North Pacific Fisheries Commission

1st Meeting of the Technical Working Group on Pacific Saury Stock Assessment REPORT

20-22 February 2017

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North Pacific Fisheries Commission
1st Meeting of the Technical Working Group on Pacific Saury Stock Assessment

20-22 February 2017
Yokohama, Japan

REPORT

Agenda Item 1. Opening of the Meeting

1. The 1st Meeting of the Technical Working Group on Pacific Saury Stock Assessment (TWG PSSA) took place in Yokohama, Japan on 20-22 February 2017 at the National Research Institute of Fisheries Science (NRIFS), Japan Fisheries Research and Education Agency (FRA), and was attended by Members from China, Japan, the Republic of Korea, the Russian Federation, and Chinese Taipei. The meeting was opened by the TWG PSSA leader Dr. Mitsuo Sakai (Japan). The Secretariat then outlined the meeting schedule and procedures.

Agenda Item 2. Selection of Chair and Rapporteur

2. The TWG PSSA leader proceeded with the selection of the Chair and Rapporteur. Dr. Sakai (Japan) was unanimously elected to chair the Workshop. Mr. Alexander Meyer was selected as Rapporteur with the assistance of Dr. Dharmamony Vijai (Japan).

Agenda Item 3. Adoption of Agenda

3. The agenda was adopted without amendment.

Agenda Item 4. Brief Overview of the Framework, Results of the 1st Pacific Saury Stock Assessment Workshop and Intersessional Work, if Any

4. The Chair presented an overview of the PSSA framework, the results of the 1st PSSA Workshop, and the tasks for the current TWG PSSA meeting referring to the PSSA Workshop Final Report and NPFC-2017-TWG PSSA01-WP06.

5. It was noted that suggestions on harvest control rules (HCR) should be included as part of discussions on conducting stock assessment (Agenda Item 8), and that HCR are needed to be able to make recommendations to the Small Scientific Committee on Pacific Saury (SSC PS). The Members agreed on the importance of discussing HCR but noted the difficulty in reaching

an agreement due to the limited time available. The Members therefore agreed to first reach an agreement on the stock assessment, and then begin discussions of HCR, which can be continued by the SSC PS and the Scientific Committee (SC).

Agenda Item 5. Provision of Close-to-Completion Standardized CPUE and Catch for Stock Assessment

6. Japan presented on the standardization of catch per unit fishing effort (CPUE) data of Pacific saury caught by the Japanese stick-held dip net fishery during 1980 to 2015 (NPFC-2017-TWG PSSA01-WP01). Japan used generalized linear models (GLM) and generalized additive models (GAM) to standardize CPUE of Pacific saury, including spatial, temporal, vessel tonnage, and environmental variables. Cross validation analysis showed that GLM tended to be more suitable than GAM.

7. China encouraged Japan to investigate the small confidence intervals.

8. Japan presented biomass and model-standardized stock size index estimation of age-1 Pacific saury based on Japanese fisheries independent survey data (NPFC-2017-TWG PSSA01-WP02 (Rev. 1)). Japan estimated the biomass using area-swept method and the age-1 stock size index using the Delta-lognormal model, based on data from surveys conducted independently by Tohoku National Fisheries Research Institute. Japan highlighted that a combination of fisheries dependent information and fisheries independent data can provide a more reliable stock assessment, by mitigating the biases in the former and the uncertainties in the latter.

9. China questioned the representation of this data set in quantifying stock dynamics and encouraged Japan to continue to investigate issues related to this survey.

10. When asked whether migration of Pacific saury may produce inaccuracies in the data, Japan explained that migration mainly occurred in a south-north direction during the survey period and should therefore not impact the data in a significant way. Chinese Taipei pointed out the possibility that Pacific saury may migrate east-west during the survey period.

11. It was pointed out that covariates, such as survey methods and equipment, should be included in GLM.

12. It was suggested that Japan should study if there is any spatial correlation between survey stations.

13. It was suggested that Japan should quantify the model fit of the first stage of the model.

14. Korea presented its CPUE standardization data for Pacific saury (NPFC-2017-TWG PSSA01-WP03). Korea standardized the CPUE using GLM selected by Akaike Information Criteria (AIC), including year, month, gross register tonnage (grt), and region as variables. Korea found that the trends of the nominal and the standardized CPUE were similar, but the standardized CPUE fluctuated more than the nominal CPUE.

15. It was suggested that Korea should conduct a sensitivity analysis.

16. It was pointed out that the mapping of the Convention Area was incorrect and it was advised that Korea should revise its data using the correct Convention Area boundary. The participants recommended that the Secretariat provide shapefile of the Convention Area to the Members.

17. Chinese Taipei presented its CPUE standardization data for Pacific saury (NPFC-2017-TWG PSSA01-WP04 (Rev.1)). Chinese Taipei standardized CPUE using GLM selected by AIC, including year, month, SST, grt, and area as variables. The standardized CPUE shows a slight increase from 2001 to 2010, a sharp increase from 2010 to 2014, and a slight drop in 2015.

18. Japan noted that Chinese Taipei’s CPUE was lower when sea surface water temperature (SSWT) was in the range of 11-13^{o}C. However, in Japan’s experience, 11-13^{o}C SSWT is an optimal range for catching Pacific saury.

19. It was suggested that Chinese Taipei consider using GAM, in light of the non-linear relationship between SSWT and CPUE. Chinese Taipei explained that it decided to use GLM based on the good results achieved by Japan using GLM, but that it would also consider using GAM.

20. Russia presented its CPUE standardization for Pacific saury (NPFC-2017-TWG PSSA01-WP05). Russia standardized CPUE data using GLM selected by AIC, including year, month, year-month interaction, and identified vessels as variables.

21. It was suggested that Russia should examine the relationship between SST and CPUE and whether there was a time lag between the two.

22. Russia presented simulations comparing the performance of different models for estimating total abundance. Russia concluded that when the abundance of fish was not strictly connected with constant geographical features, including positional coordinates as a variable may lead to

misleading results. It was suggested that fishing behavior may need to be improved in the simulation.

23. China presented preliminary results from its CPUE standardization for Pacific saury. China standardized CPUE data using GLM and GAM, including date, fishing position, catch, SST, company, fishing vessel as variables.

24. Following the presentations, the Members held a general discussion. The key points of the discussion were as follows:
    a. Members should conduct more model simulations, such as those presented by Russia, to improve our understanding of the performance of CPUE standardizations;
    b. The difference in quality and measures in Members' standardizations makes it difficult to decide which CPUEs to include in a base case scenario or what weight to attribute to each CPUE. The confidence interval and coefficient of variation (CV) of each Members' CPUE, and how they are calculated, need to be clarified.

Agenda Item 6. Development of Base Case Scenario for Stock Assessment

25. China presented its efforts for stock assessment (NPFC-2017-TWG PSSA01-WP08). Eight scenarios with different combinations of data and priors were considered. China concluded that in the Convention Area Pacific saury was not overfished and overfishing is not occurring and that Pacific saury was not being fully exploited. In addition, China highlighted the importance of considering all information from different fishing grounds.

26. Chinese Taipei presented its efforts for stock assessment (NPFC-2017-TWG PSSA01-WP09). Four scenarios with different combinations of data and model configurations were considered. Chinese Taipei concluded that the Northwest Pacific saury was not overfished and overfishing is not occurring.

27. Japan presented its efforts for stock assessment (NPFC-2017-TWG PSSA01-WP07). Forty scenarios with different combinations of different data weighting, different production functions, hyperstability/hyperdepletion, and different prior distributions were explored. Japan concluded that the Northwest Pacific saury may not be overfished and overfishing may not be occurring.

28. The Working Group also discussed about plausible prior distributions for model parameters, which can be found in Annex D.

29. The Working Group also had a lengthy discussion of the caveats associated with using Japan's survey data because the survey q tended to have a value larger than 1, which suggests that the survey biomass may be overestimated due to possible herding by the trawl gear or extrapolating fish abundance to the unfished regions with less abundant Pacific saury.

30. The Working Group also discussed about the convergence issue and the numerical stability in the estimation of the posterior distribution.

31. The Working Group noted the uncertainties associated with the scale of the stock biomass estimate, which may influence the reliability of the absolute biomass estimate.

32. Following the presentations, the Working Group held a general discussion and further analyses. The Working Group noted that there remained uncertainty surrounding the catchability coefficient (q) of the Japanese survey data and therefore developed three base case scenarios, each with a different q prior, as outlined in the stock assessment report, to be completed by 15 March 2017.

33. The Working Group had a lengthy discussion to identify plausible base case scenarios. The Working Group recommended the following three scenarios be considered as the base case scenarios:
    a. Including four sets of CPUEs and Japan survey data with survey catchability (q) prior defined from 0 to 1;
    b. Including four sets of CPUEs and Japan survey data with survey catchability (q) prior being fixed at 1;
    c. Including four sets of CPUEs and Japan survey data with survey catchability (q) prior being defined from 0 to larger than 1.

Agenda Item 7. Scenarios for Sensitivity Analysis

34. The Members agreed to conduct the following analyses and include the results in the stock assessment report, to be completed by 15 March 2017:
    a. Analysis of the results in which the Japanese survey data are not included;
    b. Comparison of the results across the different model configurations of China, Japan, and Chinese Taipei for the three base case scenarios and the scenario in which the Japanese survey data are not included;
    c. Analysis of the sensitivity to the mean value of r for the lognormal prior distribution in Chinese Taipei's model.

Agenda Item 8. Conduction of Pacific Saury Stock Assessment for Base Case Scenario and Sensitivity Scenarios

Agenda Item 8.1 Stock biomass and fishing mortality and associated uncertainties

Agenda Item 8.2 Biological reference points

Agenda Item 8.3 Risk analyses of alternative catch levels

35. The Members agreed to complete the Pacific saury stock assessment for base case scenario and sensitivity scenarios and include the results in the stock assessment report, to be completed by 15 March 2017.

Agenda Item 9. How to Present the Stock Assessment Results for the SSC PS and SC

36. The Members held a discussion on how to present the stock assessment results for the SSC PS and the SC. The Working Group developed a common template for the stock assessment report and agreed to complete the report by 15 March 2017.

Agenda Item 10. Other Matters

37. The Working Group agreed to recommend initiating discussions at the upcoming SSC PS meeting and SC meeting.

Agenda Item 11. Adoption of the Report

38. The report of the TWG PSSA was adopted by consensus.

Agenda Item 12. Close of the Meeting

39. The TWG PSSA closed at 18:55 on 22 February 2017.

Annexes

Annex A – Agenda

Annex B – List of Documents

Annex C – Participants List

Annex D – Pacific Saury Stock Assessment

*Any products of this working group, including presentations and reports, do not affect the legal position on the territorial rights of Members.

Annex A

NPFC-2017-TWG PSSA01-MIP02

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Agenda

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Annex B

NPFC-2017-TWG PSSA01-MIP05

North Pacific Fisheries Commission

1st Meeting of the Technical Working Group on Pacific Saury Stock Assessment

20-22 February 2017

Yokohama, Japan

PROVISIONAL LIST OF DOCUMENTS

MEETING INFORMATION PAPERS

Symbol	Title
NPFC-2017-TWG PSSA01-MIP01	Meeting Information
NPFC-2017-TWG PSSA01-MIP02	Provisional Agenda
NPFC-2017-TWG PSSA01-MIP03 (Rev. 1)	Annotated Provisional Agenda
NPFC-2017-TWG PSSA01-MIP04 (Rev. 2)	Indicative Schedule
NPFC-2017-TWG PSSA01-MIP05 (Rev. 1)	Provisional List of Documents

REFERENCE DOCUMENTS

Title
Convention on the Conservation and Management of High Seas Fisheries Resources in the North Pacific Ocean
NPFC Administrative Documents

WORKING PAPERS

Symbol	Title
NPFC-2017-TWG PSSA01-WP01	Standardization of CPUE data of Pacific saury (*Cololabis saira*) caught by the Japanese stick-held dip net fishery during 1980 to 2015
NPFC-2017-TWG PSSA01-WP02 (Rev. 1)	Biomass and stock size index estimation of age-1 Pacific saury based on fisheries independent survey data by Japan
NPFC-2017-TWG PSSA01-WP03	Summary of CPUE standardization - Korea
NPFC-2017-TWG PSSA01-WP04 (Rev. 1)	Summary of CPUE standardization report from Chinese Taipei
NPFC-2017-TWG PSSA01-WP05	CPUE standardization for the Pacific saury in the Russian EEZ in the Northwest Pacific Ocean
NPFC-2017-TWG PSSA01-WP06	Framework for Pacific saury stock assessment
NPFC-2017-TWG PSSA01-WP07	Stock assessment of Pacific saury in the North Pacific Ocean for 2016 by using state-space biomass dynamics model - Japan
NPFC-2017-TWG PSSA01-WP08	Pacific saury (*Cololabis saira*) stock assessment summary in 2017 - China
NPFC-2017-TWG PSSA01-WP09	Stock assessment of Pacific saury (*Cololabis saira*) in the Western North Pacific Ocean - Chinese Taipei

INFORMATION PAPERS (IP)

Symbol	Title
NPFC-2016-WS PSSA01-Final Report	Final report of the Pacific Saury Stock Assessment Workshop
NPFC-2017-TWG PSSA01-IP01	Check list for CPUE standardization protocol
NPFC-2017-TWG PSSA01-IP02	Examples of plots and tables for CPUE standardization protocol

NGO and Others

Symbol	Organization & Title

Annex C

1st Meeting of the Technical Working Group on Pacific Saury Stock Assessment

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Annex D

PACIFIC SAURY STOCK ASSESSMENT

1. Executive Summary

This report provides an analysis and evaluation of the current status of Pacific saury (*Cololabis saira*) stock in the North Pacific Ocean through the stock assessment procedures by employing the Bayesian state-space biomass dynamic model. The saury is widely distributed from the subarctic to the subtropical regions of the North Pacific Ocean, while their fishing grounds are limited to the west of 165 ^{0}E. However, the main fishing grounds differ among Members (China, Japan, Korea, Russia and Chinese Taipei,). For example, the Convention Area is the main fishing ground for China, Korea and Chinese Taipei while Japan and Russia fish mainly in their own EEZs. This report summarizes the results of the meeting of the Technical Working Group for Pacific saury stock assessment (TWG PSSA), held at Yokohama from 20-22 February 2017 and further analyses made by TWG PSSA

TWG-PSSA conducted stock assessment analysis by employing the Bayesian state-space biomass dynamic models. The models account for process and model errors in addition to observation errors in the biomass indices such as standardized CPUE series for commercial fisheries by Members as well as fishery-independent survey by Japan. Based on the TWG PSSA recommendations (Paragraph 33), following three base-case scenarios differing in survey catchability (*q*) of the Japanese survey biomass index were explored: 1) including CPUEs and *q* prior defined from 0 to 1, 2) including CPUEs and *q* prior fixed at 1, 3) including CPUEs and *q* prior defined from 0 to larger than 1 (free *q*). A sensitivity analysis was conducted without using the Japanese survey biomass index (excluding survey *q*).

Comparison of estimated parameters by China, Japan and Chinese Taipei are shown in the Table 8-1. Mean MSY (x10,000 mt) evaluated by China, Japan and Chinese Taipei ranged from 50.65 to 59.35, 51.4 to 62.2, and 54.23 to 60.67 respectively. For the base-case scenario-3 (S3, free *q*), estimation of q value was above 1. B_{2016}/B_{MSY} (>1) and F_{2015}/F_{MSY} (<1) values calculated by all members showed a healthy trend.

Based on the model results, 1) China concluded that the exploitable biomass was above B_{MSY} and the current status of stock indicates that the Pacific saury was not overfished and is not experiencing overfishing. 2) Chinese-Taipei concluded that based on the current stock status Pacific saury did not appear to be overfished and is not experiencing overfishing. 3) Japan results shows that the biomass level is currently above the level of MSY for any scenarios and concluded that the continuation of the current catch level may not cause severe decline in the population size in the next decade, but recommended a status quo level or reduction of catch to keep the population size above the MSY level.

Table 8-1 Summary of the estimated key parameters and management quantities by China, Japan, and Chinese Taipei, based on three scenarios.

		China		Japan		Chinese Taipei	
Scenarios	Parameters	mean	median	mean	median	mean	median
S1 (q 0-1)	K (10,000 mt)	790.26	704.00	579.4	511.2	462.80	444
	r	1.03	0.77	0.965	0.704	0.73	0.61
	Shape (s, Z, M)	0.57	0.32	0.729	0.569	0.99	0.79
	B_{1980}/K	0.14	0.32	0.185	0.175	0.19	0.18
	MSY (10,000 mt)	59.35	57.07	62.2	59.5	60.67	58.34
	F_{MSY}	0.19	0.18	0.251	0.248	0.33	0.32
	B_{MSY} (10,000 mt)	346.66	310.1	265.5	237.1	224.8	216.70
	B_{1980} (10,000 mt)	105.98	97.91	102.7	91.8	88.38	82.92
	B_{2015} (10,000 mt)	356.63	333.1	364.9	328.5	307	292.60
	F_{1980}	0.25	0.24	0.269	0.259	0.36	0.34
	F_{2015}	0.11	0.11	0.108	0.110	0.13	0.13
	q5 (Biomass)	0.77	0.79	0.779	0.815	0.82	0.85
	B_{2016}/K	0.51	0.52	0.702	0.680	0.7	0.7
	B_{2016}/B_{MSY}	1.16	1.18	1.529	1.463	1.44	1.44
	F_{2015}/F_{MSY}	0.64	0.58	0.522	0.433	0.43	0.4
S2 (q=1)	K (10,000 mt)	615.85	527.80	466.6	414.3	390.8	381
	r	1.13	0.89	1.022	0.765	0.76	0.65
	Shape (s, Z, M)	0.56	0.33	0.74	0.49	1.08	0.85
	B_{1980}/K	0.14	0.14	0.173	0.167	0.19	0.18
	MSY (10,000 mt)	54.48	52.91	56.4	54.9	57.19	55.05
	F_{MSY}	0.22	0.22	0.281	0.279	0.36	0.35
	B_{MSY} (10,000 mt)	268.16	237.40	213.5	197.6	192.30	189.10
	B_{1980} (10,000 mt)	78.66	75.43	75.4	72.3	72.39	69.77
	B_{2015} (10,000 mt)	261.56	260.00	264.2	263.5	246.50	243.70
	F_{1980}	0.32	0.32	0.341	0.329	0.45	0.42
	F_{2015}	0.14	0.14	0.139	0.137	0.16	0.16
	q5 (Biomass)	1	1	1	1	1	1
	B_{2016}/K	0.5	0.52	0.657	0.641	0.68	0.68
	B_{2016}/B_{MSY}	1.13	1.16	1.421	1.375	1.38	1.38
	F_{2015}/F_{MSY}	0.70	0.64	0.543	0.496	0.47	0.45
S3 (free q)	K (10,000 mt)	457.96	409.8	310.70	267.80	223.8	200.1
	r	1.28	1.13	1.212	0.993	0.97	0.9
	Shape (s, Z, M)	0.56	0.36	0.827	0.676	0.17	1.68
	B_{1980}/K	0.14	0.14	0.164	0.158	0.18	0.18
	MSY (10,000 mt)	50.65	48.66	51.40	49.70	54.23	53.04
	F_{MSY}	0.29	0.28	0.394	0.390	1	0.69
	B_{MSY} (10,000 mt)	200.97	178.80	144.30	125.50	117.8	108.80
	B_{1980} (10,000 mt)	63.39	55.79	49.30	42.90	40.98	34.95
	B_{2015} (10,000 mt)	210.86	189.20	169.80	147.90	131.4	113.70
	F_{1980}	0.46	0.43	0.571	0.555	2.83	1.14
	F_{2015}	0.21	0.19	0.244	0.244	0.59	0.37
	q5 (Biomass)	1.46	1.37	1.774	1.802	2.46	2.16
	B_{2016}/K	0.51	0.51	0.623	0.604	0.66	0.67
	B_{2016}/B_{MSY}	1.15	1.16	1.317	1.266	1.22	1.22
	F_{2015}/F_{MSY}	0.72	0.69	0.640	0.610	0.58	0.53
Sensitivity test S4 (no biomass)	K (10,000 mt)	536.15	454.75	375.7	303.3	216	189.2
	r	1.25	1.07	1.143	0.939	0.96	0.89
	Shape (s, Z, M)	0.56	0.35	0.823	0.673	1.86	1.87
	B_{1980}/K	0.14	0.31	0.167	0.16	0.18	0.18
	MSY (10,000 mt)	52.92	50.16	54.5	51.8	55.64	54.26
	F_{MSY}	0.27	0.26	0.365	0.359	1.07	0.76
	B_{MSY} (10,000 mt)	234.01	199.45	173.6	14.3	116.2	106.5
	B_{1980} (10,000 mt)	70.52	61.14	60.3	48.4	39.57	33.63
	B_{2015} (10,000 mt)	244.98	217.90	217.1	174.4	132	113.3
	F_{1980}	0.43	0.39	0.51	0.492	2.99	1.23
	F_{2015}	0.18	0.17	0.208	0.207	0.59	0.38
	q5 (Biomass)	NA	NA	NA	NA	NA	NA
	B_{2016}/K	0.52	0.53	0.654	0.637	0.69	0.7
	B_{2016}/B_{MSY}	1.17	1.19	1.384	1.34	1.25	1.26
	F_{2015}/F_{MSY}	0.69	0.65	0.59	0.562	0.54	0.5

Contents

2. Introduction

Based on general assumption that there is one management stock in the Western North Pacific Ocean (WNPO), we present here the Pacific saury stock assessment in the WNPO. We applied a Bayesian statistical framework to estimate parameters of production models to assess the saury stock in the WNPO area using catch and effort from 1950 to 2015. The Bayesian method provided direct estimates of parameter uncertainty that were straightforward to interpret and were appropriate for risk analyses. The objectives of this study are to conduct a benchmark stock assessment for the Pacific saury in the WNPO; to develop Bayesian posterior distributions for quantities of management interest using the Markov chain Monte Carlo (MCMC) algorithm; to examine the sensitivity of the results of the assessment to changes in its prior assumptions; and to conduct a retrospective analysis of stock assessment estimates.

1) Distribution

Pacific saury (*Cololabis saira* Brevoort, 1856) has a wide distribution extending in the subartic and subtropical areas of the North Pacific Ocean from inshore waters of Japan and Kuril Islands eastward to Gulf of Alaska and southward to Mexico. Pacific saury is a commercially important fish in the Western North Pacific Ocean (Parin, 1968; Hubbs and Wisner,1980).

2) Migration

Saury migrates extensively between the feeding grounds in the Oyashio waters around Hokkaido and the Kuril Islands in summer and the spawning areas in the Kuroshio waters off southern Japan in winter (Fukushima, 1979; Kosaka, 2000). Pacific saury migrate not only in east-west directions, but also the north and south directions. The fishes distributed on the east of 160E migrate eastward in fall and reach waters off Japan after October in recent years (Suyama et al.2012).

3) Population structure

Genetic study suggested that no genetic structuring groups in the Pacific saury population based on 141 individuals collected from five distant locales (East China Sea, Sea of Okhotsk, northwest Pacific, central North Pacific, and northeast Pacific) (Chow et al., 2009). It is important to note that there should be some distinction within the stock structure to take account of some regional differences as there are some regional important fisheries operating in some areas (i.e., WNPO).

4) Spawning season and grounds

The spawning season of the Pacific saury is relatively long, beginning in September and ending in June of the following year (Watanabe and Lo, 1989). The Pacific saury spawns over a vast area from the Japanese coastal waters to eastern offshore waters (Baitaliuk, 2013); the main spawning grounds are considered to be located in the Kuroshio-Oyashio transition region in fall and spring and in the Kuroshio waters and the Kuroshio Extension waters in winter (Watanabe and Lo, 1989).

5) Food and feeding

The larvae of the Pacific saury prey on the nauplii of copepods and other small sized zooplankton. As they grow, they begin to prey on larger zooplankton such as krill (Odate 1977). The Pacific saury is preyed upon by large fish ranked higher in the food chain, such as *Thunnus alalunga* (Nihira 1988) and coho salmon, *Oncorhynchus kisutsh* (Sato and Hirakawa, 1976) as well as by animals such as minke whale *Balaenoptera acutorostrata* (Konishi *et al*. 2009) and sea birds (Ogi, 1984).

6) Age and growth

Based on analysis of daily increments in otoliths after hatching the fish reach approximately 20 cm in knob length (distance from the tip of lower jaw to the posterior end of the muscular knob at the base of a caudal peduncle; hereafter as body length) in 6 or 7 months after hatching (Watanabe et al. 1988, Suyama et al.,1992) with some variation in growth rate depending on the hatch month during this long spawning season (Kurita et al., 2004) or geographical differences (Suyama et al. 2012b). The maximum lifespan is 2 years (Suyama et al. 2006). The age 1 fish grow to over 27 cm in body length by June and July when the research vessel surveys are conducted and reach over 29 cm in the fishing season between August and December (Suyama et al. 2006).

7) Reproduction

General minimum biological size of Pacific saury is about 25 cm in the field (Hatanaka 1956) or rearing experiments (Nakaya et al. 2010), although in very rare cases, saury may spawn at 22 cm length (Sugama, 1957; Hotta, 1960). Under rearing experiments, Pacific saury starts spawning 8 month after hatching, and it continues for about 3 months (Suyama et al., 2016). Batch fecundity is about 1,000 to 3,000 (Kosaka, 2000).

3. Fishery

1) History of the Pacific saury fishery

Pacific saury fisheries in Japan have a long history as a local coastal fishery since 1544, but the industrialized fishery was developed in the early 1900s with motorization of fishing boats (Nakagami 2013). Stick-held dip net fishery using fishing lights was introduced in 1939 and the fishery has been further developed to date. The stick-held dip net fishery is a main fishing method for Pacific saury in Japan, harvesting 99% of the catch by the fishery. The Korea's saury fisheries was operated by gillnet since the late 1950s in Tsushima Warm Current region and by stick-held dip net since the early 1950s in the Kuroshio-Oyashio Current region (Gong and Suh 2013). Russian saury fishery by stick-held dip net was developed in the 1970s. Chinese Taipei started saury fishery in 1975 when the fishery had the first record of commercial catch (NPFC01-2016-AR Chinese Taipei Rev 2). China has been developing the saury fishery in the high seas since 2012 (NPFC-2016-WS PSSA01-WP01). In the eastern Pacific, small amounts of saury catch (224 kg) were recorded as incidental catch by Canadian commercial fisheries from 1997 to 2013 (Wade and Curtis 2015).

While Japanese and Russian vessels operate mainly within their EEZ, Chinese Taipei, Korean and Chinese vessels operate mainly in the high seas of the North Pacific.

2) Status of NPFC Members' fisheries

(1) China

(i) General fishing statistics:

Fishing days, number of vessels and annual catch amount (mt) are shown in Table 3-1.

Table 3-1 General fishing statistics of saury fishery of China.

Year	Fishing Gear	Numbers of fishing vessels	Fishing days	Catch Amount (MT)
2015	Stick-held dip net	42	3,816	48502.748
2014	Stick-held dip net	44	6,435	76129.44
2013	Stick-held dip net	19	2187	23191.3
2012	Stick-held dip net	2	274	2014.00

(ii) Vessel size:

The GT of vessels ranged from 971 MT to 1687 MT, most of them ranged from 1400MT to 1600MT.

(iii) Main fishing ground and season:

Fishery starts from June and finishes in November. Main fishing ground is shown in Figure 3-1.

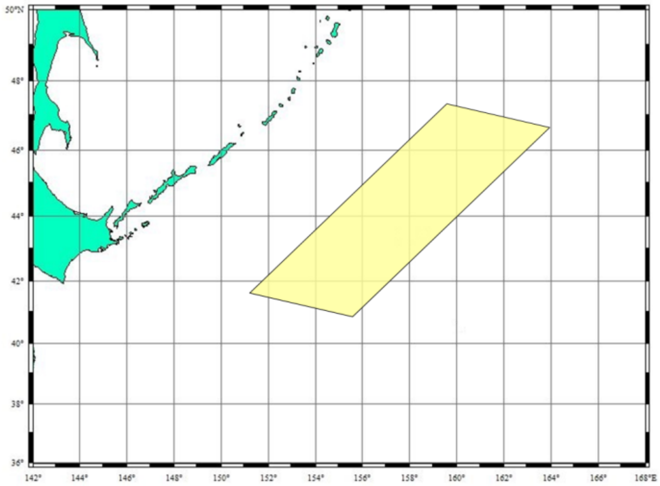


Figure 3-1. Main fishing ground of saury fishery of China.

(iv) Main fishing port:
Main fishing ports for saury fishery are Yantai, Xiamen, and Fuzhou.

(v) Utilization of products: Main utilization is for food.

(vi) Economic impacts: Not available.

(2) Japan

(i) General fishing statistics:

Fishing days, number of vessels and annual catch amount (mt) are shown in Table 3-2.

Table 3-2 General fishing statistics of saury fishery of Japan

Year	Fishing Gear	Numbers of fishing vessels	Fishing days	Catch Amount (MT)	Other Fishing Gears	Catch Amount of Others (MT)
2015	Stick-held dip net	208	9473	112264	others*	Not available
2014	Stick-held dip net	210	10116	226210	others*	1310
2013	Stick-held dip net	217	9099	155835	others*	1454
2012	Stick-held dip net	218	10737	218654	others*	2815
2011	Stick-held dip net	214	8023	213942	others*	1411
2010	Stick-held dip net	236	12700	205798	others*	1691
2009	Stick-held dip net	239	11281	306609	others*	4134
2008	Stick-held dip net	239	10531	346990	others*	7737
2007	Stick-held dip net	247	10910	290593	others*	5930
2006	Stick-held dip net	258	10182	239239	others*	5346
2005	Stick-held dip net	288	10151	229970	others*	4481
2004	Stick-held dip net	314	11963	199208	others*	5163
2003	Stick-held dip net	324	15700	255518	others*	9283
2002	Stick-held dip net	370	21255	199111	others*	6171
2001	Stick-held dip net	379	17212	263882	others*	5916
2000	Stick-held dip net	394	24931	210656	others*	5814

* others: Gill nets, set-net and by-catch

(ii) Main fishing ground and season:

The fishing grounds were mainly concentrated within Japanese EEZ in the Pacific Ocean, north of latitude 34^{o}54’06” N. The fishing season begins in August in the area between the eastern coast of Hokkaido and the coast of Kuril Islands, then vessels move southwards to the area off the coasts of Aomori, Iwate, and Miyagi prefectures from late September to early October, and to the areas off the coasts of Fukushima, Ibaraki and Chiba prefectures in the late fishing season from November to December (Figure 3-2).

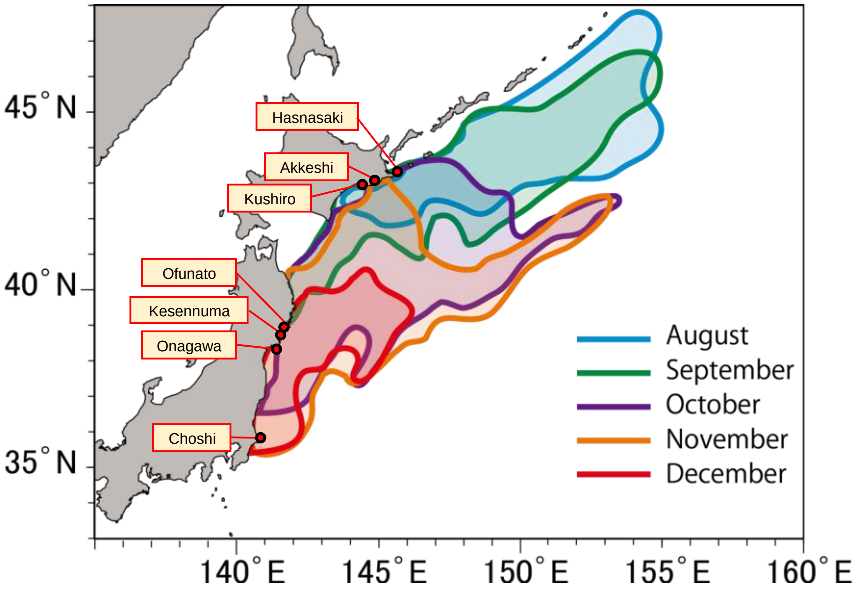


Figure 3-2. Monthly changes of the fishing grounds for Japanese Pacific saury stick-held dip nets fisheries which were licensed by the MAFF. This figure is based on data from 2006 to 2015. Main fishing ports are indicated.

Pacific saury stick-held dip net fishery which is licensed by the Minister of Agriculture, Forestry and Fisheries (MAFF), Japan is permitted from August to December. Additionally, albeit on a small scale, drift net Pacific saury fishery is conducted in July in waters off the coast of eastern Hokkaido, and small size of stick-held dip net fishery is conducted in the period between October and February of the following year off Mie and Wakayama prefectures, licensed by the prefectural governor. The Pacific saury is also caught in the set-net fishery in many areas including the Sea of Japan.

(iii) Vessel size (GRT):

The sizes of the Pacific saury stick-held dip net fishery vessels licensed by the Ministry of Agriculture, Forestry and Fisheries (MAFF) range from 10 to 200 gross registered tonnage (GRT). The major size of the fishing vessel has separated into two groups: large (more than 100 GT) and small (less than 50 GRT) in recent years. In 2015, a total of 151 (<50 GRT: 96, >100 GRT: 55) Pacific saury fishing vessels were in operation (Figure 3-3 and 3-4).

Figure 3-3. The smallest (Left; 19 gross tons) and largest (Right; 199 gross tons) Pacific saury stick-held dip net fishery vessels licensed by the Ministry of Agriculture, Forestry and Fisheries.

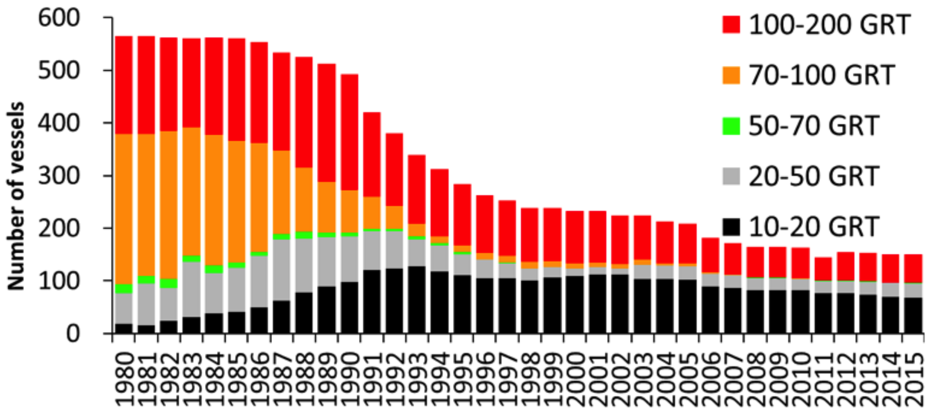


Figure 3-4. Number of the Pacific saury stick-held dip net fishery vessels by size in Japan between 1980 and 2015.

(iv) Main fishing port:

Fishing ports for saury fishery in Japan are Hanasaki, Akkeshi, Kushirod, Ofunato, Onagawa, Kesennuma and Choshi (Figure 3-2). Landing in these 7 fishing ports comprised 88 and 91 % of the total landing for Pacific saury in 2014 and 2015, respectively (Figure 3-5).

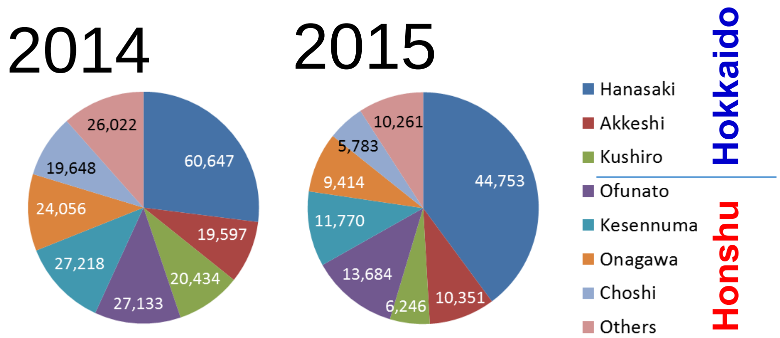


Figure 3-5. Landing (MT) in main fishing ports in 2014 and 2015.

(v) Utilization of products:

The most of the Pacific saury caught by Japanese fishing vessels are consumed domestically. About 40% (27.2 to 48.2% in 2003-2011) of fish are consumed fresh such as baked fish or sashimi. These are mainly age-1 fish. Other about 40% (33.3 to 53.4%) of fish are used in processed food such as cans, dried fish, salted fish or grilled fish with sweet soya sauce. The rest of fish (about 20% from 15.9 to 27.4%) are used as bait in fisheries, food for aquaculture or fertilizer (Figure 3-6).

(vi) Economic impacts:

The total landing amounts of Pacific saury are about 16 to 26 billion yen (155 to 252 million USD), and account for 4.0 to 8.1% of total Japan’s fish production. There are processing factories and freeze stores near the port dealing mainly on Pacific saury. These factories support regional economy and employments.

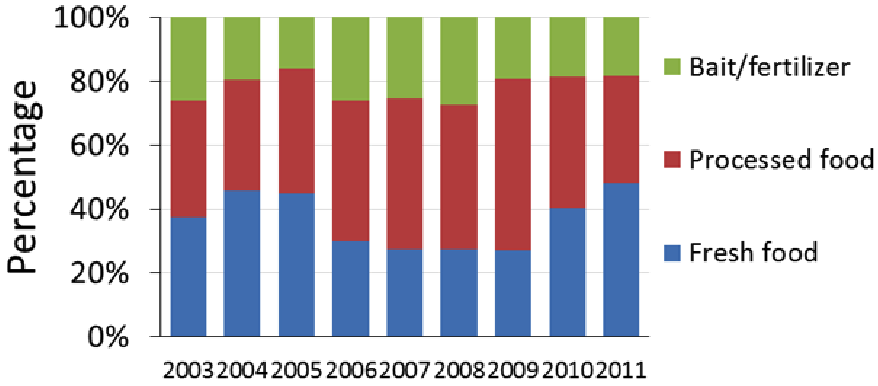


Figure 3-6. Utilization of Pacific saury by Japan from 2003 to 2011. Data based on MAFF statistics.

