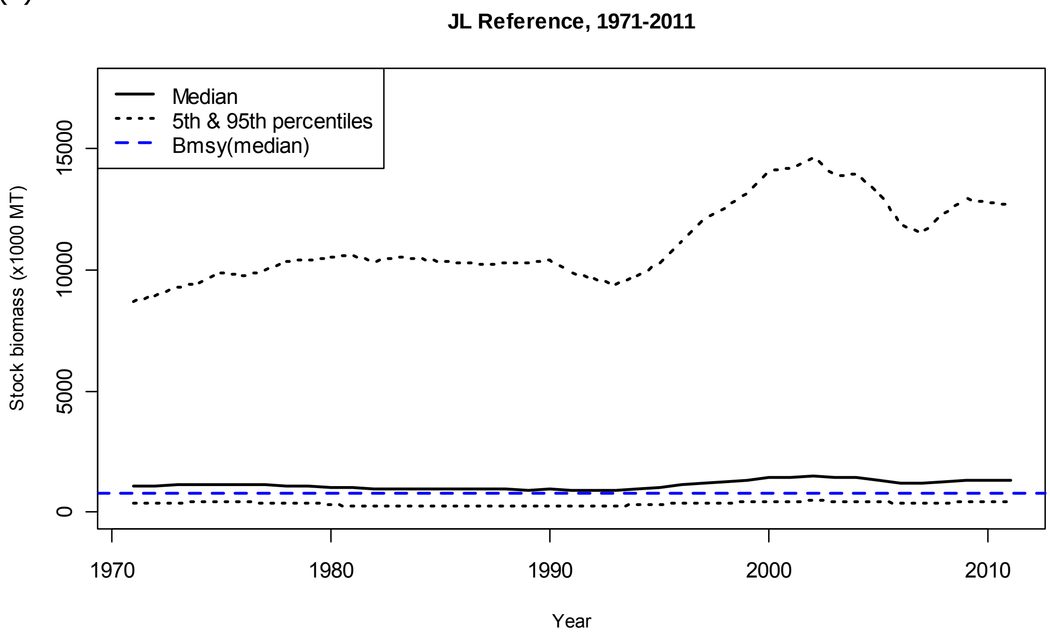


Figure 6 (cont'd). Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{msy}). (b) **JESP_Ref** case. (d) **JETW_Ref** case.

(e)



(f)

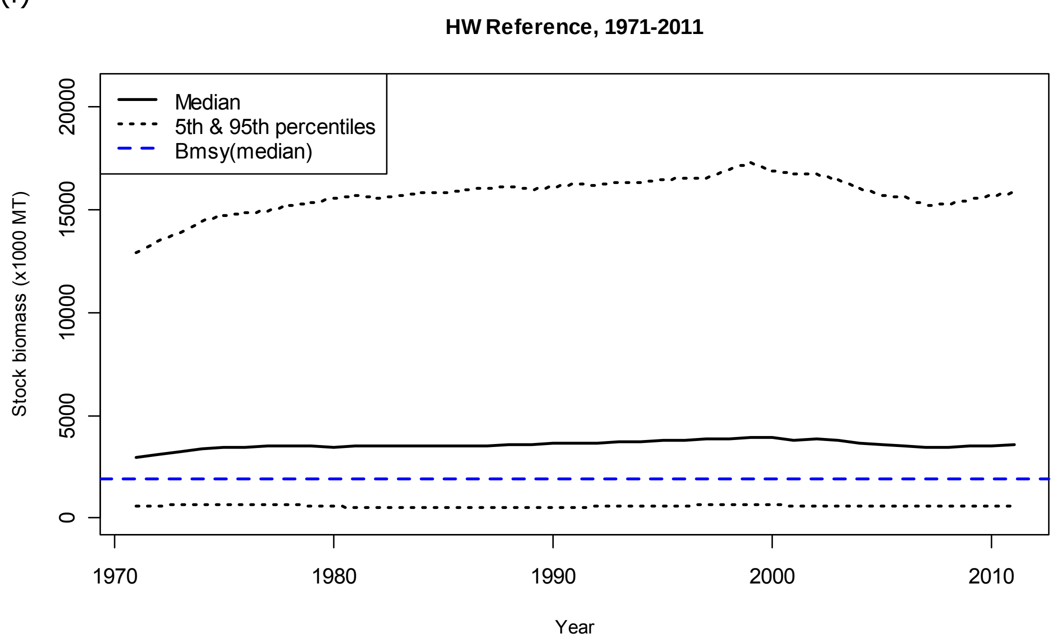


Figure 6 (cont'd). Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{msy}). (e) **JL_Ref** case. (f) **HW_Ref** case.

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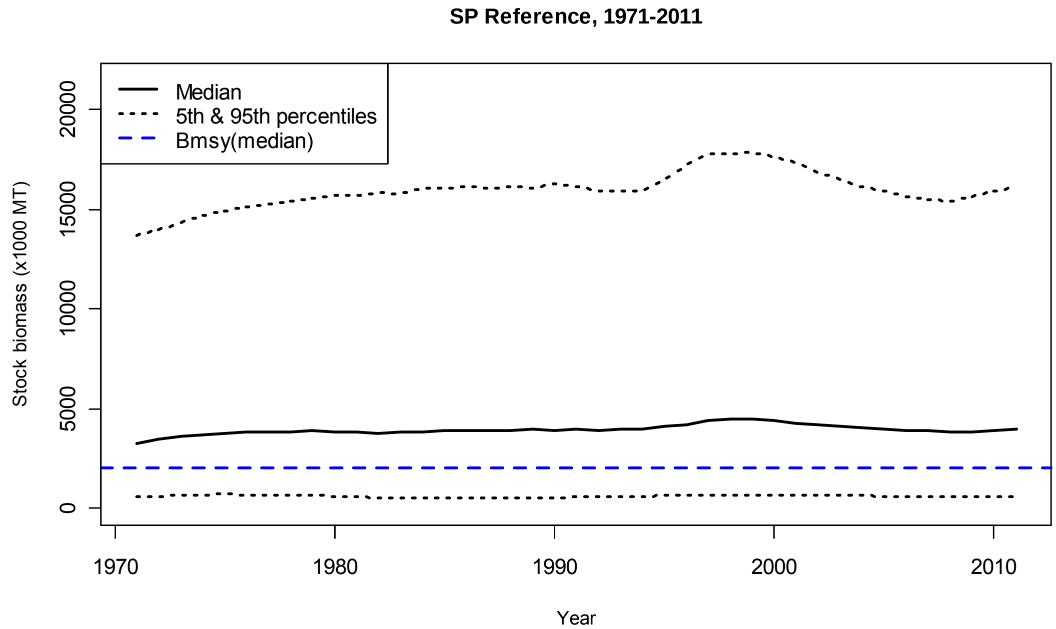
(g)



(h)

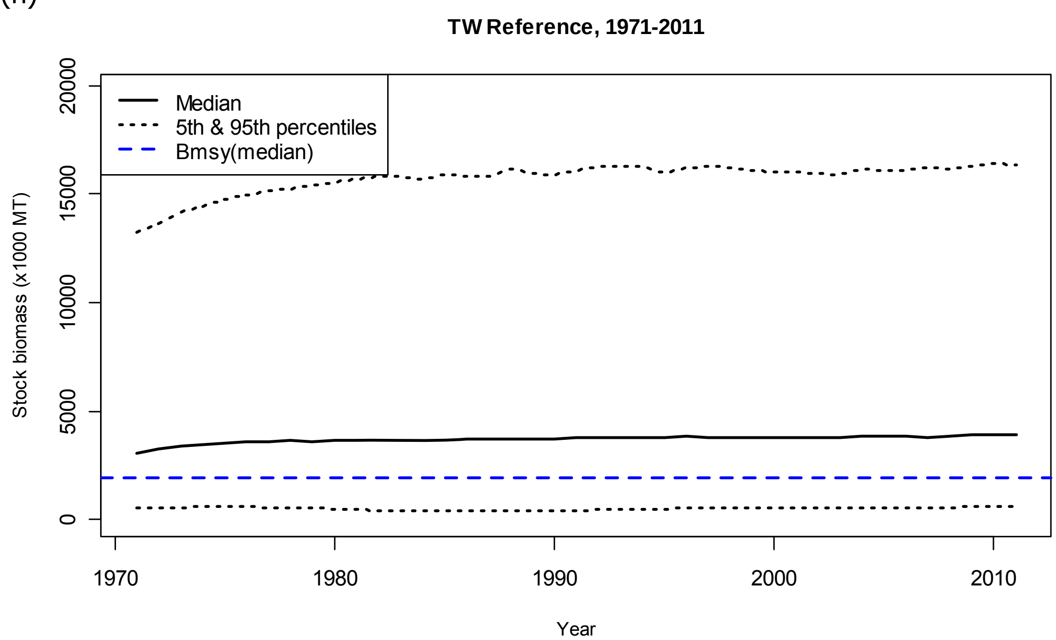


Figure 6 (cont'd). Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{msy}). (e) **SP_Ref** case. (f) **TW_Ref** case.

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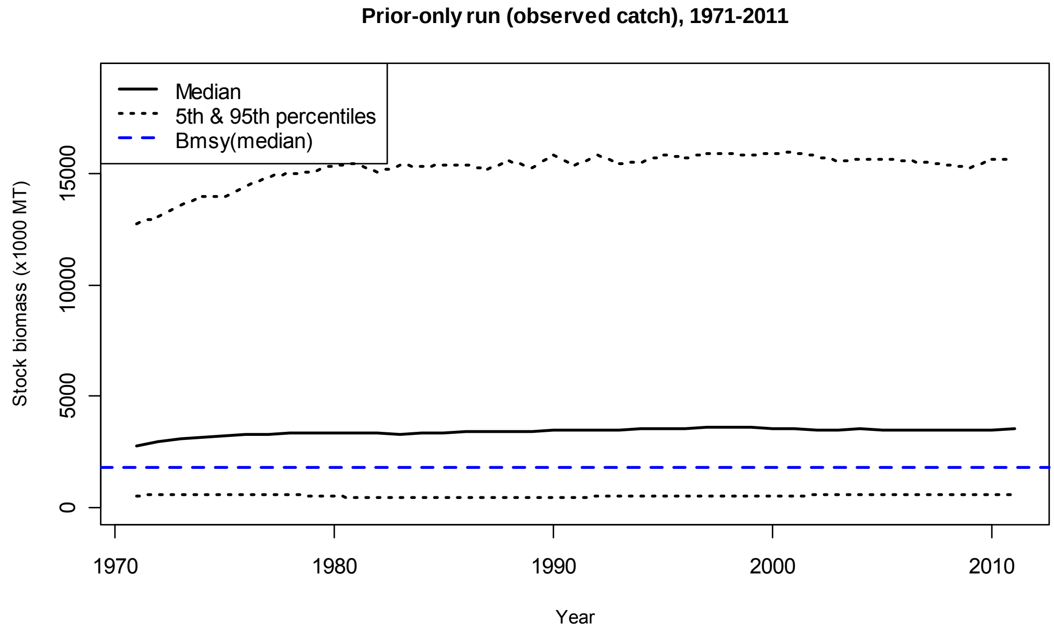
(a)



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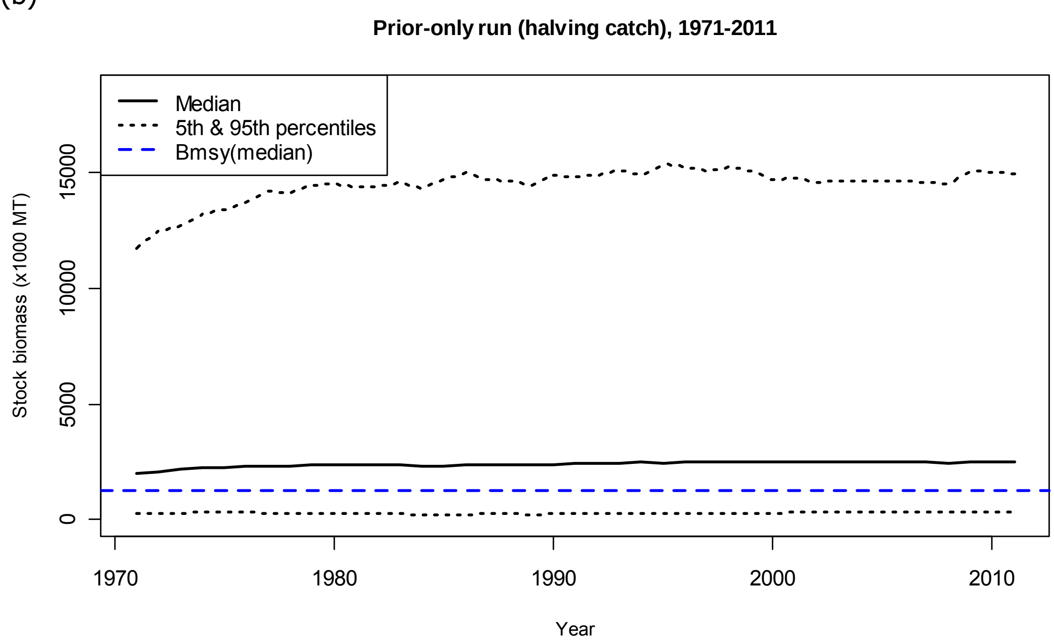

Figure 7. Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{msy}). (a) **Ponly_obscat** case. (b) **Ponly_hlfcat** case.

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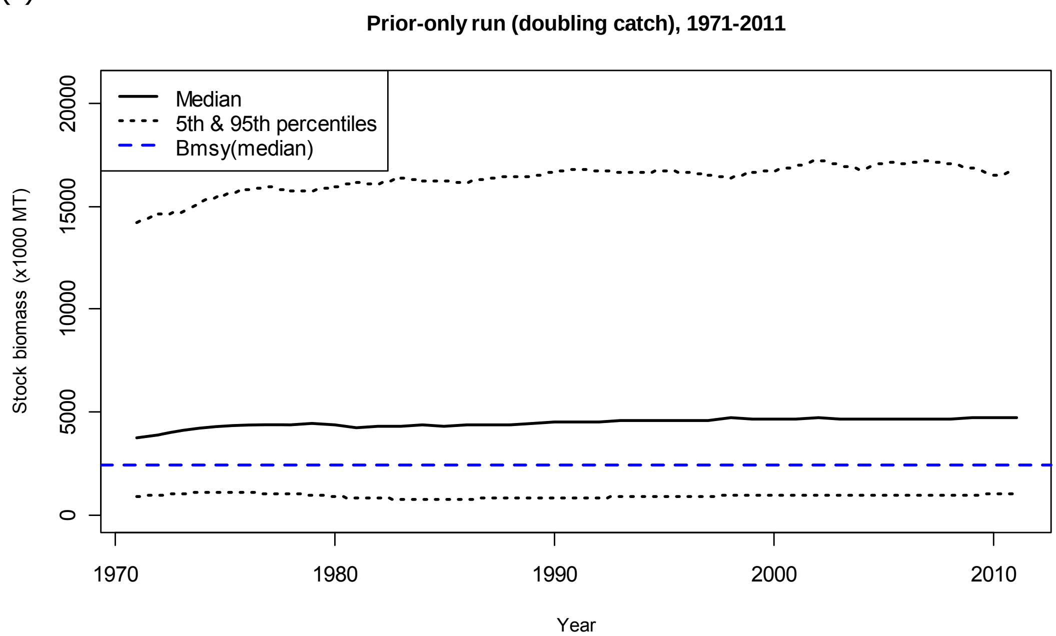
(c)



(d)

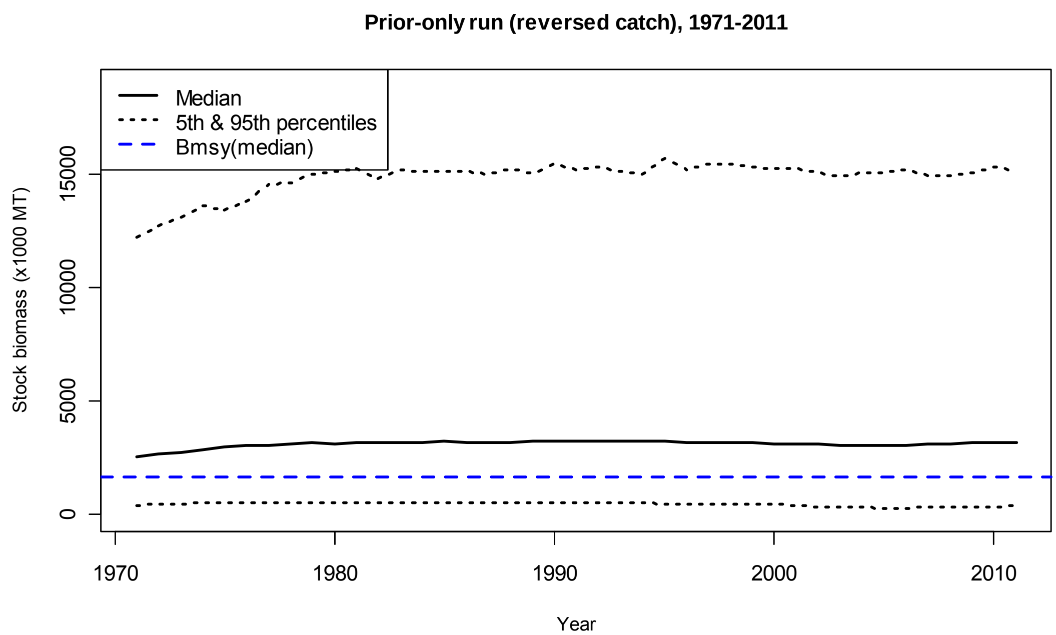


Figure 7 (cont'd). Median estimate and 90% confidence limits for the historical stock dynamics of north Pacific blue shark. The black solid and dotted lines represent the median, 5th and 95th percentiles, respectively. The blue dashed line indicates the median estimate for the biomass at maximum sustainable yield (B_{msy}). (c) **Ponly_dblcat** case. (f) **Ponly_rvscat** case.

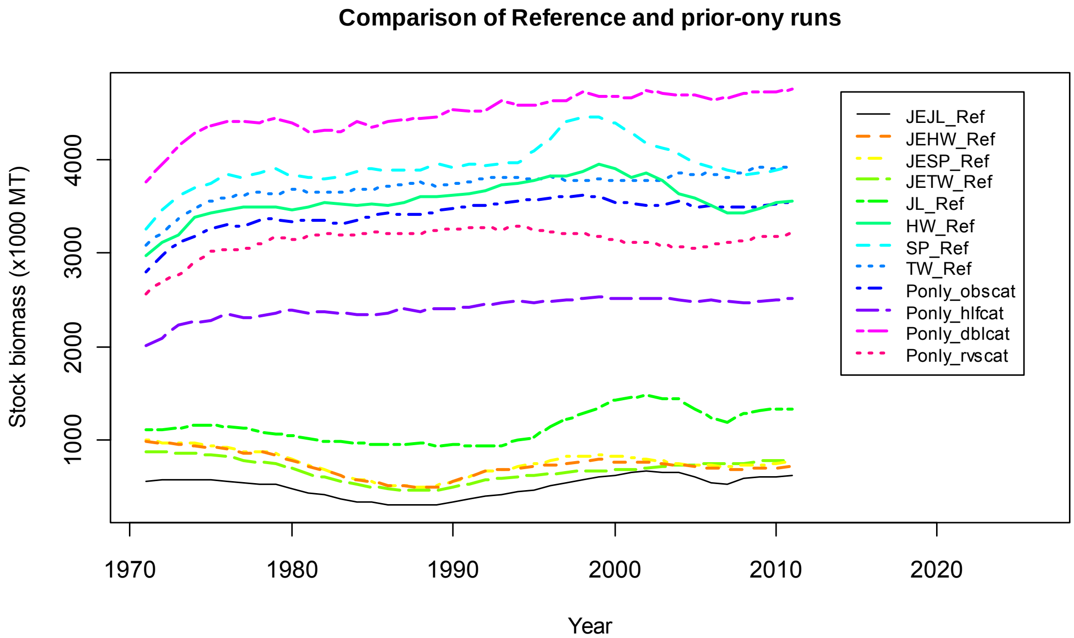


Figure 8. Comparison of median trajectories for the historical stock dynamics of north Pacific blue shark. Each line represents one of the eight reference cases (**JEJL_Ref, JEHW_Ref, JESP_Ref**, **JETW_Ref**, **JL_Ref**, **HW_Ref**, **SP_Ref**, **TW_Ref**) or four prior-only runs (**Ponly_obscat**, **Ponly_hlfcat**, **Ponly_dblcat**, **Ponly_rvscat**).

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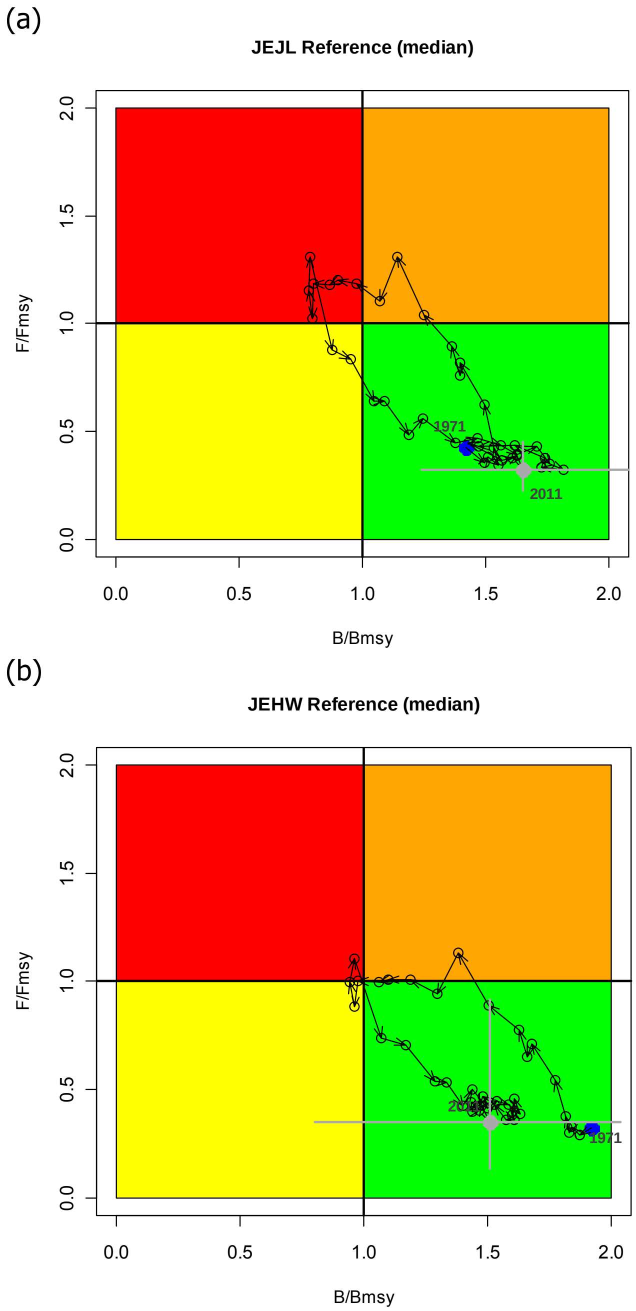
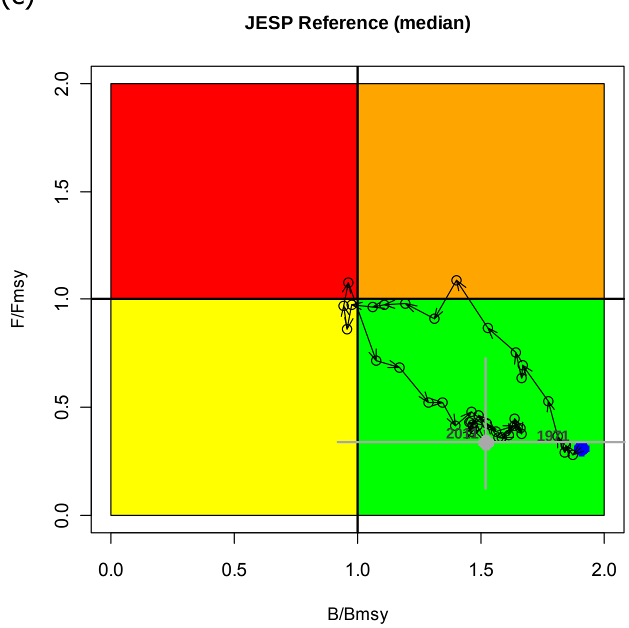