(3) Korea

(i) General fishing statistics:

Pacific saury (*Cololabis saira*) is the target species harvested by Korean distant water stick-held dip net fishery in the Northwest Pacific Ocean. It was in the 1960s when Korean research survey vessels from National Institute of Fisheries Science (NIFS, previously named NFRDI) have commenced saury fishing using stick-held dip net, while three commercial fishing vessels started fishing in the area in 1985. The largest catch was over 50 thousand tons in 1997. The lowest catch was 11 thousand tons in 2015 (Figure 3-7).

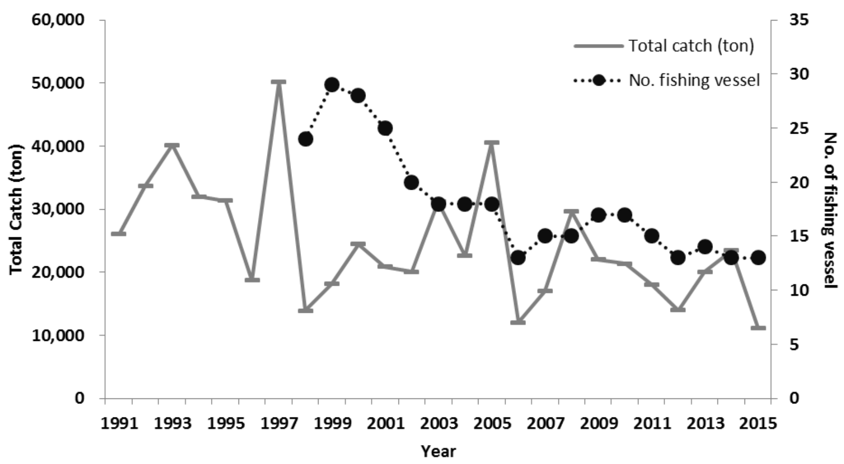


Figure 3-7. Total catch by Korean vessels and number of fishing vessels.

(ii) Main fishing ground and season:

Fishing season in Korea lasts from May to December, and major catch occurs in September and October (Figure 3-9).

(iii) Vessel size (GT):

The number of fishing vessels reached 29 in 1999 and has been decreasing thereafter.

The sizes of fishing vessels vary from 240 tons to 1037 tons. The average size of vessel was relatively stable until 2012, but increased in the last three years (Fig 3-10).

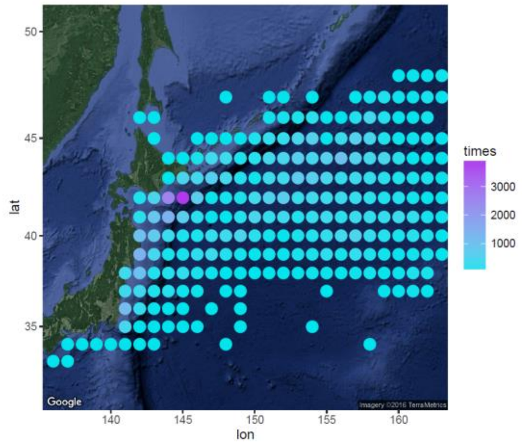


Figure 3-8. Accumulated fishing position over 30 years of Korean saury fishery.

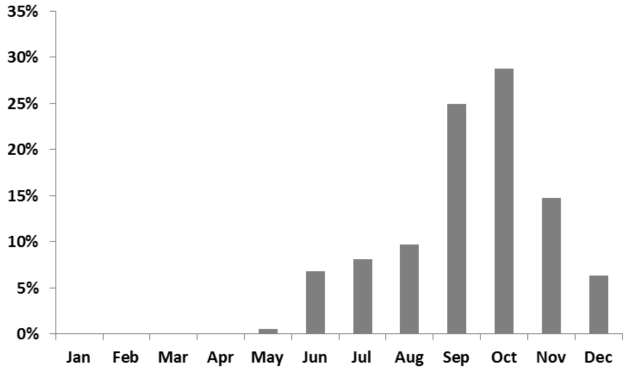


Figure 3-9. Catch rates of saury fishery of Korea by months (1985-2015)

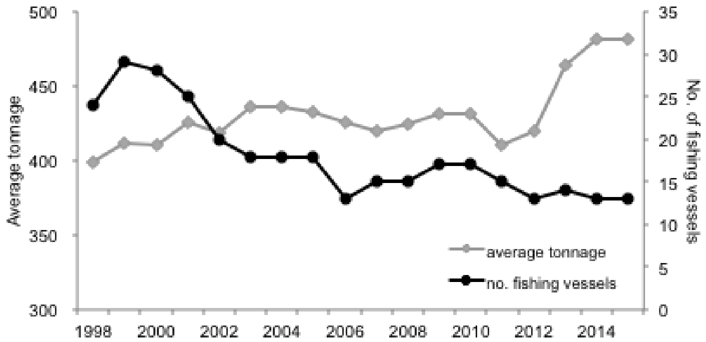


Figure 3-10. Average tonnage and number of fishing vessels

(iv) Main fishing port:

The main fishing port is Busan, which is the largest fishing port in Korea.

(v) Utilization of products:

Most of the saury catch were distributed and consumed domestically.

(vi) Economic impacts: Not available.

(4) Russia

(i) General fishing statistics:

Fishing days, number of vessels and annual catch amount (mt) are shown in Table 3-3.

Table 3-3. General fishing statistics of saury fishery in Russia.

Year	Fishing Gear	Numbers of fishing vessels	Fishing days	Catch Amount (MT)
2015	Stick-held dip net	45	1569	28878
2014	Stick-held dip net	62	3152	83367
2013	Stick-held dip net	65	2276	52933
2012	Stick-held dip net	58	2645	63105
2011	Stick-held dip net	51	2456	62064
2010	Stick-held dip net	46	1545	31686
2009	Stick-held dip net	51	1804	37693
2008	Stick-held dip net	49	2666	93866
2007	Stick-held dip net	57	2852	110692
2006	Stick-held dip net	49	2324	77691
2005	Stick-held dip net	48	2321	87602
2004	Stick-held dip net	37	2049	83735
2003	Stick-held dip net	48	1943	57646
2002	Stick-held dip net	63	1715	36602
2001	Stick-held dip net	41	1527	34616
2000	Stick-held dip net	28	845	14827
1999	Stick-held dip net	11	311	4576
1998	Stick-held dip net	14	205	3057
1997	Stick-held dip net	16	328	4493
1996	Stick-held dip net	18	434	6684
1995	Stick-held dip net	28	650	14283

(ii) Main fishing ground and season:
Fishery starts from June and finishes in November. Fishing grounds are shown in Figure 3-11.

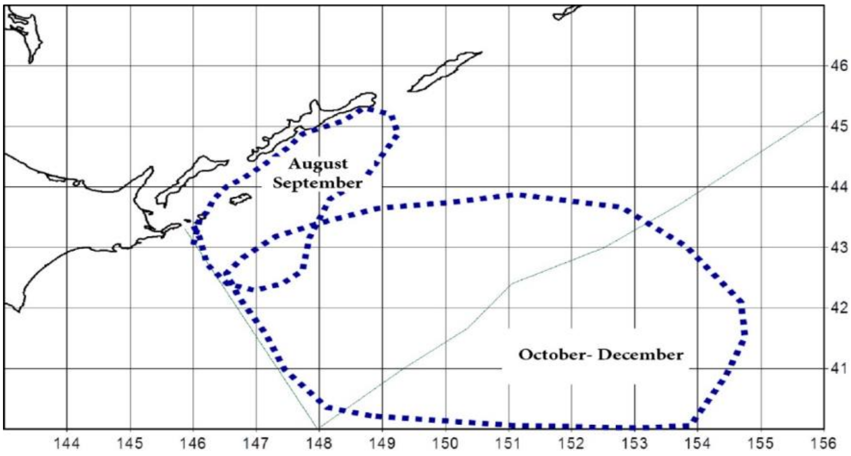


Figure 3-11. Main fishing grounds of Russia.

(iii) Vessel size (GT):
The GT of vessels ranged from 780 MT to 2500 MT, most of them ranged from 1100MT to 1300MT. The most common type of vessel in the saury fishery is shown in Figure 3-12.

Figure 3-12. The most common type of Russian vessel in the fishery of saury.

(iv) Main fishing port: Fishing ports for saury fishery in Russia are Yuzhno-Kurilsk, Korsakov, Vladivostok, Petropavlovsk-Kamchatskiy.

(v) Utilization of products:
Main utilization is for food.

(vi) Economic impacts: Not available.

(5) Chinese Taipei

(i) General fishing statistics:

Fishing days, number of vessels and annual catch amount (mt) are shown in Table 3-4.

Table 3-4. The fishing effort and annual catch for the Pacific saury fishery of Chinese Taipei from 2011 to 2015

Year	No. of vessels	Fishing days	Catch (tons)
2011	74	7,456	160,532
2012	85	7,349	161,514
2013	90	7,405	182,619
2014	91	7,709	229,937
2015	90	5,866	152,271

(ii) Main fishing ground and season:

General fishing grounds are mainly distributed from the subarctic domain to subarctic front of the northwestern Pacific including Oyashio front of the coastal waters including EEZs of Japan and Russia from 35 to 47°N and 141 to 178°E, which generally covered the saury migratory route (Figure 3-13). The fishing season of stick-held dip net fishery by Chinese Taipei begins mainly in July after the end of squid fishing season in the Southwest Atlantic Ocean, and ends in November (Figure 3-14) (NPFC-2016-WS PSSA01-WP04a).

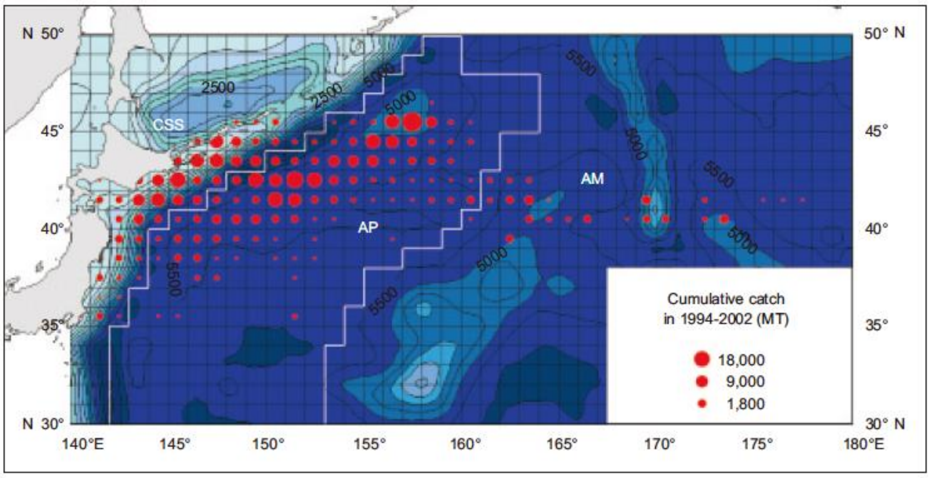


Figure 3-13. Fishing ground of saury fishery of Chinese Taipei (Huang et al 2007).

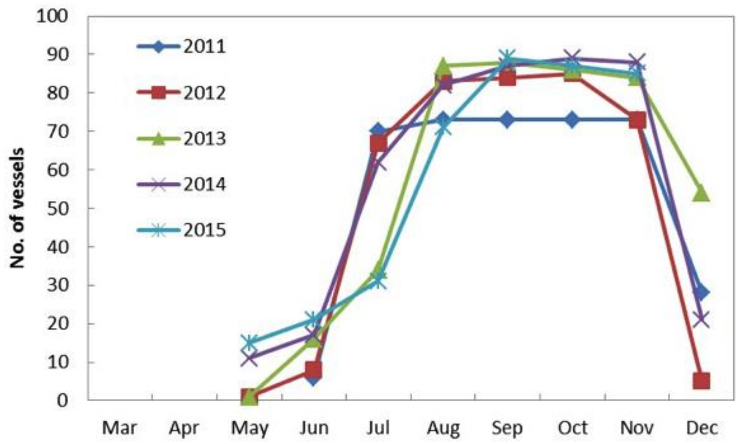


Figure 3-14. Monthly variations in number of operating vessels for the Pacific saury of Chinese Taipei in the Northwest Pacific from 2011 to 2015

(iii) Vessel size (GT):

Fishing vessel size in Chinese Taipei mostly ranged from 700 to 1000 tons with only a few vessels larger than 1000 tons (NPFC-2016-WS PSSA01-WP05b).

(iv) Main fishing port:

Fishing port for saury fishery is Kaohsiung.

(v) Utilization of products: Food and Fish bait (Sakai et al. 2014).

(vi) Economic impacts: Not available.

4. Data used for the stock assessment

1) Fishery-dependent data

(1) Catch

Fishery catch data from 1950-2015 for assessing WNPO saury were taken from the most recent summary of available fishery-dependent data (NPFC-2016-WS PSSA01-WP01; -WP02, -WP04a; -WP07; -WP09). Commercial catch statistics of Pacific saury by China, Japan, Korea, Russia, Chinese Taipei and Vanuatu in the WNPO area were collected from 1950 to 2015 (Table 4-1). More specifically, Japan, Chinese Taipei, Korea, China, Russia and Vanuatu directly provided catch data from 1995-2015, 1995-2015, 2007-2015, 2012-2015, 1995-2015, and 2015 to the North Pacific Fishery Commission (NPFC), respectively, and the historical catches for Japan, Chinese Taipei, Korea, and Russia from 1950-1994, 1989-1994, 1950-1994, and 1956- 1994 were collected from the Food and Agriculture Organization of the United Nations (FAO) dataset, respectively (NPFC-2016-WS PSSA01-Final Report). Japan included coastal and offshore stick-held dip net and other coastal gears (gill nets, set-net and by-catch). Chinese Taipei included distant stick-held dip net and other gears (trawlers, drift net and by-catch before 1996). Korea and China included the distant water stick-held dip net fisheries. Russia included offshore stick-held dip net fisheries. The main fishing ground based on the historical catch by each member are shown in Figure 4-1.

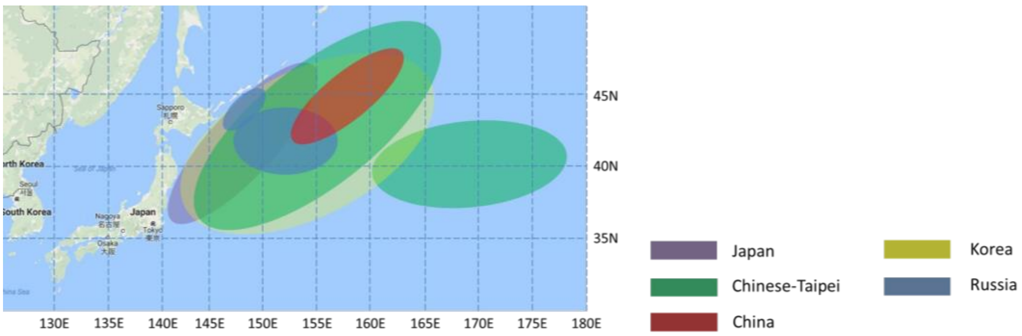


Figure 4-1. Main fishing grounds for the Pacific saury by NPFC members in the Western North Pacific Ocean. This figure was compiled based on the Working Papers NPFC-2016-WS PSSA01-WP07, NPFC-2016-WS PSSA01-WP04a, NPFC-2016-WS PSSA01-WP09, NPFC-2016-WS PSSA01-WP02, and NPFC-2016-WS PSSA01-WP01.

Table 4-1. Pacific saury catches (metric ton) in the Western North Pacific Ocean by members, 1950-2015; "-" indicates less than 1 metric ton.

Year	China	Japan	Korea	Russia	Chinese-Taipei	Vanuatu	Total
1950	-	200,000	3,500	-	-	-	203,500
1951	-	250,000	3,500	-	-	-	253,500
1952	-	250,000	3,800	-	-	-	253,800
1953	-	253,700	6,500	-	-	-	260,200
1954	-	292,700	8,200	-	-	-	300,900
1955	-	497,000	8,700	-	-	-	505,700
1956	-	327,800	14,700	200	-	-	342,700
1957	-	421,500	22,900	200	-	-	444,600
1958	-	575,100	20,700	300	-	-	596,100
1959	-	522,600	31,300	2,200	-	-	556,100
1960	-	287,100	14,900	12,900	-	-	314,900
1961	-	473,800	28,500	24,300	-	-	526,600
1962	-	483,200	38,900	44,800	-	-	566,900
1963	-	384,500	12,500	72,500	-	-	469,500
1964	-	210,700	25,400	26,700	-	-	262,800
1965	-	231,400	32,300	42,400	-	-	306,100
1966	-	241,800	39,400	44,600	-	-	325,800
1967	-	220,100	27,900	48,000	-	-	296,000
1968	-	140,200	29,900	51,000	-	-	221,100
1969	-	63,300	29,700	31,300	-	-	124,300
1970	-	93,100	25,000	44,800	-	-	162,900
1971	-	190,300	30,600	42,900	-	-	263,800
1972	-	196,600	38,500	46,500	-	-	281,600
1973	-	406,300	34,100	50,300	-	-	490,700
1974	-	135,462	31,723	50,900	-	-	218,085
1975	-	221,573	25,958	69,031	-	-	316,562
1976	-	105,419	42,121	40,005	-	-	187,545
1977	-	253,465	23,175	66,597	-	-	343,237
1978	-	360,213	21,744	77,965	-	-	459,922
1979	-	277,960	17,178	68,900	-	-	364,038
1980	-	187,155	12,395	38,600	-	-	238,150
1981	-	160,319	10,844	31,700	-	-	202,863

Continued

1982	-	206,958	7,449	26,293	-	-	240,700
1983	-	239,658	4,597	7,606	-	-	251,861
1984	-	209,974	1,923	30,447	-	-	242,344
1985	-	245,944	4,393	23,423	-	-	273,760
1986	-	217,229	8,924	24,902	-	-	251,055
1987	-	197,084	6,779	23,484	-	-	227,347
1988	-	291,575	4,495	50,927	-	-	346,997
1989	-	246,821	3,367	68,368	12,036	-	330,592
1990	-	308,271	23,103	72,618	31,877	-	435,869
1991	-	303,567	26,034	49,943	19,473	-	399,017
1992	-	265,884	33,708	50,172	34,235	-	383,999
1993	-	277,461	40,144	48,145	36,435	-	402,185
1994	-	261,587	31,987	26,385	12,550	-	332,509
1995	-	273,510	31,321	25,140	13,772	-	343,743
1996	-	229,227	18,681	10,280	8,236	-	266,424
1997	-	290,812	50,227	7,091	21,887	-	370,017
1998	-	144,983	13,922	4,665	12,794	-	176,364
1999	-	141,011	18,138	4,808	12,541	-	176,498
2000	-	216,471	24,457	17,390	27,868	-	286,186
2001	-	269,797	20,869	40,407	39,750	-	370,823
2002	-	205,282	20,088	51,709	51,283	-	328,362
2003	-	264,804	31,219	57,104	91,515	-	444,642
2004	-	204,371	22,625	81,572	60,832	-	369,400
2005	-	234,451	40,509	87,456	111,491	-	473,907
2006	-	244,586	12,009	76,920	60,578	-	394,093
2007	-	296,521	16,976	119,433	87,277	-	520,207
2008	-	354,727	29,591	93,677	139,514	-	617,509
2009	-	310,744	22,001	35,213	104,219	-	472,177
2010	-	207,488	21,360	35,268	165,692	-	429,808
2011	-	215,353	18,068	62,311	160,531	-	456,263
2012	2,014	221,470	13,961	61,585	161,514	-	460,544
2013	23,191	149,204	20,055	47,212	182,619	-	422,281
2014	76,129	227,527	23,431	70,154	229,937	-	627,178
2015	48,503	112,264	11,204	23,964	152,271	6,600	354,806

(2) Abundance indices

Estimates of standardized fishery-dependent catch-per-unit effort (CPUE) of WNPO saury were available for Japanese offshore stick-held dip net fisheries, Chinese Taipei's distant water stick-held dip net fisheries, and Russian offshore stick-held dip net fisheries (Table 4-2). More specifically, generalized linear models (GLM) and generalized additive models (GAM) were used to standardize CPUE of Pacific saury stick-held dip net fishery data of 70-200 GRT vessels by Japan from 1980 to 2015 (n = 36) (Sakai et al., 2017). Four groups of variables were considered in the standardization: spatial variables (area and longitude), temporal variables (year and month), vessel tonnage and environmental variable (e.g., sea surface temperature, SST). The cross validation analysis suggested that GLM tended to be more suitable than GAM in analysis of CPUE.

For Chinese Taipei's distant water stick-held dip net fisheries, aggregated data by 1x1 degree grids, including year, month, sea water temperature, vessel tonnage, and area from 2001 to 2015 (n = 15) were used for CPUE standardization (Huang et al., 2017). Three GLM models were developed. Among the three models, model 2 is the best model since its Akaike information criterion (AIC) is the smallest.

Operational data in the Russian Exclusive Economic Zone in the Northwest Pacific Ocean from the Russian offshore stick-held dip net fisheries in 2000-2015 (n = 16) collected by Russian Vessel Monitoring System (VMS) were used for CPUE standardization (Kulik and Antonenko, 2017). Six GLM models were developed. Among the six models, model-4 with covariates of year, month, month-year interaction and vessel unique identifiers is the best model since its AIC is the smallest.

Table 4-2. Pacific saury standardized catch-per-unit-effort (CPUE) for the Western North Pacific Ocean stock by NPFC members, 1980-2015. “-” indicates no effort or data not available. “JPN” = Japan, “CT” = Chinese Taipei, “RS” = Russia.

Year	JPN CPUE	CT CPUE	RS CPUE
1980	0.91	-	-
1981	0.73	-	-
1982	0.57	-	-
1983	0.97	-	-
1984	0.87	-	-
1985	1.50	-	-
1986	1.31	-	-
1987	1.15	-	-
1988	2.56	-	-
1989	3.60	-	-
1990	2.34	-	-
1991	3.51	-	-
1992	4.69	-	-
1993	3.83	-	-
1994	4.74	-	-
1995	3.30	-	-
1996	1.99	-	-
1997	4.02	-	-
1998	1.18	-	-
1999	1.00	-	-
2000	1.55	-	12.11
2001	2.56	1.73	12.86
2002	1.39	1.57	11.79
2003	2.64	2.30	20.22
2004	3.26	1.52	27.71
2005	6.07	1.92	26.01
2006	5.05	1.30	19.86
2007	6.54	2.04	25.39
2008	7.21	2.66	24.65
2009	4.49	1.48	14.01
2010	1.91	1.88	13.72
2011	3.00	2.35	17.88
2012	2.56	2.65	14.92
2013	1.71	3.09	15.10
2014	3.37	3.57	17.54
2015	1.71	3.29	18.17

2) Fishery-independent data

Tohoku National Fisheries Research Institute of Japan has been conducting the stock assessment surveys in June and July every year since 2003 in the areas from waters off the Japanese coast (143°E) to the Central Pacific (165°W) by research vessels (NPFC-2017-TWG PSSA01-WP02 (Rev. 1)). Based on the data of the surveys, biomass of Pacific saury was estimated by area swept method (Table 4-3). We used these data as biomass index obtained by fishery-independent survey.

Table 4-3. Estimated biomass of Pacific saury based on area swept method using the results of scientific research cruises.

Year	Biomass (1,000t)	2.5%	97.5%	CV.round
2003	5,024	3,216	6,819	0.189
2004	3,828	1,979	5,789	0.270
2005	4,073	2,601	5,706	0.195
2006	3,516	2,184	5,214	0.221
2007	2,831	1,680	4,006	0.209
2008	4,606	3,256	8,139	0.224
2009	3,756	2,106	5,804	0.255
2010	2,076	1,381	2,812	0.183
2011	2,485	1,830	3,214	0.153
2012	1,920	1,141	2,869	0.241
2013	2,823	1,698	4,173	0.233
2014	2,529	1,475	3,404	0.216
2015	2,272	1,468	3,109	0.195

5. Bayesian state-space biomass dynamic model (model descriptions)

1) Annual biomass dynamics:

$$B_t = B_{t-1} + rB_{t-1}\left(1-\left(\frac{B_{t-1}}{K}\right)^M\right) - C_t$$

where B_{t-1} and C_{t-1} denote biomass and catch (landings), respectively, for year t-1. Carrying capacity, K, is the biomass of the population at equilibrium prior to commencement of the fishery; r is the intrinsic population growth rate; and M (= Z, =s) is the production shape parameter.

We assumed lognormal error structures and used a reparametrization ($P_t = B_t/K$) by expressing the annual biomass as a proportion of carrying capacity as in Millar and Meyer (1999). The state equations are rewritten as

$$P_t = \left(P_{t-1} + r_{t-1}\cdot P_{t-1}\left(1-P_{t-1}^M\right) - \frac{C_{t-1}}{K}\right)\exp(u_t)$$

$$P_1 = \exp(u_1)$$

$$u_1 \sim N\left(\mu_{P_1}, \sigma_{P_1}^2\right)$$

$$u_t \sim N(0,\sigma^2) \quad t = 2,\ldots,N$$

where t is year t, N is number of years, u_1 is a normal random variable with a mean of μ_{P_1} and variance $\sigma_{P_1}^2$ accounting for the uncertainty of initial condition. u_t is also a normal random variable with a mean of zero and variance σ^2 to account accounting for stochastic process dynamics.
The observation equations are

$$I_{i,t} = q_i K P_t \exp\left(\varepsilon_{i,t}\right)$$

$$\varepsilon_{i,t} \sim N\left(0,\tau_i^2\right) \qquad i = 1 \text{ to } 3;\ t = 1,\ldots,N$$

where $I_{i,t}$ is the relative abundance of index i at time t; q_i is the catchability coefficient for index i, which describes the effectiveness of each unit of fishing effort; and $\varepsilon_{i,t}$ is a normal random variable with a mean of zero and variance τ_i^2 to account accounting for the natural sampling variation of index i.

2) Base-case scenarios and sensitivity test:

Unfortunately, since little is known about the catchability (*q*) on stick-held dip net gear, we were limited to use least-informative prior for *q*.

Based on the recommended base-case scenarios, three base-case scenarios differing in catchability of the Japanese survey biomass index were explored and also sensitivity analysis was examined without using the Japanese survey biomass index.

i) Base case model 1: Including four sets of CPUEs and Japan survey data with survey catchability (*q*) prior defined from 0 to 1; (note this Base case is the Base Case 2 for Japan)

ii) Base case model 2: Including four sets of CPUEs and Japan survey data with survey catchability (*q*) prior being fixed at 1; (note this Base case is the Base Case 1 for Japan)

iii) Base case model 3: Including four sets of CPUEs and Japan survey data with survey catchability (*q*) prior being defined from 0 to larger than 1.

iv) Sensitivity model: The analysis for excluding the biomass index the Japanese survey (no survey *q*)

6. Priors

1) Prior distribution

The Bayesian analysis requires prior probability distributions for each of the model parameters. There were six parameters in the model: carrying capacity (*K*), intrinsic growth rate (*r*), catchability (*q*), initial biomass as a proportion of carrying capacity (P1 or B_1/K), process error variance (σ^2) and observation error variance (τ^2). Regarding assumption of the prior distribution in detail, refer to each member's stock assessment report in Section 7. Stock Assessment.

2) Convergence to posterior distribution

A critical issue in using MCMC methods is how to determine when random draws have converged to the posterior distribution. Convergence of the MCMC samples to the posterior distribution was checked by monitoring the trace and diagnosing the autocorrelation plot.

Gelman and Rubin (1992) and Heidelberger and Welch (1983) diagnostics as implemented in the R language (R Development Core Team, 2008) and the CODA package (Best et al., 1995) were also examined.

3) Diagnostics of model fitting

The predicted CPUE indices for each model were compared to the observed CPUE to determine model fit. Specifically, the root mean-squared error (RMSE) of the CPUE fit was used for the diagnostic of the model goodness of fit with lower RMSE indicating a better fit when comparing models with the same number of parameters. The goodness of fit among different models with same data structure was evaluated by Deviance information criterion (DIC) (Spiegelhalter et al., 2002). The standardized log-residuals from the CPUE fit were visually examined for time trends. The Shapiro-Wilk test was used to test the normality of the standardized log-residuals. The estimates of production model can be problematic when the data are not informative about whether the population has a high *K* and a low *r* or vice versa (Hilborn and Walters, 1992). The posterior correlation between model parameters was examined for the base-case model.

4) Retrospective error

Retrospective analysis was conducted to examine the consistency among successive model estimates of population size, or related assessment variables obtained as new data are gathered. Within-model retrospective analysis which trims the most recent 8 years of data in successive model runs were used to examined changes in the estimates of exploitable biomass. Modified Mohn's (1999) DR statistic was calculated as (Hurtado-Ferro et al., 2015):

$$DR = \frac{1}{npeels} \times \frac{B_{Y-y,tip} - B_{Y-y,ref}}{B_{Y-y,ref}}$$

where *B* denotes exploitable biomass, *y* denotes year, *npeels* denotes the number of years that are dropped in successive fashion and the assessment rerun, *Y* is the last year in the full time series, *tip* denotes the terminal estimate from an assessment with a reduced time series, and *ref* denotes the assessment using the full time series.

7. Stock assessment

1) Member stock assessment report: CHINA

Based on preliminary analysis, 9 models differing in number of abundance indices and prior distribution of catchability and intrinsic growth rate were explored. All scenarios included total catch and all available CPUE indices from four members (Table CH7.1). Scenario 1-3 and 5-7 included biomass index from Japanese survey. Scenario 1-4 applied inverse-gamma distribution on catchability while scenario 5-8 used uniform distribution for catchability. Different ranges of catchability q5 were considered among different scenarios, such as 0 to 1 (scenario 1 and 5), equal to 1 (scenario 2 and 6), and 0 to larger than 1 (scenario 3 and 8). Scenario 9 considered lognormal distribution of intrinsic growth rate instead of uniform distribution.

Posterior distributions were estimated and the convergence of the posterior distributions was examined with Gelman and Rubin statistics (Gelman and Rubin, 1992). MSY-based biological reference points were estimated from the generalized Bayesian state-space production model.

A Shapiro-Wilk normality test was used to examine the normality of the observation error. The root mean square error of the observation error was calculated to measure the model fit. A retrospective analysis was conducted to verify whether any possible systematic inconsistencies exist among the model estimates of biomass and fishing mortality based on increasing periods of data (Mohn, 1999). A sensitivity analysis of the model outputs to the number of indices and prior distributions were tested by excluding the biomass index from the Japanese survey and changing the prior distributions of catchability and intrinsic growth rate. The results of the sensitivity analysis helped to understand whether the assessment model was robust in capturing the changes of indices and priors.

Stochastic projections were applied to the assessment to show the possible changes in exploitable biomass. A five-year catch scenario was projected starting in 2016. The catch was set at 0.8, 0.9, 1.0, 1.1, and 1.2 multiples average catch of recent 5 years. A risk analysis was conducted to show how the probabilities of overfishing and becoming overfished change as projected catch changes in the future. The prediction skill of the model was evaluated using cross validation (Kell et al., 2016). The data from 1980 to 2010 were used to build the model and make predictions of biomass under reported annual catch from 2010 to 2015. The similarity between predicted biomass and observed CPUE and biomass indices was quantified with a linear regression model.

(1) Assessment results for the base-case scenarios

The posterior densities of model parameters showed that the densities were smooth and unimodal for the base-case scenarios (Figure CH7.1, CH7.2, and CH7.3). Mean, median, and coefficient variance (CV) of posterior estimates of model parameters were summarized in Table CH7.2. The posterior distributions of the model parameters were adequately sampled with the MCMC simulations. All parameters showed well convergence of posterior distributions with Gelman and Rubin statistic for all parameters equal to 1.

The correlations among posterior estimates of key parameters were examined for base-case scenarios (Figure CH7.4, CH7.5, and CH7.6). The correlations were high between K, BMSY, and catchability, whereas the correlations between other parameters were relatively low. There was no correlation between most parameters and P1, s, and MSY.

(2) Diagnostics and caveats

All standardized log-residuals from the indices did not show significant temporal trends (Figure CH7.7, CH7.8, and CH7.9). All standardized log-residuals from the indices fit of the base-case scenarios did not fail the Shapiro-Wilk normality test ($p > 0.05$, Table CH7.3). The root mean square errors for the four CPUE indices showed the same pattern from different scenarios (Table CH7.3). The predicted indices showed a well fit to the CPUE from Russia and a lack of fit to the CPUE from Chinese Taipei. The deviance information criteria (DIC) values from different scenarios indicated that the minimum value of DIC was 440.63 (S2) and the maximum value of DIC was 460.07 (S1; Table CH7.3).

There was no obvious retrospective pattern in the estimates of exploitable biomass and fishing mortality (Figure CH7.10, CH7.11, and CH7.12). The Mohn's rho statistics for exploitable biomass of the three base-case scenarios were 0.17, 0.26, and 0.12 respectively. The Mohn's rho statistics for fishing mortality of the three base-case scenarios were -0.16, -0.23, and -0.03. Overall, the retrospective analysis suggested that there was no consistent pattern of bias in the estimates of the terminal exploitable biomass and fishing mortality.

(3) Biological reference points

The estimated mean and CV of maximum sustainable yield from the base-case scenarios 1, 2, and 3 were 593,500 mt (CV=0.28), 544,800 mt (CV=0.24), and 506,500 mt (CV=0.21; Table CH7.2). The estimated mean and CV of exploitable biomass to produce MSY from these three scenarios were 3,466,600 mt (CV=0.39), 2,681,600 mt (CV=0.39), and 2,009,700 mt (CV=0.48) respectively. The estimated fishing mortalities to produce MSY of the three base-case scenarios were 0.19 (CV=0.32), 0.22 (CV=0.28), and 0.29 (CV=0.37).

(4) Stock status（Kobe plots included here）

The temporal trends of Bratio (B/B_{MSY}) and Fratio (F/F_{MSY}) from the three base-case scenarios showed similar patterns (Figure CH7.13, CH7.14, and CH7.15). The estimated mean, median, and CV of exploitable biomass and fishing mortality from the base-case scenarios were listed in Table CH7.4, CH7.5 and CH7.6. The exploitable biomass of Pacific saury fluctuated above B_{MSY} between 1989 to 1997 and 2003 to 2015. The exploitable biomass was above B_{MSY} and stayed relatively stable during the last 5 years. The fishing mortality decreased from above F_{MSY} to under F_{MSY} during 1980 to 1986. The fishing mortality was under F_{MSY} and stayed relatively stable after 1986. The current status of stock indicated that the Pacific saury was not overfished or experiencing overfishing (Figure CH7.16, CH7.17, and CH7.18).

(5) Sensitivity analysis (for sensitivity analysis)

The sensitivity analysis for excluding the biomass index from the Japanese survey (S4) showed that the estimated mean of key parameters fell in between the results from S2 and S3 (Table CH7.7 and CH7.8). The absolute change in mean of key parameters ranged from 0.05% to 3.17% when distribution of catchability changed from inverse-gamma distribution to uniform distribution and q5 was less than 1. The model results were robust to changes in distribution of catchability when q5 equaled 1 (i.e. absolute changes in mean varied from 0.14% to 4.56%. The absolute change in mean of key parameters (i.e. 0.96% to 68.92%) exceeded 50% when catchability distribution changed from inverse-gamma distribution to uniform distribution and q5 was free to be greater than 1. The absolute changes in means (1.65% to 66.08%) were also greater than 50% when catchability distribution was changed and biomass index was excluded from the model. Fishing mortality in 1980 and 2015 exhibited relatively high changes in mean, which were greater than 50%. The model outputs were robust to changes in distribution of r when r was changed from uniform distribution to lognormal distribution. The absolute changes in mean of key parameters were between 0.02% to 27.19%.

(6) Projection

The cross validation results from the three base-case scenarios showed similar patterns between predicted relative biomass and observed indices (Figure CH7.19, CH7.20, and CH7.21). The predicted relative biomass showed a positive correlation with observed CPUE from Japan, Russia, Korea, and biomass index from Japanese survey. The Adjusted R2 of the simple linear regression model decreased from CPUE from Russia, Japan, biomass index, and CPUE from Korea (Figure CH7.19, CH7.20, CH7.21). The predicted relative biomass had a poor fit with the observed CPUE from Chinese Taipei.

A five-year projection was conducted through 2020 for three base-case scenarios. 0.8, 0.9, 1, 1.1, and 1.2 of average catch over the last 5 years was assumed for the future projection. For scenario 1 with q5 ranged from 0 to 1, the exploitable biomass would remain above BMSY through 2020 for all catch scenarios (Figure CH7.22). For scenario 2 and 3 with fixed q equaled to 1 and free q that could be greater than 1, the exploitable biomass were greater than BMSY under catch scenarios 0.8×catch till 1.1×catch (Figure CH7.23 and CH7.24). For catch scenarios 1.2×catch under model scenario 2 and 3, the stock had a greater than 50% probability of being overfished in 2018 and 2017 respectively (Table CH7.9).

(7) Conclusion/Summary

The current stock status indicated that the Pacific saury was not overfished or experiencing overfishing based on three base-case scenarios. The current catch level was not harmful to the Pacific saury population. This integrated Bayesian state-space stock assessment model for Pacific saury has been conducted with all available data. However, estimated catchability of biomass index from Japanese survey was greater than 1 when prior range of catchability was set from 0 to values greater than 1. Additional research on catchability of biomass index from Japanese survey is necessary. Other approach such as maximum likelihood could be used to compare model outputs with Bayesian approach in order to improve the stock assessment.

Table CH7.1. Prior assumptions of catchability and intrinsic growth rate from different scenarios.

Scenarios	q1-q4	q5	r
S1	1/q~Gamma(0.01,0.01)	1/q~Gamma(0.01,0.01) > 1	U(0,3)
S2	1/q~Gamma(0.01,0.01)	1/q=1	U(0,3)
S3	1/q~Gamma(0.01,0.01)	1/q~Gamma(0.01,0.01)	U(0,3)
S4	1/q~Gamma(0.01,0.01)	-	U(0,3)
S5	q~U(0,1)	q~U(0,1)	U(0,3)
S6	q~U(0,1)	q=1	U(0,3)
S7	q~U(0,1)	q~U(0,5)	U(0,3)
S8	q~U(0,1)	-	U(0,3)
S9	1/q~Gamma(0.01,0.01)	1/q~Gamma(0.01,0.01)	logN(log(1.4)- $\sigma^2/2$, σ^2); CV=1

Table CH7.2. Summary of estimated mean, median, and CV of model parameters from base-case scenarios.

	S1				S2				S3			
Parameter	**Mean**	**SD**	**Median**	**CV**	**Mean**	**SD**	**Median**	**CV**	**Mean**	**SD**	**Median**	**CV**
K (10000 mt)	790.26	303.99	704.00	0.38	615.85	255.62	527.80	0.42	457.96	222.42	409.80	0.49
r	1.03	0.76	0.77	0.74	1.13	0.75	0.89	0.66	1.28	0.74	1.13	0.57
q1	0.01	0.00	0.01	0.22	0.01	0.00	0.01	0.11	0.02	0.01	0.01	0.41
q2	0.05	0.01	0.05	0.21	0.06	0.00	0.06	0.08	0.09	0.04	0.08	0.41
q3	0.03	0.01	0.03	0.24	0.04	0.01	0.04	0.14	0.06	0.03	0.05	0.43
q4	0.01	0.00	0.01	0.24	0.01	0.00	0.01	0.13	0.01	0.00	0.01	0.42
q5	0.77	0.16	0.79	0.20	1.00	0.00	1.00	0.00	1.46	0.60	1.37	0.41
σ^2	0.05	0.02	0.05	0.47	0.05	0.02	0.05	0.47	0.05	0.02	0.05	0.46
$\tau1^2$	0.13	0.04	0.13	0.32	0.13	0.04	0.12	0.31	0.13	0.04	0.12	0.32
$\tau2^2$	0.02	0.01	0.01	0.73	0.02	0.01	0.01	0.71	0.02	0.01	0.01	0.73
$\tau3^2$	0.22	0.10	0.19	0.47	0.22	0.10	0.19	0.47	0.21	0.10	0.19	0.46
$\tau4^2$	0.19	0.09	0.17	0.48	0.19	0.09	0.17	0.47	0.19	0.09	0.17	0.46
$\tau5^2$	0.06	0.03	0.05	0.56	0.06	0.03	0.05	0.58	0.06	0.03	0.05	0.58
P1	0.14	0.05	0.14	0.33	0.14	0.05	0.14	0.34	0.14	0.04	0.14	0.28
s	0.57	0.60	0.32	1.07	0.56	0.58	0.33	1.05	0.56	0.53	0.36	0.95
MSY (10000 mt)	59.35	16.60	57.07	0.28	54.48	12.99	52.91	0.24	50.65	10.81	48.66	0.21
FMSY	0.19	0.06	0.18	0.32	0.22	0.06	0.22	0.28	0.29	0.11	0.28	0.37
BMSY (10000 mt)	346.66	135.35	310.10	0.39	268.16	104.98	237.40	0.39	200.97	97.13	178.80	0.48
B1980 (10000 mt)	105.98	39.40	97.91	0.37	78.66	21.35	75.43	0.27	63.39	31.72	55.79	0.50
B2015 (10000 mt)	356.63	98.52	333.10	0.28	261.56	31.08	260.00	0.12	210.86	97.38	189.20	0.46
F1980	0.25	0.08	0.24	0.33	0.32	0.08	0.32	0.26	0.46	0.21	0.43	0.46
F2015	0.11	0.03	0.11	0.23	0.14	0.02	0.14	0.12	0.21	0.09	0.19	0.44
P2015	0.48	0.12	0.49	0.25	0.47	0.13	0.49	0.28	0.48	0.11	0.48	0.22
Bratio2015	1.10	0.29	1.11	0.26	1.07	0.29	1.09	0.27	1.08	0.24	1.08	0.22
Fratio2015	0.64	0.26	0.58	0.41	0.70	0.26	0.64	0.37	0.72	0.21	0.69	0.30

Table CH7.3. Diagnostics of model fitting for base-case scenarios.

	Shapiro-Wilk test P-value					RMSE					DIC
Scenarios	**Index1**	**Index2**	**Index3**	**Index4**	**Index5**	**Index1**	**Index2**	**Index3**	**Index4**	**Index5**	
S1	0.23	0.95	0.07	0.43	0.51	0.32	0.08	0.43	0.40	0.20	460.07
S2	0.21	0.93	0.07	0.41	0.47	0.32	0.08	0.42	0.40	0.20	440.63
S3	0.20	0.90	0.08	0.46	0.54	0.32	0.08	0.42	0.39	0.20	458.98

Note: Index1 to Index5 represent the CPUE indices from Japan, Russia, Korea, Chinese Taipei and biomass index from Japanese survey.

Table CH7.4. Estimated mean, CV, and median exploitable biomass (10000 mt) and fishing mortality from the scenarios 1.

	Exploitable biomass (10000 mt)			Fishing mortality		
Year	Mean	CV	Median	Mean	CV	Median
1980	105.98	0.37	97.91	0.25	0.33	0.24
1981	103.77	0.35	96.46	0.22	0.31	0.21
1982	108.73	0.34	101.00	0.24	0.30	0.24
1983	124.94	0.34	116.50	0.22	0.30	0.22
1984	140.07	0.34	130.30	0.19	0.30	0.19
1985	170.18	0.34	158.10	0.18	0.30	0.17
1986	189.28	0.34	176.30	0.15	0.30	0.14
1987	218.96	0.34	204.10	0.11	0.30	0.11
1988	294.79	0.32	276.10	0.13	0.29	0.13
1989	355.74	0.33	332.30	0.10	0.30	0.10
1990	377.15	0.32	353.10	0.13	0.29	0.12
1991	423.95	0.33	397.50	0.10	0.30	0.10
1992	467.53	0.33	438.05	0.09	0.30	0.09
1993	467.08	0.33	435.80	0.09	0.30	0.09
1994	457.83	0.33	427.70	0.08	0.31	0.08
1995	402.47	0.33	377.00	0.09	0.30	0.09
1996	339.56	0.34	316.20	0.09	0.30	0.08
1997	326.59	0.33	304.60	0.12	0.30	0.12
1998	243.50	0.35	226.15	0.08	0.31	0.08
1999	228.79	0.33	213.30	0.08	0.30	0.08
2000	261.78	0.28	244.50	0.12	0.24	0.12
2001	290.72	0.27	271.00	0.14	0.23	0.14
2002	286.94	0.28	267.80	0.12	0.24	0.12
2003	454.04	0.27	424.10	0.10	0.23	0.10
2004	518.55	0.27	483.70	0.08	0.23	0.08
2005	545.91	0.27	508.30	0.09	0.23	0.09
2006	459.95	0.27	428.65	0.09	0.23	0.09
2007	507.27	0.27	472.40	0.11	0.23	0.11
2008	538.43	0.27	502.10	0.12	0.23	0.12
2009	370.07	0.28	344.70	0.14	0.23	0.14
2010	317.96	0.27	295.60	0.14	0.23	0.15
2011	369.65	0.27	344.50	0.13	0.23	0.13
2012	333.23	0.27	310.20	0.15	0.23	0.15
2013	353.22	0.27	328.50	0.13	0.23	0.13
2014	392.62	0.27	365.90	0.17	0.22	0.17
2015	356.63	0.28	333.10	0.11	0.23	0.11

Table CH7.5. Estimated mean, CV, and median exploitable biomass (10000 mt) and fishing mortality from the scenarios 2.

	Exploitable biomass (10000 mt)			Fishing mortality		
Year	Mean	CV	Median	Mean	CV	Median
1980	78.66	0.27	75.43	0.32	0.26	0.32
1981	76.83	0.24	74.47	0.28	0.24	0.27
1982	80.84	0.23	78.48	0.31	0.23	0.31
1983	92.61	0.23	89.91	0.29	0.22	0.28
1984	103.81	0.23	101.00	0.25	0.23	0.24
1985	126.22	0.23	122.50	0.23	0.23	0.22
1986	140.32	0.23	136.40	0.19	0.23	0.18
1987	162.56	0.23	158.30	0.15	0.23	0.14
1988	220.33	0.22	215.10	0.17	0.22	0.16
1989	264.70	0.23	257.50	0.13	0.23	0.13
1990	281.77	0.22	275.60	0.16	0.22	0.16
1991	314.46	0.22	308.00	0.13	0.23	0.13
1992	345.90	0.22	338.90	0.12	0.23	0.11
1993	345.14	0.22	339.00	0.12	0.22	0.12
1994	337.87	0.23	330.50	0.10	0.23	0.10
1995	296.21	0.23	289.30	0.12	0.23	0.12
1996	250.12	0.23	244.10	0.11	0.23	0.11
1997	241.34	0.23	235.20	0.16	0.22	0.16
1998	178.06	0.23	173.60	0.10	0.23	0.10
1999	168.30	0.22	164.80	0.11	0.22	0.11
2000	193.46	0.13	191.70	0.15	0.13	0.15
2001	214.69	0.12	212.70	0.18	0.12	0.17
2002	211.13	0.13	208.40	0.16	0.13	0.16
2003	335.24	0.11	333.30	0.13	0.11	0.13
2004	382.43	0.11	381.30	0.10	0.11	0.10
2005	403.42	0.10	402.60	0.12	0.11	0.12
2006	337.82	0.11	336.00	0.12	0.11	0.12
2007	373.91	0.11	372.40	0.14	0.11	0.14
2008	396.93	0.11	395.10	0.16	0.11	0.16
2009	271.48	0.12	269.60	0.18	0.12	0.18
2010	233.42	0.11	231.50	0.19	0.11	0.19
2011	272.13	0.10	270.90	0.17	0.10	0.17
2012	245.29	0.11	243.20	0.19	0.11	0.19
2013	260.23	0.11	258.40	0.16	0.11	0.16
2014	289.92	0.11	287.90	0.22	0.10	0.22
2015	261.56	0.12	260.00	0.14	0.12	0.14

Table CH7.6. Estimated mean, CV, and median exploitable biomass (10000 mt) and fishing mortality from the scenarios 3.

	Exploitable biomass (10000 mt)			Fishing mortality		
Year	Mean	CV	Median	Mean	CV	Median
1980	63.39	0.50	55.79	0.46	0.46	0.43
1981	61.89	0.50	54.58	0.40	0.46	0.37
1982	65.67	0.50	58.30	0.45	0.45	0.41
1983	75.42	0.51	66.31	0.41	0.46	0.38
1984	84.23	0.51	74.28	0.36	0.47	0.33
1985	102.27	0.50	90.77	0.33	0.47	0.30
1986	113.89	0.51	101.40	0.27	0.48	0.25
1987	132.28	0.51	118.25	0.21	0.48	0.19
1988	181.09	0.47	163.50	0.23	0.44	0.21
1989	218.10	0.48	196.00	0.18	0.45	0.17
1990	228.52	0.47	205.35	0.23	0.45	0.21
1991	256.48	0.48	229.40	0.19	0.45	0.17
1992	283.12	0.48	253.15	0.16	0.45	0.15
1993	282.11	0.49	252.25	0.17	0.45	0.16
1994	274.51	0.49	245.95	0.15	0.46	0.14
1995	241.74	0.49	215.70	0.17	0.46	0.16
1996	203.23	0.51	180.90	0.16	0.47	0.15
1997	196.20	0.50	174.05	0.23	0.46	0.21
1998	143.50	0.52	126.85	0.16	0.52	0.14
1999	135.80	0.50	121.05	0.16	0.49	0.15
2000	157.12	0.46	140.00	0.22	0.43	0.20
2001	174.51	0.45	156.90	0.25	0.42	0.24
2002	171.00	0.46	152.80	0.23	0.43	0.21
2003	272.11	0.45	245.60	0.19	0.41	0.18
2004	309.21	0.45	278.05	0.14	0.43	0.13
2005	327.45	0.45	297.05	0.17	0.41	0.16
2006	274.25	0.45	247.05	0.17	0.42	0.16
2007	303.59	0.45	275.20	0.20	0.42	0.19
2008	323.23	0.44	291.40	0.23	0.41	0.21
2009	220.32	0.46	197.50	0.26	0.43	0.24
2010	189.40	0.46	170.90	0.27	0.43	0.25
2011	221.08	0.45	199.30	0.24	0.41	0.23
2012	198.96	0.45	178.75	0.28	0.42	0.26
2013	210.87	0.45	190.55	0.24	0.42	0.22
2014	235.49	0.44	212.15	0.31	0.41	0.30
2015	210.86	0.46	189.20	0.21	0.44	0.19

Table CH7.7. Effect of prior distribution in priors and biomass index from Japanese survey on model parameters K, r, s, P1, P2015, q5, MSY, F_{MSY}, and B_{MSY}.

Scenarios		K (10000 mt)	r	s	P1	P2015	q5	MSY (10000 mt)	FMSY	BMSY (10000 mt)
S1	Mean	790.26	1.03	0.57	0.14	0.48	0.77	59.35	0.19	346.66
	CV	0.38	0.74	1.07	0.33	0.25	0.20	0.28	0.32	0.39
S2	Mean	615.85	1.13	0.56	0.14	0.47	1.00	54.48	0.22	268.16
	CV	0.42	0.66	1.05	0.34	0.28	0.00	0.24	0.28	0.39
S3	Mean	457.96	1.28	0.56	0.14	0.48	1.46	50.65	0.29	200.97
	CV	0.49	0.57	0.95	0.28	0.22	0.41	0.21	0.37	0.48
S4	Mean	536.15	1.25	0.56	0.14	0.49	-	52.92	0.27	234.01
	CV	0.56	0.60	1.00	0.32	0.26	-	0.26	0.41	0.56
S5	Mean	793.64	1.05	0.55	0.14	0.47	0.79	59.38	0.19	347.60
	CV	0.42	0.72	1.08	0.34	0.27	0.20	0.29	0.33	0.44
	Change(%)	0.43	2.73	-2.49	-1.56	-1.58	2.86	0.05	1.13	0.27
S6	Mean	587.77	1.11	0.58	0.14	0.49	1.00	54.40	0.23	258.53
	CV	0.42	0.67	1.01	0.33	0.26	0.00	0.24	0.27	0.41
	Change(%)	-4.56	-1.66	4.14	2.70	3.62	0.00	-0.14	3.40	-3.59
S7	Mean	306.89	1.48	0.67	0.14	0.46	2.45	47.87	0.43	136.54
	CV	0.76	0.46	0.83	0.30	0.24	0.38	0.23	0.36	0.73
	Change(%)	-32.99	15.70	19.85	0.96	-3.81	67.82	-5.48	48.27	-32.06
S8	Mean	347.01	1.41	0.66	0.14	0.48	-	49.02	0.40	154.14
	CV	0.74	0.51	0.85	0.31	0.25	-	0.24	0.41	0.71
	Change(%)	-35.28	12.97	17.18	2.91	-1.65	-	-7.36	46.64	-34.13
S9	Mean	457.85	0.93	0.69	0.15	0.49	1.46	51.84	0.29	205.02
	CV	0.57	0.50	0.76	0.30	0.24	0.39	0.22	0.35	0.52
	Change(%)	-0.02	-27.19	23.72	3.46	2.48	0.04	2.36	-0.36	2.02

Table CH7.8. Effect of prior distribution in priors and biomass index from Japanese survey on model parameters B, F, Bratio, and Fratio in a specific year.

Scenarios		B1980 (10000 mt)	B2015 (10000 mt)	F1980	F2015	Bratio2015	Fratio2015
S1	Mean	105.98	356.63	0.25	0.11	1.10	0.64
	CV	0.37	0.28	0.33	0.23	0.26	0.41
S2	Mean	78.66	261.56	0.32	0.14	1.07	0.70
	CV	0.27	0.12	0.26	0.12	0.27	0.37
S3	Mean	63.39	210.86	0.46	0.21	1.08	0.72
	CV	0.50	0.46	0.46	0.44	0.22	0.30
S4	Mean	70.52	244.98	0.43	0.18	1.11	0.69
	CV	0.55	0.49	0.48	0.48	0.25	0.33
S5	Mean	104.40	348.95	0.26	0.11	1.09	0.65
	CV	0.42	0.32	0.34	0.24	0.27	0.44
	Change(%)	-1.49	-2.15	3.03	3.17	-1.31	2.51
S6	Mean	77.48	260.23	0.33	0.14	1.10	0.68
	CV	0.27	0.12	0.27	0.12	0.26	0.36
	Change(%)	-1.49	-0.51	1.71	0.47	3.18	-3.29
S7	Mean	40.38	129.19	0.73	0.35	1.01	0.82
	CV	0.62	0.60	0.41	0.41	0.23	0.29
	Change(%)	-36.30	-38.73	58.60	68.92	-6.87	13.53
S8	Mean	45.67	153.27	0.67	0.30	1.06	0.77
	CV	0.62	0.60	0.46	0.48	0.24	0.33
	Change(%)	-35.23	-37.44	56.30	66.08	-4.57	11.71
S9	Mean	62.79	207.72	0.45	0.20	1.07	0.72
	CV	0.45	0.42	0.42	0.41	0.23	0.32
	Change(%)	-0.94	-1.49	-2.46	-0.86	-1.60	0.13

Table CH7.9. Probability of being overfished ($B<B_{MSY}$) under different catch scenarios during 2016 to 2020 from three base-case scenarios.

		2016	2017	2018	2019	2020
S1	0.8×catch	0.36	0.34	0.32	0.30	0.29
	0.9×catch	0.38	0.36	0.35	0.34	0.33
	1.0×catch	0.39	0.38	0.38	0.38	0.38
	1.1×catch	0.40	0.41	0.41	0.42	0.42
	1.2×catch	0.41	0.43	0.45	0.46	0.47
S2	0.8×catch	0.39	0.36	0.34	0.33	0.32
	0.9×catch	0.40	0.39	0.38	0.37	0.37
	1.0×catch	0.42	0.42	0.42	0.42	0.43
	1.1×catch	0.44	0.45	0.47	0.48	0.49
	1.2×catch	0.46	0.49	0.51	0.53	0.55
S3	0.8×catch	0.37	0.35	0.33	0.31	0.31
	0.9×catch	0.40	0.39	0.39	0.39	0.39
	1.0×catch	0.43	0.44	0.45	0.46	0.48
	1.1×catch	0.46	0.49	0.52	0.54	0.56
	1.2×catch	0.48	0.54	0.58	0.61	0.64

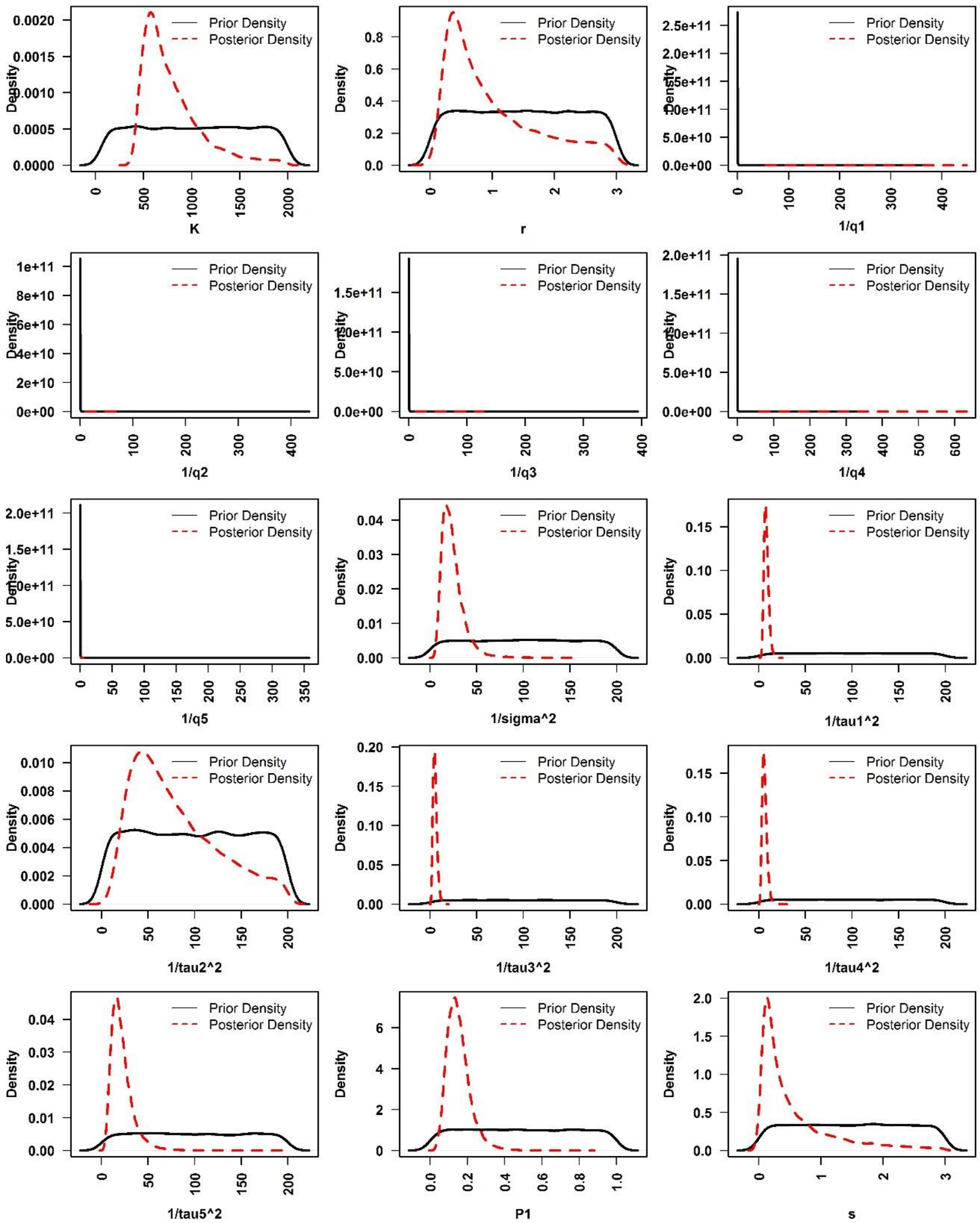


Figure CH7.1. Prior density (black solid lines) and posterior density (red dash lines) of model parameters from scenario 1.

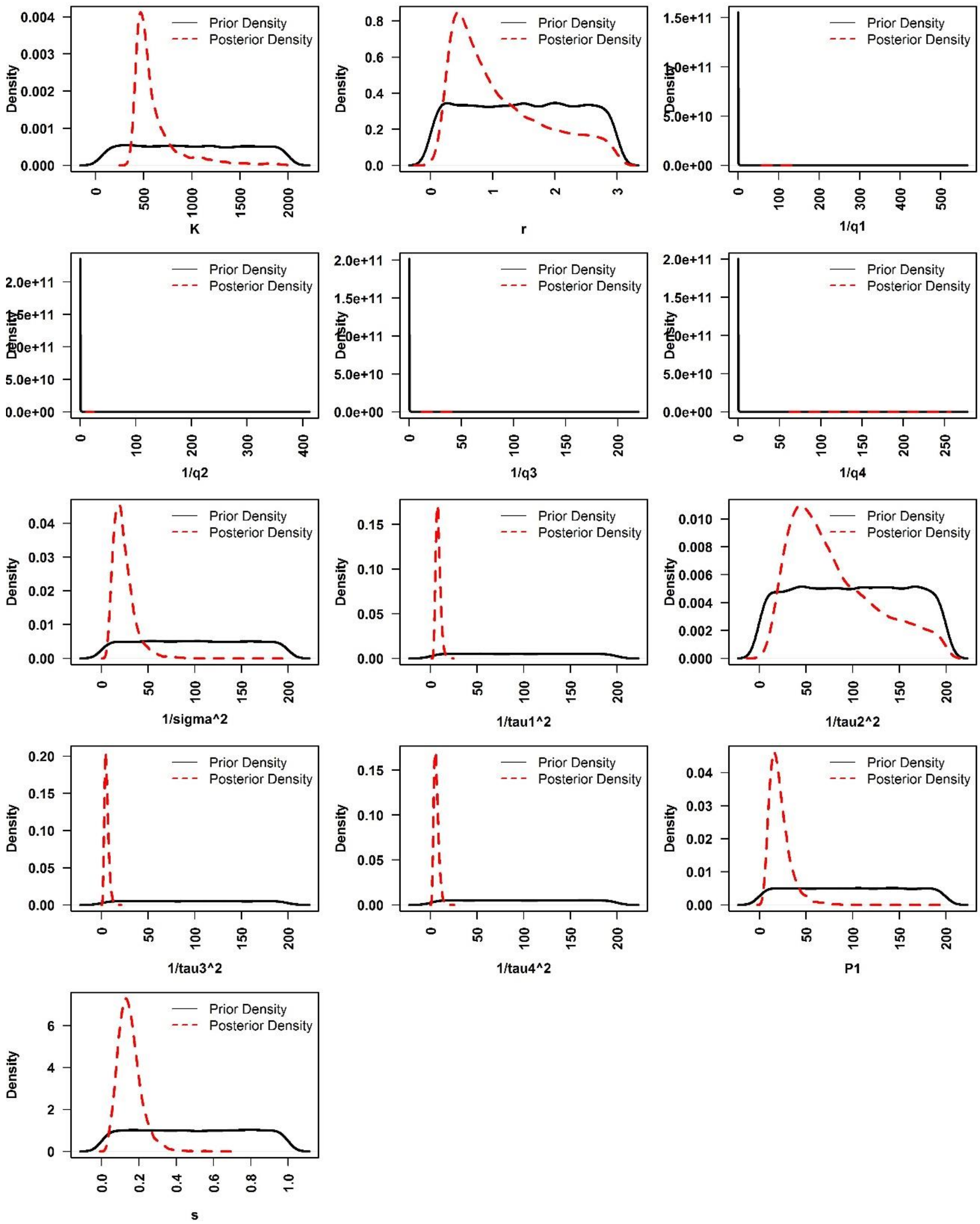


Figure CH7.2. Prior density (black solid lines) and posterior density (red dash lines) of model parameters from scenario 2.

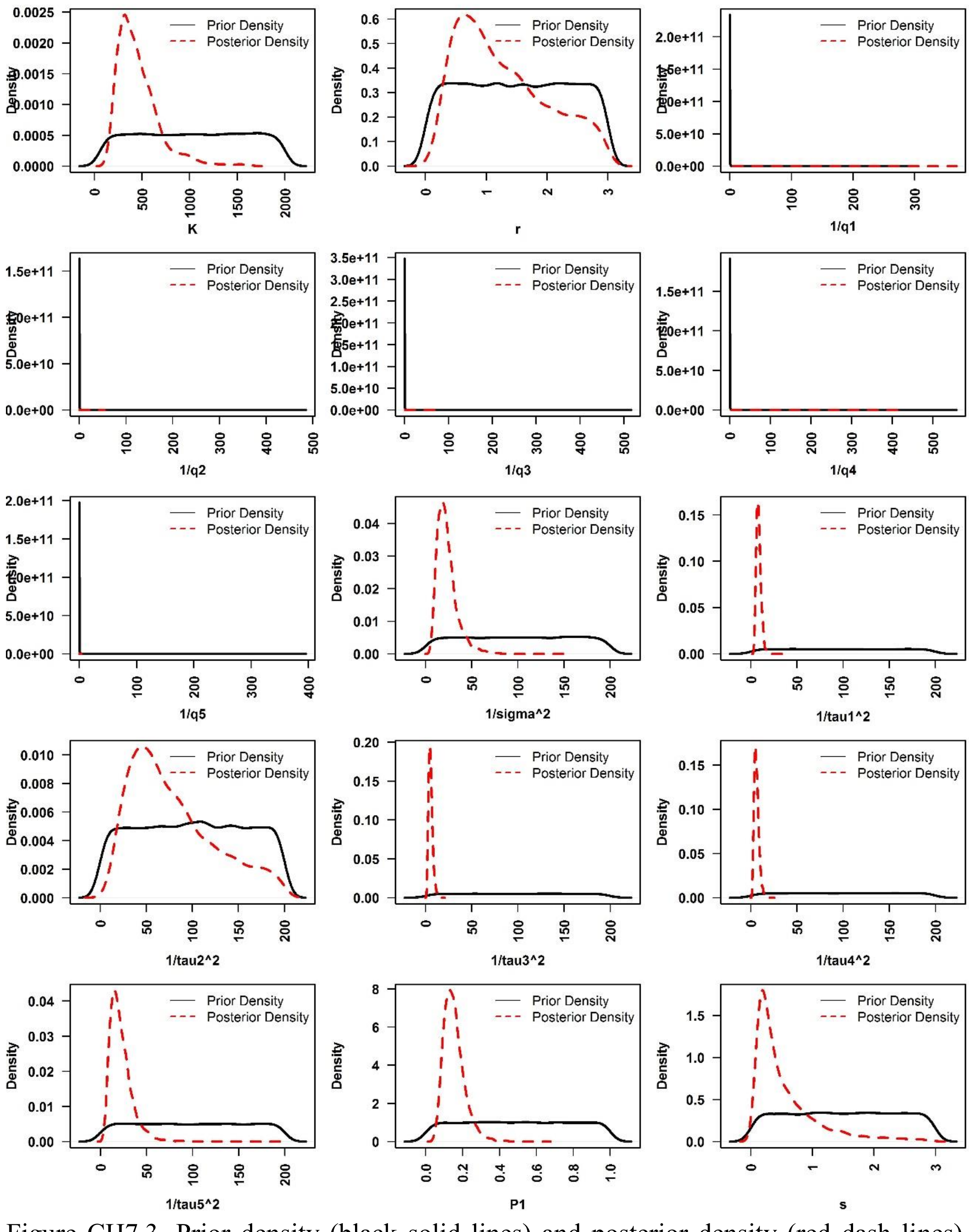


Figure CH7.3. Prior density (black solid lines) and posterior density (red dash lines) of model parameters from scenario 3.

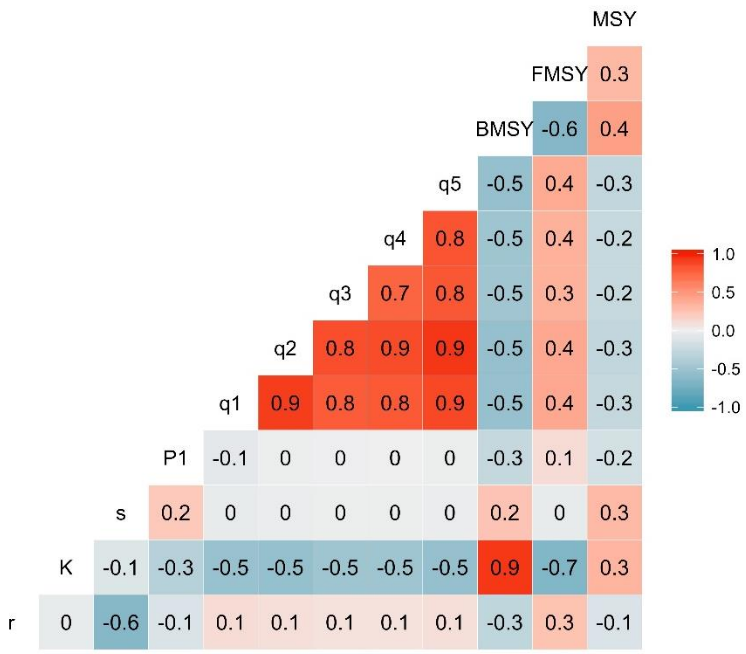


Figure CH7.4. Correlation matrix of posterior estimates for the scenario 1 model. Red background represents positive correlation and blue background represents negative correlation.

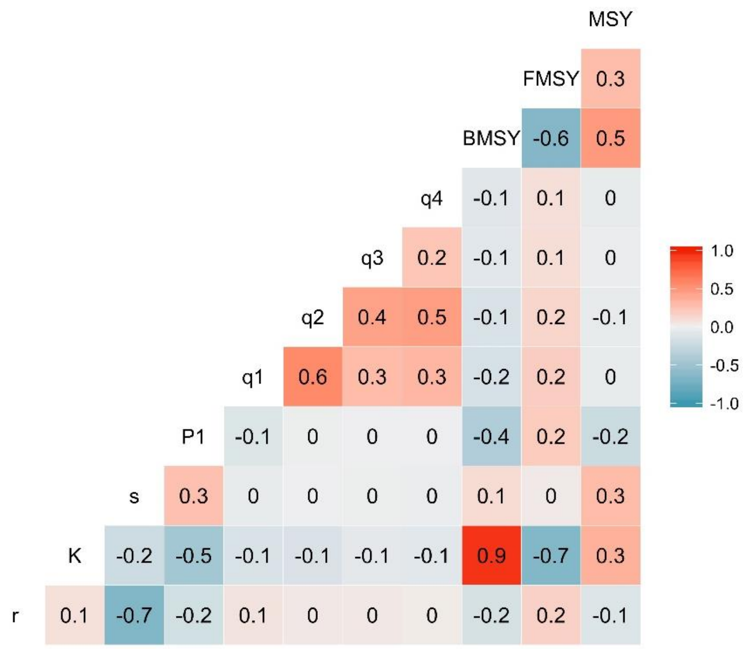


Figure CH7.5. Correlation matrix of posterior estimates for the scenario 2 model. Red background represents positive correlation and blue background represents negative correlation.

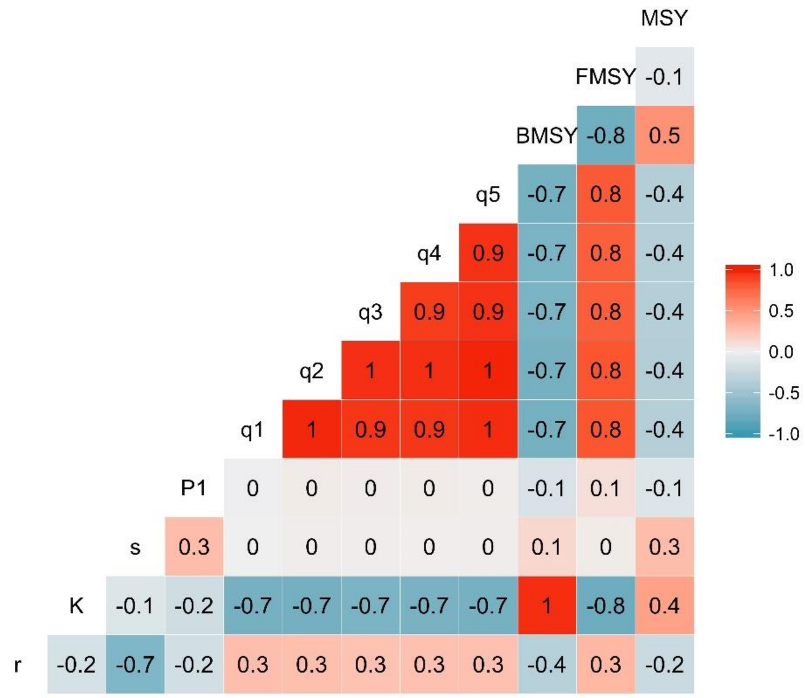


Figure CH7.6. Correlation matrix of posterior estimates for the scenario 3 model. Red background represents positive correlation and blue background represents negative correlation.

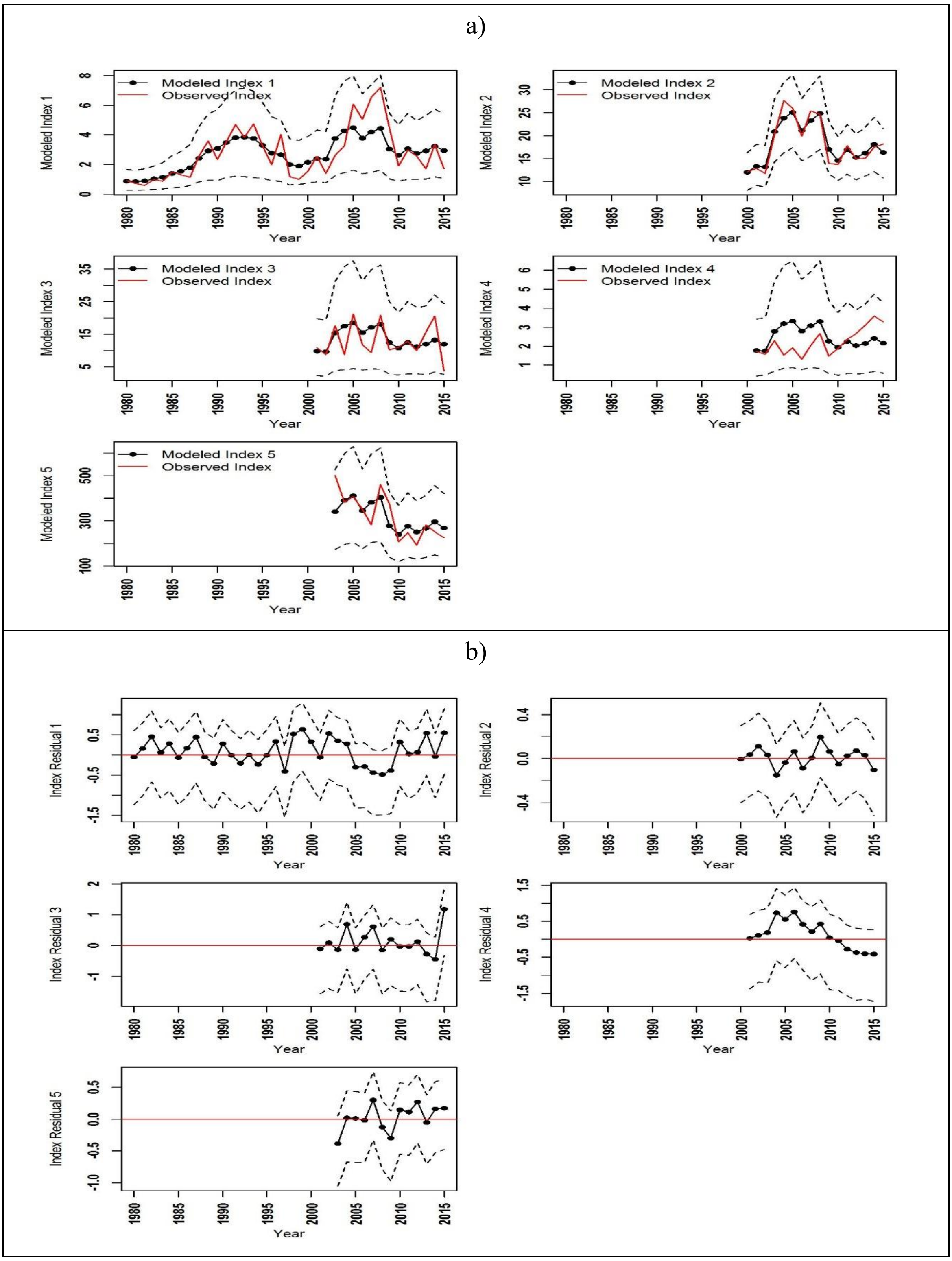


Figure CH7.7. (a) Temporal trend of observed and predicted CPUE indices and biomass index from scenario 1; (b) time-series of log-residuals of observed and predicted indices from scenario 1. Indices 1 to 5 represent CPUE indices from Japan, Russia, Korea, Chinese Taipei and biomass index from Japanese survey.