Figure 9. Kobe plot for the eight reference cases in the blue shark stock assessment. The plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis). Colors represent the magnitude of risk of stock collapse green (safe) to red (high risk). The solid blue circle indicates the median estimate in 1971 (the start year of stock assessment calculation). The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011, respectively. The open black circles and connected solid black arrows are the medians in years between 1971 and 2011 and historical directions of stock status. (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

(c)



(d)

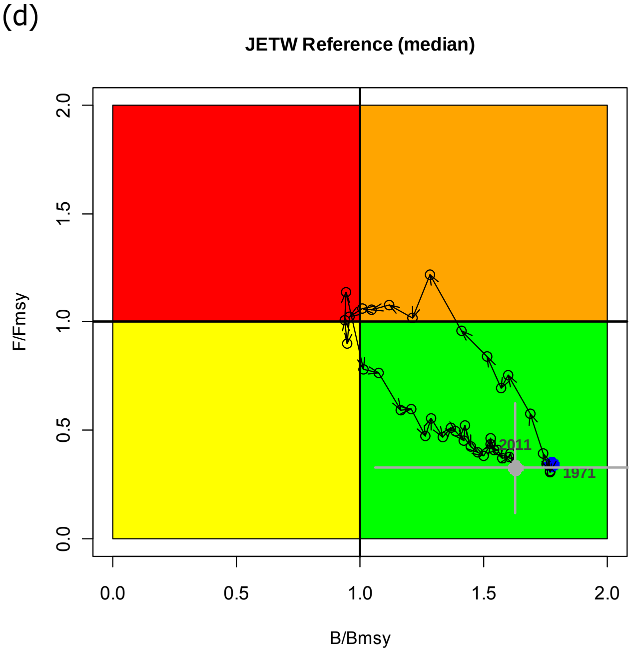
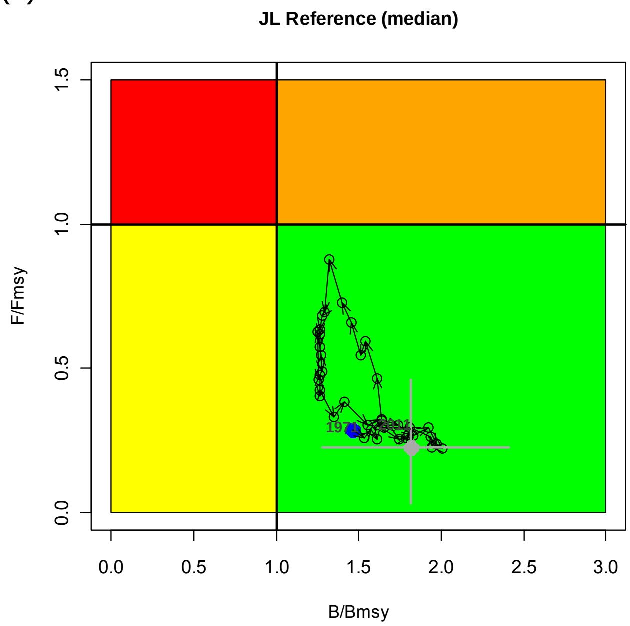


Figure 9 (cont'd). Kobe plot for the eight reference cases in the blue shark stock assessment. The plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis). Colors represent the magnitude of risk of stock collapse green (safe) to red (high risk). The solid blue circle indicates the median estimate in 1971 (the start year of stock assessment calculation). The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011, respectively. The open black circles and connected solid black arrows are the medians in years between 1971 and 2011 and historical directions of stock status. (c) **JESP_Ref** case. (d) **JETW_Ref** case.

(e)



(f)

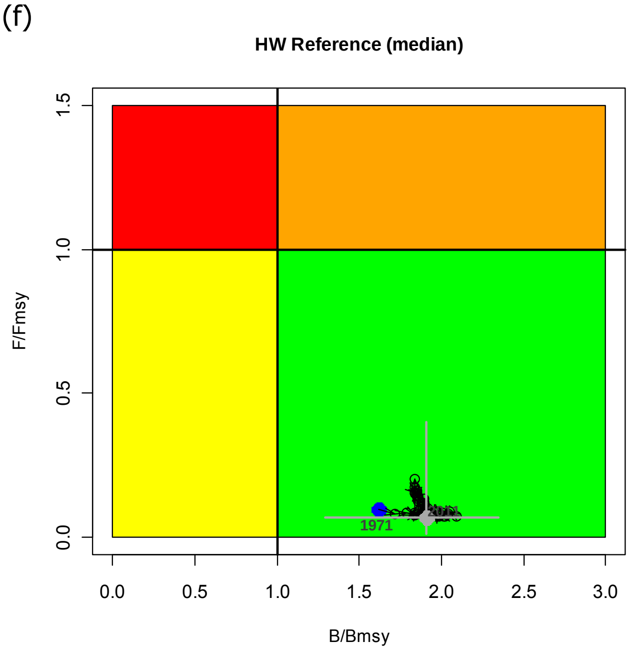


Figure 9 (cont'd). Kobe plot for the eight reference cases in the blue shark stock assessment. The plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis). Colors represent the magnitude of risk of stock collapse green (safe) to red (high risk). The solid blue circle indicates the median estimate in 1971 (the start year of stock assessment calculation). The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011, respectively. The open black circles and connected solid black arrows are the medians in years between 1971 and 2011 and historical directions of stock status. (e) **JL_Ref** case. (f) **HW_Ref** case.

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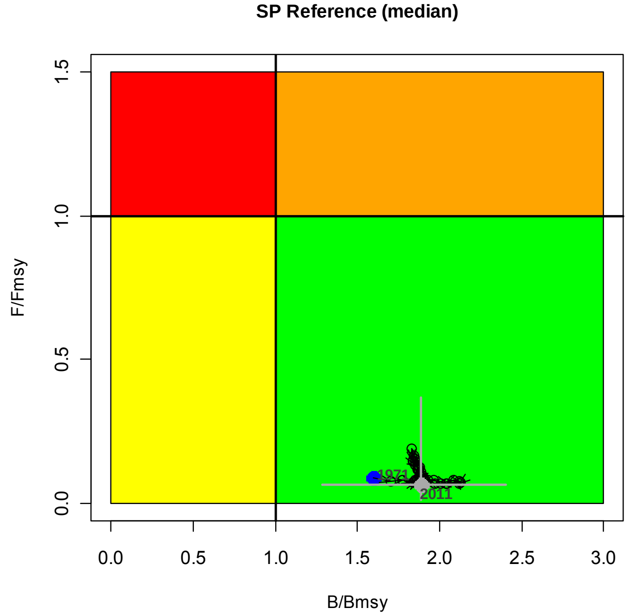
(g)



(h)

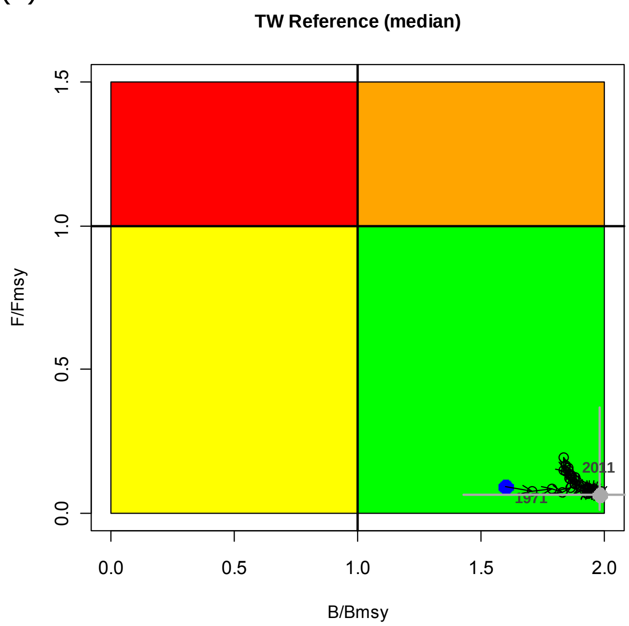


Figure 9 (cont'd). Kobe plot for the eight reference cases in the blue shark stock assessment. The plot illustrates degrees of stock depletion (horizontal axis) and over-fishing (vertical axis). Colors represent the magnitude of risk of stock collapse green (safe) to red (high risk). The solid blue circle indicates the median estimate in 1971 (the start year of stock assessment calculation). The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011, respectively. The open black circles and connected solid black arrows are the medians in years between 1971 and 2011 and historical directions of stock status. (g) **SP_Ref** case. (h) **TW_Ref** case.

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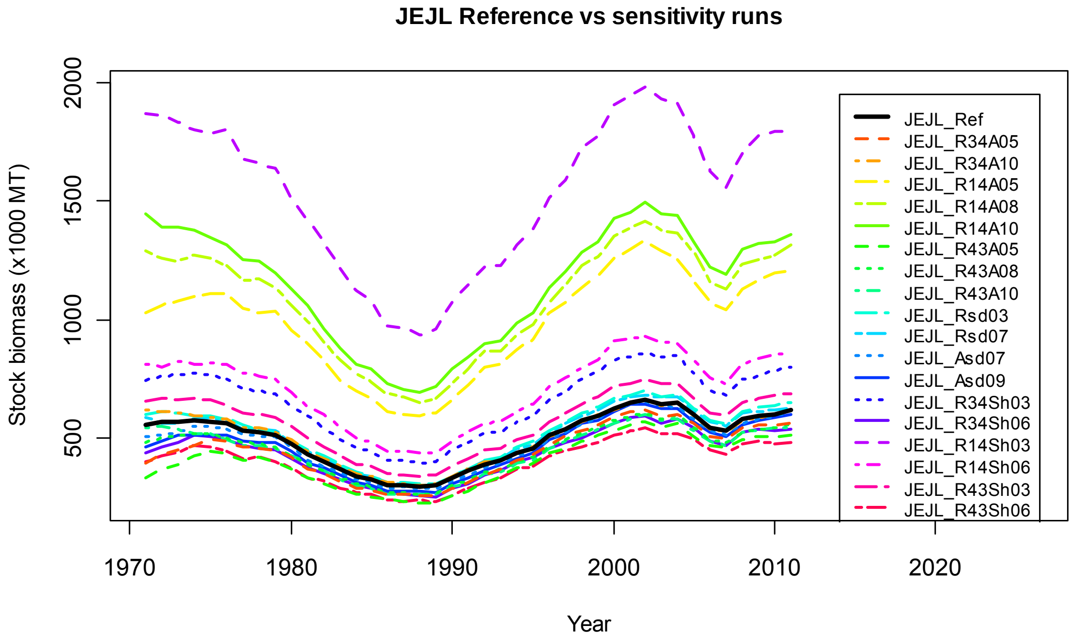
(a)



(b)

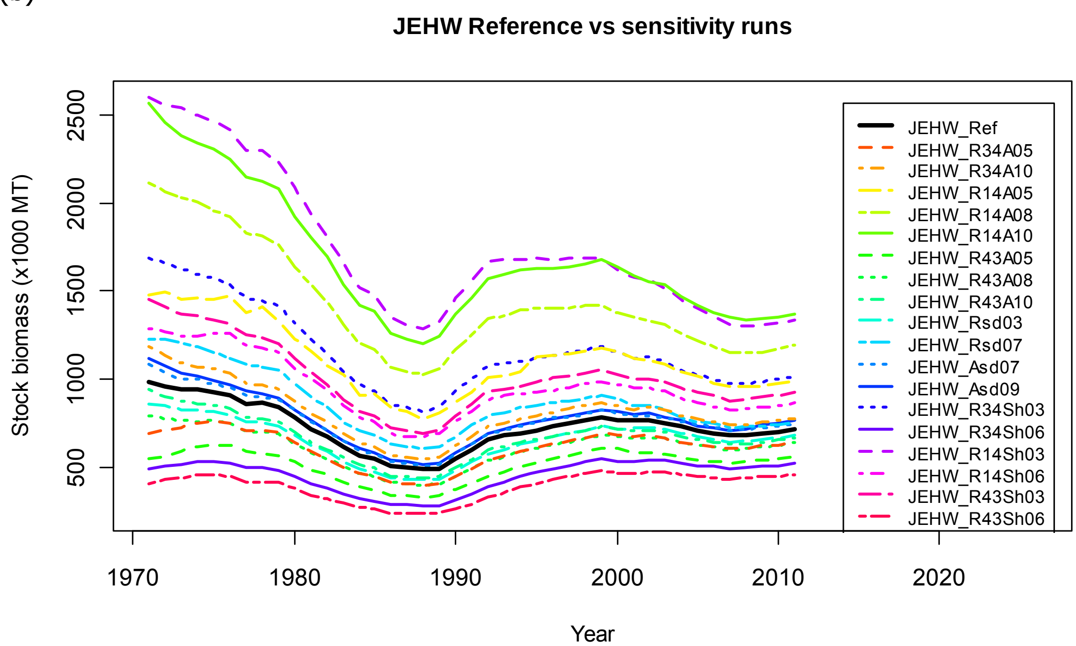


Figure 10. Comparison of median trajectories of historical blue shark stock dynamics between the reference case (JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref) and sensitivity runs. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs. (a) **JEJL_Ref** case and sensitivity runs. (b) **JEHW_Ref** case and sensitivity runs.