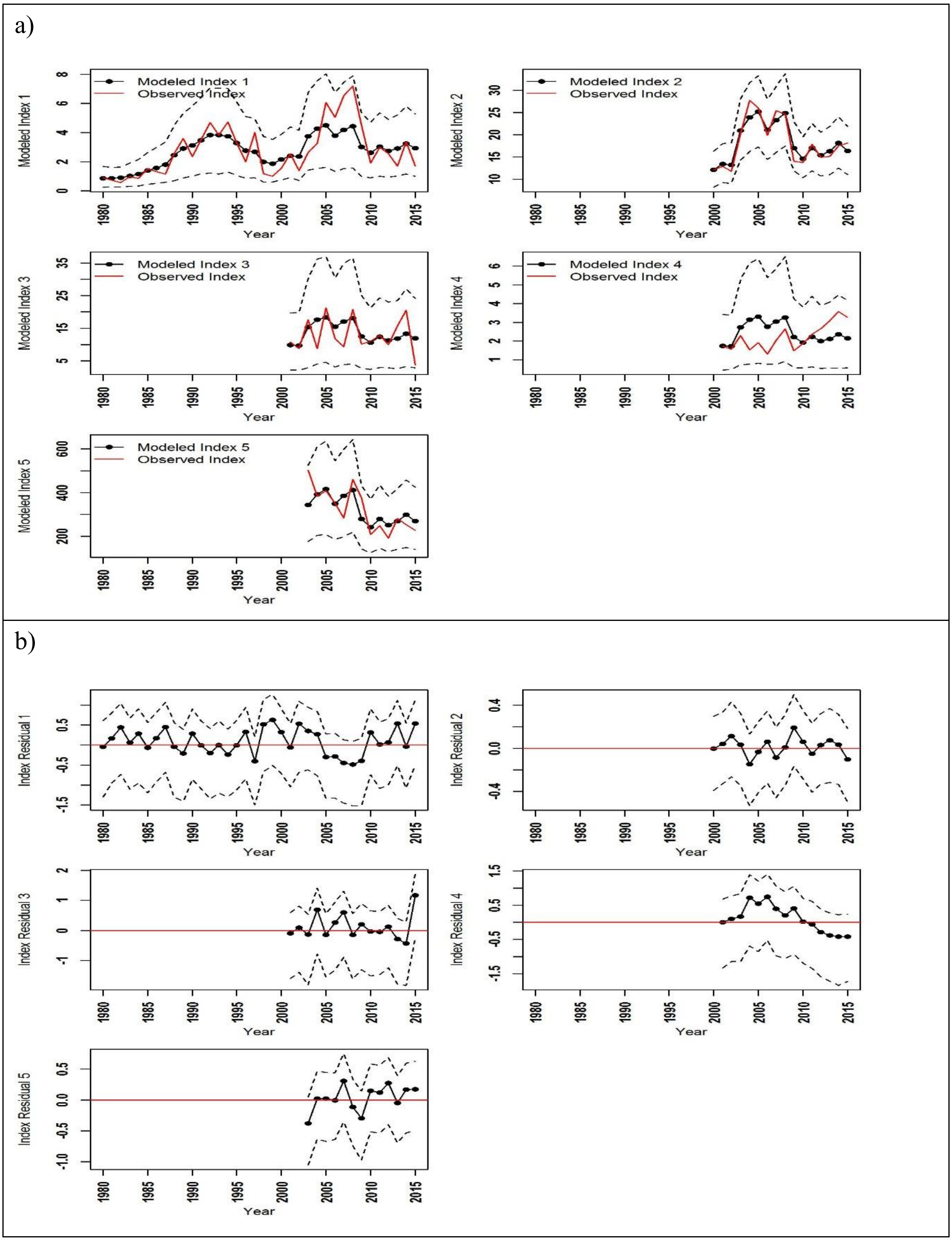


Figure CH7.8. (a) Temporal trend of observed and predicted CPUE indices and biomass index from scenario 2; (b) time-series of log-residuals of observed and predicted indices from scenario 2. Indices 1 to 5 represent CPUE indices from Japan, Russia, Korea, Chinese Taipei and biomass index from Japanese survey.

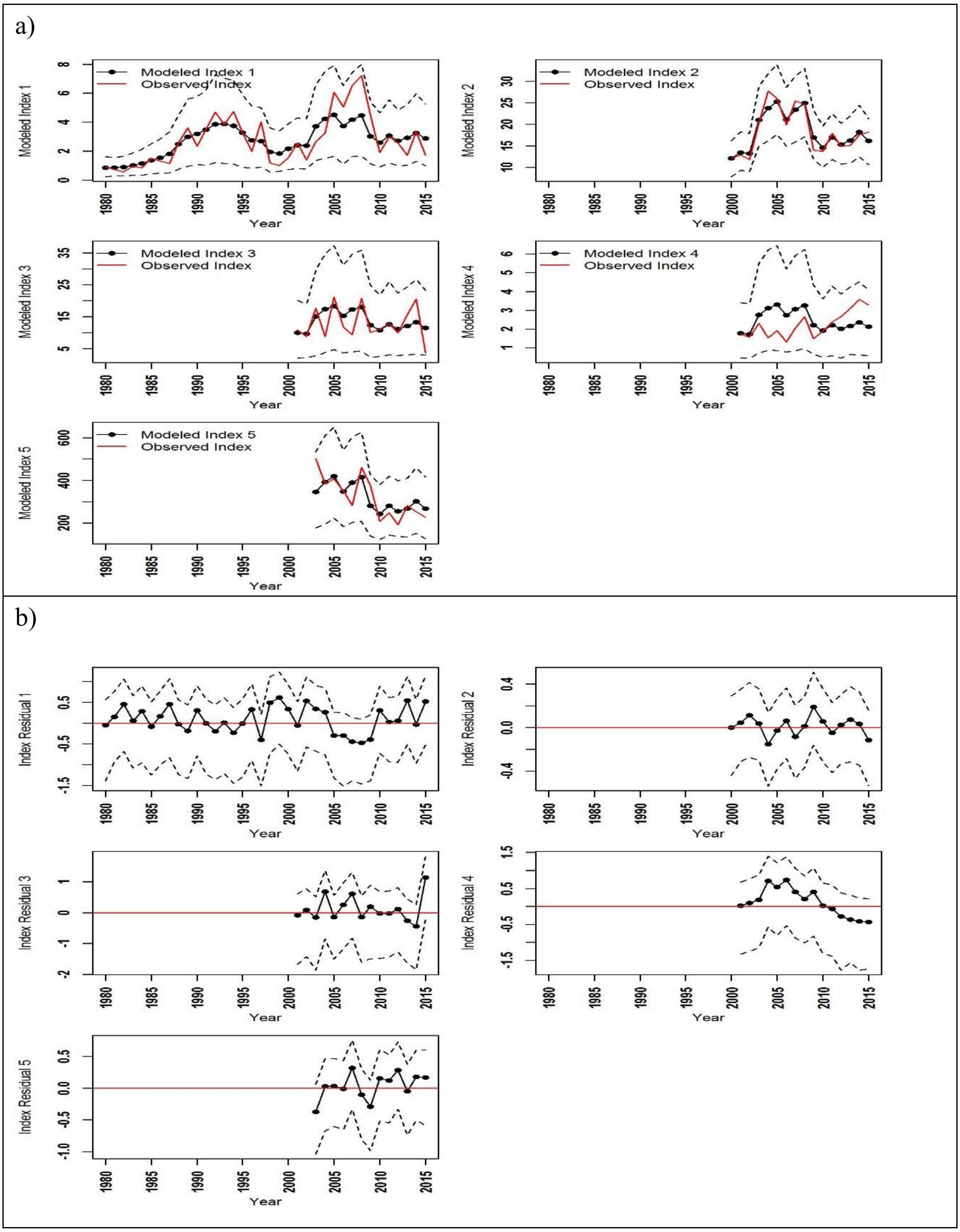


Figure CH7.9. (a) Temporal trend of observed and predicted CPUE indices and biomass index from scenario 3; (b) time-series of log-residuals of observed and predicted indices from scenario 3. Indices 1 to 5 represent CPUE indices from Japan, Russia, Korea, Chinese Taipei and biomass index from Japanese survey.

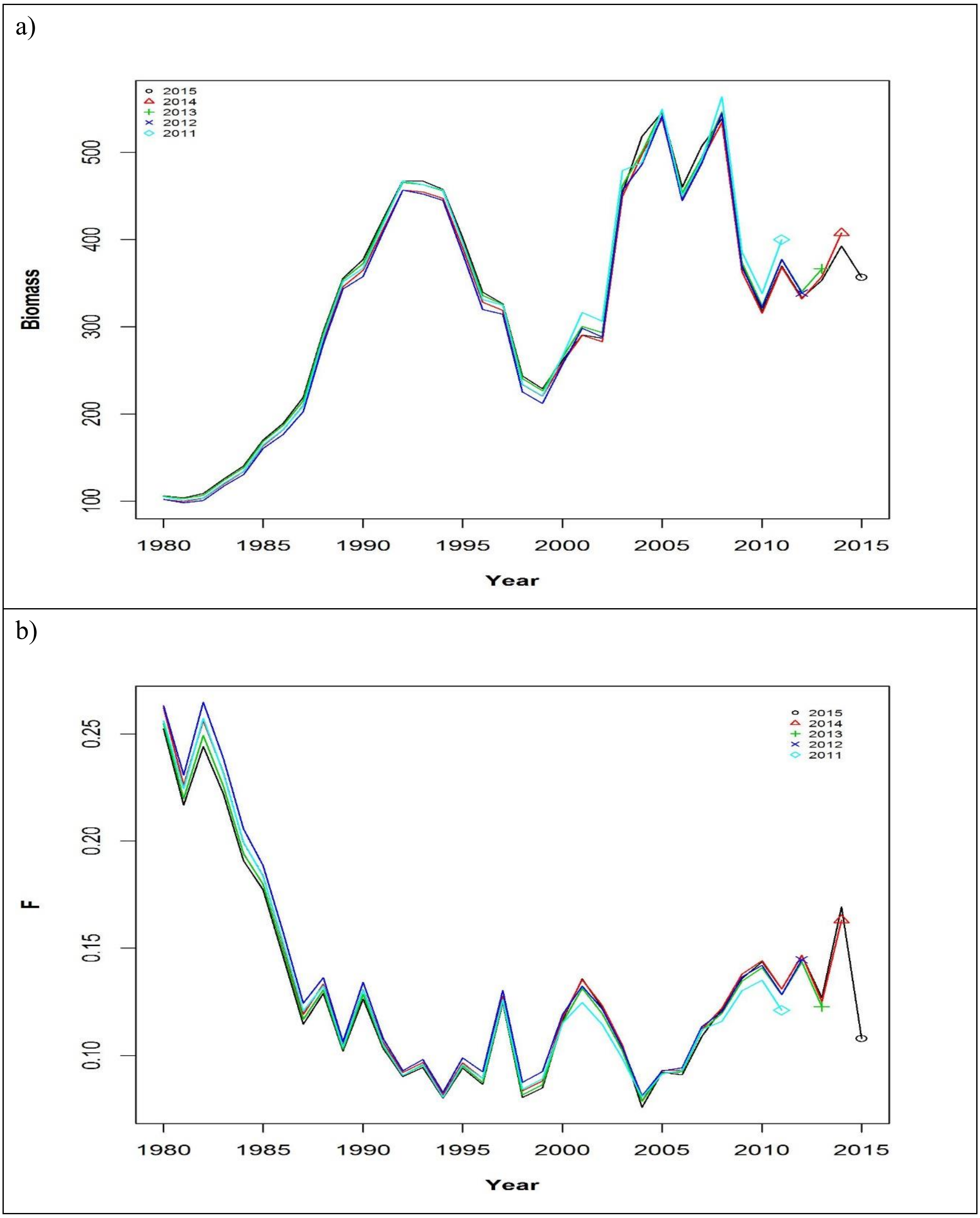


Figure CH7.10. Retrospective analysis from scenario 1 on changes in (a) exploitable biomass (×10000 mt) and (b) fishing mortality based on successive removals of five-year of assessment data and refits of the baseline production model.

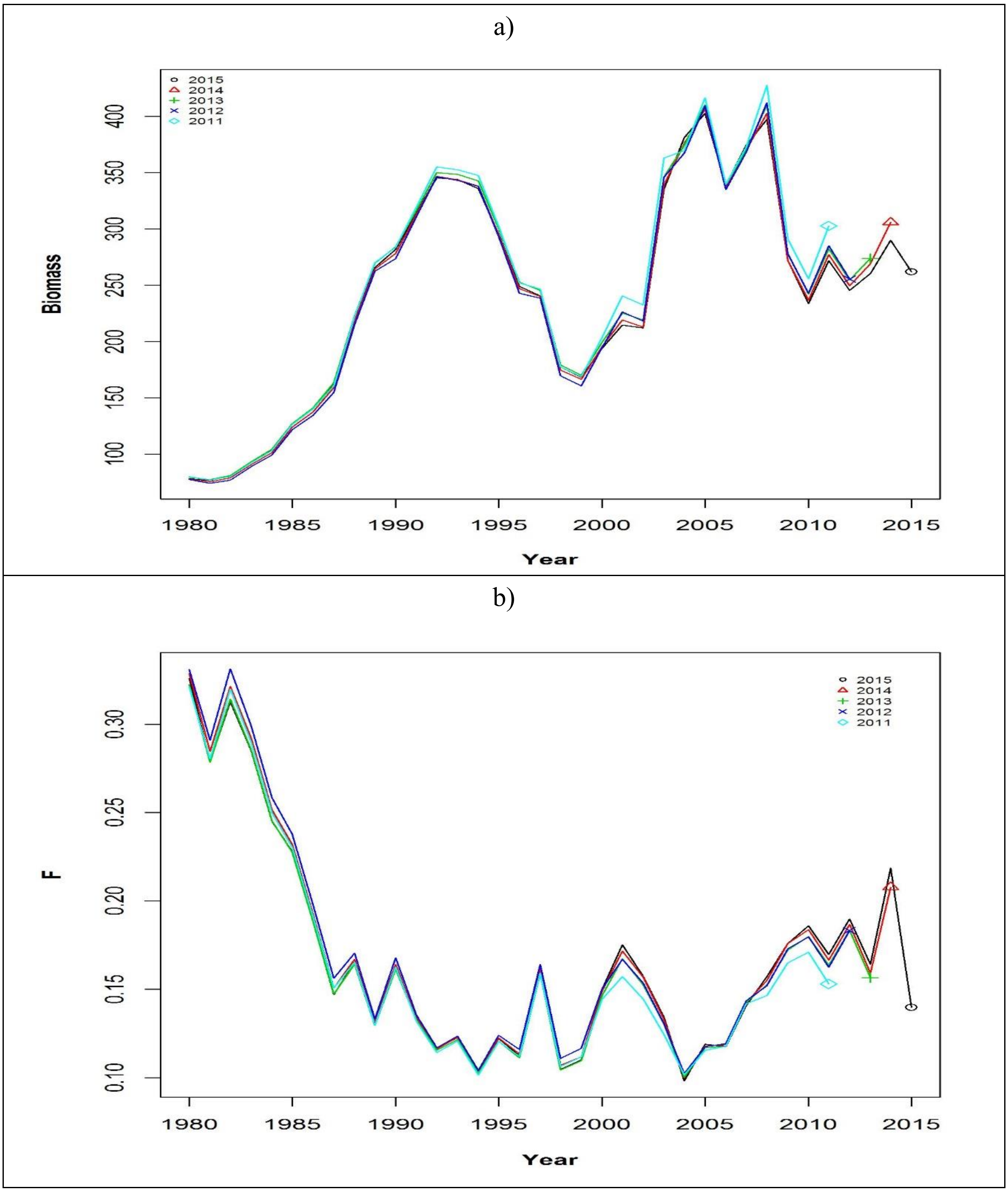


Figure CH7.11. Retrospective analysis from scenario 2 on changes in (a) exploitable biomass (×10000 mt) and (b) fishing mortality based on successive removals of five-year of assessment data and refits of the baseline production model.

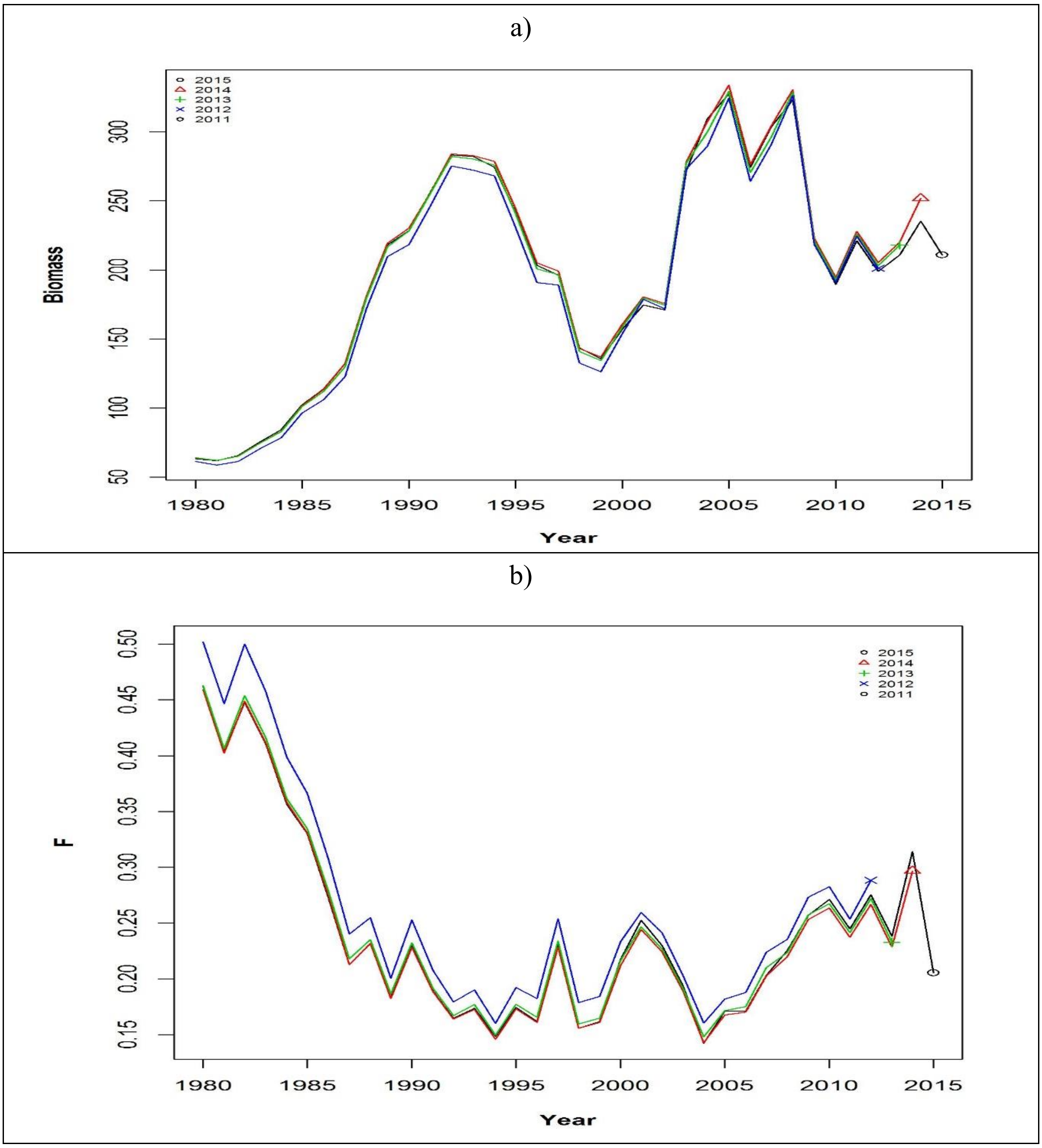


Figure CH7.12. Retrospective analysis from scenario 1 on changes in (a) exploitable biomass (×10000 mt) and (b) fishing mortality based on successive removals of five-year of assessment data and refits of the baseline production model.

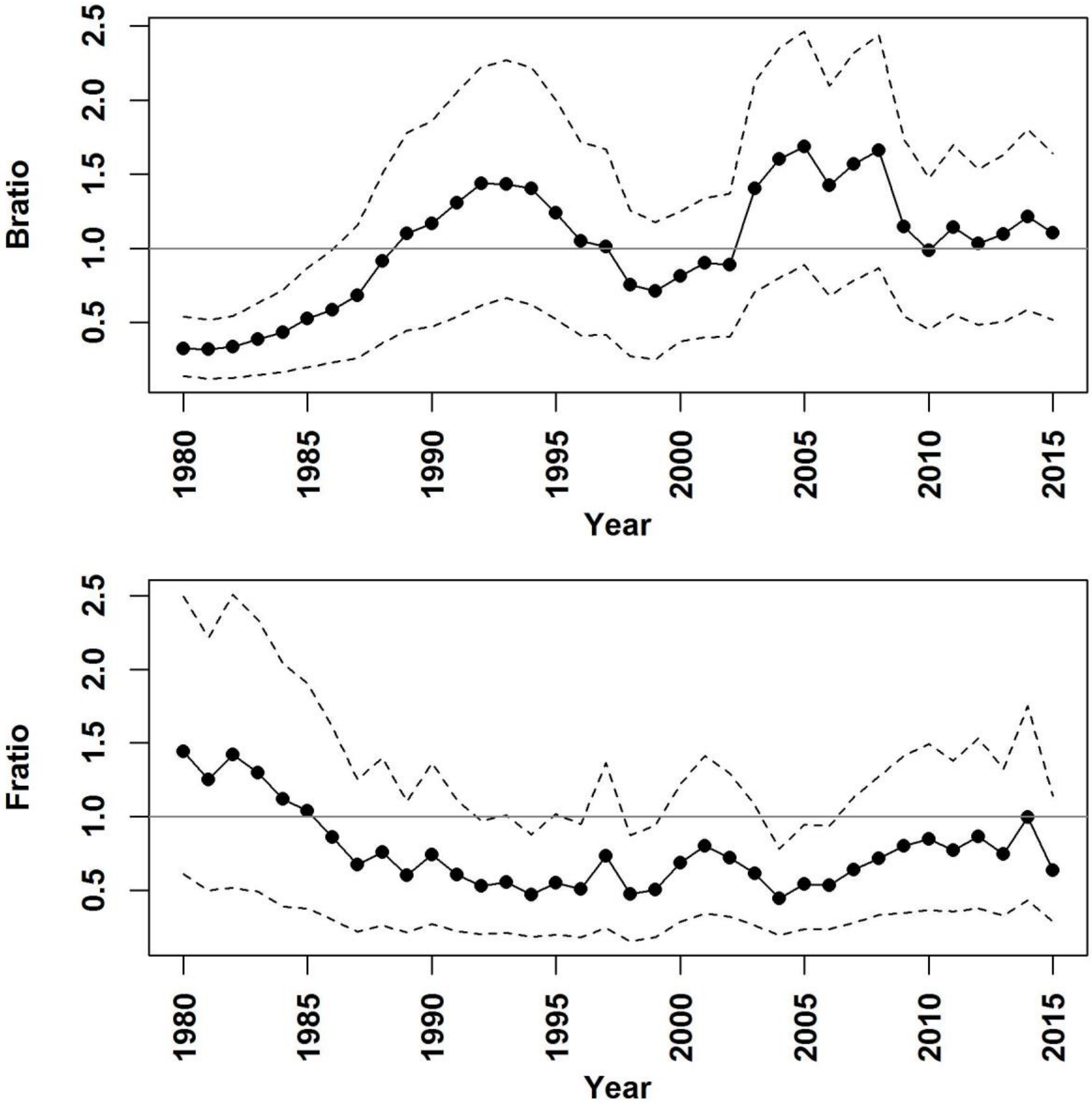


Figure CH7.13. Temporal trend of Bratio (B/B_{MSY}) and Fratio (F/F_{MSY}) from scenario 1. Estimated mean values from the posterior distribution (solid line) and 95% confidence interval (dash lines) are presented.

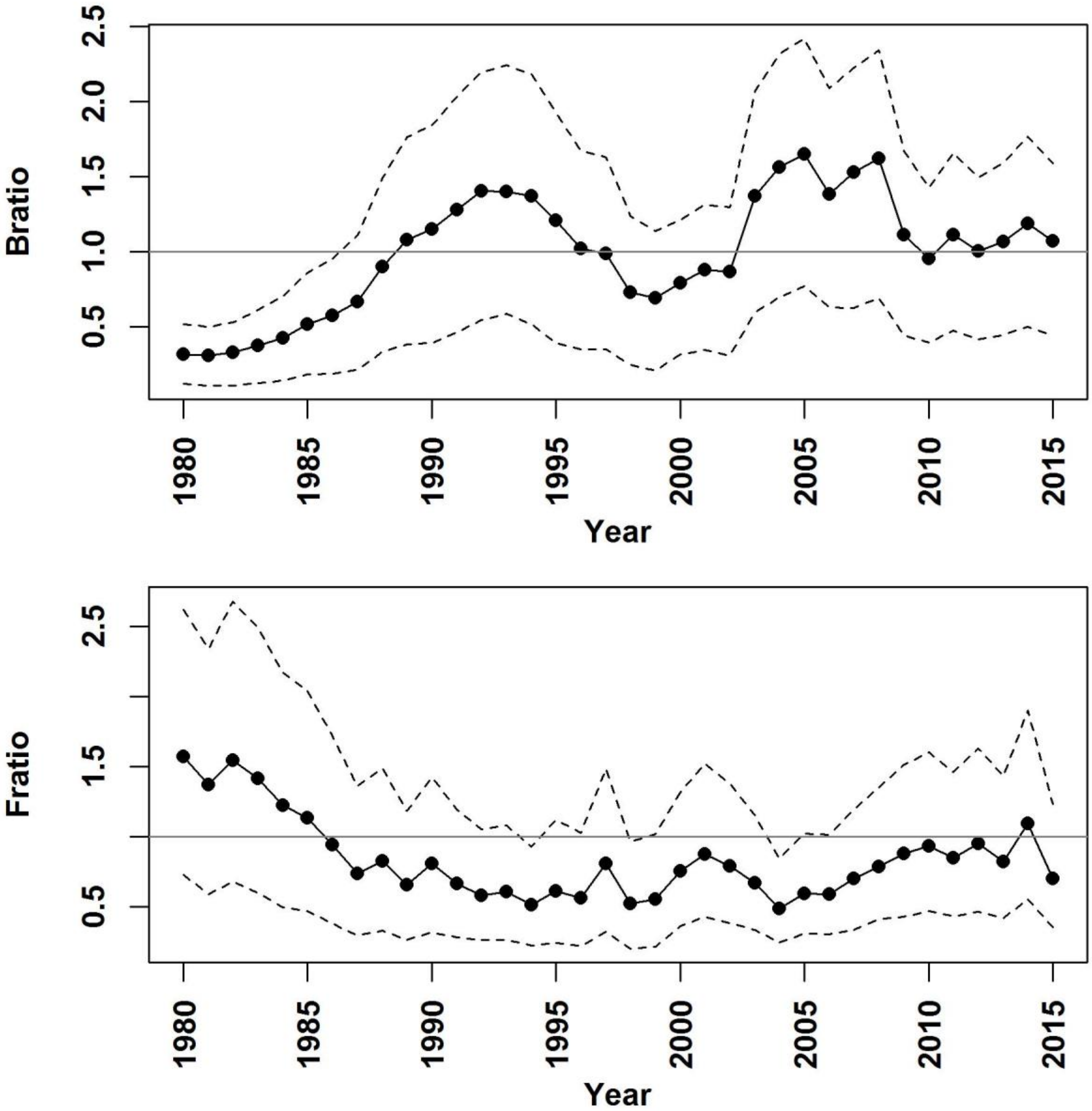


Figure CH7.14. Temporal trend of Bratio (B/B_{MSY}) and Fratio (F/F_{MSY}) from scenario 2. Estimated mean values from the posterior distribution (solid line) and 95% confidence interval (dash lines) are presented.

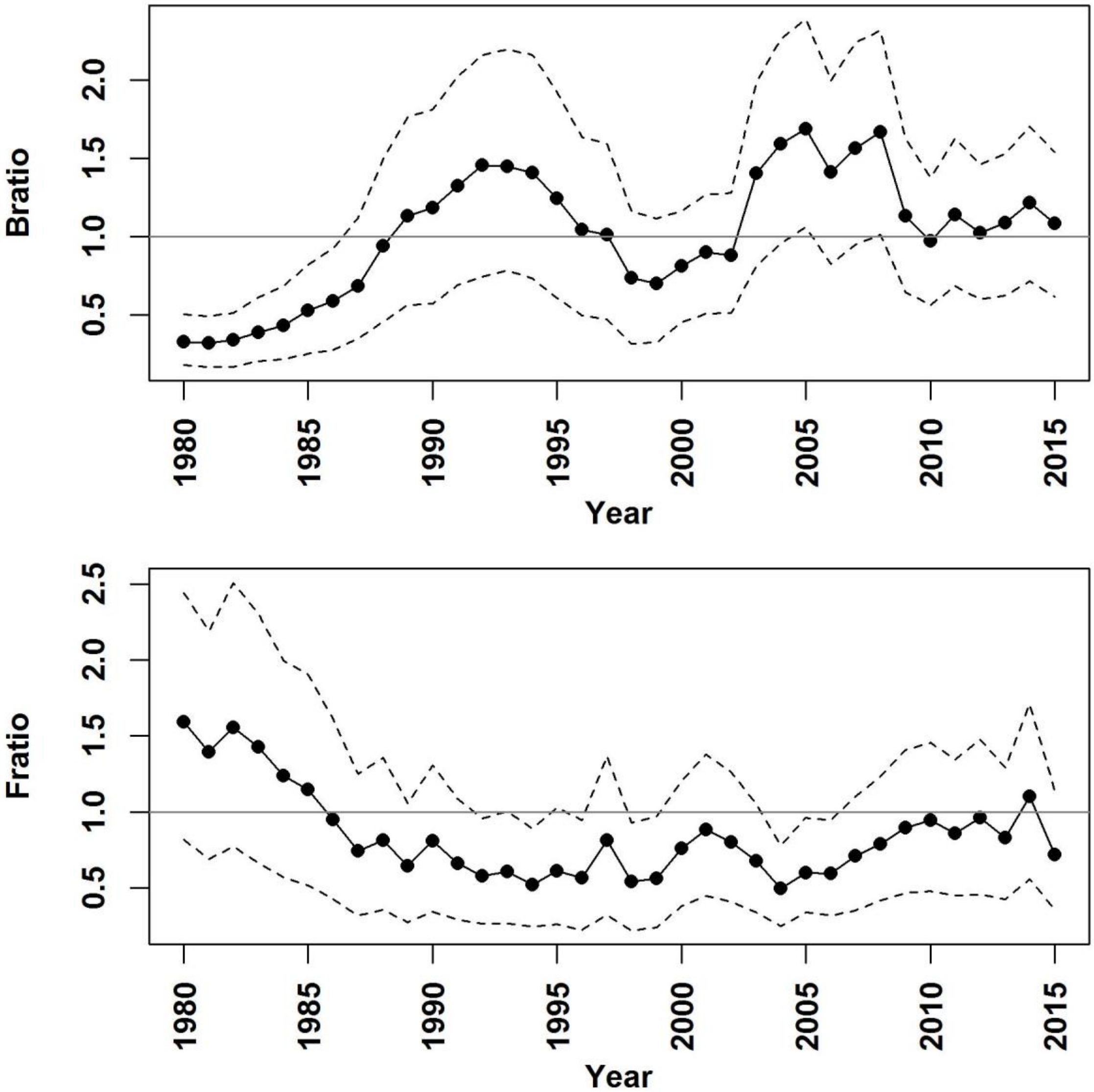


Figure CH7.15. Temporal trend of Bratio (B/B_{MSY}) and Fratio (F/F_{MSY}) from scenario 3. Estimated mean values from the posterior distribution (solid line) and 95% confidence interval (dash lines) are presented.

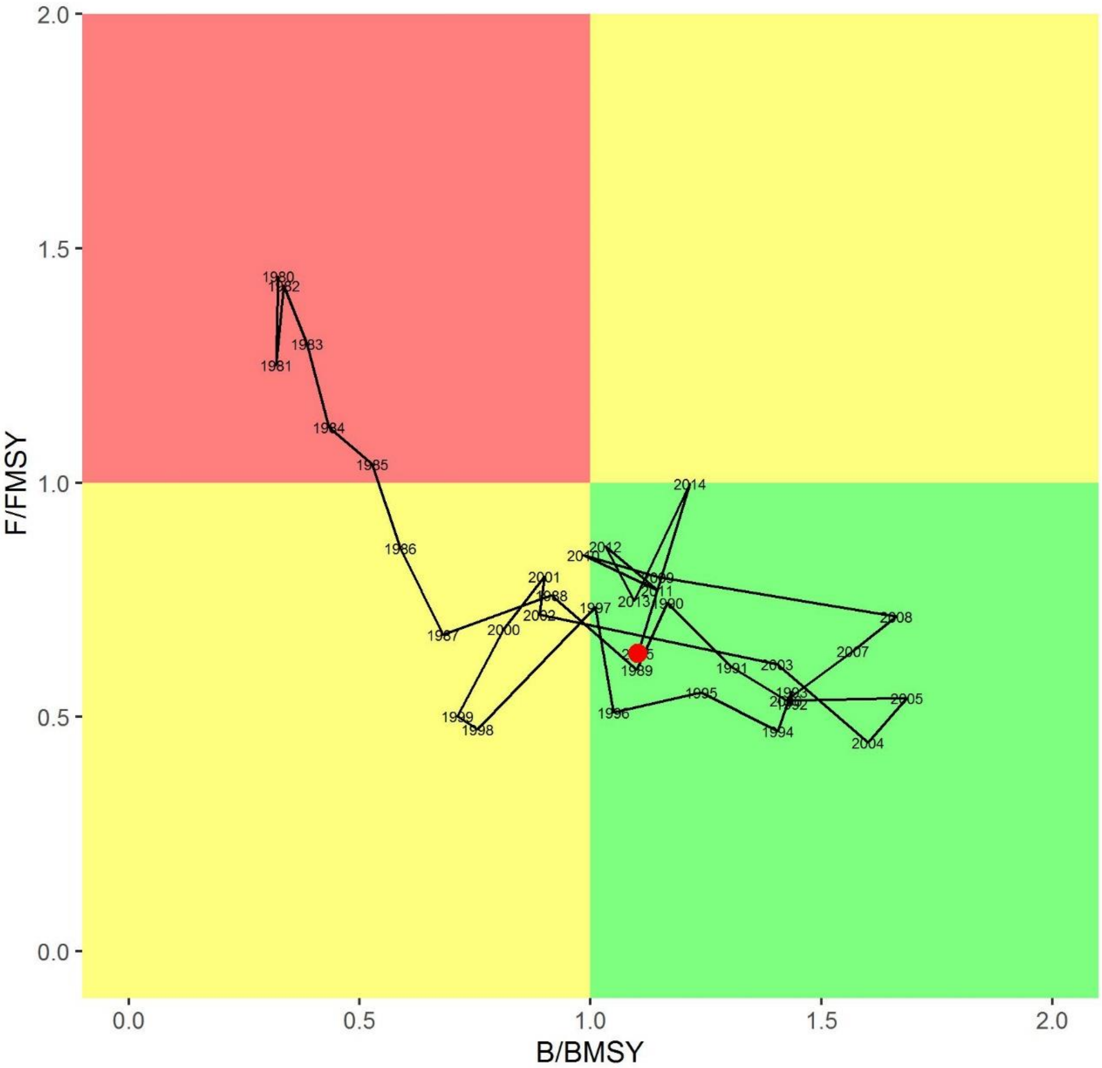


Figure CH7.16. Kobe diagram of scenario 1 shows the estimated trajectories of relative exploitable biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) of Pacific saury during 1980 to 2015. The red dot represents the stock status in 2015.

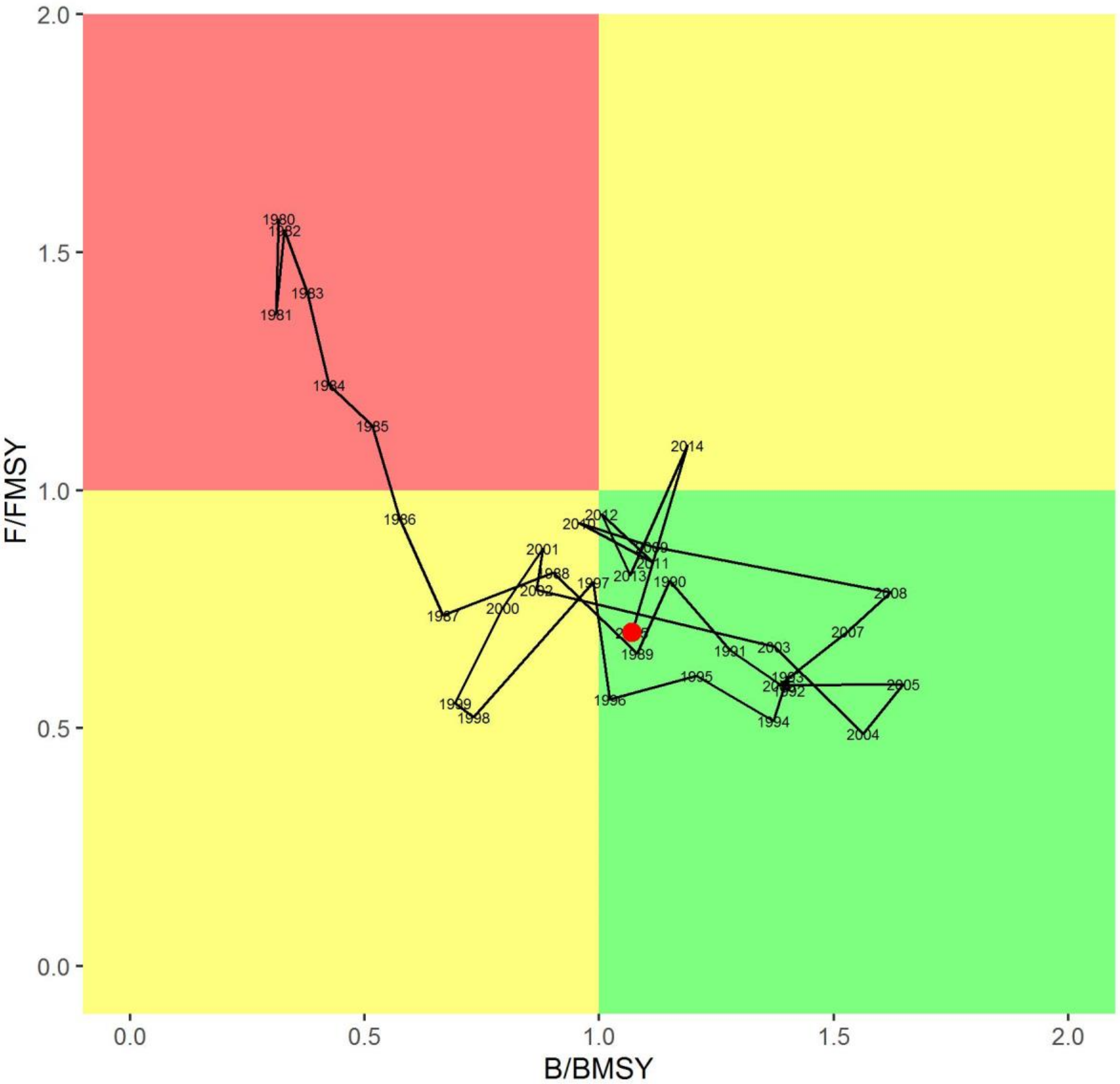


Figure CH7.17. Kobe diagram of scenario 2 shows the estimated trajectories of relative exploitable biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) of Pacific saury during 1980 to 2015. The red dot represents the stock status in 2015.

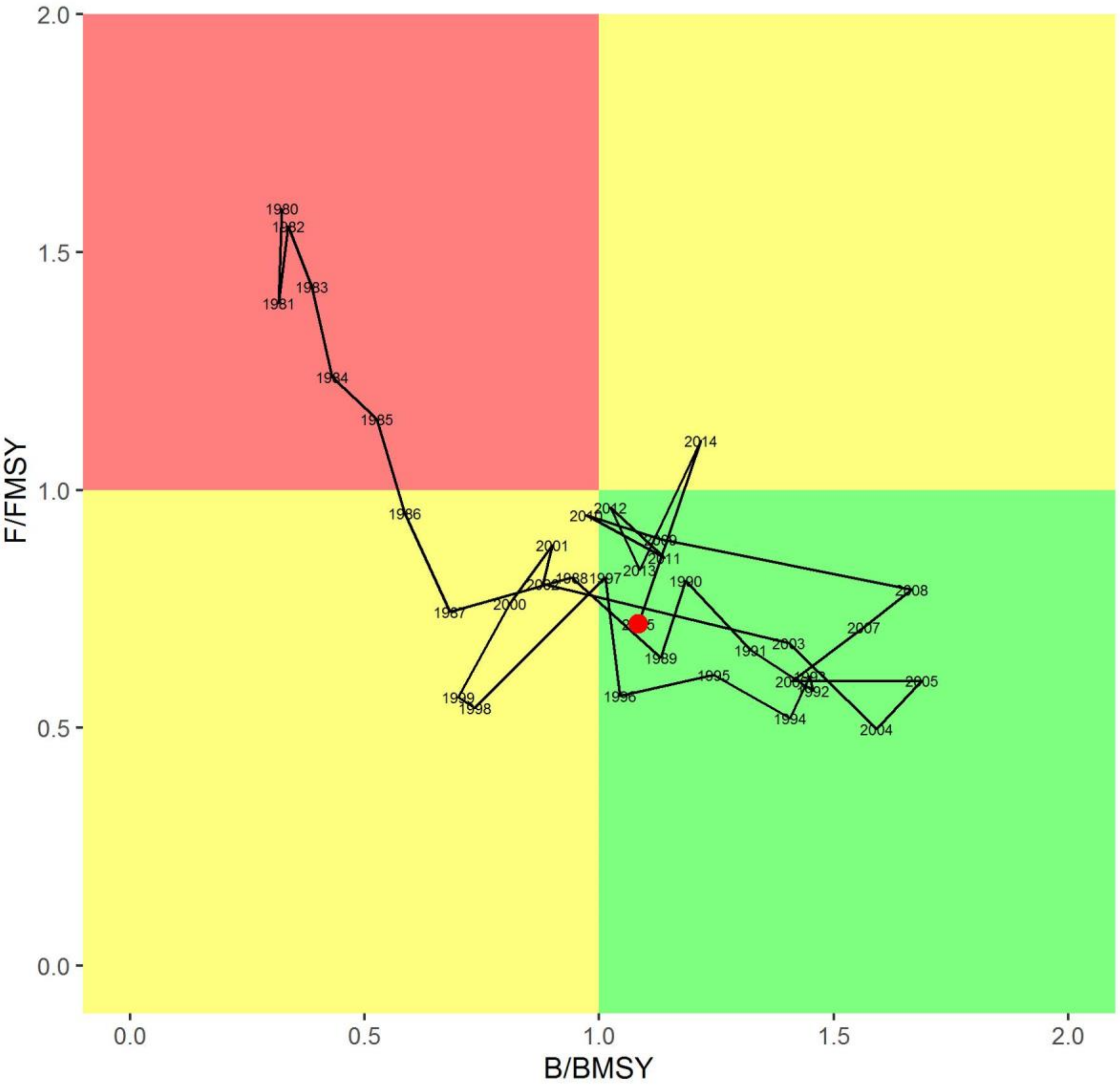


Figure CH7.18. Kobe diagram of scenario 3 shows the estimated trajectories of relative exploitable biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) of Pacific saury during 1980 to 2015. The red dot represents the stock status in 2015.

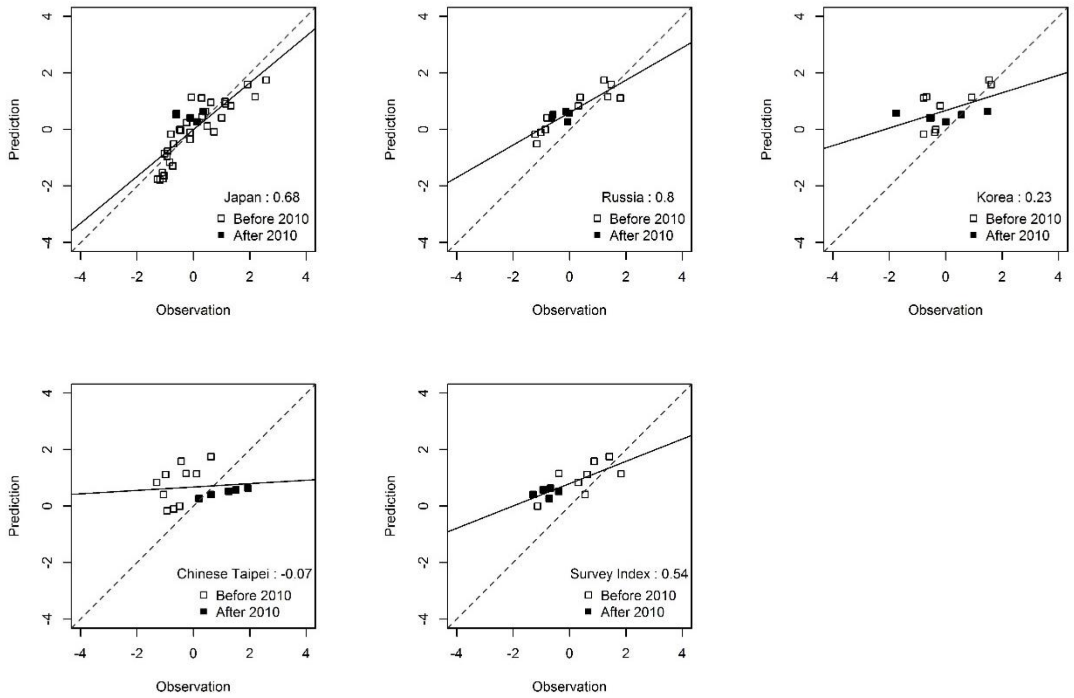


Figure CH7.19. Predicted relative biomass and observed CPUE indices and biomass index from different members under scenario 1. The values in the plots are adjusted R^2 from a linear regression model. The solid lines represent linear regression fit and the dash lines represent 1:1 line.

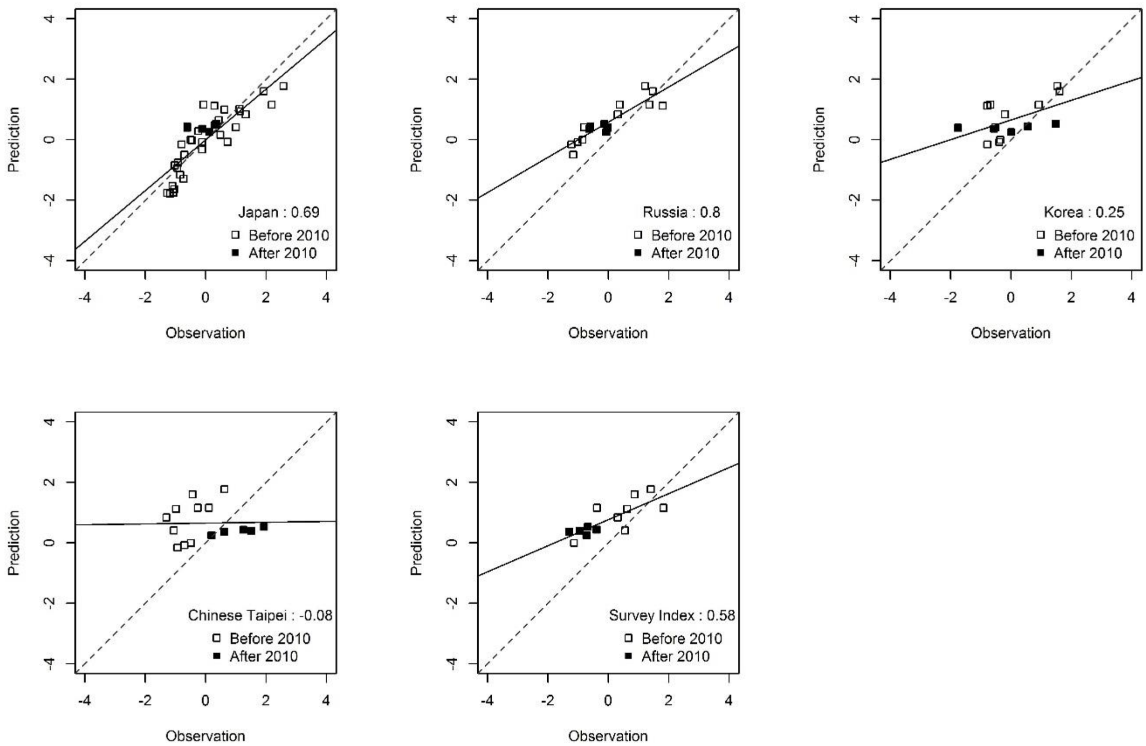


Figure CH7.20. Predicted relative biomass and observed CPUE indices and biomass index from different members under scenario 2. The values in the plots are adjusted R^2 from a linear regression model. The solid lines represent linear regression fit and the dash lines represent 1:1 line.

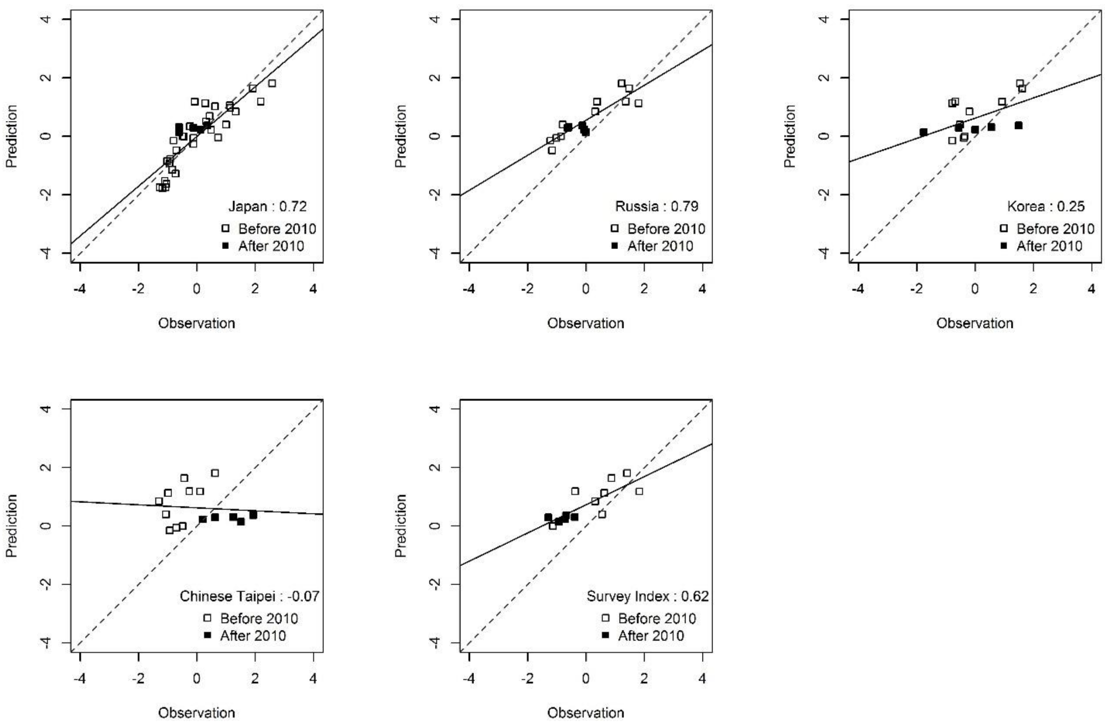


Figure CH7.21. Predicted relative biomass and observed CPUE indices and biomass index from different members under scenario 3. The values in the plots are adjusted R^2 from a linear regression model. The solid lines represent linear regression fit and the dash lines represent 1:1 line.

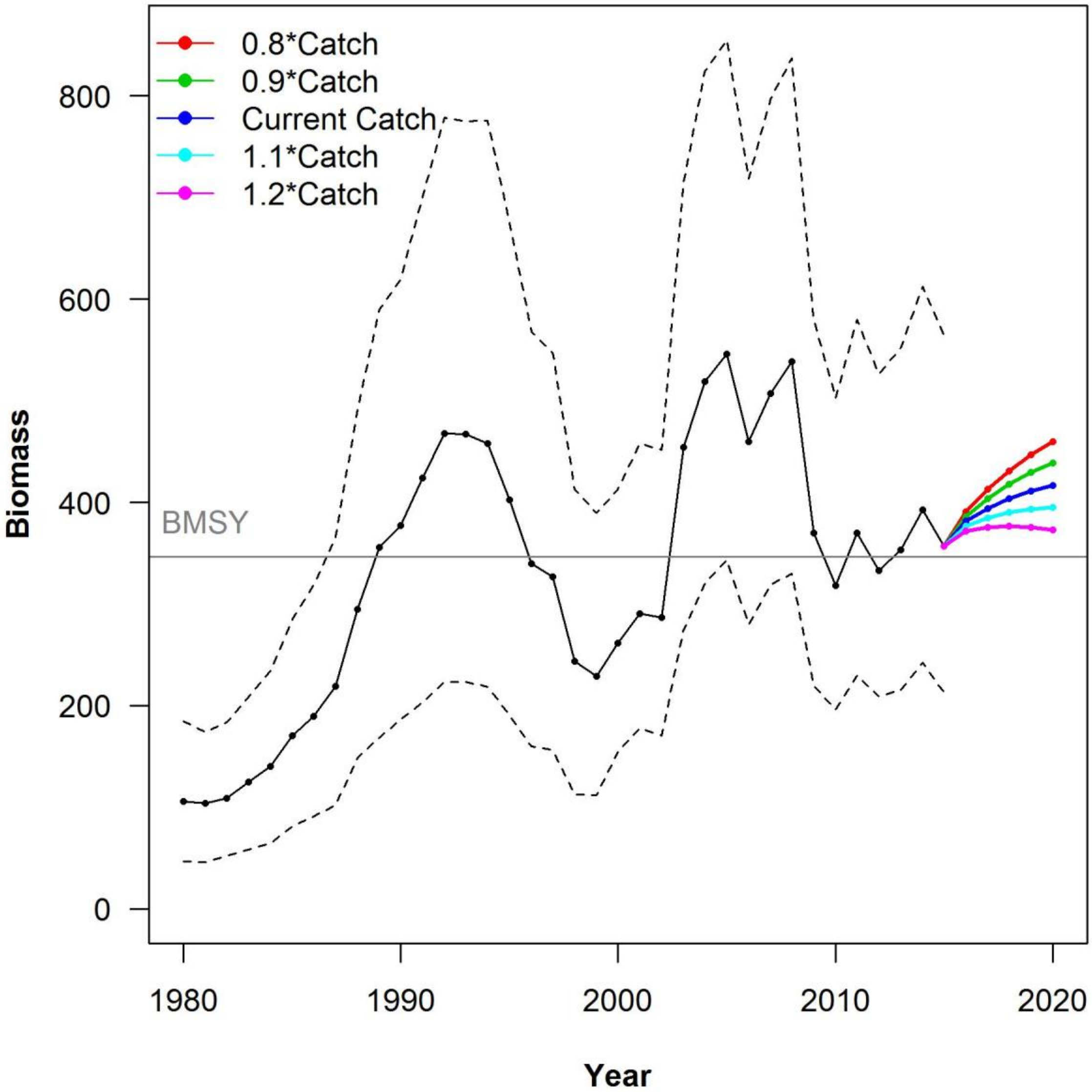


Figure CH7.22. Stochastic projection of expected exploitable biomass (×10000 mt) of Pacific saury during 2016 - 2020 under scenario 1 with alternative catches.

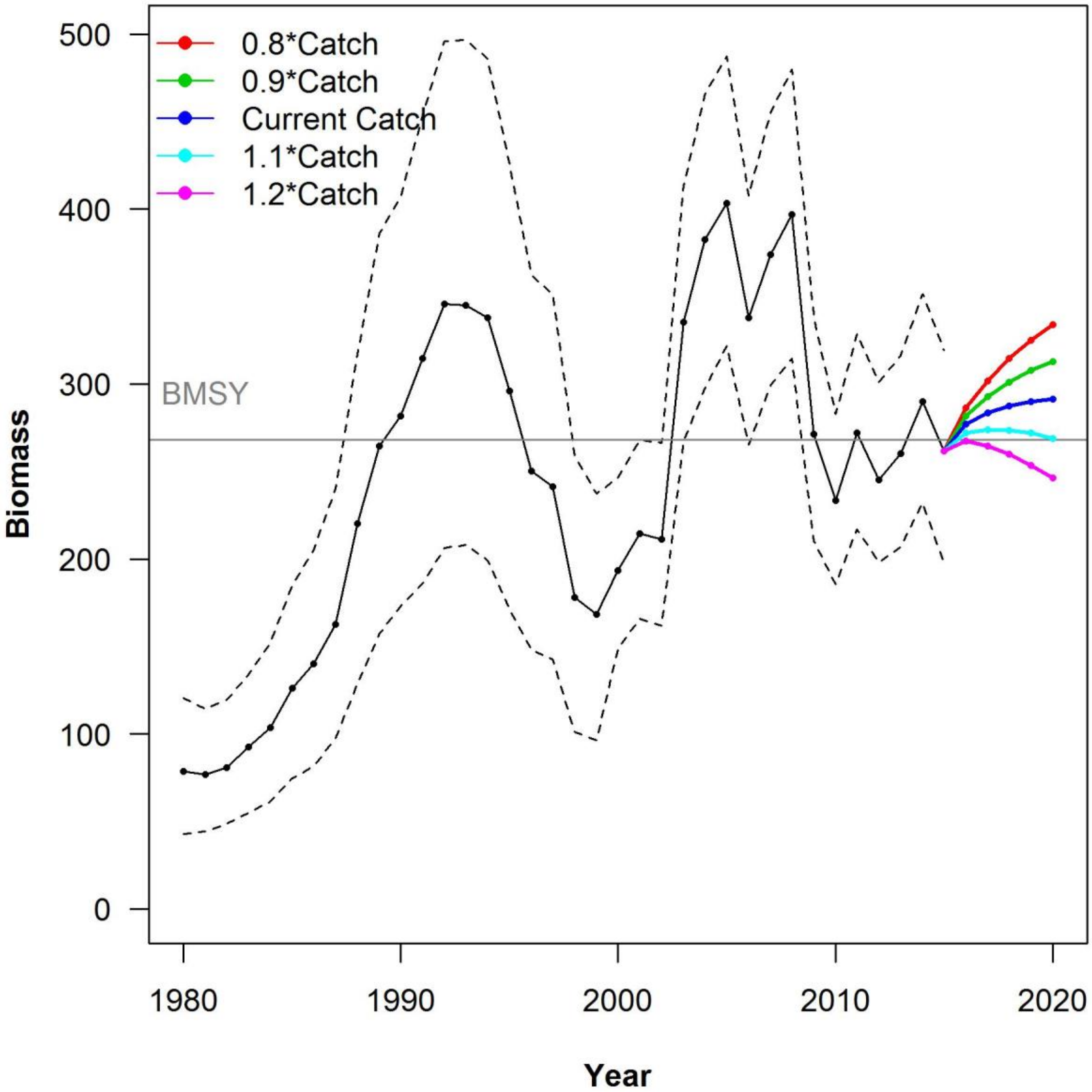


Figure CH7.23. Stochastic projection of expected exploitable biomass (×10000 mt) of Pacific saury during 2016 - 2020 under scenario 2 with alternative catches.

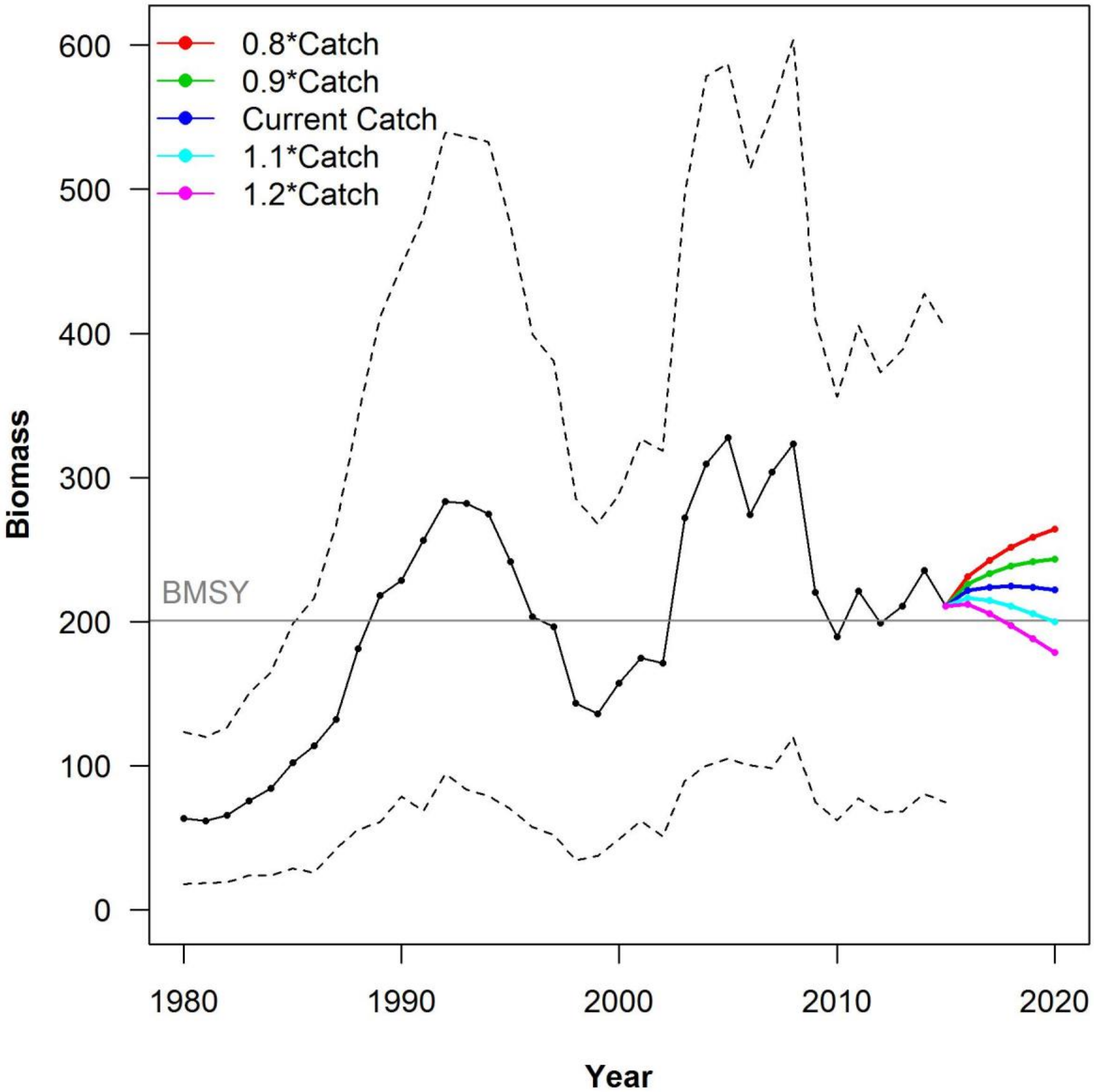


Figure CH7.24. Stochastic projection of expected exploitable biomass (×10000 mt) of Pacific saury during 2016 - 2020 under scenario 3 with alternative catc

2) Member stock assessment report: JAPAN

Stock assessment was conducted for the North Pacific saury (Kitakado et al. 2017, NPFC-2017-TWG PSAA01-WP07). Models employed in the analysis are the state-space biomass dynamic models. The models account for process and model errors in addition to observation errors in the biomass indices such as standardized CPUE series for commercial fisheries by Chinese Taipei, Japan, Korea and Russia, as well as fishery-independent survey by Japan. Given that the biomass indices observed are not synchronized possibly because of difference in spatial use of fishing and survey grounds, several options were considered for selection of the indices in the original analyses and developed a wide range of models/scenarios for assessing sensitivity to key assumptions such as types of production function, hyperstability/hyperdepletion, and priors.

In discussion of the 2017 February meeting, TWG PSSA agreed on the dataset and specification of assessment for the Pacific saury stock assessment group. Here, results of analyses were shown to meet the agreement.

The population dynamics is modelled by the following equations:

$$B_t = \left\{ B_{t-1} + B_{t-1} f(B_{t-1}) - C_{t-1} \right\} e^{u_t}, \quad u_t \sim N(0, \tau^2)$$
$$f(B_t) = r\left[1 - \left(\frac{B_t}{K}\right)^z\right]$$

where

B_t : the biomass at the beginning of year t
C_t : the total catch of year t
u_t : the process error in year t
$f(B)$: the production function (Pella-Tomlinson)
r : the intrinsic rate of natural increase
K : the carrying capacity
z: the degree of compensation

The multiple biomass indices are modelled as follows:

$$I_{t,f} = q_f B_t \exp(v_{t,f})$$
$$v_{t,f} \sim N(0, \sigma_f^2)$$

where

$I_{t,f}$: the biomass index in year *t* for biomass index *f*

q_f : the catchability coefficient for biomass index *f*

$v_{t,f}$: the error term (sum of model and observation errors) in year *t* for biomass index *f*

σ_f^2 : the observation error in year *t* for biomass index *f*

Parameters in the models were estimated via Bayesian methods with a Markov chain Mote Carlo simulation. With respect to prior distribution, independent flat priors were used as non-informative priors as default (Figure JPN-1).

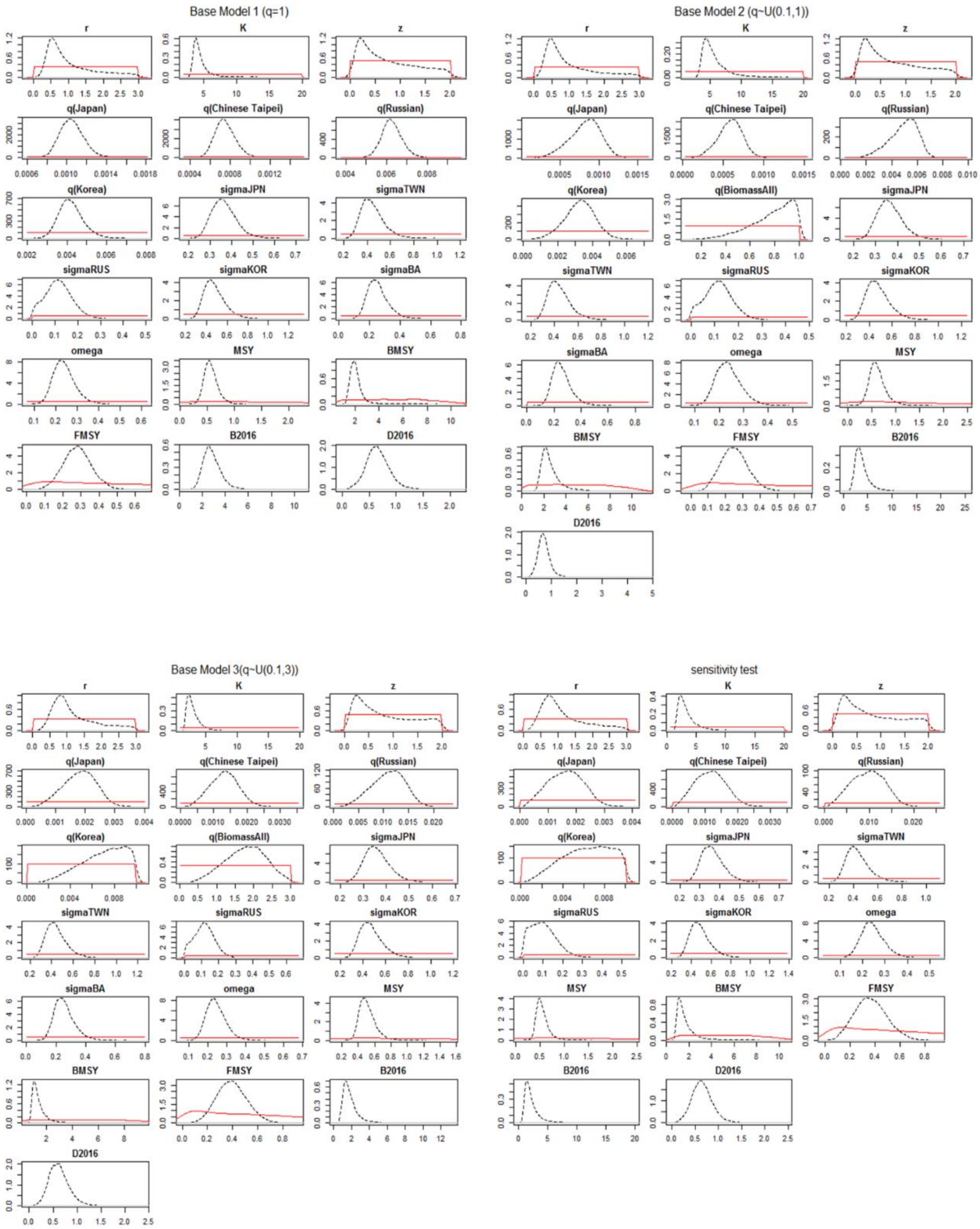


Figure JPN-1. Prior and posterior distributions for key parameters and management quantities under three base case scenarios (and sensitivity run).

(1) Assessment results for the base-case scenarios

Results for the three base scenarios were shown in Figure JPN-2, where estimated median trajectories (and 95% credible intervals) for population biomass and depletion level (biomass relative to the carrying capacity) under the three base case scenarios were presented. The results showed that the biomass level is currently above the level of MSY for any scenarios.

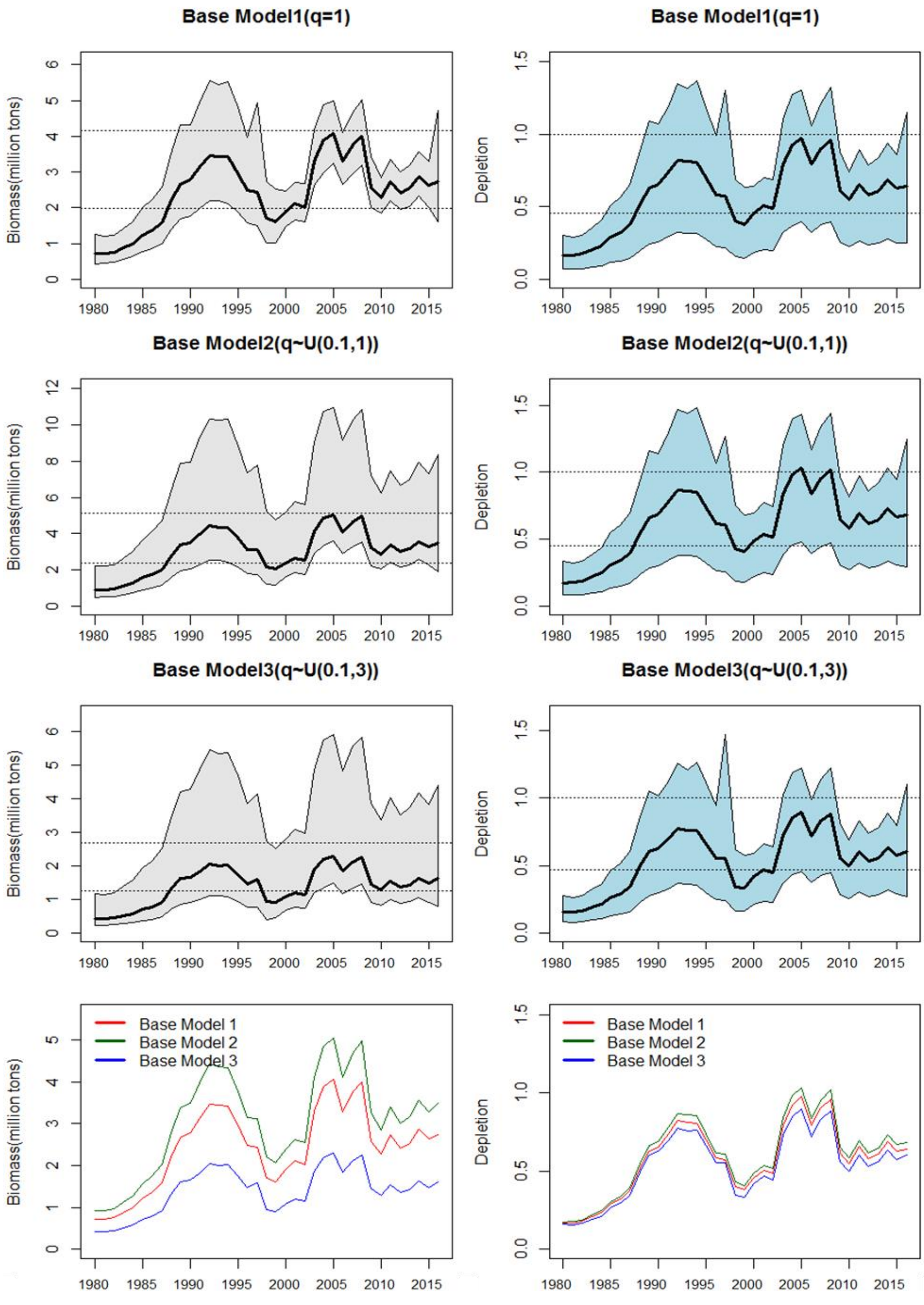


Figure JPN-2. Estimated median trajectories (and 95% credible intervals) for population biomass and depletion level (biomass relative to the carrying capacity) under the three base case scenarios. The two horizontal lines show the MSY level and carrying capacity.