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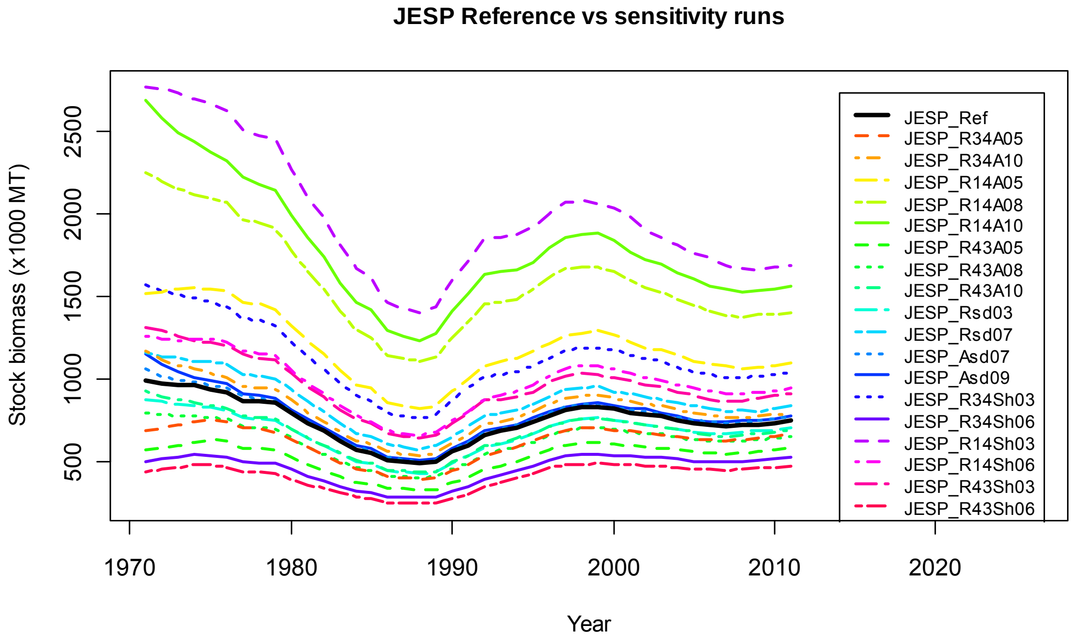
(c)



(d)

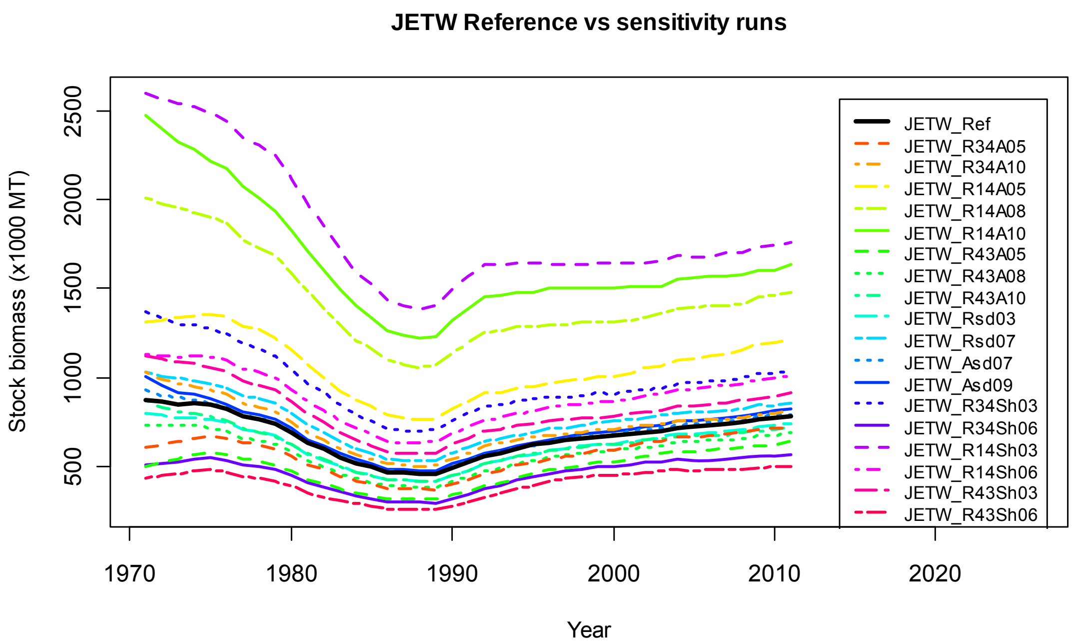
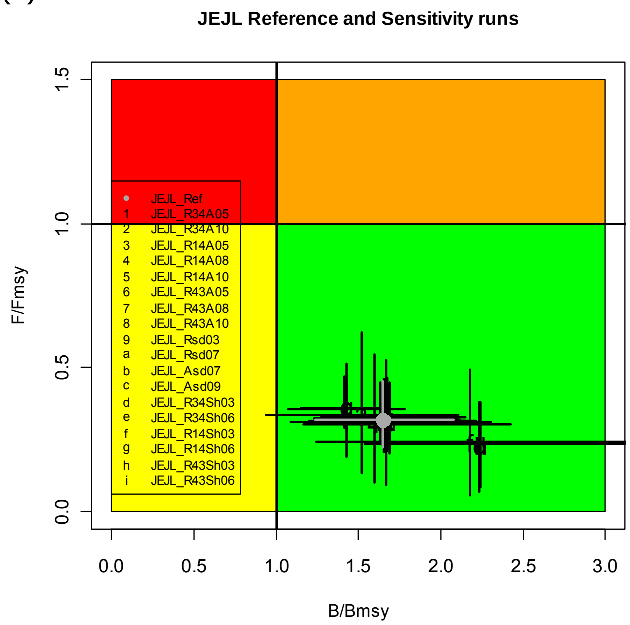


Figure 10 (cont'd). Comparison of median trajectories of historical blue shark stock dynamics between the reference case (JEJL_Ref, JEHW_Ref, JESP_Ref, JETW_Ref) and sensitivity runs. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs. (c) **JESP_Ref** case and sensitivity runs. (d) **JETW_Ref** case and sensitivity runs.

(a)



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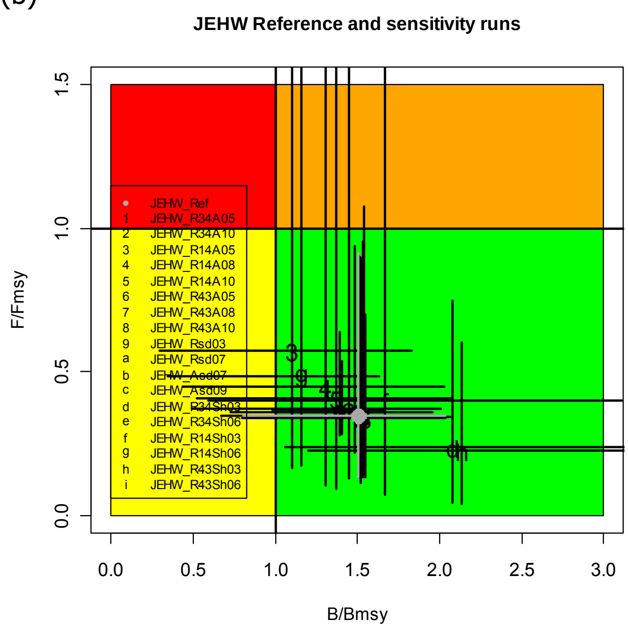
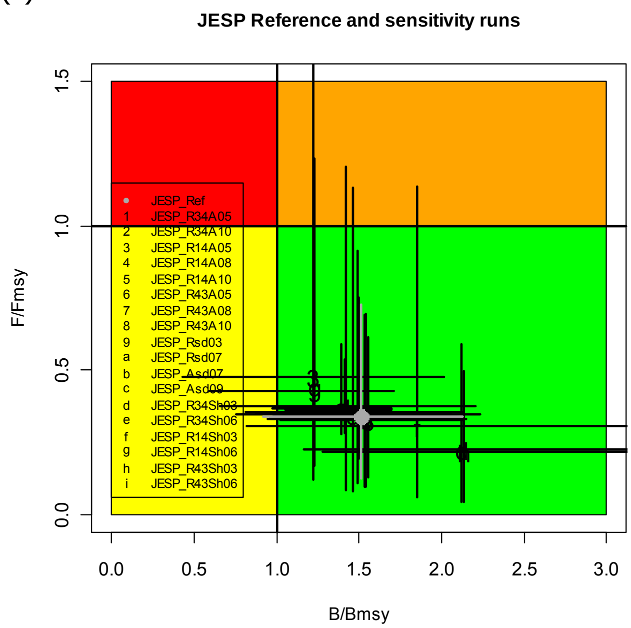


Figure 11. Kobe plot for the four reference cases and sensitivity runs of the north Pacific blue shark stock assessment. The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011 for the reference case, respectively. Other different symbols (numbers and alphabets) and its horizontal and vertical solid black lines indicate the median and 90% confidence limits in 2011 for various sensitivity runs. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs. (a) **JEJL_Ref** case and sensitivity runs. (b) **JEHW_Ref** case and sensitivity runs.

(c)



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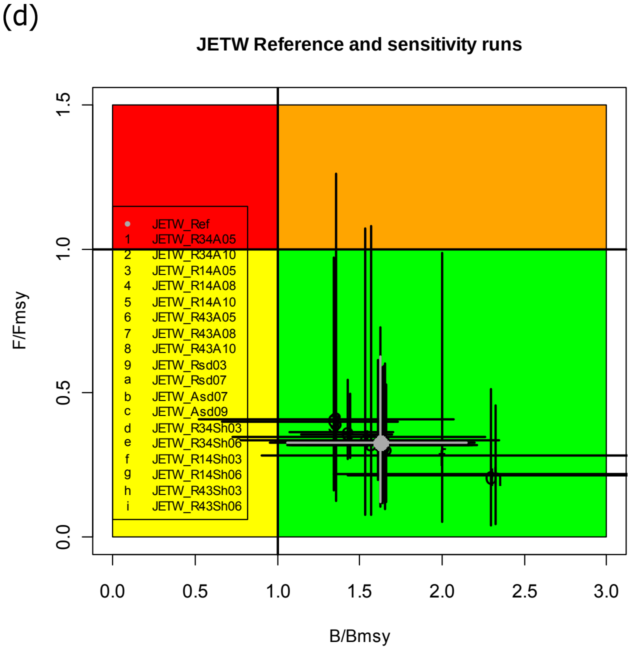
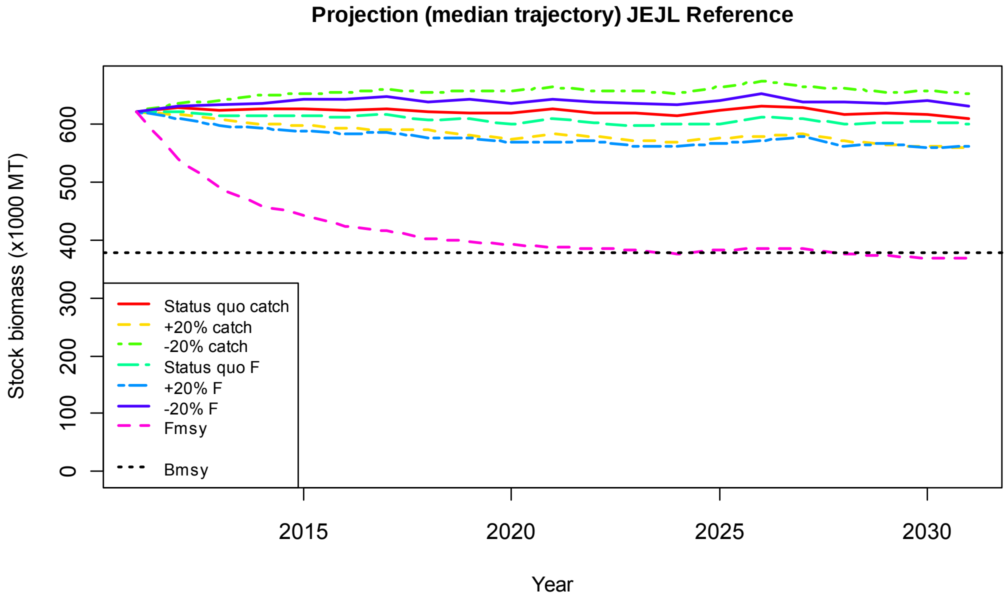


Figure 11 (cont'd). Kobe plot for the four reference cases and sensitivity runs of the north Pacific blue shark stock assessment. The solid gray circle and its horizontal and vertical solid gray lines indicate the median and 90% confidence limits in 2011 for the reference case, respectively. Other different symbols (numbers and alphabets) and its horizontal and vertical solid black lines indicate the median and 90% confidence limits in 2011 for various sensitivity runs. See Table 2 for run identifiers and detailed descriptions of the sensitivity runs. (c) **JESP_Ref** case and sensitivity runs. (d) **JETW_Ref** case and sensitivity runs.