(2) Diagnostics and caveats

The models were diagnosed with respect to shapes of posterior distributions (see Figure JPN-1), residual plots (see Figure JPN-3) and retrospective pattern (see Figure JPN-4). Standardized residual plots showed that the residuals are almost perfectly within the 95% range and the variance is homogeneous across years.

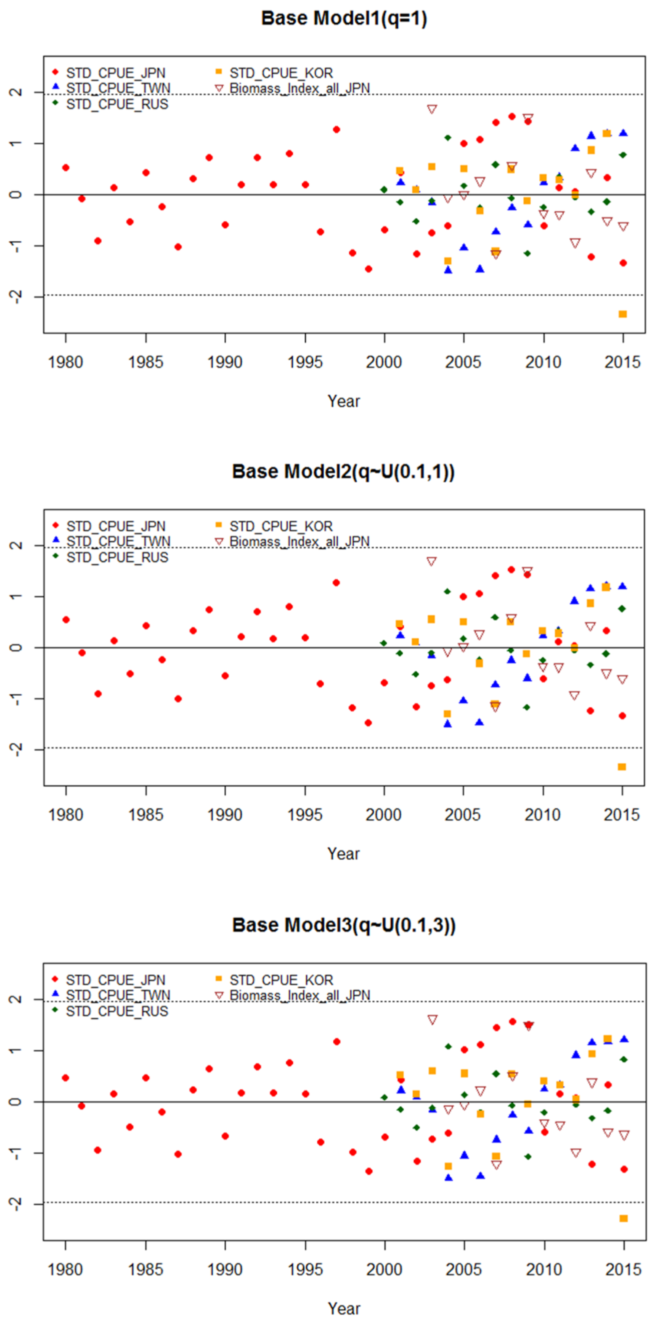


Figure JPN-3. Residual plots for CPUE and fishery-independent survey biomass index.

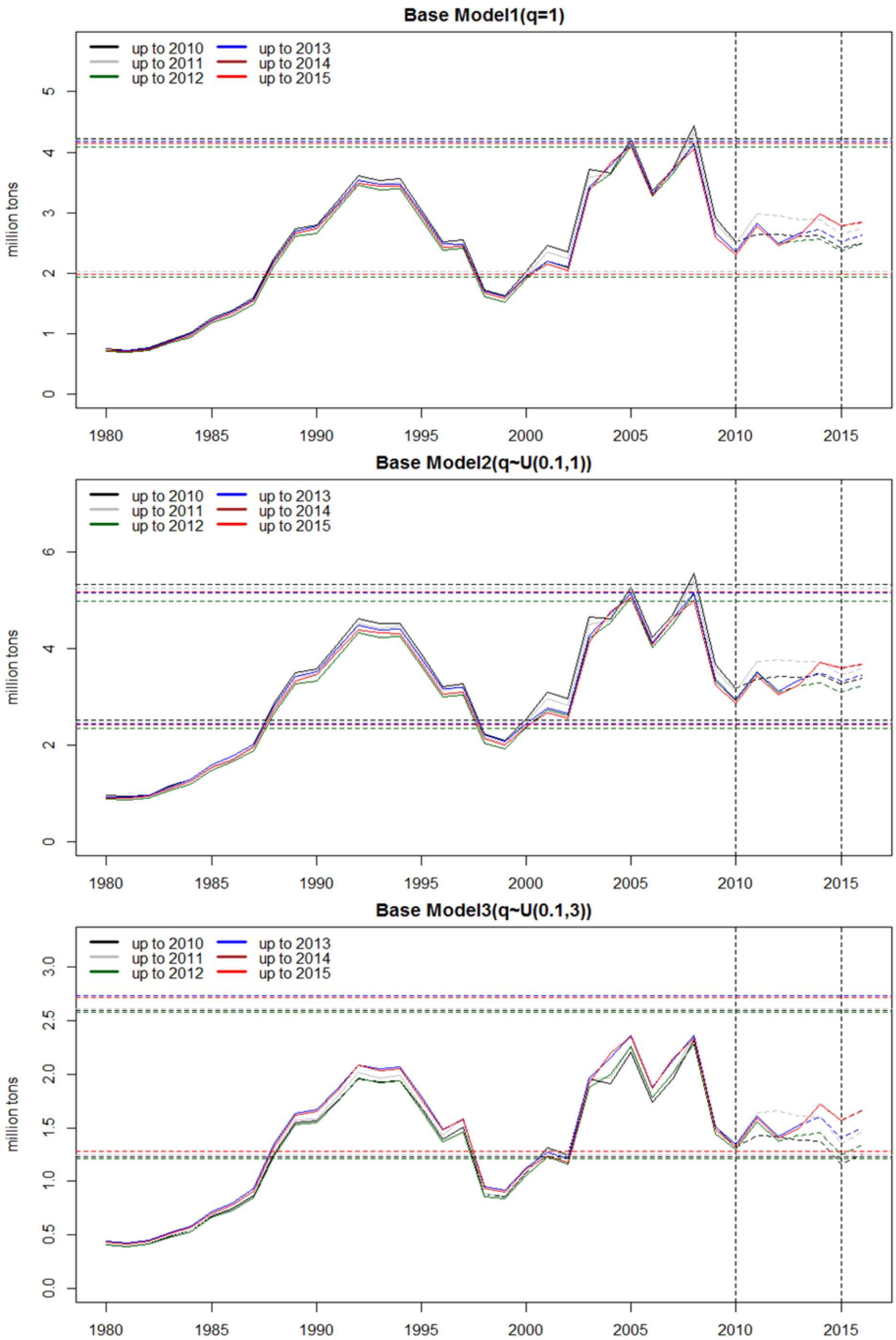


Figure JPN-4. Results of retrospective analysis. The solid lines are the median trajectories, and the horizontal lines are the median of carrying capacity and MSY level under different data period to be used. The horizontal lines show MSY level and carrying capacity and the vertical ones indicates the maximum range of retrospective period.

(3) Biological reference points

Table JPN-1 summarized the estimates of key parameters and management quantities for the base case scenarios. In addition, Table JPN-2 showed the mean, median and cv of yearly biomass for the base cases. Similar tables (Tables JPN-3 and -4) are shown for the sensitivity test, where no biomass information was used.

Table JPN-1. Summary of parameter estimates and management quantities under base cases.

Base Case 1 ($q = 1$)

Parameter	mean	median	CV	2.5%	97.5%
K	4.666	4.143	0.411	3.156	10.121
r	1.022	0.765	0.654	0.309	2.733
z	0.740	0.590	0.736	0.090	1.902
B1980/K	0.173	0.167	0.334	0.074	0.305
MSY	0.564	0.549	0.233	0.348	0.863
Fmsy	0.281	0.279	0.282	0.130	0.443
Bmsy	2.135	1.976	0.370	1.375	4.339
B1980	0.754	0.723	0.286	0.426	1.261
B2015	2.642	2.635	0.124	2.02	3.299
F1980	0.341	0.329	0.277	0.189	0.559
F2015	0.139	0.137	0.128	0.109	0.179
Coefficient for survey(q)	1	1	NA	1	1
B2016/K	0.657	0.641	0.342	0.249	1.151
B2016/Bmsy	1.421	1.375	0.337	0.587	2.513
F2015/Fmsy	0.543	0.496	0.386	0.296	1.079

Base Case 2 (q~U(0.1,1))

Parameter	mean	median	CV	2.5%	97.5%
K	5.794	5.112	0.406	3.455	12.71
r	0.965	0.704	0.706	0.243	2.744
z	0.729	0.569	0.755	0.079	1.897
B1980/K	0.185	0.175	0.368	0.085	0.335
MSY	0.622	0.595	0.306	0.330	1.081
Fmsy	0.251	0.248	0.318	0.107	0.420
Bmsy	2.655	2.371	0.394	1.521	5.597
B1980	1.027	0.918	0.476	0.490	2.240
B2015	3.649	3.285	0.375	2.269	7.331
F1980	0.269	0.259	0.358	0.106	0.486
F2015	0.108	0.110	0.257	0.049	0.159
q	0.779	0.815	0.220	0.374	0.993
B2016/K	0.702	0.680	0.350	0.295	1.244
B2016/Bmsy	1.529	1.463	0.364	0.669	2.744
F2015/Fmsy	0.522	0.433	7.425	0.205	0.989

Table JPN-1 (continued).

Base Case 3 ($q \sim \mathrm{U}(0.1,3)$)

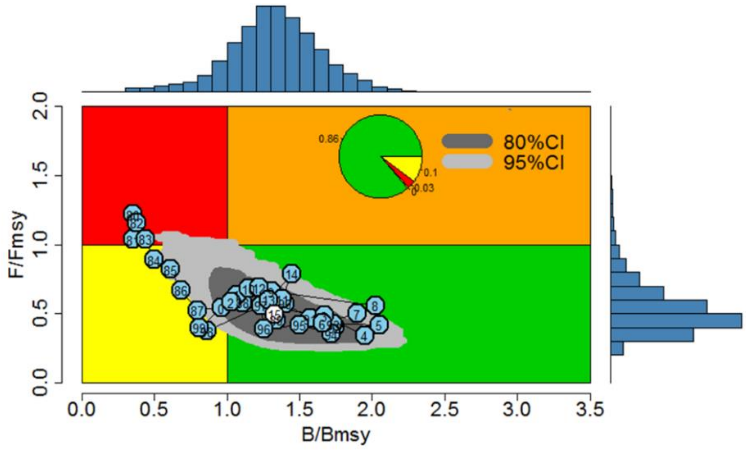
Parameter	mean	median	CV	2.5%	97.5%
K	3.107	2.678	0.499	1.677	7.244
r	1.212	0.993	0.536	0.409	2.797
z	0.827	0.676	0.689	0.122	1.940
B1980/K	0.164	0.158	0.297	0.084	0.275
MSY	0.514	0.497	0.209	0.357	0.763
Fmsy	0.394	0.390	0.301	0.174	0.639
Bmsy	1.443	1.255	0.458	0.829	3.193
B1980	0.493	0.429	0.514	0.235	1.175
B2015	1.698	1.479	0.468	0.912	3.808
F1980	0.571	0.555	0.368	0.203	1.015
F2015	0.244	0.244	0.320	0.095	0.396
q	1.774	1.802	0.302	0.694	2.754
B2016/K	0.623	0.604	0.339	0.267	1.101
B2016/Bmsy	1.317	1.266	0.323	0.613	2.288
F2015/Fmsy	0.640	0.610	0.311	0.339	1.116

Table JPN-2. Estimated biomass (million tons) with associated CVs under the three base case scenarios.

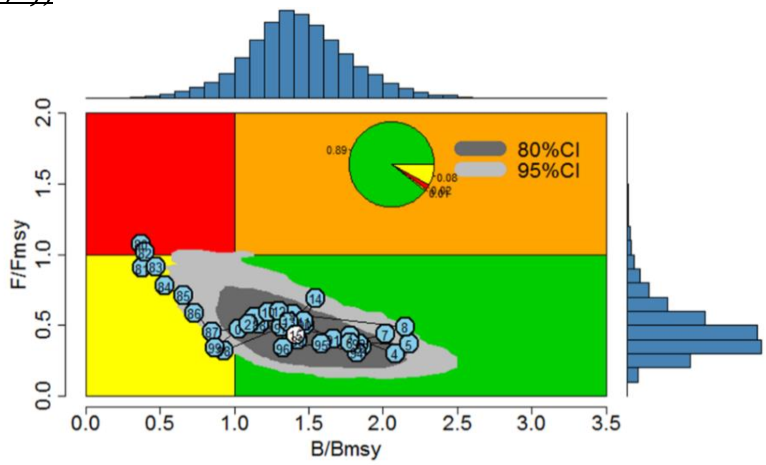
Year	Base case 1			Base case 2 (q~U(0.1,1))			Base case 3 (q~U(0.1,3))		
	mean	median	cv	mean	median	cv	mean	median	cv
1980	0.754	0.723	0.286	1.027	0.918	0.476	0.493	0.429	0.514
1981	0.745	0.717	0.258	1.023	0.919	0.458	0.48	0.414	0.514
1982	0.786	0.761	0.246	1.076	0.965	0.447	0.512	0.443	0.503
1983	0.914	0.887	0.243	1.258	1.131	0.445	0.59	0.51	0.519
1984	1.032	0.998	0.246	1.418	1.271	0.445	0.66	0.571	0.523
1985	1.27	1.226	0.247	1.745	1.568	0.443	0.816	0.707	0.519
1986	1.413	1.368	0.248	1.945	1.748	0.437	0.908	0.782	0.523
1987	1.642	1.59	0.249	2.243	2.014	0.428	1.059	0.917	0.509
1988	2.261	2.198	0.24	3.069	2.769	0.417	1.502	1.32	0.484
1989	2.749	2.665	0.247	3.746	3.369	0.428	1.829	1.612	0.489
1990	2.846	2.779	0.23	3.869	3.496	0.414	1.888	1.664	0.484
1991	3.214	3.13	0.234	4.399	3.96	0.425	2.102	1.828	0.501
1992	3.575	3.467	0.239	4.926	4.431	0.438	2.351	2.053	0.499
1993	3.538	3.437	0.239	4.856	4.366	0.436	2.299	1.997	0.502
1994	3.528	3.43	0.248	4.843	4.348	0.437	2.309	2.014	0.503
1995	3.056	2.962	0.246	4.186	3.761	0.436	2.003	1.75	0.5
1996	2.556	2.482	0.242	3.495	3.147	0.431	1.679	1.468	0.496
1997	2.592	2.444	0.317	3.518	3.118	0.458	1.843	1.587	0.509
1998	1.76	1.713	0.251	2.452	2.198	0.447	1.087	0.939	0.569
1999	1.652	1.612	0.234	2.287	2.066	0.432	1.042	0.904	0.528
2000	1.922	1.909	0.131	2.644	2.381	0.376	1.242	1.081	0.46
2001	2.127	2.105	0.123	2.926	2.625	0.378	1.377	1.197	0.455
2002	2.052	2.021	0.135	2.825	2.54	0.383	1.323	1.146	0.465
2003	3.332	3.31	0.116	4.582	4.116	0.372	2.149	1.874	0.453
2004	3.898	3.883	0.127	5.378	4.851	0.376	2.52	2.193	0.464
2005	4.074	4.065	0.108	5.605	5.041	0.37	2.634	2.292	0.451
2006	3.315	3.289	0.112	4.573	4.105	0.373	2.132	1.847	0.461
2007	3.776	3.763	0.114	5.197	4.673	0.371	2.442	2.122	0.457
2008	4.019	3.993	0.113	5.532	4.978	0.371	2.598	2.262	0.453
2009	2.618	2.582	0.14	3.614	3.255	0.388	1.676	1.453	0.475
2010	2.293	2.274	0.112	3.166	2.845	0.375	1.475	1.28	0.461
2011	2.742	2.731	0.108	3.782	3.397	0.367	1.772	1.538	0.456
2012	2.427	2.41	0.109	3.345	3.008	0.37	1.566	1.362	0.455
2013	2.556	2.534	0.114	3.528	3.158	0.375	1.648	1.432	0.456
2014	2.885	2.861	0.109	3.972	3.566	0.371	1.872	1.631	0.454
2015	2.642	2.635	0.124	3.649	3.285	0.375	1.698	1.479	0.468
2016	2.842	2.732	0.283	3.891	3.499	0.45	1.859	1.619	0.523

(4) Stock status (Kobe plots included here)

Base case 1 ($q = 1$)



Base case 2 ($q \sim U(0.1,1)$)



Base case 3 ($q \sim U(0.1,3)$)

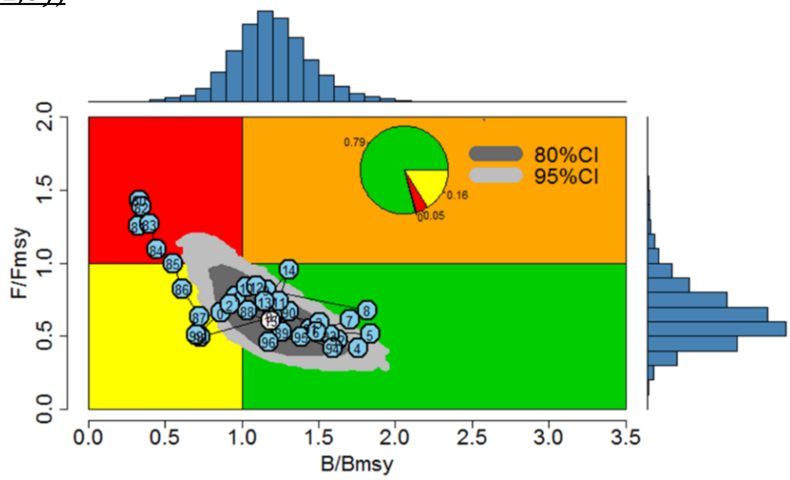


Figure JPN-5. Kobe plots under the base case scenarios.

(5) Sensitivity analysis (without use of fishery-independent biomass estimates)

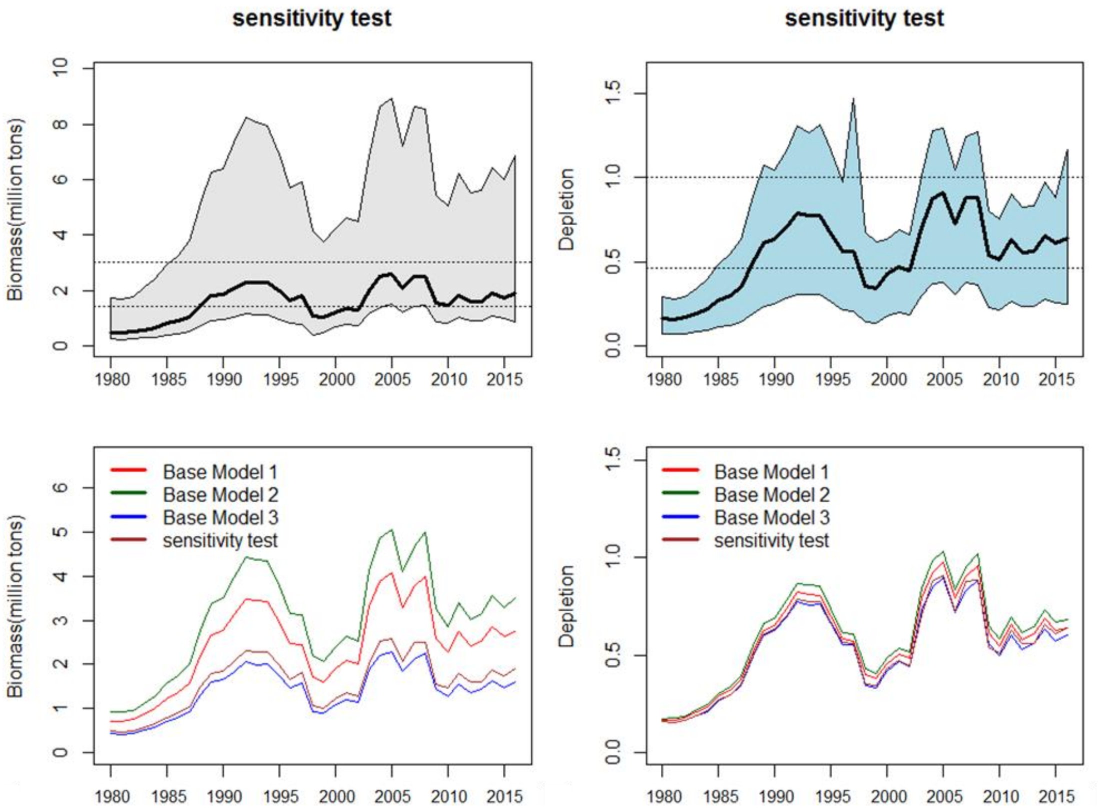


Figure JPN-6. Estimated trajectories for population biomass and depletion level for the sensitivity test, where only CPUE indices were used, and comparison with those under the three base case scenarios.

Table JPN-3. Parameter estimates and management quantities under the sensitivity test.

	mean	median	CV	2.50%	97.50%
K	3.757	3.033	0.631	1.716	11.14
r	1.143	0.939	0.566	0.331	2.76
z	0.823	0.673	0.696	0.105	1.941
B1980/K	0.167	0.16	0.332	0.073	0.294
MSY	0.545	0.518	0.271	0.359	0.902
FMSY	0.365	0.359	0.344	0.137	0.627
BMSY	1.736	1.413	0.59	0.846	4.879
B1980	0.603	0.484	0.69	0.242	1.743
B2015	2.171	1.744	0.653	0.978	6.009
F1980	0.51	0.492	0.434	0.137	0.985
F2015	0.208	0.207	0.393	0.06	0.369
q	NA	NA	NA	NA	NA
B2016/K	0.654	0.637	0.35	0.249	1.164
B2016/Bmsy	1.384	1.34	0.341	0.58	2.481
F2015/Fmsy	0.59	0.562	0.363	0.253	1.123

Table JPN-4. Estimated biomass with associated CVs under the sensitivity test.

Year	Base case 1			Base case 2 (q~U(0.1,1))			Base case 3 (q~U(0.1,3))			Sensitivity test		
	mean	median	cv	mean	median	cv	mean	median	cv	mean	median	cv
1980	0.754	0.723	0.286	1.027	0.918	0.476	0.493	0.429	0.514	0.603	0.484	0.69
1981	0.745	0.717	0.258	1.023	0.919	0.458	0.48	0.414	0.514	0.591	0.473	0.7
1982	0.786	0.761	0.246	1.076	0.965	0.447	0.512	0.443	0.503	0.627	0.5	0.694
1983	0.914	0.887	0.243	1.258	1.131	0.445	0.59	0.51	0.519	0.726	0.572	0.71
1984	1.032	0.998	0.246	1.418	1.271	0.445	0.66	0.571	0.523	0.816	0.647	0.721
1985	1.27	1.226	0.247	1.745	1.568	0.443	0.816	0.707	0.519	1.004	0.8	0.714
1986	1.413	1.368	0.248	1.945	1.748	0.437	0.908	0.782	0.523	1.119	0.889	0.726
1987	1.642	1.59	0.249	2.243	2.014	0.428	1.059	0.917	0.509	1.299	1.043	0.705
1988	2.261	2.198	0.24	3.069	2.769	0.417	1.502	1.32	0.484	1.817	1.485	0.653
1989	2.749	2.665	0.247	3.746	3.369	0.428	1.829	1.612	0.489	2.216	1.802	0.661
1990	2.846	2.779	0.23	3.869	3.496	0.414	1.888	1.664	0.484	2.288	1.859	0.661
1991	3.214	3.13	0.234	4.399	3.96	0.425	2.102	1.828	0.501	2.554	2.075	0.668
1992	3.575	3.467	0.239	4.926	4.431	0.438	2.351	2.053	0.499	2.869	2.307	0.679
1993	3.538	3.437	0.239	4.856	4.366	0.436	2.299	1.997	0.502	2.822	2.277	0.675
1994	3.528	3.43	0.248	4.843	4.348	0.437	2.309	2.014	0.503	2.819	2.282	0.683
1995	3.056	2.962	0.246	4.186	3.761	0.436	2.003	1.75	0.5	2.444	1.986	0.677
1996	2.556	2.482	0.242	3.495	3.147	0.431	1.679	1.468	0.496	2.051	1.66	0.678
1997	2.592	2.444	0.317	3.518	3.118	0.458	1.843	1.587	0.509	2.195	1.816	0.658
1998	1.76	1.713	0.251	2.452	2.198	0.447	1.087	0.939	0.569	1.364	1.077	0.771
1999	1.652	1.612	0.234	2.287	2.066	0.432	1.042	0.904	0.528	1.292	1.023	0.72
2000	1.922	1.909	0.131	2.644	2.381	0.376	1.242	1.081	0.46	1.526	1.228	0.651
2001	2.127	2.105	0.123	2.926	2.625	0.378	1.377	1.197	0.455	1.675	1.349	0.642
2002	2.052	2.021	0.135	2.825	2.54	0.383	1.323	1.146	0.465	1.592	1.275	0.653
2003	3.332	3.31	0.116	4.582	4.116	0.372	2.149	1.874	0.453	2.492	2.002	0.64
2004	3.898	3.883	0.127	5.378	4.851	0.376	2.52	2.193	0.464	3.124	2.516	0.655
2005	4.074	4.065	0.108	5.605	5.041	0.37	2.634	2.292	0.451	3.221	2.591	0.638
2006	3.315	3.289	0.112	4.573	4.105	0.373	2.132	1.847	0.461	2.588	2.069	0.65
2007	3.776	3.763	0.114	5.197	4.673	0.371	2.442	2.122	0.457	3.112	2.5	0.643
2008	4.019	3.993	0.113	5.532	4.978	0.371	2.598	2.262	0.453	3.122	2.511	0.639
2009	2.618	2.582	0.14	3.614	3.255	0.388	1.676	1.453	0.475	1.936	1.547	0.658
2010	2.293	2.274	0.112	3.166	2.845	0.375	1.475	1.28	0.461	1.824	1.463	0.65
2011	2.742	2.731	0.108	3.782	3.397	0.367	1.772	1.538	0.456	2.228	1.795	0.641
2012	2.427	2.41	0.109	3.345	3.008	0.37	1.566	1.362	0.455	1.986	1.594	0.644
2013	2.556	2.534	0.114	3.528	3.158	0.375	1.648	1.432	0.456	2.008	1.617	0.646
2014	2.885	2.861	0.109	3.972	3.566	0.371	1.872	1.631	0.454	2.337	1.885	0.635
2015	2.642	2.635	0.124	3.649	3.285	0.375	1.698	1.479	0.468	2.171	1.744	0.653
2016	2.842	2.732	0.283	3.891	3.499	0.45	1.859	1.619	0.523	2.351	1.9	0.684

(6) Projection

Future projection was conducted under the assumption of -20 to 20% increase/decrease from the average catch of most recent five years (2011-2015). The median trajectories are shown in Figure JPN-7. A more stochastic evaluation was given in Table JPN-5.

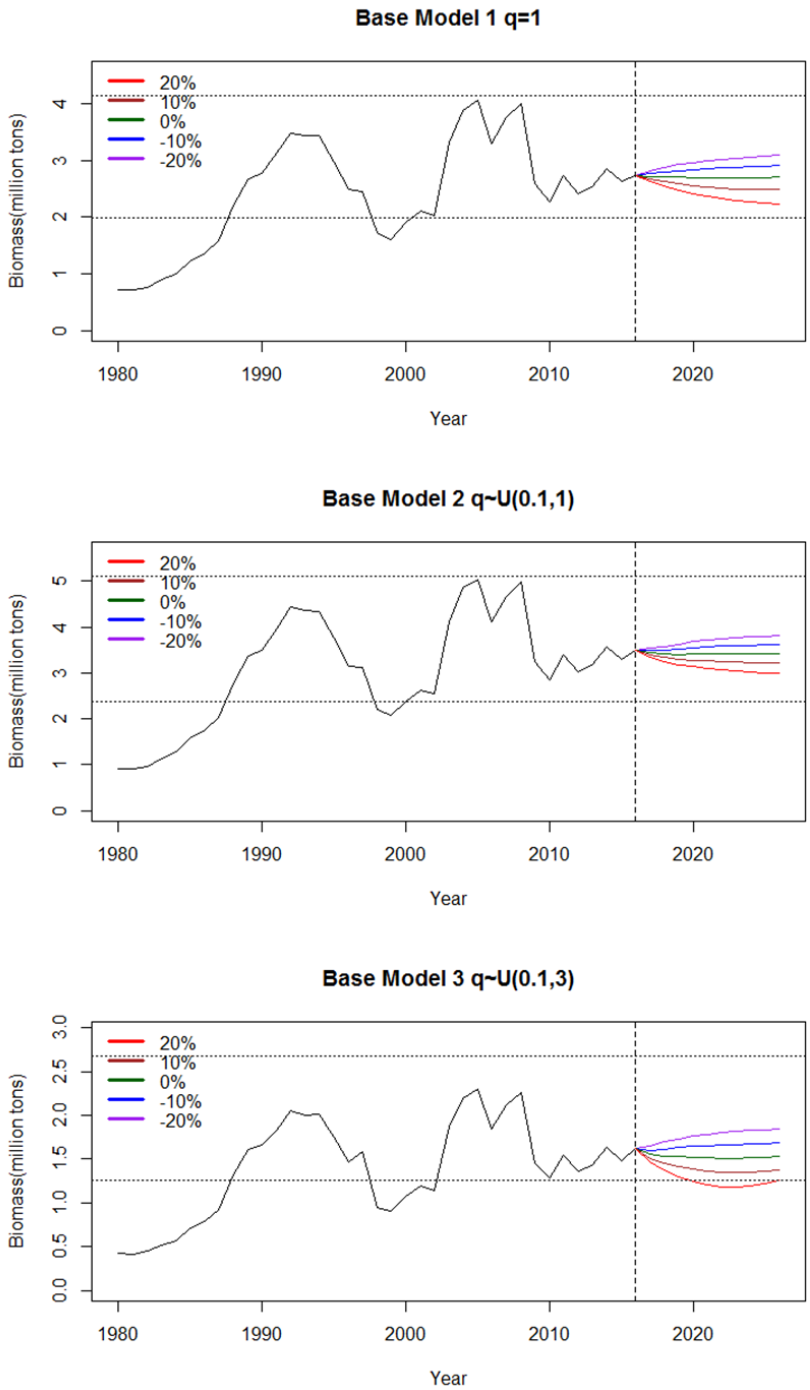


Figure JPN-7. Median trajectories under five different catch levels.

Table JPN-5. KOBE2 strategy matrix under the three base case scenarios.

Base case 1 ($q = 1$)

Year	Catch fraction	Red	Orange	Yellow	Green	B<Bmsy	F>Fmsy
2015		3.0%	0.4%	10.2%	86.5%	13.1%	3.4%
	0.8	3.8%	0.6%	5.0%	90.7%	8.8%	4.4%
	0.9	6.5%	1.4%	4.4%	87.7%	10.9%	7.9%
2019	1	10.1%	3.3%	3.5%	83.2%	13.6%	13.4%
	1.1	14.3%	6.9%	2.5%	76.3%	16.8%	21.2%
	1.2	19.2%	11.6%	1.7%	67.4%	20.9%	30.9%

Base case 2 (q~U(0.1,1))

Year	Catch fraction	Red	Orange	Yellow	Green	B<Bmsy	F>Fmsy
2015		1.6%	0.6%	8.2%	89.6%	9.8%	2.3%
	0.8	2.6%	0.8%	3.7%	93.0%	6.2%	3.4%
	0.9	4.0%	1.6%	3.4%	91.1%	7.4%	5.6%
2019	1	6.1%	3.3%	2.8%	87.9%	8.9%	9.4%
	1.1	8.7%	5.6%	2.3%	83.6%	11.0%	14.2%
	1.2	11.5%	9.3%	1.8%	77.4%	13.3%	20.9%

Base case 3 (q~U(0.1,3))

Year	Catch fraction	Red	Orange	Yellow	Green	B<Bmsy	F>Fmsy
2015		4.5%	0.2%	16.0%	79.3%	20.5%	4.7%
	0.8	5.5%	0.5%	4.3%	89.6%	9.9%	6.0%
	0.9	11.3%	1.6%	3.5%	83.5%	14.8%	12.9%
2019	1	19.5%	5.2%	2.5%	72.6%	21.9%	24.6%
	1.1	29.1%	10.5%	1.4%	58.5%	30.5%	39.5%
	1.2	40.2%	14.9%	0.8%	42.7%	41.0%	55.1%

(7) Conclusion/Summary

Although the results are different between scenarios, they showed that the current median depletion level is above 60% of the carrying capacity and B-ratio and F-ratio are in the safe zone (green) with high probabilities. For considering management implications, population dynamics was projected for some scenarios with respect to the reduction, status quo, and increase from the current catch level. Continuation of the current catch level may not cause severe decline in the population size in the next decade, but a safer option is of course status quo level or reduction of catch to keep the population size above enough the MSY level. Given these results shown here, it is concluded that the current catch level is not harmful to the saury population although continued works/efforts for improving data and models would be required toward better stock assessment and development of management procedures based on the assessment.

3) Member stock assessment report: CHINESE TAIPEI

(1) Assessment results for the base-case scenarios

Description of Bayesian production model

Annual biomass dynamics:

$$B_t = B_{t-1} + rB_{t-1}\left(1-\left(\frac{B_{t-1}}{K}\right)^M\right) - C_t$$

where B_{t-1} and C_{t-1} denote biomass and catch (landings), respectively, for year t-1. Carrying capacity, K, is the biomass of the population at equilibrium prior to commencement of the fishery; r is the intrinsic population growth rate; and M is the production shape parameter.

We assumed lognormal error structures and used a reparametrization ($Pt = B_t/K$) by expressing the annual biomass as a proportion of carrying capacity as in Millar and Meyer (1999). The state equations are rewritten as

$$P_t = \left(P_{t-1} + r_{t-1}\cdot P_{t-1}\left(1-P_{t-1}^M\right) - \frac{C_{t-1}}{\nu}\right)\exp(u_t)$$

$$P_1 = \exp(u_1)$$

$$u_1 \sim N\left(\mu_{P_1}, \sigma_{P_1}^2\right)$$

$$u_t \sim N(0,\sigma^2) \quad t = 2,\ldots,N$$

where t is year t, N is number of years, u_1 is a normal random variable with a mean of and variance to account accounting for the uncertainty of initial condition. u_t is also a normal random variable with a mean of zero and variance σ^2 to account accounting for stochastic process dynamics.

The observation equations are

$$I_{i,t} = q_i K P_t \exp\left(\varepsilon_{i,t}\right)$$

$$\varepsilon_{i,t} \sim N\left(0,\tau_i^2\right) \qquad i = 1 \text{ to } 3;\ t = 1,\ldots,N$$

where I_i,t is the relative abundance of index i at time t; q_i is the catchability coefficient for index i, which describes the effectiveness of each unit of fishing effort; and $\varepsilon_{i,t}$ is a normal random variable with a mean of zero and variance to account accounting for the natural sampling variation of index i.

The Bayesian analysis requires prior probability distributions for each of the model parameters. These priors are summarized in Table CT1. It is common for fishery data to contain insufficient information to reliably estimate both the carrying capacity, K, and the intrinsic rate of increase, r. A solution to this is to incorporate less informative prior information with respect to one of these parameters. In this study, we provided less informative prior with the mean value of *r* based on the demographic method of McAllister et al. (2001) and the estimated value of resilience from FishBase (Froese and Pauly, 2000). The prior distribution for r was a lognormal distribution with mean of and CV of 1 ($CV_r = \left(\exp\left(\sigma_r^2\right) - 1\right)^{1/2}$).

The prior chosen for K was uninformative, as little is known about the carrying capacity of WNPO saury population. We specified a vague prior for carrying capacity using a lognormal distribution with mean of $\log(150) - 0.5\sigma_K^2$ (1,000 mt) and CV of 1 to cover the reasonable range of predictions. This mean value was chosen to reflect the magnitude of exploitable biomass likely needed to support the observed fishery catches. The prior distribution for *M* was a gamma distribution with scale and shape parameters were equal with $\lambda = k = 2$. Therefore, the prior mean is equal to 1 and the CV is around 70%, which implied the production curve was centered on the symmetric Schaefer model as the default with adequate flexibility to estimate a non-symmetric production function if needed.

Unfortunately, since little is known about the catchability (q) on stick-held dip net gear, we were limited to use least-informative prior for q. The priors for the q were chosen to be a diffuse inverse-gamma distribution with scale parameter $\lambda = 0.01$ and shape parameter $k = 0.01$. Following Meyer and Millar (1999), we used inverse gamma prior for the process and observation error variances. The parameters were set to $\lambda = 4$ and $k = 0.1$ for the process error variance (σ^2), and $\lambda = 2$ and $k = 0.45$ for the observation variance (τ^2) priors. The initial state of the stock was described as a proportion of carrying capacity ($P1=B_{1950}/K$). We specified an uninformative prior for P1 using a lognormal distribution with mean of 0.7 with a CV of 1 based on an assumption that the Pacific saury population was lightly exploited in 1980.
Based on the recommended base-case scenarios, three models differing in catchability of the Japanese survey biomass index were explored.

i) Model 1: Including four sets of CPUEs and Japan survey data with survey catchability (q) prior defined from 0 to 1;
ii) Model 2: Including four sets of CPUEs and Japan survey data with survey catchability (q) prior being fixed at 1;
iii) Model 3: Including four sets of CPUEs and Japan survey data with survey catchability (q) prior being defined from 0 to larger than 1.

Trends in biomass (10,000 metric ton) and ratio of biomass to carrying capacity (*K*) (right panels) of the Western North Pacific saury based on the three base-case models and the Bayesian model average were shown in Figure CT1 and Table CT5.

(2) Diagnostics and caveats

The autocorrelation function plot indicated a thinning interval of 25 which was large enough to address potential autocorrelation in the MCMC runs. The visual inspection of trace plots of the major parameters showed the good mixing of the three chains (i.e., moving around the parameter space), also indicative of convergence of the MCMC chains. The Gelman and Rubin statistic for all parameters, including all variance terms, equaled 1, which indicated convergence of the Markov chains. Similarly, the Heidelberger and Welch test could not reject the hypothesis that the MCMC chains were stationary at the 95% confidence level for any of the parameters. Overall, these diagnostics indicated that the posterior distribution of the model parameters was adequately sampled with the MCMC simulations.

Plots of posterior densities of the parameters r, K, M, σ^2, τ^2, P_1, survey catchability, MSY, B_{MSY}, and F_{MSY} were shown in Figures CT2, CT3 and CT4, together with their respective prior densities. The predicted CPUE indices for each model were compared to the observed CPUE to determine model fit. Plots of residual diagnostics by fishery and survey indices for the three base-case models were shown in Figures CT5, CT6, and CT7.

Retrospective analyses show that the time-series of exploitable biomass estimate with the removal of most 8 years of data in successive model runs match very well with the full time series assessment (Figure CT8).

(3) Biological reference points

Summaries of posterior quantiles of parameters and quantities of management interest of the three base-case models were provided in Tables CT2, CT3, and CT4.

(4) Stock status

Kobe phase plot for the three base-case models of the Western North Pacific saury from 1980 to 2015 with uncertainty for 2015 and the percentage of circles within each color quadrant were shown in Figures CT9 and CT10.

(5) Sensitivity analysis (for sensitivity analysis)

Sensitivity model (without the Japanese biomass survey index)

Plot of posterior densities of the parameters r, K, M, σ^2, τ^2, P_1, survey catchability, MSY, B_{MSY}, and F_{MSY} was shown in Figure CT11, together with their respective prior densities. Plot of residual diagnostics by fishery indices was shown in Figure CT12. Summaries of posterior quantiles of parameters and quantities of management interest of the sensitivity model were provided in Table CT6. Trends in biomass (10,000 metric ton) and ratio of biomass to carrying capacity (K) were shown in Figure CT13 and Table CT5. Kobe phase plot of the sensitivity model was shown in

Figure CT10.

Analysis of the sensitivity to the mean value of the lognormal r prior distribution

The base-case model 2 was run with the mean values for the *r* prior changed by ±25% of their input value, e.g., 0.75*value and 1.25*value. Trends in biomass (10,000 metric ton) for testing the sensitivity of the mean values of the lognormal *r* prior distribution in model 2 was shown in Figure 14.

(6) Projection

Stochastic projections of expected exploitable biomass (10,000 metric tons) of the Western North Pacific saury during 2016- 2019 under five fractions of average catch from 2011 to 2015 for the three base-case models were shown in Figure CT15.

(7) Conclusion/Summary

Exploitable biomass of Western North Pacific saury was relative stable and above BMSY since 2010 based on the three base-case scenarios. The Kobe plots showed that the current stock status does not appear to have been overfished or to have experienced overfishing and likely within the green quadrant (Prob(B2015 > BMSY and F2015 < FMSY) ranged from 57% to 94%). The risk analyses of status quo catch based on stock projections during 2016-2019 showed that there would be less chance of the stock being overfished (2% - 11%) or experiencing overfishing (5% - 14%) in 2019. Annual catches would need to increase to 1.2-fold of the status quo catch level to have a small or moderate risk of overfishing (17% - 48%). The stock assessment concludes that Western North Pacific saury is healthy and is sufficient to sustain recent exploitation levels. However, we recognized the catchability of Japanese biomass survey as one potential sources of uncertainty in stock assessment results and estimates of management quantities.

Table CT1. Summary of specified priors for Bayesian state-space model.

Parameter	Description	Prior
r	Intrinsic growth rate (yr^{-1})	$r \sim \log N\left(\log(1.4)-\frac{\sigma_r^2}{2},\sigma_r^2\right);\ CV_r=1$
K	Carrying capacity (10,000 mt)	$K \sim \log N\left(\log(150)-\frac{\sigma_K^2}{2},\sigma_K^2\right);\ CV_K=1$
M	Production shape	$M \sim Gamma(2,2)$
q	Catchability	$1/q \sim Gamma(0.01,0.01)$
τ^2	Observation error variance	$1/\tau^2 \sim Gamma(2,0.45)$
P_1	Initial condition (B_1/K)	$P_1 \sim \log N\left(\log(0.7)-\frac{\sigma_{P_1}^2}{2},\sigma_{P_1}^2\right);\ CV_{P_1}=1$
σ^2	Process error variance	$1/\sigma^2 \sim Gamma(4,0.1)$

$CV_\theta = \left(\exp\left(\sigma_\theta^2\right)-1\right)^{1/2}$

Table CT2. Summary of posterior quantities of parameters derived from the base-case model 1 for the Pacific saury in the Western North Pacific Ocean.

Parameter	Mean	Median	CV	2.50%	97.50%
K	462.9	444	0.21	327.5	711.9
r	0.73	0.61	0.59	0.3	1.86
M	0.99	0.79	0.74	0.18	3.01
B_{1980}/K	0.19	0.18	0.27	0.11	0.31
MSY	60.67	58.34	0.25	37.09	97.88
F_{MSY}	0.33	0.32	0.3	0.17	0.55
B_{MSY}	224.8	216.7	0.22	152.2	346.6
B_{1980}	88.38	82.92	0.33	47.38	161.1
B_{2015}	307	292.6	0.25	197	500.4
F_{1980}	0.36	0.34	0.4	0.16	0.7
F_{2015}	0.13	0.13	0.24	0.07	0.2
Survey q	0.82	0.85	0.16	0.52	0.99
B_{2016}/K	0.7	0.7	0.16	0.47	0.9
$B_{2016}/B_{\mathrm{MSY}}$	1.44	1.44	0.16	1.01	1.91
$F_{2015}/F_{\mathrm{MSY}}$	0.43	0.4	0.35	0.21	0.79

Table CT3. Summary of posterior quantities of parameters derived from the base-case model 2 for the Pacific saury in the Western North Pacific Ocean.

Parameter	Mean	Median	CV	2.50%	97.50%
K	390.8	381	0.16	302.4	541
r	0.76	0.65	0.56	0.34	1.88
M	1.08	0.85	0.74	0.19	3.27
B_{1980}/K	0.19	0.18	0.26	0.11	0.3
MSY	57.19	55.05	0.23	36.88	89.9
F_{MSY}	0.36	0.35	0.28	0.2	0.6
B_{MSY}	192.3	189.1	0.16	140.9	261.1
B_{1980}	72.39	69.56	0.27	42.49	
B_{2015}	246.5	243.7	0.16	177.2	332.2
F_{1980}	0.45	0.42	0.36	0.22	0.82
F_{2015}	0.16	0.16	0.18	0.11	0.22
Survey q	1	1	1	1	1
B_{2016}/K	0.68	0.68	0.16	0.45	0.88
$B_{2016}/B_{\mathrm{MSY}}$	1.38	1.38	0.15	0.97	1.79
$F_{2015}/F_{\mathrm{MSY}}$	0.47	0.45	0.33	0.25	0.84

Table CT4. Summary of posterior quantities of parameters derived from the base-case model 3 for the Pacific saury in the Western North Pacific Ocean.

Parameter	Mean	Median	CV	2.50%	97.50%
K	223.8	200.1	0.48	89.41	486.2
r	0.97	0.9	0.42	0.43	1.93
M	1.71	1.68	0.56	0.27	3.69
B_{1980}/K	0.18	0.18	0.21	0.12	0.27
MSY	54.23	53.04	0.18	38.56	77.44
F_{MSY}	1	0.69	1.1	0.25	5.32
B_{MSY}	117.8	108.8	0.42	51.04	237.3
B_{1980}	40.98	34.95	0.55	15.71	98.85
B_{2015}	131.4	113.7	0.57	41.2	320.1
F_{1980}	2.83	1.14	1.19	0.28	9.21
F_{2015}	0.59	0.37	1.67	0.12	1.98
Survey q	2.46	2.16	0.52	0.8	5.63
B_{2016}/K	0.66	0.67	0.18	0.41	0.88
$B_{2016}/B_{\mathrm{MSY}}$	1.22	1.22	0.17	0.82	1.63
$F_{2015}/F_{\mathrm{MSY}}$	0.58	0.53	0.46	0.27	1.16

Table CT5. Estimates of exploitable biomass (10,000 metric ton) derived from the three base-case models and the sensitivity model (without the Japanese biomass survey) for the Pacific saury in the Western North Pacific Ocean.

Year	Model 1			Model 2			Model 3			Sensitivity test		
	Mean	Median	CV	Mean	Median	CV	Mean	Median	CV	Mean	Median	CV
1980	88.38	82.92	0.3	72.39	69.56	0.3	40.98	34.95	0.6	39.57	33.63	0.5
1981	91.84	86.57	0.3	74.51	71.92	0.3	41.02	34.76	0.6	39.64	33.45	0.6
1982	100.6	94.74	0.3	81.51	78.82	0.3	44.92	38.18	0.6	43.55	36.72	0.6
1983	116.2	109.2	0.3	93.75	90.65	0.3	50.56	42.39	0.6	48.9	40.71	0.6
1984	132.9	125	0.3	106.6	103.1	0.3	56.61	47.26	0.6	54.75	45.27	0.6
1985	160.5	150.9	0.3	129.2	124.8	0.3	68.24	56.91	0.6	65.98	54.49	0.6
1986	182.6	172.2	0.3	147.1	142.1	0.3	77.84	65.31	0.6	75.61	62.72	0.6
1987	213.9	201.9	0.3	173.5	168	0.3	93.92	80.09	0.6	91.72	77.45	0.6
1988	277	262.4	0.3	227	220.9	0.2	128.1	112	0.6	125.5	109.2	0.5
1989	324.8	308.4	0.3	267	260.3	0.2	152.6	134.1	0.5	149.8	131.4	0.5
1990	343.4	326.9	0.3	282.3	276.4	0.2	159.7	139.8	0.5	156.4	136.4	0.5
1991	374.2	355.8	0.3	305.8	299	0.2	169.3	146.9	0.6	164.5	142.3	0.5
1992	405.4	385.1	0.3	330.2	322.3	0.2	182.7	157.4	0.6	177	152.4	0.6
1993	403.6	383.7	0.3	328.5	320.6	0.2	180.6	155.6	0.6	175.3	150	0.6
1994	400.5	379.6	0.3	325.8	317.5	0.2	181.8	157.7	0.6	176.6	152.3	0.6
1995	364	346	0.3	296.8	289.9	0.2	169.7	147.7	0.5	166.2	144.5	0.5
1996	321	306	0.3	262.7	257.1	0.2	153.6	135.4	0.5	151.1	133.1	0.5
1997	326.3	299.9	0.4	274.8	252.7	0.3	193.7	175.6	0.4	195.8	178.1	0.4
1998	238	227	0.3	189.3	185.8	0.3	86.34	61.81	0.8	80.84	54.03	0.9
1999	229.9	218.4	0.3	184.7	180	0.3	89.74	70.13	0.7	85.44	64.23	0.8
2000	252.1	240.8	0.3	204.3	200.4	0.2	106.1	89.24	0.6	102.1	83.92	0.6
2001	281.3	269.1	0.3	228.4	225.1	0.2	122.3	105.9	0.6	118.1	101.3	0.6
2002	287.3	274.3	0.3	232.7	229.8	0.2	126.1	109.3	0.6	120.9	104.7	0.6
2003	392.2	375.3	0.2	317.6	314.8	0.2	173.7	151.9	0.5	158.3	138.4	0.5
2004	408.6	389.8	0.2	329.3	326.3	0.2	176.7	153.4	0.6	164.9	142.2	0.6
2005	462.9	441.9	0.2	374.1	370.4	0.2	202.4	176	0.5	192.8	166.7	0.5
2006	409.7	390.5	0.3	329.1	326	0.2	174.7	150.5	0.6	167.1	141.6	0.6
2007	433.9	413.5	0.2	349.8	346.1	0.2	187.8	162.3	0.6	184.6	157.8	0.6
2008	474	452.4	0.3	383.3	378.6	0.2	205.6	178.7	0.6	194.8	168.5	0.6
2009	356.9	340.5	0.3	286.4	284	0.2	149.8	128.4	0.6	140.5	118.6	0.6
2010	311.2	296.7	0.2	250.7	248.1	0.1	134.4	116.8	0.6	135	116.4	0.6
2011	337.5	321.6	0.2	272.6	269.5	0.1	148	129.6	0.5	151	131.8	0.5
2012	322.5	307.8	0.2	260.6	257.6	0.1	141.7	123.9	0.5	147.5	128.4	0.5
2013	341.8	325.5	0.2	275.7	272.9	0.2	150.1	131.1	0.5	151.7	132.1	0.5
2014	371	353.8	0.2	300.4	296.7	0.2	166.1	146.3	0.5	171	149.7	0.5
2015	307	292.6	0.3	246.5	243.7	0.2	131.4	113.7	0.6	132	113.3	0.6
2016	322.1	308.1	0.2	260.8	259.1	0.2	146.9	130.5	0.5	148.1	131.5	0.5

Table CT6. Summary of posterior quantities of parameters derived from the sensitivity model (without the Japanese biomass survey) for the Pacific saury in the Western North Pacific Ocean.

Parameter	Mean	Median	CV	2.50%	97.50%
K	216	189.2	0.49	88.29	478.7
r	0.96	0.89	0.4	0.43	1.86
M	1.86	1.87	0.53	0.3	3.87
B_{1980}/K	0.18	0.18	0.2	0.12	0.27
MSY	55.64	54.26	0.18	39.3	79.63
F_{MSY}	1.07	0.76	1.08	0.26	6.91
B_{MSY}	116.2	106.5	0.43	50.77	235.7
B_{1980}	39.57	33.63	0.54	15.63	95.37
B_{2015}	132	113.3	0.58	41.49	329.2
F_{1980}	2.99	1.23	1.15	0.29	9.21
F_{2015}	0.59	0.38	1.66	0.11	1.94
Survey q	NA	NA	NA	NA	NA
B_{2016}/K	0.69	0.7	0.18	0.43	0.9
$B_{2016}/B_{\mathrm{MSY}}$	1.25	1.26	0.16	0.84	1.66
$F_{2015}/F_{\mathrm{MSY}}$	0.54	0.5	0.46	0.25	1.1

Table CT7. Projected probabilities of stock status phases of the Western North Pacific saury in 2019 under five fractions of average catch from 2011 to 2015 for the three base-case models.

Model	Catch fraction	$B < B_{MSY}$ and $H > H_{MSY}$	$B > B_{MSY}$ and $H > H_{MSY}$	$B < B_{MSY}$ and $H < H_{MSY}$	$B > B_{MSY}$ and $H < H_{MSY}$	$B < B_{MSY}$	$H > H_{MSY}$
1	0.8	0.00	0.00	0.00	0.99	0.01	0.01
	0.9	0.01	0.01	0.00	0.97	0.01	0.02
	1	0.02	0.03	0.00	0.95	0.02	0.05
	1.1	0.03	0.06	0.00	0.90	0.03	0.09
	1.2	0.05	0.11	0.00	0.83	0.06	0.17
2	0.8	0.01	0.00	0.01	0.98	0.01	0.01
	0.9	0.02	0.01	0.01	0.96	0.02	0.03
	1	0.04	0.04	0.01	0.92	0.04	0.08
	1.1	0.06	0.09	0.00	0.85	0.06	0.14
	1.2	0.10	0.15	0.00	0.74	0.10	0.25
3	0.8	0.02	0.00	0.01	0.97	0.03	0.02
	0.9	0.04	0.01	0.01	0.93	0.06	0.05
	1	0.11	0.03	0.01	0.86	0.11	0.14
	1.1	0.22	0.07	0.00	0.70	0.22	0.29
	1.2	0.38	0.10	0.00	0.52	0.38	0.48

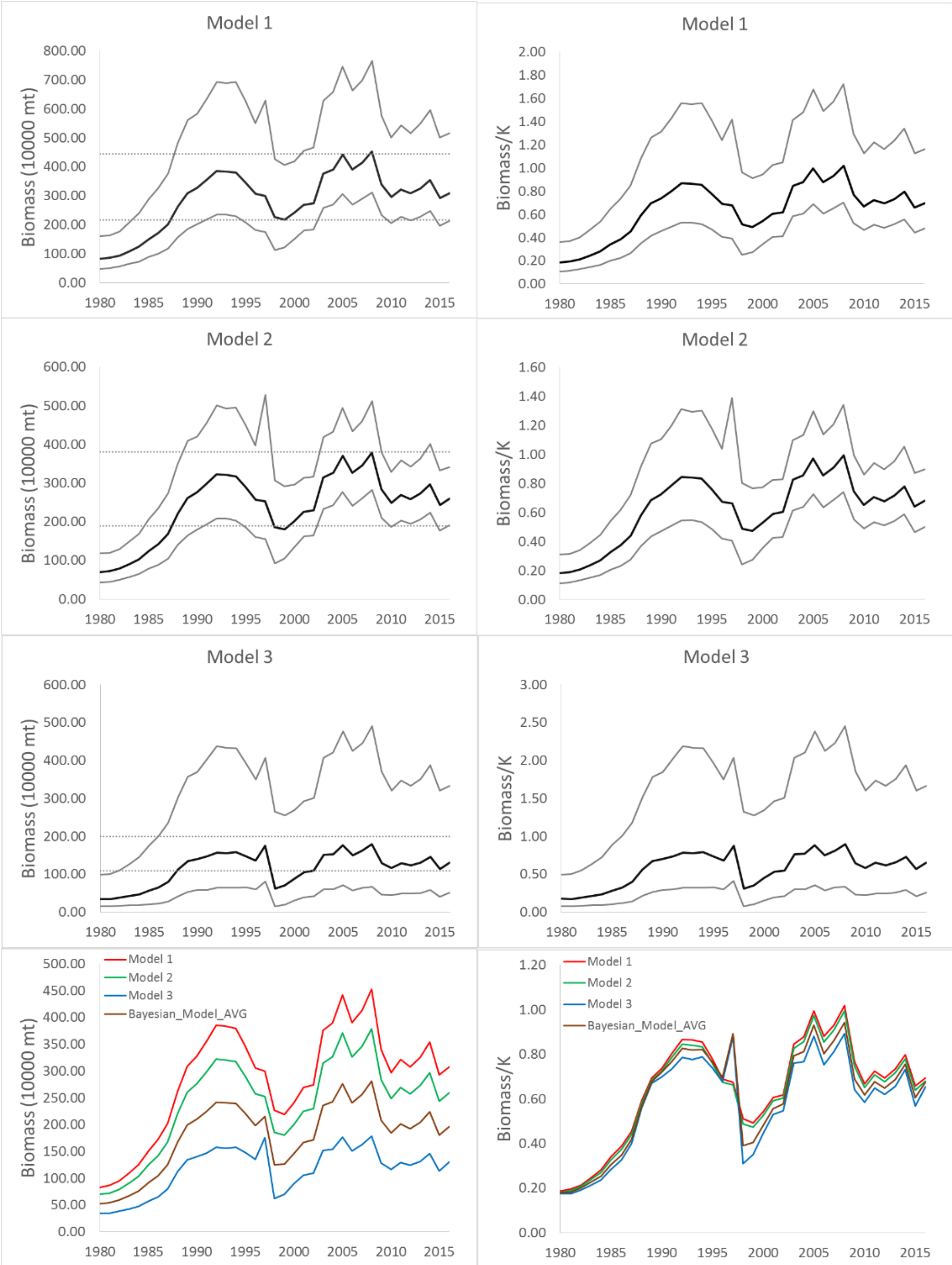


Figure CT1. Trends in biomass (10,000 metric ton) (left panels) and ratio of biomass to carrying capacity (*K*) (right panels) of the Western North Pacific saury based on the three base-case models and the Bayesian model average. Gray lines denote the 95% confidence interval. The upper and lower horizontal dashed lines denote the carrying capacity and B_{MSY}, respectively.

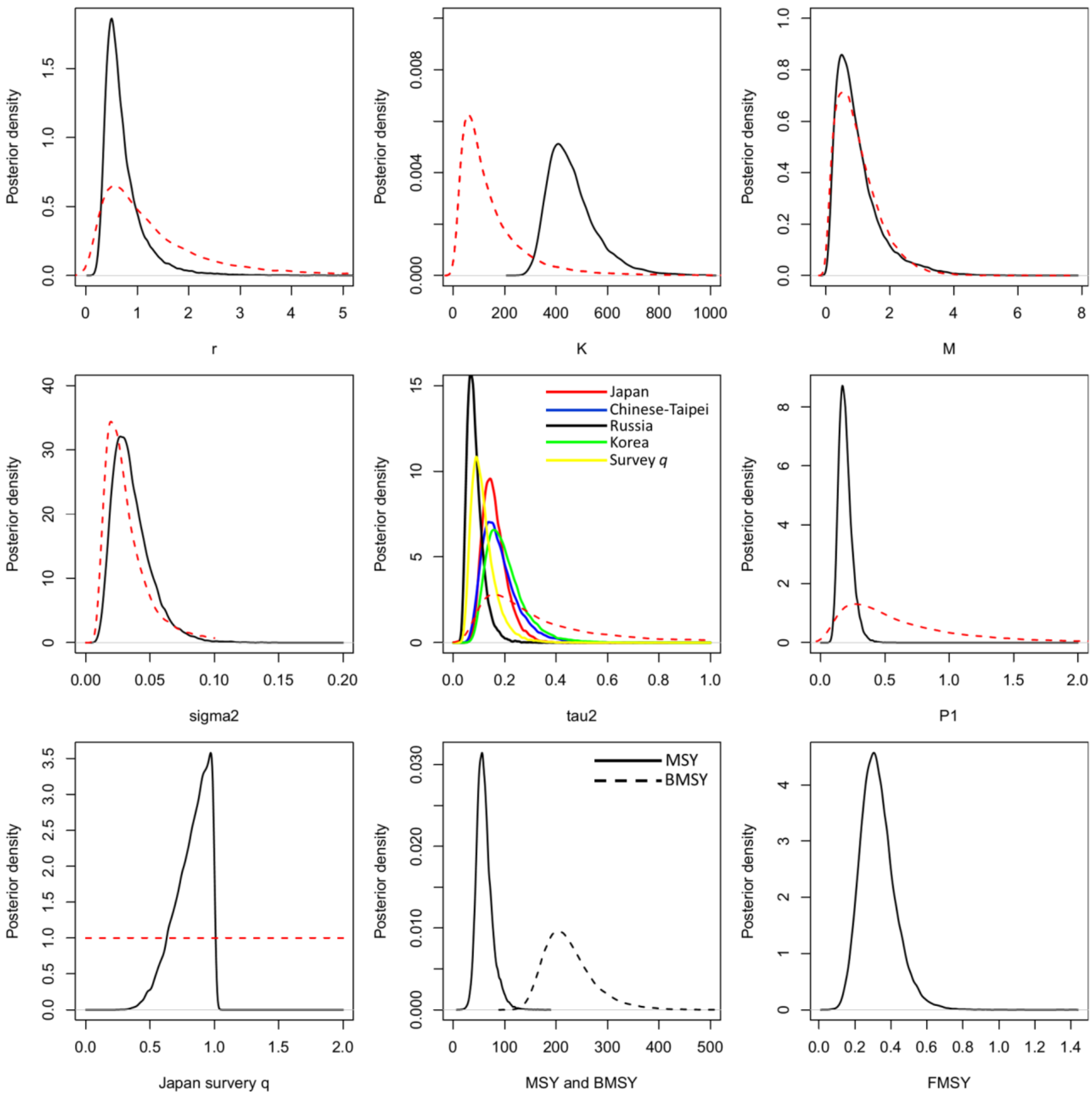


Figure CT2. Kernel density estimates of the posterior and prior (red dashed lines) distributions of various model and management parameters for the base-case model 1 for the Pacific saury in the Western North Pacific Ocean.

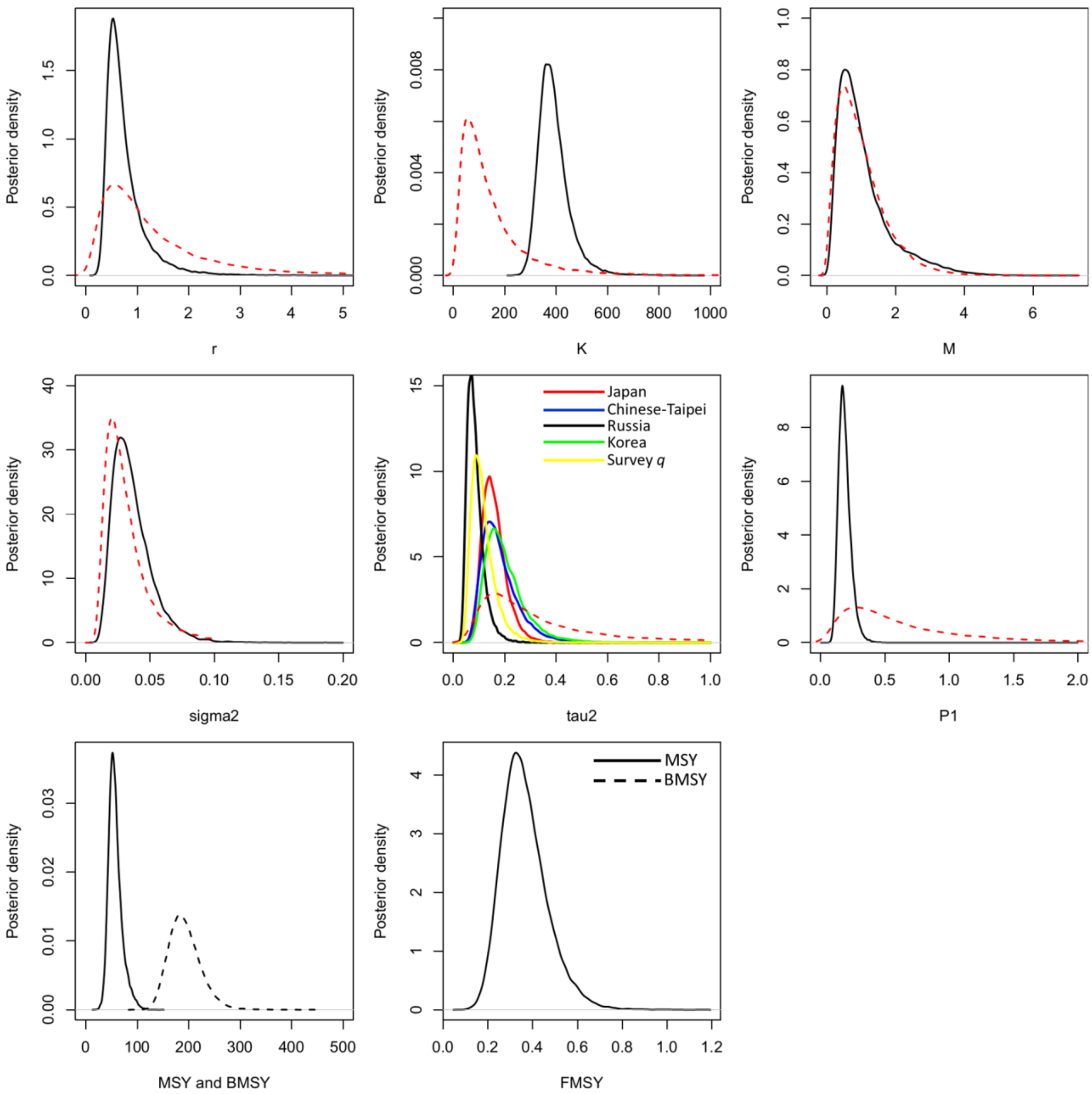


Figure CT3. Kernel density estimates of the posterior and prior (red dashed lines) distributions of various model and management parameters for the base-case model 2 for the Pacific saury in the Western North Pacific Ocean.

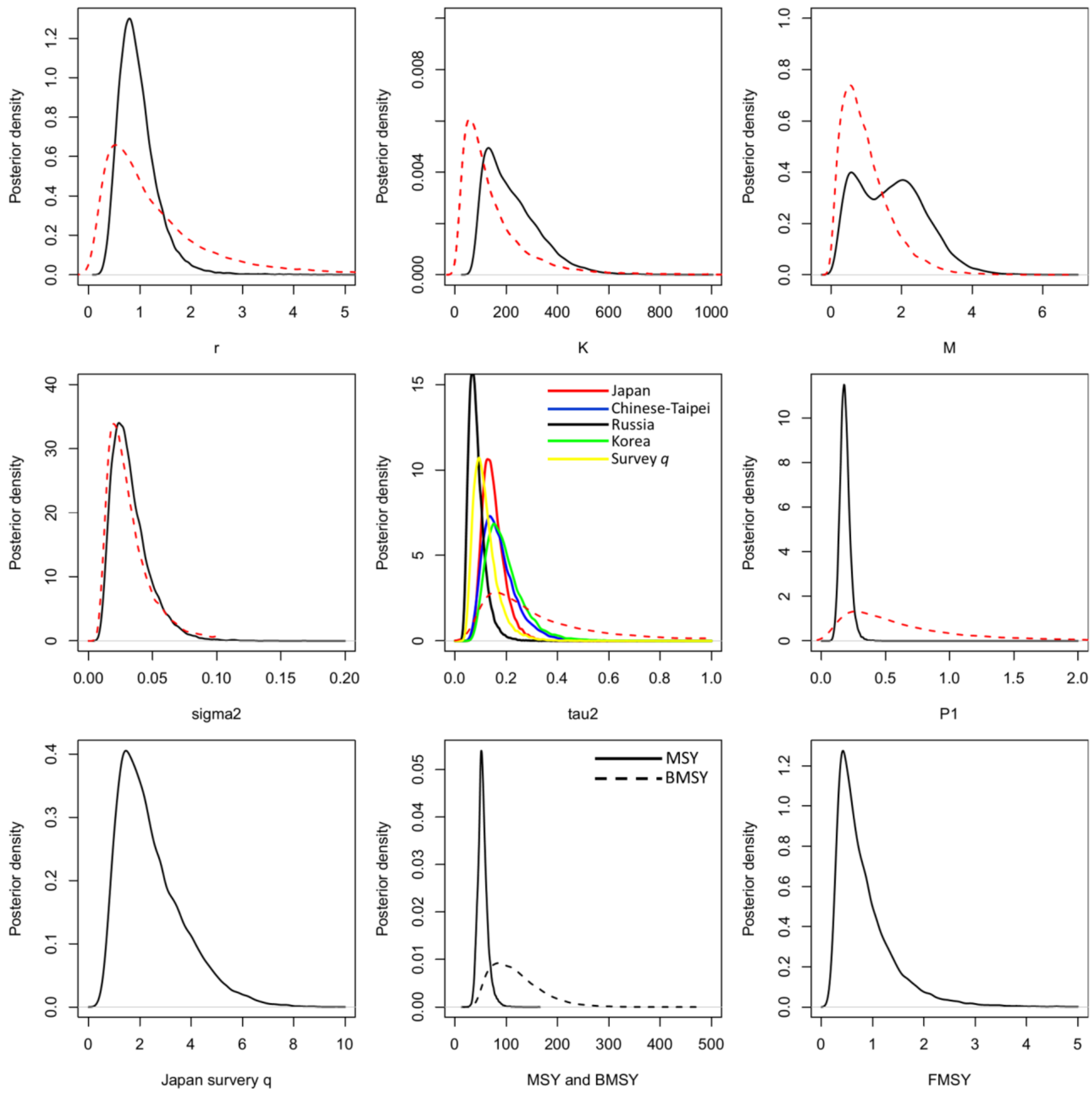


Figure CT4. Kernel density estimates of the posterior and prior (red dashed lines) distributions of various model and management parameters for the base-case model 3 for the Pacific saury in the Western North Pacific Ocean.

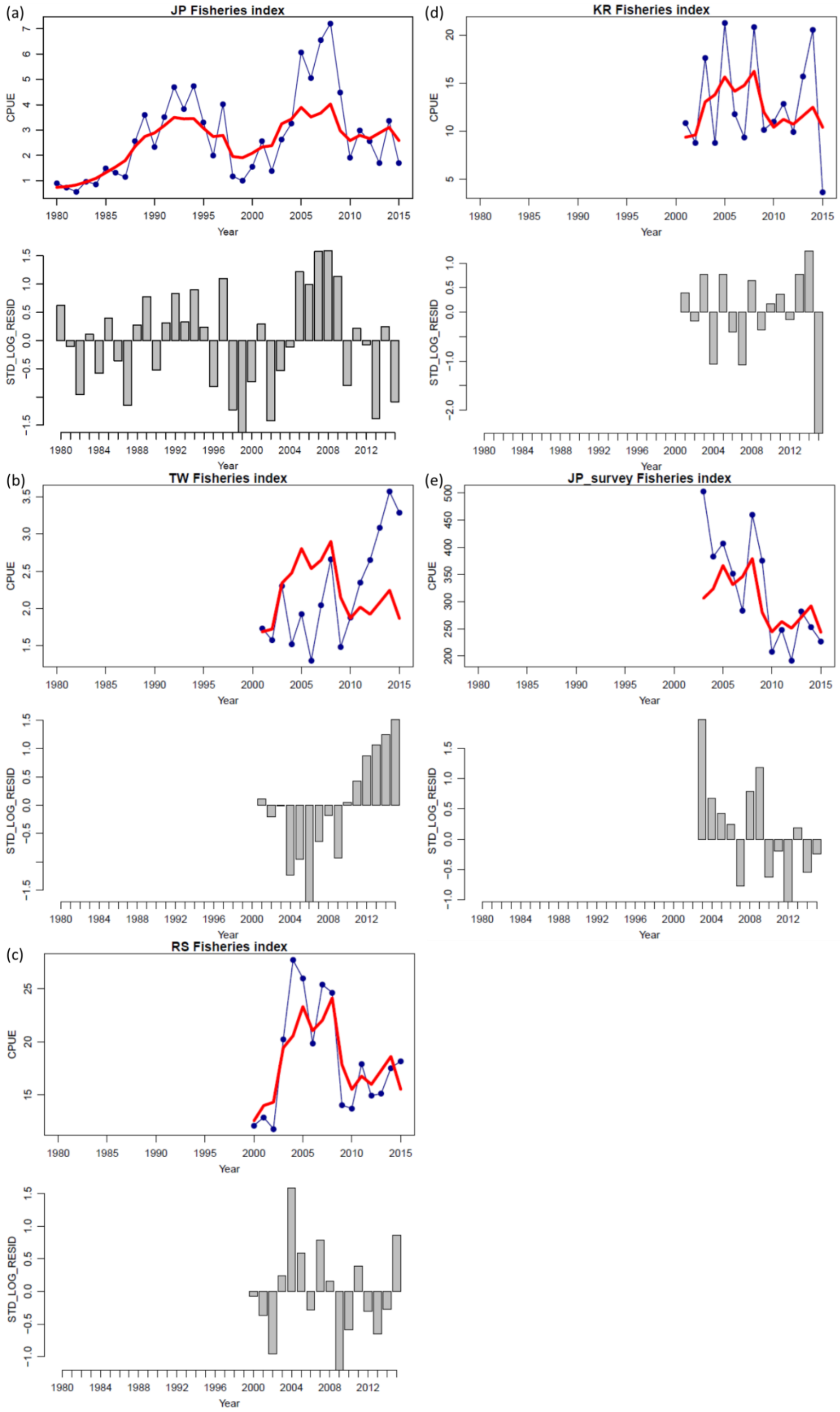


Figure CT5. Time-series of observed (blue circle-line) and predicted (red solid line) catch per unit effort (CPUE) of Western North Pacific saury and standardized log-residuals for the indices of Japan (a), Chinese-Taipei (b), Russia (c), Korea (d), and the Japanese biomass survey (e) derived from the base-case model 1.