(a)



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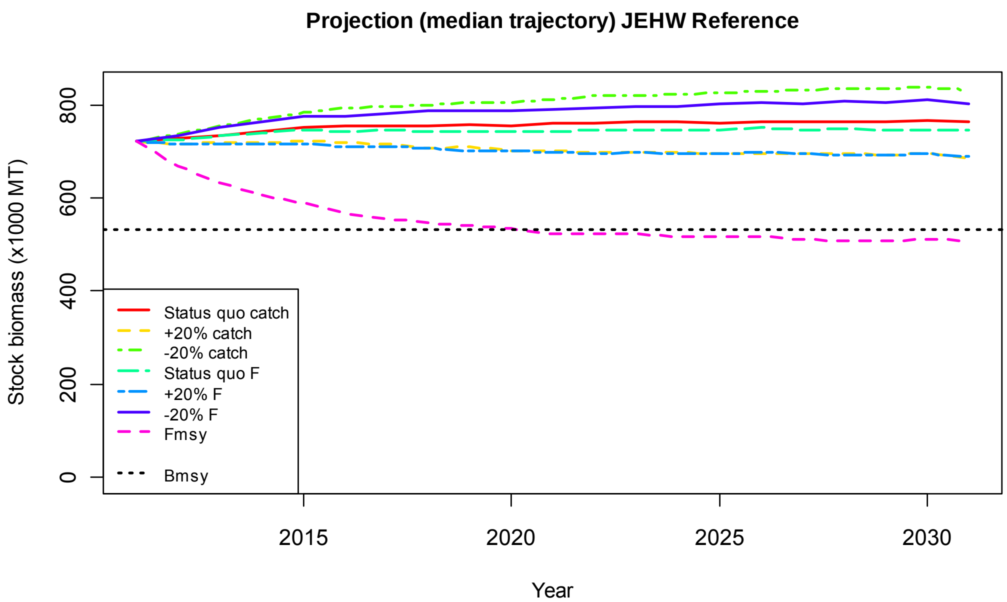

Figure 12. Comparison of future projected stock biomass (medians) of blue shark under different constant catch harvest policies (status quo, +20%, -20%) and different constant *F* harvest policies (status quo, +20%, -20%, F_{msy}) in the four reference cases. Status quo catch was based on the average catch over recent five years of 2006-2010 and status quo *F* was based on the average *F* over the recent five years. The biomass level at the maximum sustainable yield, MSY (B_{msy}) was also plotted (black dotted line). (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

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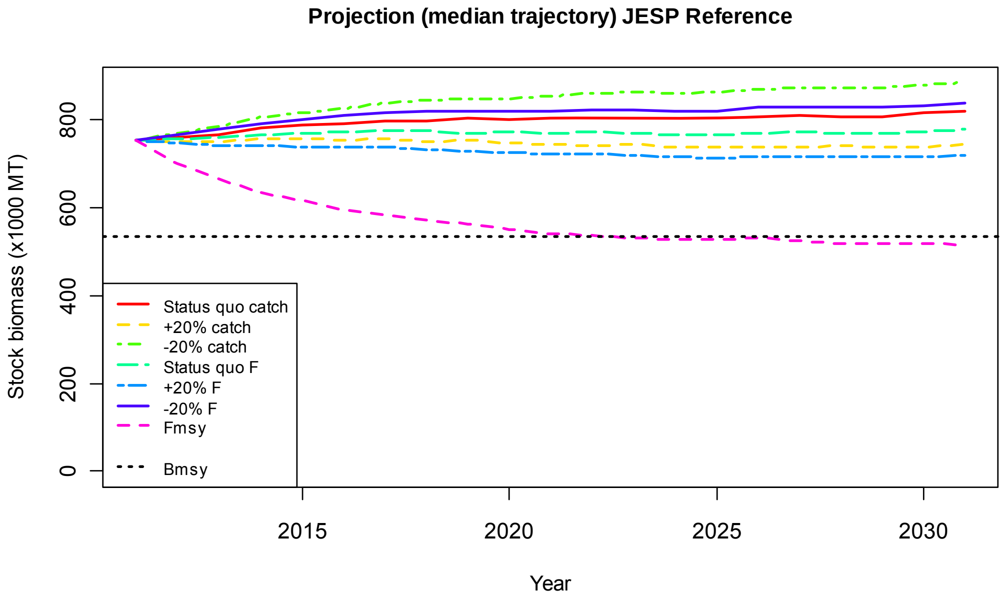
(c)



(d)

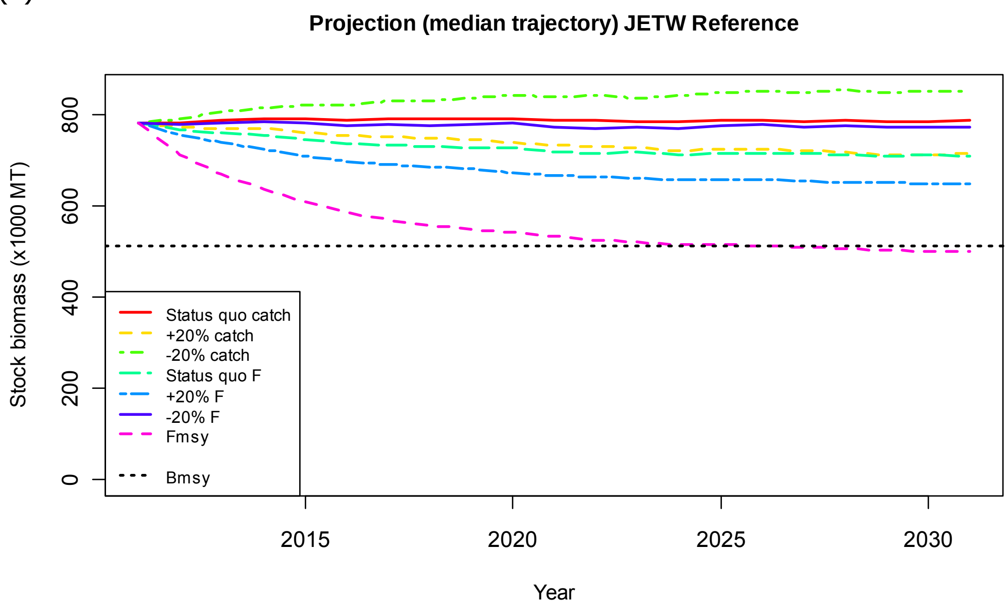


Figure 12 (cont'd). Comparison of future projected stock biomass (medians) of blue shark under different constant catch harvest policies (status quo, +20%, -20%) and different constant *F* harvest policies (status quo, +20%, -20%, F_{msy}) in the four reference cases. Status quo catch was based on the average catch over recent five years of 2006-2010 and status quo *F* was based on the average *F* over the recent five years. The biomass level at the maximum sustainable yield, MSY (B_{msy}) was also plotted (black dotted line). (C) **JESP_Ref** case. (d) **JETW_Ref** case.

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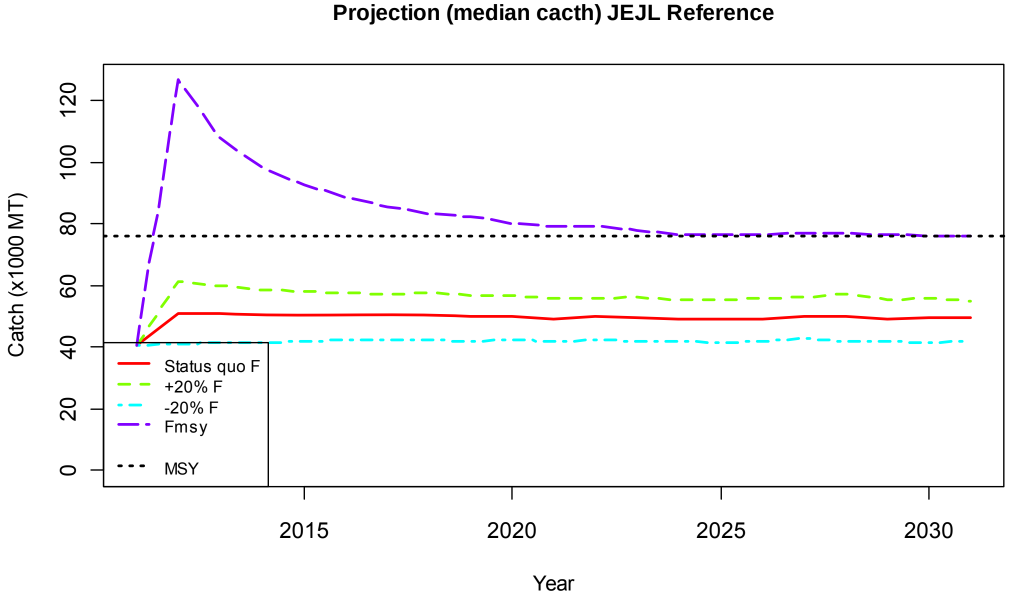
(a)



(b)

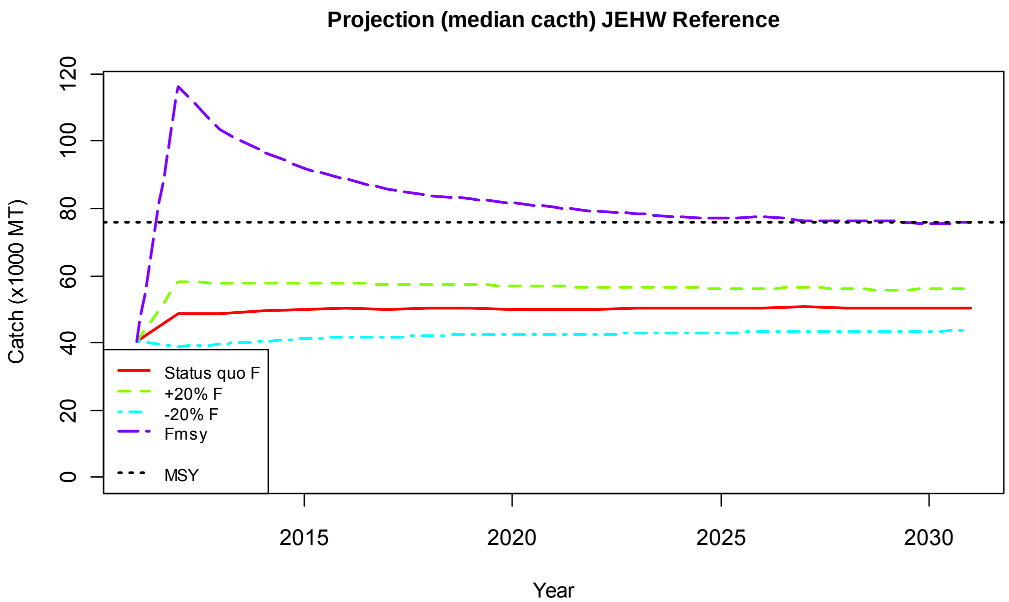


Figure 13. Comparison of future projected catches (medians) of blue shark under different constant *F* harvest policies (status quo, +20%, -20%, F_{msy}) in the four reference cases. Status quo *F* was based on the average *F* over recent five years of 2006-2010. The maximum sustainable yield (MSY) was also plotted (black dotted line). (a) **JEJL_Ref** case. (b) **JEHW_Ref** case.