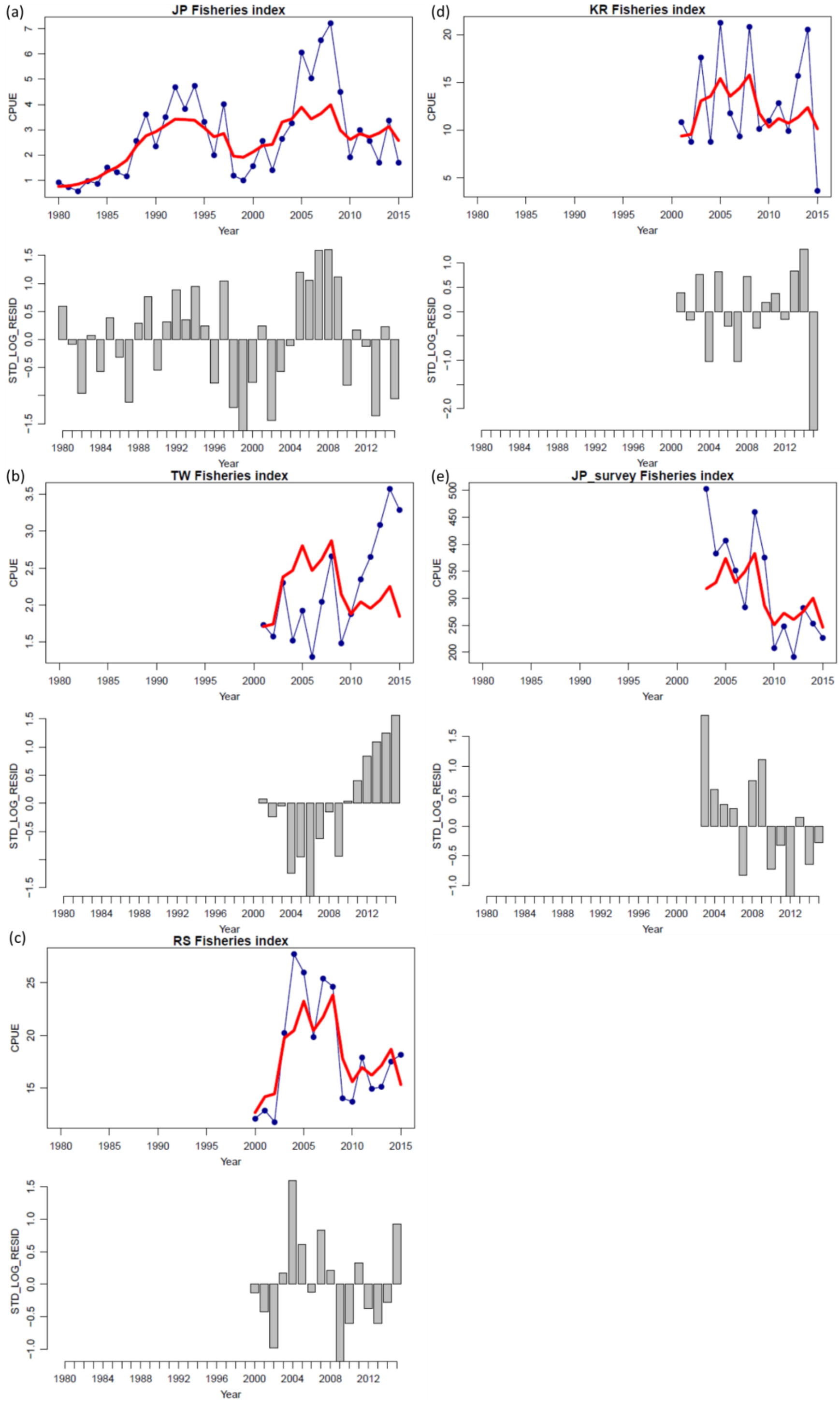


Figure CT6. Time-series of observed (blue circle-line) and predicted (red solid line) catch per unit effort (CPUE) of Western North Pacific saury and standardized log-residuals for the indices of Japan (a), Chinese-Taipei (b), Russia (c), Korea (d), and the Japanese biomass survey (e) derived from the base-case model 2.

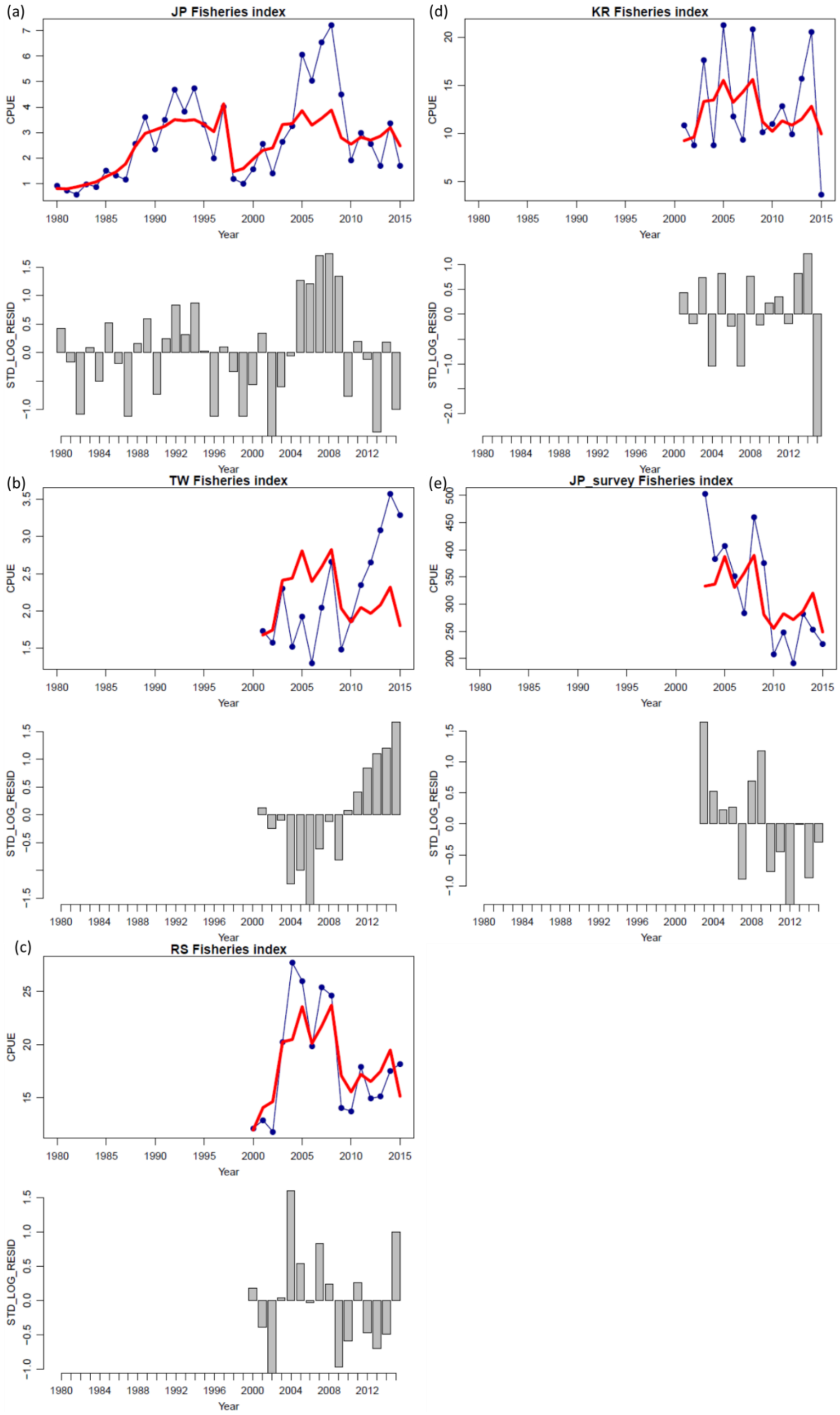


Figure CT7. Time-series of observed (blue circle-line) and predicted (red solid line) catch per unit effort (CPUE) of Western North Pacific saury and standardized log-residuals for the indices of Japan (a), Chinese-Taipei (b), Russia (c), Korea (d), and the Japanese biomass survey (e) derived from the base-case model 3.

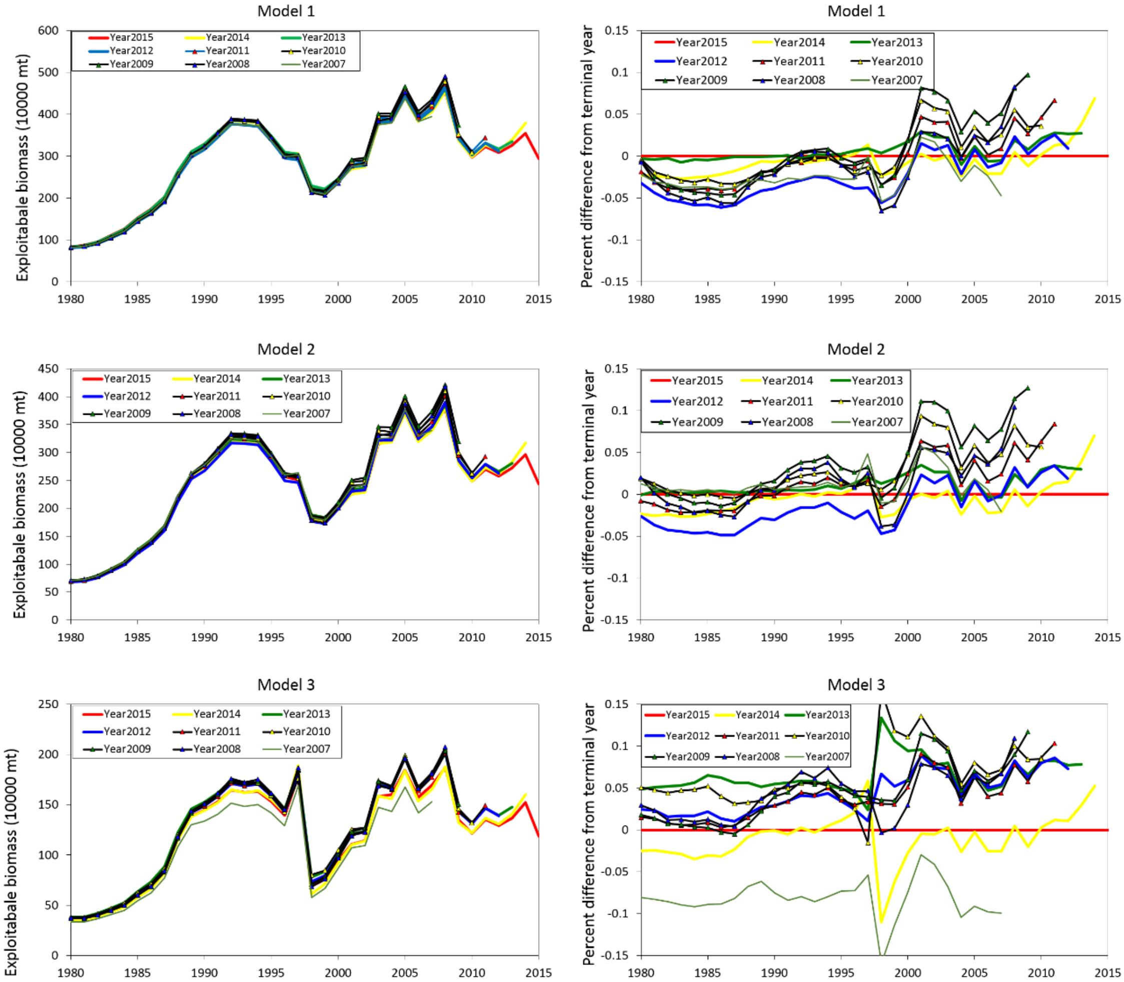


Figure CT8. Eight-years within–model retrospective plots of the absolute change in biomass (left panels) and percent difference from terminal year (right panels) for the Western North Pacific saury based on the three base-case models.

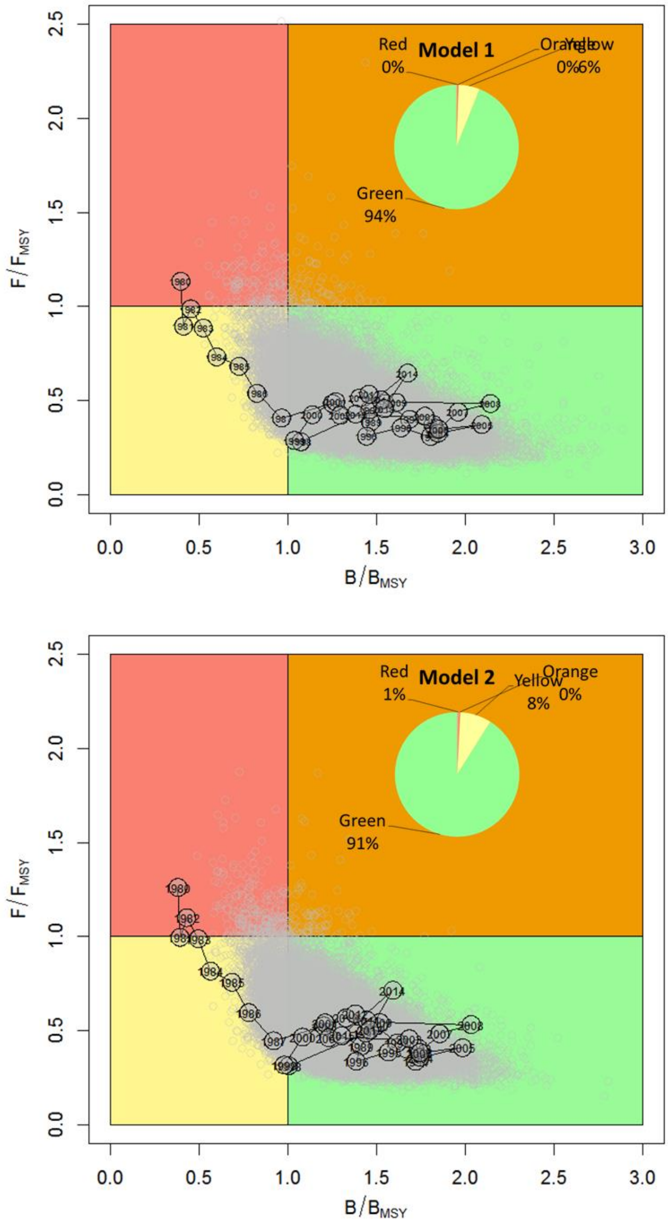
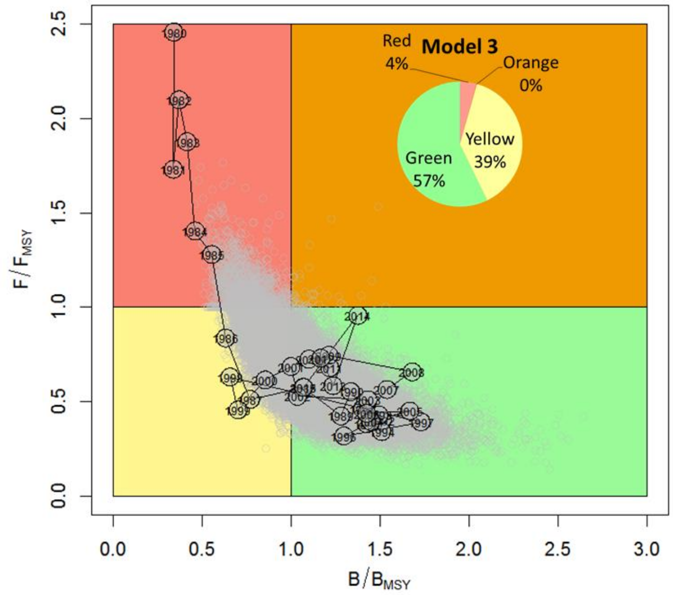


Figure CT9. Kobe phase plot for the base-case models 1 and 2 of the Western North Pacific saury from 1980 to 2015 with uncertainty for 2015 (gray circles) and the percentage of circles within each color quadrant.



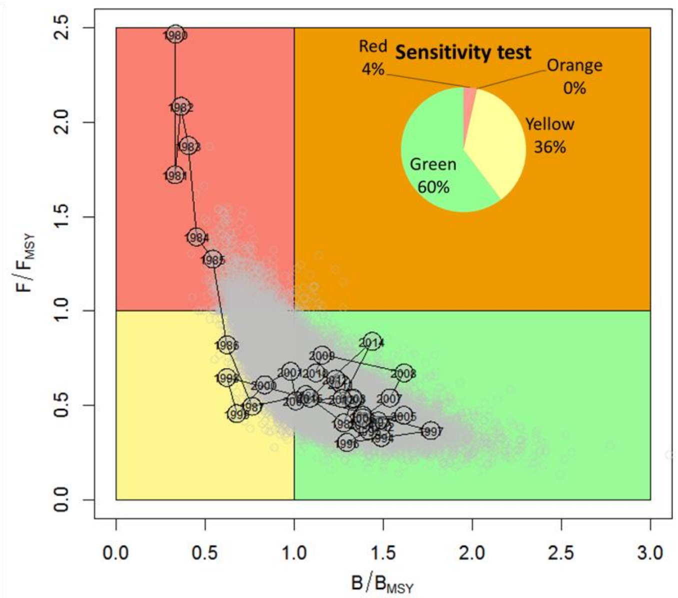


Figure CT10. Kobe phase plot for the base-case model 3 and the sensitivity model (without the Japanese biomass survey) of the Western North Pacific saury from 1980 to 2015 with uncertainty for 2015 (gray circles) and the percentage of circles within each color quadrant.

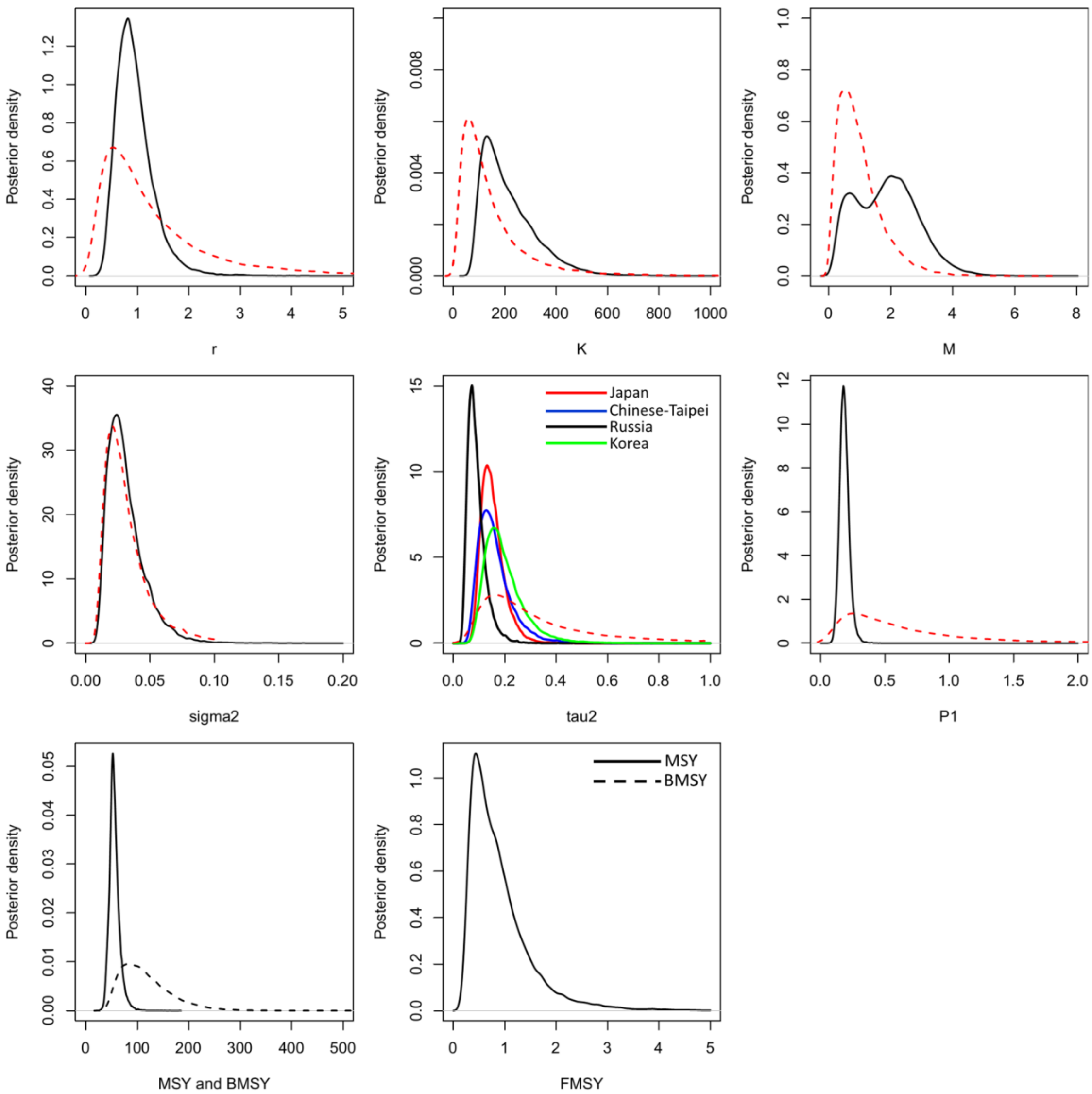


Figure CT11. Kernel density estimates of the posterior and prior (red dashed lines) distributions of various model and management parameters for the sensitivity model (without the Japanese biomass survey) for the Pacific saury in the Western North Pacific Ocean.

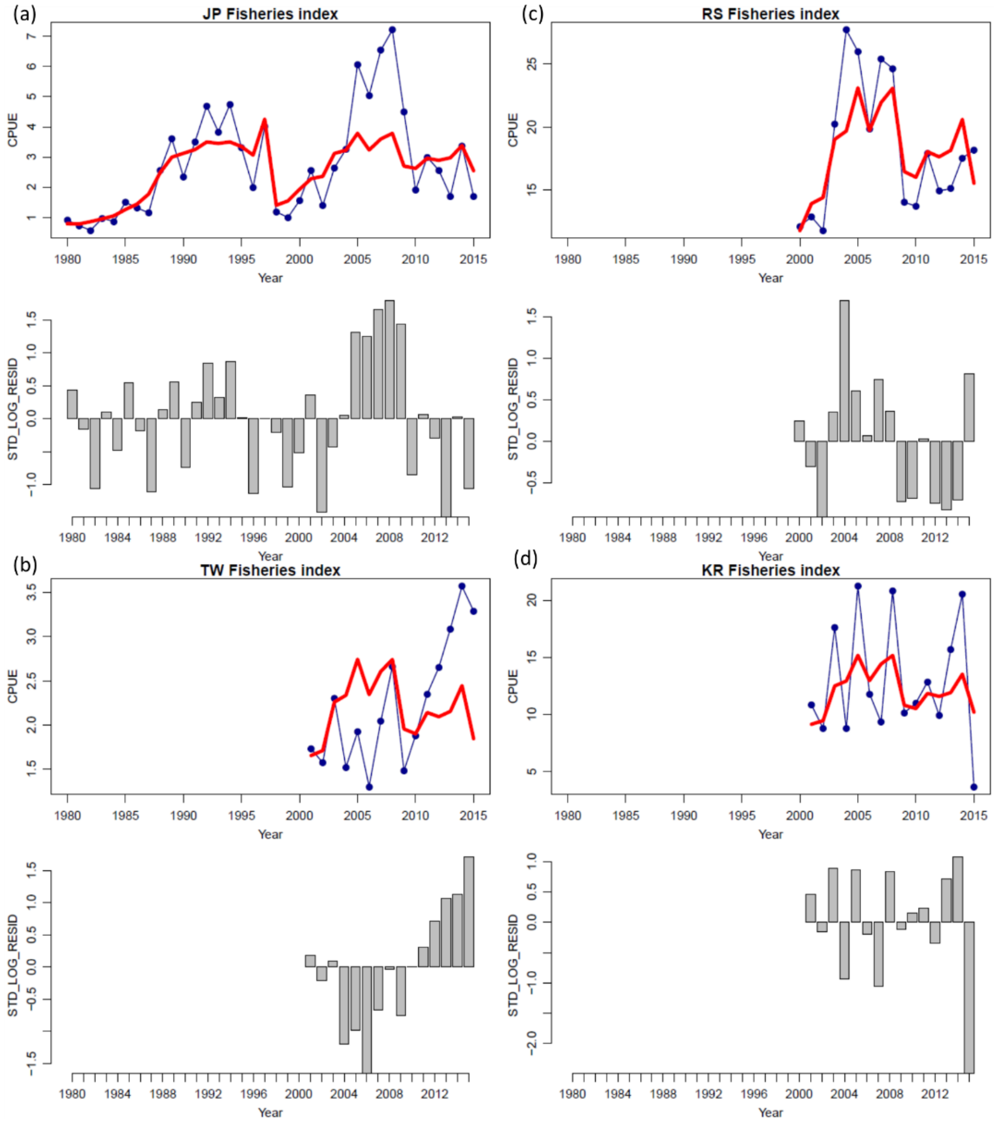


Figure CT12. Time-series of observed (blue circle-line) and predicted (red solid line) catch per unit effort (CPUE) of Western North Pacific saury and standardized log-residuals for the indices of Japan (a), Chinese-Taipei (b), Russia (c), and Korea (d) derived from the sensitivity model (without the Japanese biomass survey).

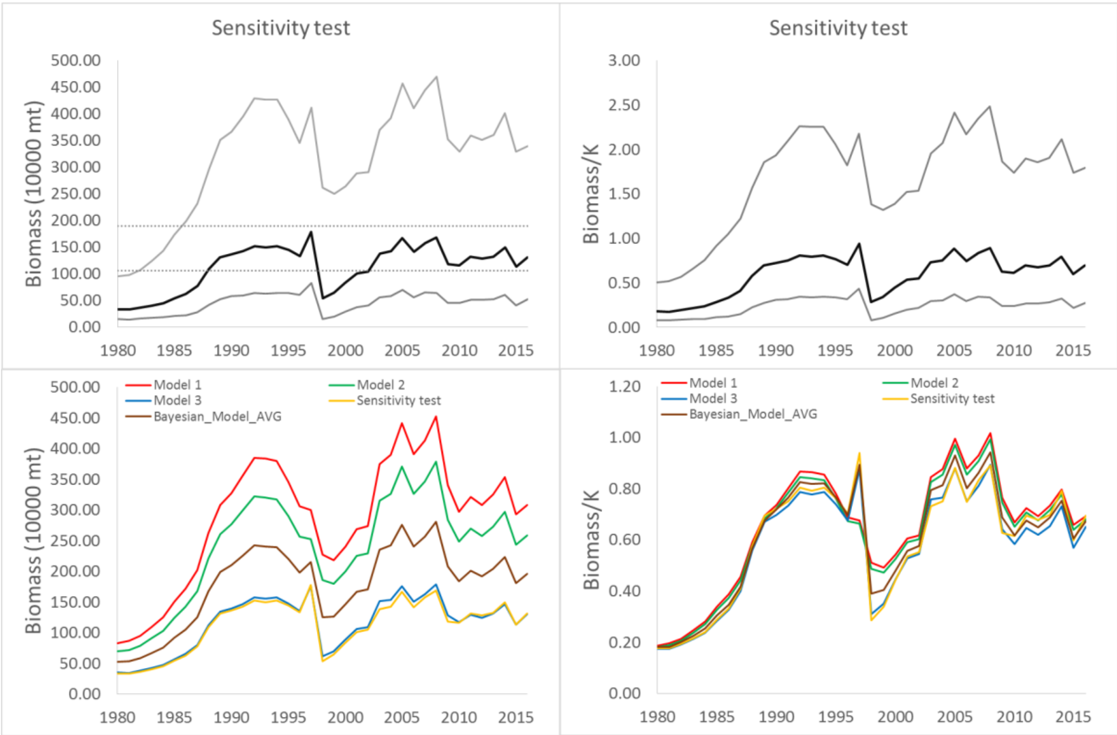


Figure CT13. Trends in biomass (10,000 metric ton) (left panels) and ratio of biomass to carrying capacity (*K*) (right panels) of the Western North Pacific saury based on the three base-case model, sensitivity model, and the Bayesian model average. Gray lines denote the 95% confidence interval. The upper and lower horizontal dashed lines denote the carrying capacity and B_{MSY}, respectively.

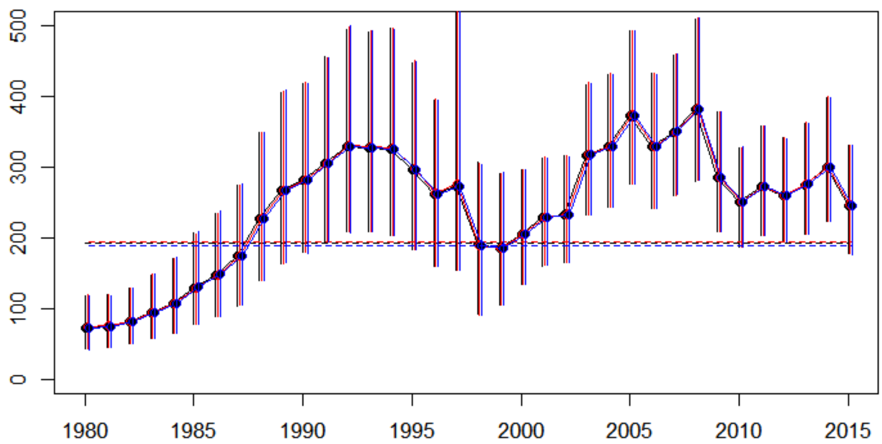


Figure CT14. Trends in biomass (10,000 metric ton) for testing the sensitivity of the mean values of the lognormal *r* prior distribution in model 2. The black, red, and blue colors denote the runs with fractions of 0.75, 1 and 1.25 of the mean value 1.4, respectively.

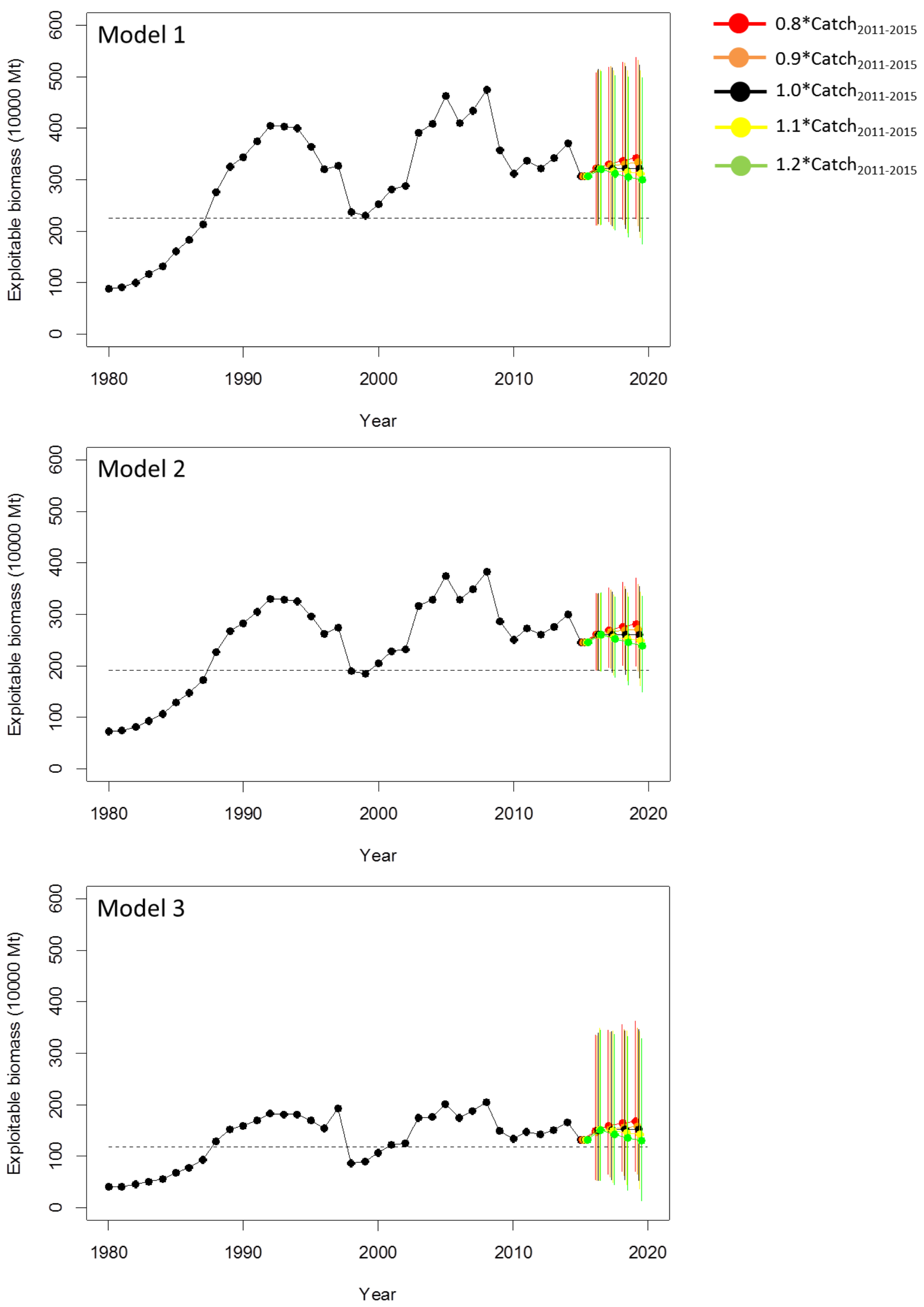


Figure CT15. Stochastic projections of expected exploitable biomass (10,000 metric tons) of the Western North Pacific saury during 2016- 2019 under five fractions of average catch from 2011 to 2015 for the three base-case models. The horizontal dashed lines denote the B_{MSY}. The vertical lines denote the 95% confidence intervals.

8. Comparison

Table 8-1 summarized the estimated key parameters and management quantities by each member (China, Japan, and Chinese Taipei), based on the recommended base-case scenarios, three models differing in catchability (q: 0-1, 1 and free) of Japanese survey biomass index and also based on sensitivity test, where no biomass information was used.

Table 8-1. Summary of the estimated key parameters and management quantities by China, Japan, and Chinese Taipei, based on three scenarios.

Scenarios	Parameters	China		Japan		Chinese Taipei	
		mean	median	mean	median	mean	median
S1 (q 0-1)	K (10,000 mt)	790.26	704.00	579.4	511.2	462.80	444
	r	1.03	0.77	0.965	0.704	0.73	0.61
	Shape (s, Z, M)	0.57	0.32	0.729	0.569	0.99	0.79
	B_{1980}/K	0.14	0.32	0.185	0.175	0.19	0.18
	MSY (10,000 mt)	59.35	57.07	62.2	59.5	60.67	58.34
	F_{MSY}	0.19	0.18	0.251	0.248	0.33	0.32
	B_{MSY} (10,000 mt)	346.66	310.1	265.5	237.1	224.8	216.70
	B_{1980} (10,000 mt)	105.98	97.91	102.7	91.8	88.38	82.92
	B_{2015} (10,000 mt)	356.63	333.1	364.9	328.5	307	292.60
	F_{1980}	0.25	0.24	0.269	0.259	0.36	0.34
	F_{2015}	0.11	0.11	0.108	0.110	0.13	0.13
	q5 (Biomass)	0.77	0.79	0.779	0.815	0.82	0.85
	B_{2016}/K	0.51	0.52	0.702	0.680	0.7	0.7
	B_{2016}/B_{MSY}	1.16	1.18	1.529	1.463	1.44	1.44
	F_{2015}/F_{MSY}	0.64	0.58	0.522	0.433	0.43	0.4
S2 (q=1)	K (10,000 mt)	615.85	527.80	466.6	414.3	390.8	381
	r	1.13	0.89	1.022	0.765	0.76	0.65
	Shape (s, Z, M)	0.56	0.33	0.74	0.49	1.08	0.85
	B_{1980}/K	0.14	0.14	0.173	0.167	0.19	0.18
	MSY (10,000 mt)	54.48	52.91	56.4	54.9	57.19	55.05
	F_{MSY}	0.22	0.22	0.281	0.279	0.36	0.35
	B_{MSY} (10,000 mt)	268.16	237.40	213.5	197.6	192.30	189.10
	B_{1980} (10,000 mt)	78.66	75.43	75.4	72.3	72.39	69.77
	B_{2015} (10,000 mt)	261.56	260.00	264.2	263.5	246.50	243.70
	F_{1980}	0.32	0.32	0.341	0.329	0.45	0.42
	F_{2015}	0.14	0.14	0.139	0.137	0.16	0.16
	q5 (Biomass)	1	1	1	1	1	1
	B_{2016}/K	0.5	0.52	0.657	0.641	0.68	0.68
	B_{2016}/B_{MSY}	1.13	1.16	1.421	1.375	1.38	1.38
	F_{2015}/F_{MSY}	0.70	0.64	0.543	0.496	0.47	0.45
S3 (free q)	K (10,000 mt)	457.96	409.8	310.70	267.80	223.8	200.1
	r	1.28	1.13	1.212	0.993	0.97	0.9
	Shape (s, Z, M)	0.56	0.36	0.827	0.676	0.17	1.68
	B_{1980}/K	0.14	0.14	0.164	0.158	0.18	0.18
	MSY (10,000 mt)	50.65	48.66	51.40	49.70	54.23	53.04
	F_{MSY}	0.29	0.28	0.394	0.390	1	0.69
	B_{MSY} (10,000 mt)	200.97	178.80	144.30	125.50	117.8	108.80
	B_{1980} (10,000 mt)	63.39	55.79	49.30	42.90	40.98	34.95
	B_{2015} (10,000 mt)	210.86	189.20	169.80	147.90	131.4	113.70
	F_{1980}	0.46	0.43	0.571	0.555	2.83	1.14
	F_{2015}	0.21	0.19	0.244	0.244	0.59	0.37
	q5 (Biomass)	1.46	1.37	1.774	1.802	2.46	2.16
	B_{2016}/K	0.51	0.51	0.623	0.604	0.66	0.67
	B_{2016}/B_{MSY}	1.15	1.16	1.317	1.266	1.22	1.22
	F_{2015}/F_{MSY}	0.72	0.69	0.640	0.610	0.58	0.53
Sensitivity test S4 (no biomass)	K (10,000 mt)	536.15	454.75	375.7	303.3	216	189.2
	r	1.25	1.07	1.143	0.939	0.96	0.89
	Shape (s, Z, M)	0.56	0.35	0.823	0.673	1.86	1.87
	B_{1980}/K	0.14	0.31	0.167	0.16	0.18	0.18
	MSY (10,000 mt)	52.92	50.16	54.5	51.8	55.64	54.26
	F_{MSY}	0.27	0.26	0.365	0.359	1.07	0.76
	B_{MSY} (10,000 mt)	234.01	199.45	173.6	14.3	116.2	106.5
	B_{1980} (10,000 mt)	70.52	61.14	60.3	48.4	39.57	33.63
	B_{2015} (10,000 mt)	244.98	217.90	217.1	174.4	132	113.3
	F_{1980}	0.43	0.39	0.51	0.492	2.99	1.23
	F_{2015}	0.18	0.17	0.208	0.207	0.59	0.38
	q5 (Biomass)	NA	NA	NA	NA	NA	NA
	B_{2016}/K	0.52	0.53	0.654	0.637	0.69	0.7
	B_{2016}/B_{MSY}	1.17	1.19	1.384	1.34	1.25	1.26
	F_{2015}/F_{MSY}	0.69	0.65	0.59	0.562	0.54	0.5

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