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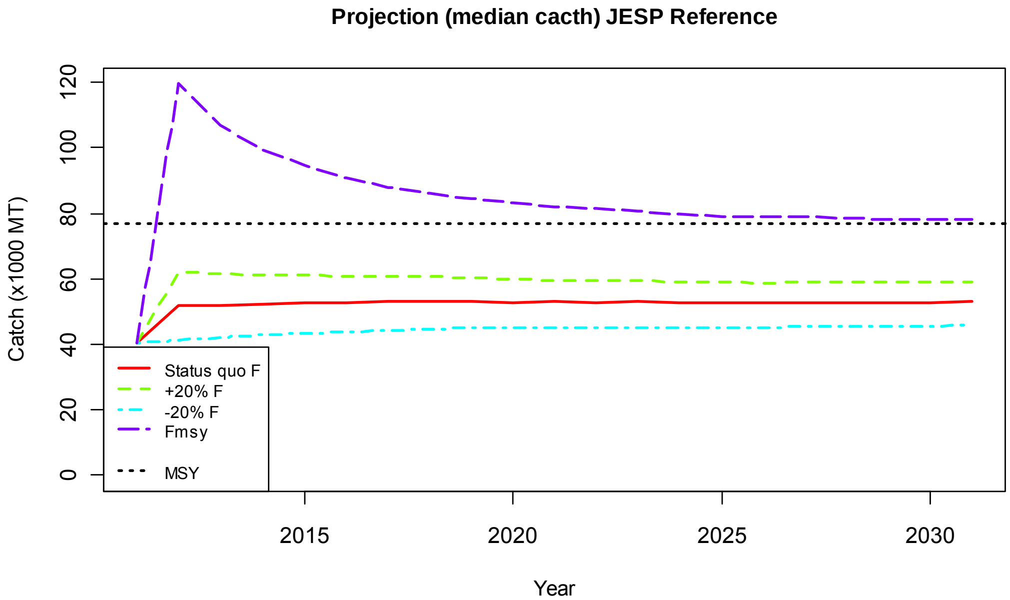
(c)



(d)

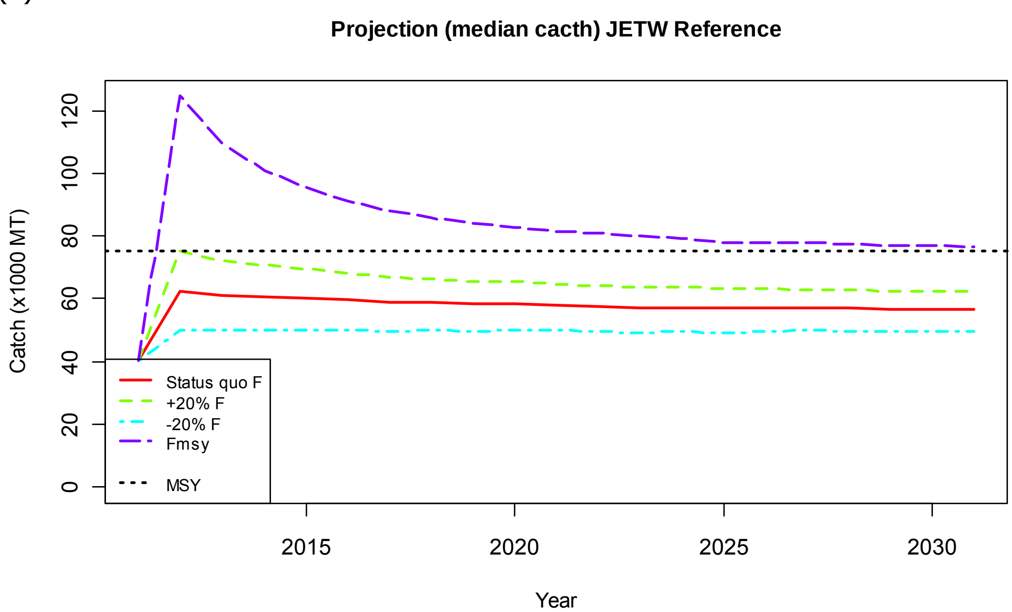


Figure 13 (cont'd). Comparison of future projected catches (medians) of blue shark under different constant *F* harvest policies (status quo, +20%, -20%, F_{msy}) in the four reference cases. Status quo *F* was based on the average *F* over recent five years of 2006-2010. The maximum sustainable yield (MSY) was also plotted (black dotted line). (c) **JESP_Ref** case. (d) **JETW_Ref** case.

Appedix.

Table A1. Diagnostic statistics for model convergence of **JEJL and JL** runs.

Diagnostic statistics	JEJL_Ref	JEJL_R14A08	JEJL_R43A08	JEJL_Rsd03	JEJL_Rsd07	JEJL_R34A05	JEJL_R34A10	JEJL_Asd07	JEJL_Asd09	JEJL_R34Sh03
Draws retained	7032621	7516799	6707535	7601105	9657343	6490340	9655548	8479356	7332426	9701548
CV(weight)	69.72	80.32	73.87	75.57	100.37	96.83	77.99	87.97	95.06	82.60
CV(likelihood*prior)	426.21	487.52	443.13	987.73	653.07	724.18	430.79	497.48	596.16	328.40
%maximum weight	0.64	0.74	0.74	0.46	0.84	0.72	0.73	0.50	0.87	0.85

Diagnostic statistics	JEJL_R34Sh06	JEJL_R14A05	JEJL_R14A10	JEJL_R43A05	JEJL_R43A10	JEJL_R14Sh03	JEJL_R14Sh06	JEJL_R43Sh03	JEJL_R43Sh06	JL_Ref
Draws retained	9993432	7395652	7530755	6135917	6943032	10487092	8883278	9186611	14742993	2461028
CV(weight)	132.03	95.64	73.64	107.67	75.99	59.67	109.86	69.40	141.16	16.15
CV(likelihood*prior)	532.85	445.37	577.49	580.04	434.60	791.42	611.97	341.08	636.43	504.94
%maximum weight	0.81	0.62	0.88	0.91	0.79	0.29	0.90	0.57	0.73	0.26

Table A2. Diagnostic statistics for model convergence of **JEHW and HW** runs.

Diagnostic statistics	JEHW_Ref	JEHW_R14A08	JEHW_R43A08	JEHW_Rsd03	JEHW_Rsd07	JEHW_R34A05	JEHW_R34A10	JEHW_Asd07	JEHW_Asd09	JEHW_R34Sh03
Draws retained	7505521	7183609	7018950	8025877	7496731	6509690	7861762	6531042	5310240	8408927
CV(weight)	22.04	21.49	19.72	14.54	31.42	34.35	15.99	30.85	41.58	9.93
CV(likelihood*prior)	213.04	172.21	225.45	248.18	208.34	317.27	197.25	871.87	222.52	152.21
%maximum weight	0.16	0.14	0.15	0.06	0.23	0.46	0.08	0.38	0.70	0.03

Diagnostic statistics	JEHW_R34Sh06	JEHW_R14A05	JEHW_R14A10	JEHW_R43A05	JEHW_R43A10	JEHW_R14Sh03	JEHW_R14Sh06	JEHW_R43Sh03	JEHW_R43Sh06	HW_Ref
Draws retained	7287085	7232478	7117727	6018740	7385486	7472701	6664014	7848429	7001497	2682409
CV(weight)	30.25	48.15	17.16	44.22	17.45	10.48	34.18	10.71	36.36	2.47
CV(likelihood*prior)	608.16	275.29	170.19	332.67	190.97	160.44	253.80	151.23	689.30	40.21
%maximum weight	0.14	0.58	0.18	0.59	0.12	0.04	0.37	0.04	0.21	0.01

Table A3. Diagnostic statistics for model convergence of **JESP and SP** runs.

Diagnostic statistics	JESP_Ref	JESP_R14A08	JESP_R43A08	JESP_Rsd03	JESP_Rsd07	JESP_R34A05	JESP_R34A10	JESP_Asd07	JESP_Asd09	JESP_R34Sh03
Draws retained	4382007	4763509	4105030	4538257	10544890	3937815	4506974	4200221	10023559	4654898
CV(weight)	13.88	10.49	15.21	13.93	26.95	18.80	12.42	18.47	29.32	10.79
CV(likelihood*prior)	213.63	263.01	171.08	241.38	175.81	155.74	194.07	198.59	254.86	152.98
%maximum weight	0.09	0.06	0.10	0.05	0.19	0.13	0.07	0.11	0.23	0.06

Diagnostic statistics	JESP_R34Sh06	JESP_R14A05	JESP_R14A10	JESP_R43A05	JESP_R43A10	JESP_R14Sh03	JESP_R14Sh06	JESP_R43Sh03	JESP_R43Sh06	SP_Ref
Draws retained	4102016	11518278	4799626	9076741	4260408	4771248	4501509	4420447	14283021	5023545
CV(weight)	28.02	17.47	9.65	19.75	13.79	8.79	16.46	10.95	31.91	1.47
CV(likelihood*prior)	280.72	223.71	245.09	235.90	194.50	146.26	688.53	152.78	397.90	42.37
%maximum weight	0.14	0.16	0.04	0.05	0.11	0.02	0.13	0.05	0.07	0.00

Table A4. Diagnostic statistics for model convergence of **JETW and TW** runs.

Diagnostic statistics	JETW_Ref	JETW_R14A08	JETW_R43A08	JETW_Rsd03	JETW_Rsd07	JETW_R34A05	JETW_R34A10	JETW_Asd07	JETW_Asd09	JETW_R34Sh03
Draws retained	4330153	4696591	4109513	4423078	4240815	4079840	4421797	4133031	3966219	4433422
CV(weight)	7.33	4.78	8.02	8.00	9.49	9.21	6.64	12.81	25.05	5.44
CV(likelihood*prior)	466.20	125.63	142.01	616.35	263.61	162.34	193.30	144.87	142.75	165.39
%maximum weight	0.04	0.01	0.04	0.03	0.10	0.03	0.02	0.06	0.35	0.02

Diagnostic statistics	JETW_R34Sh06	JETW_R14A05	JETW_R14A10	JETW_R43A05	JETW_R43A10	JETW_R14Sh03	JETW_R14Sh06	JETW_R43Sh03	JETW_R43Sh06	TW_Ref
Draws retained	4119671	4571729	4741956	3779672	5067917	4708204	4471709	4223236	3936527	4370889
CV(weight)	12.76	5.80	4.40	10.19	7.28	3.97	6.88	5.63	15.48	1.19
CV(likelihood*prior)	742.46	121.62	118.00	167.12	117.25	83.20	177.58	115.95	363.43	40.04
%maximum weight	0.03	0.01	0.01	0.02	0.03	0.01	0.01	0.02	0.04	0.00

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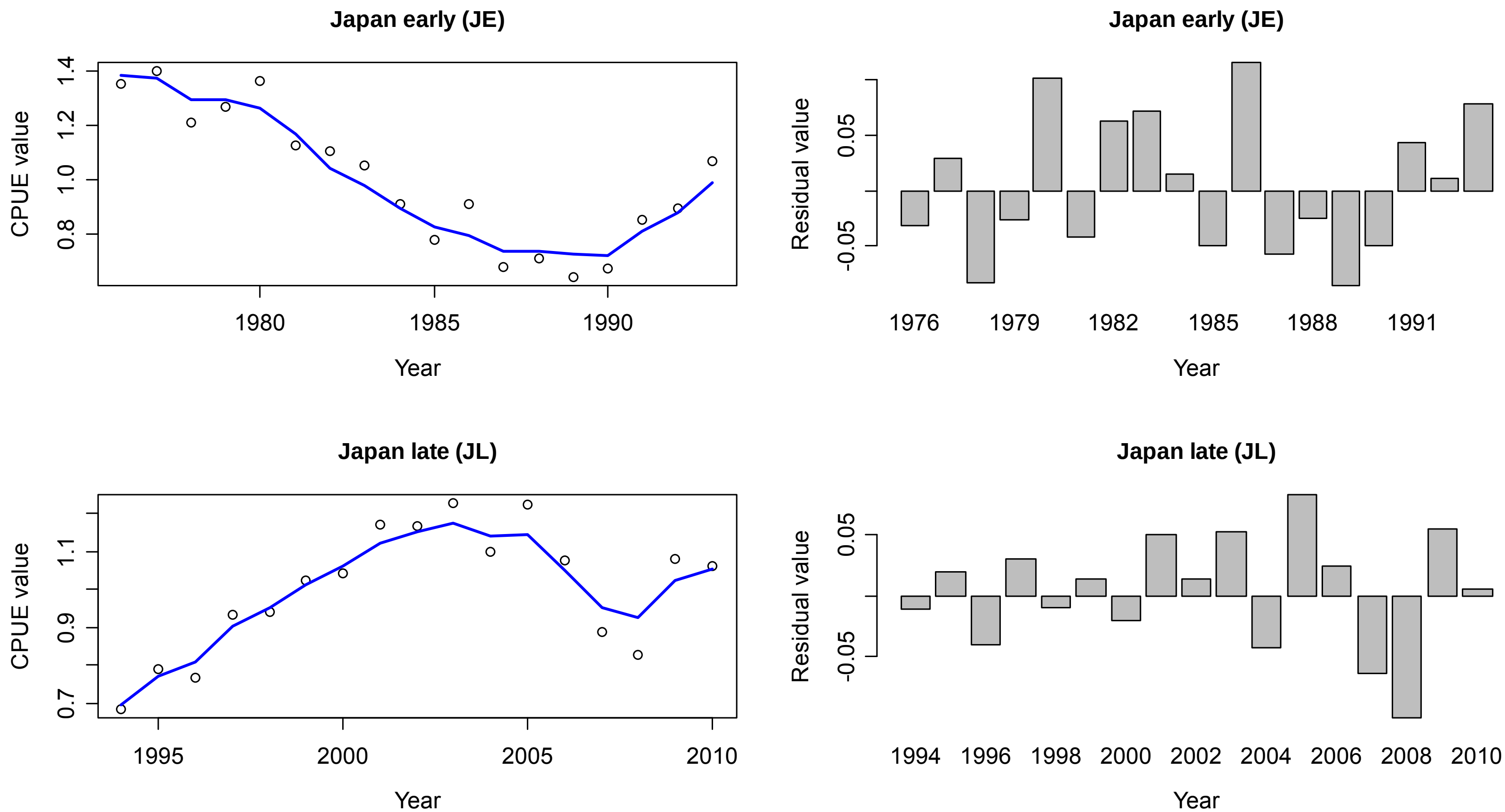

Figure 1A (a) Model fits to the standardized CPUE indices used for **JEJL_Ref** case in the blue shark stock assessment (left panels) and the residual plots (right panels). The blue solid lines are the model predicted values and the open circles are observed values. Top and bottom panels correspond to Japanese longline indices for early (1976-1993) and late (1994-2010) periods, respectively.

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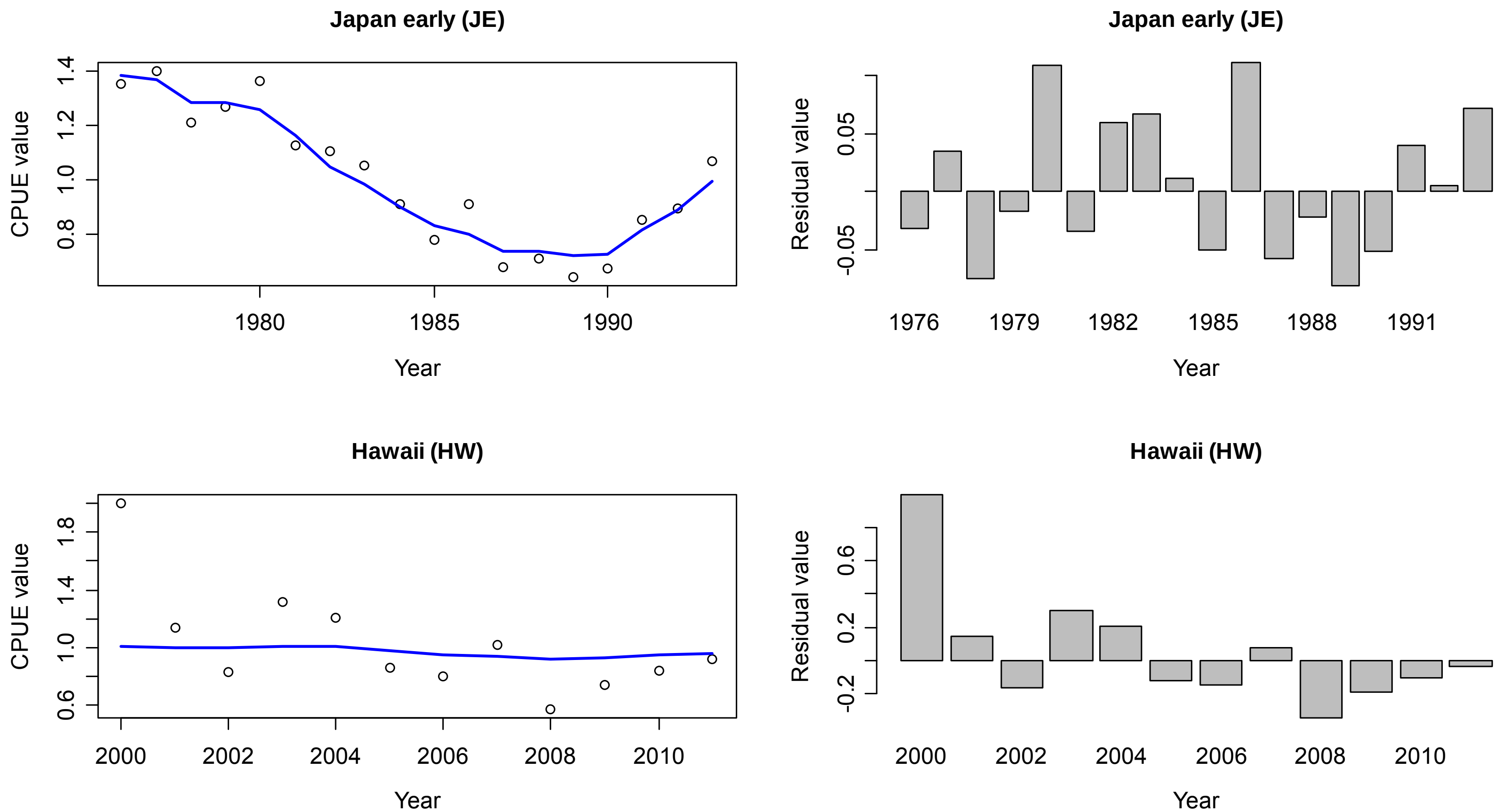

Figure 1A (b) Model fits to the standardized CPUE indices used for **JEHW_Ref** case in the blue shark stock assessment (left panels) and the residual plots (right panels). The blue solid lines are the model predicted values and the open circles are observed values. Top and bottom panels correspond to Japanese longline indices for 1976-1993 and Hawaii longline indices for 2000-2011, respectively.

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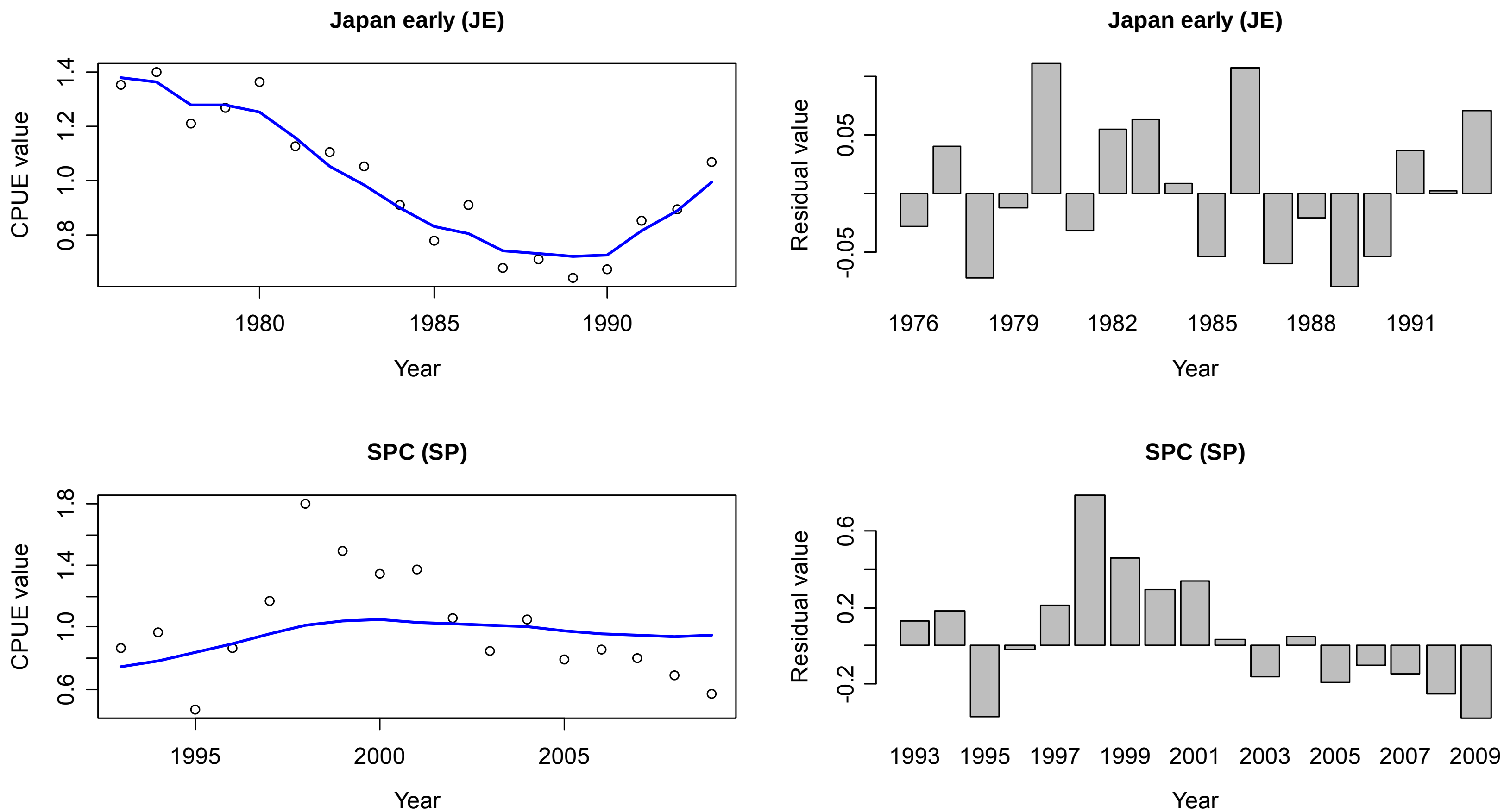

Figure 1A (c) Model fits to the standardized CPUE indices used for **JESP_Ref** case in the blue shark stock assessment (left panels) and the residual plots (right panels). The blue solid lines are the model predicted values and the open circles are observed values. Top and bottom panels correspond to Japanese longline indices for 1976-1993 and SPC longline indices for 1993-2009, respectively.

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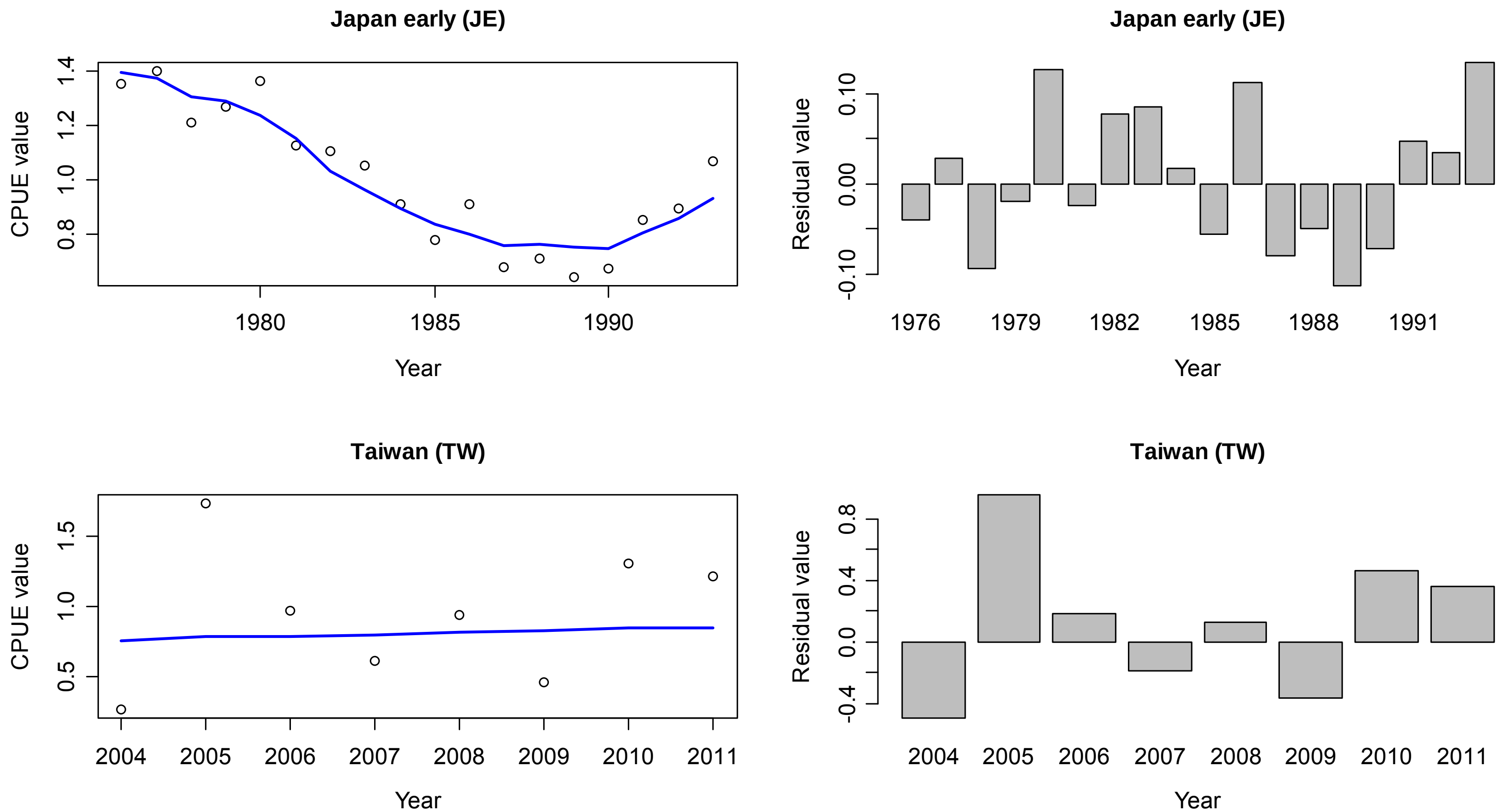

Figure 1A (d) Model fits to the standardized CPUE indices used for **JETW_Ref** case in the blue shark stock assessment (left panels) and the residual plots (right panels). The blue solid lines are the model predicted values and the open circles are observed values. Top and bottom panels correspond to Japanese longline indices for 1976-1993 and Taiwan longline indices for 2004-2011, respectively.

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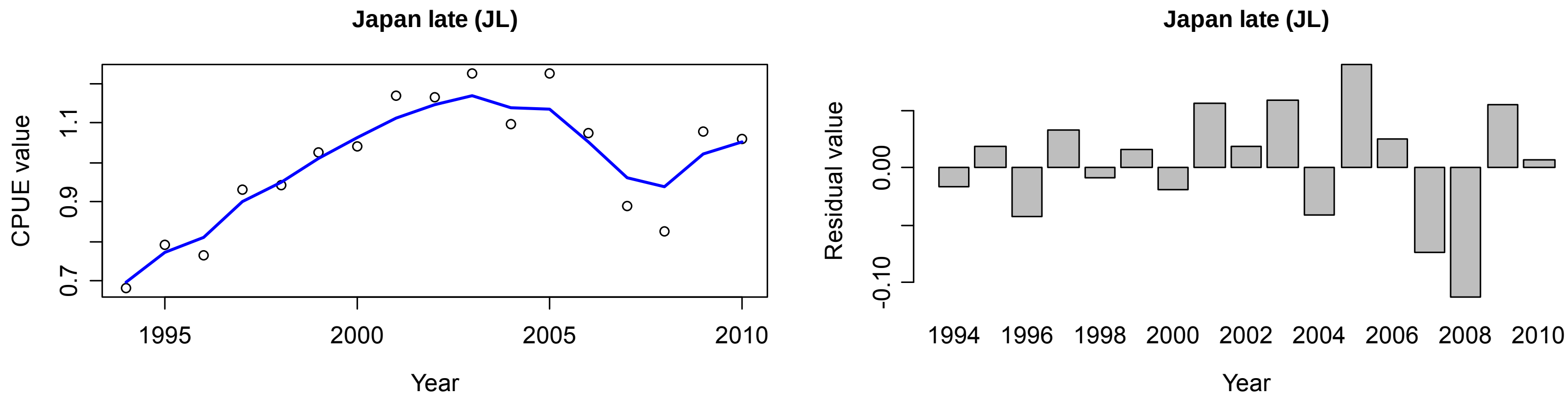

Figure 1A (e) Model fits to the standardized CPUE indices used for **JL_Ref** case in the blue shark stock assessment (left panel) and the residual plots (right panel). The blue solid line is the model prediction and the open circles are observed values. Panels correspond to Japanese longline indices for late (1994-2010) period.

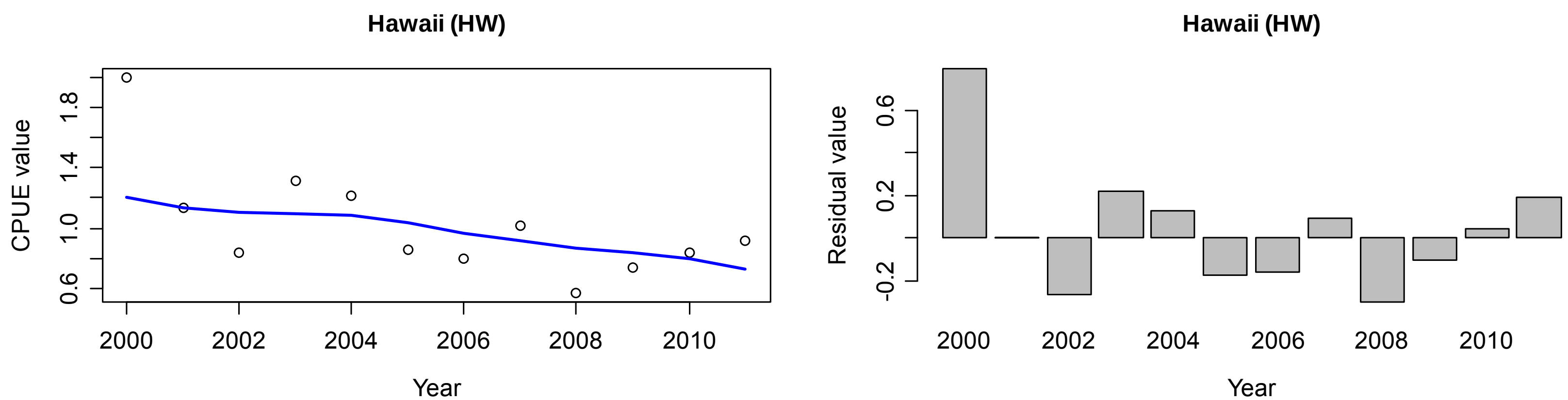

Figure 1A (f) Model fits to the standardized CPUE indices used for **HW_Ref** case in the blue shark stock assessment (left panel) and the residual plots (right panel). The blue solid line is the model prediction and the open circles are observed values. Panels correspond to Hawaii longline indices for 2000-2011.

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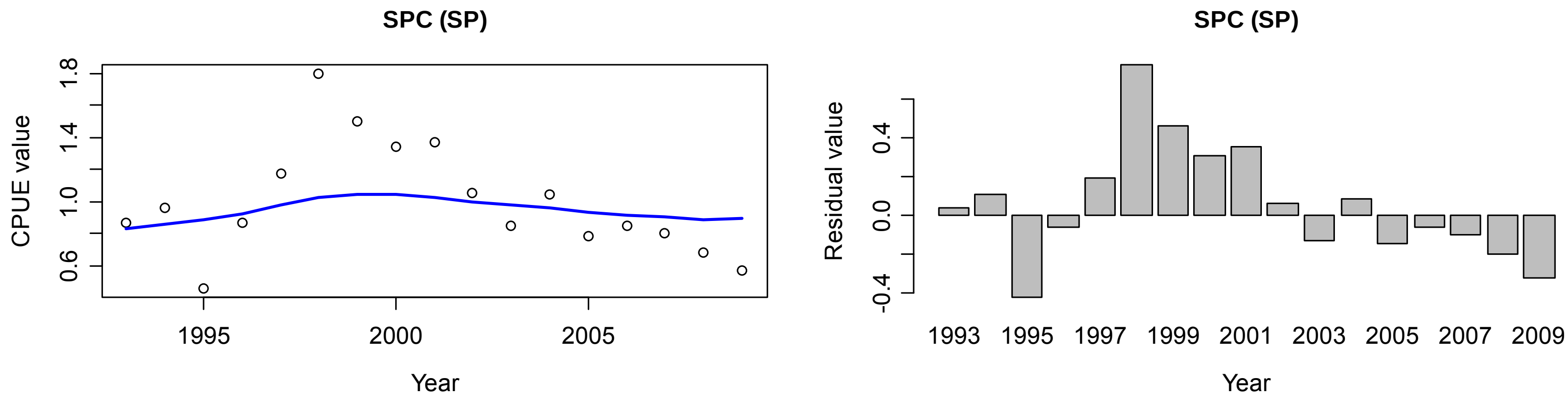

Figure 1A (g) Model fits to the standardized CPUE indices used for **SP_Ref** case in the blue shark stock assessment (left panel) and the residual plots (right panel). The blue solid line is the model prediction and the open circles are observed values. Panels correspond to SPC longline indices for 1993-2009.

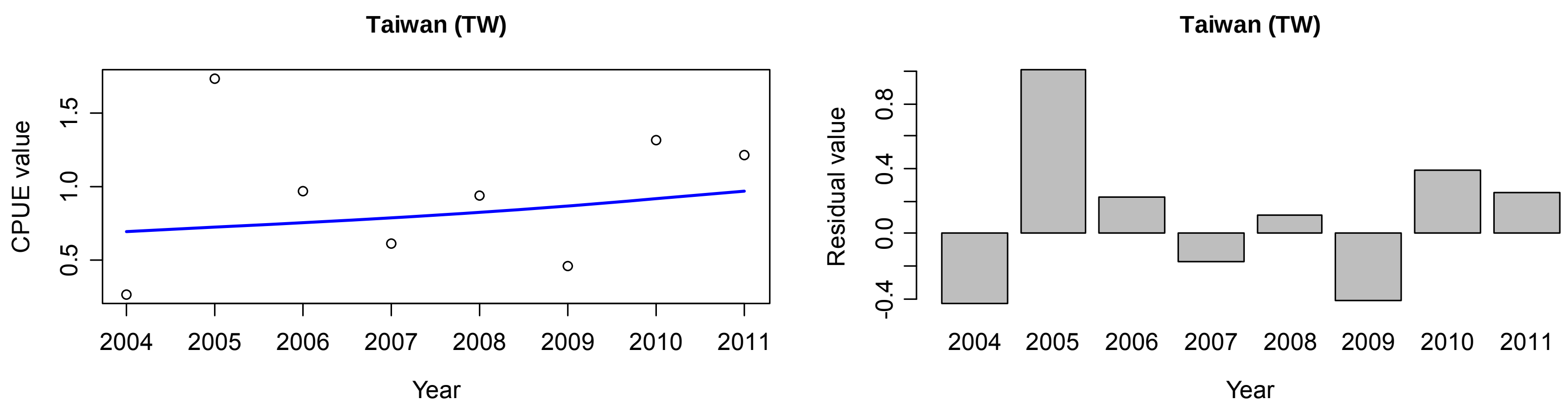

Figure 1A (h) Model fits to the standardized CPUE indices used for **TW_Ref** case in the blue shark stock assessment (left panel) and the residual plots (right panel). The blue solid line is the model prediction and the open circles are observed values. Panels correspond to Taiwan longline indices for 2004-2011.

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