North Pacific Fisheries Commission

NPFC-2019-TWG PSSA04-Final Report

4th Meeting of the Technical Working Group on Pacific Saury Stock Assessment

REPORT

6-9 March 2019

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North Pacific Fisheries Commission
4th Meeting of the Technical Working Group on Pacific Saury Stock Assessment

6-9 March 2019
Yokohama, Japan

REPORT

Agenda Item 1. Opening of the Meeting

1. The 4th Meeting of the Technical Working Group on Pacific Saury Stock Assessment (TWG PSSA) of the North Pacific Fisheries Commission (NPFC) took place in Yokohama, Japan on 6-9 March 2019, and was attended by Members from Canada, China, Japan, the Republic of Korea, the Russian Federation, and Chinese Taipei. Dr. Larry Jacobson also attended the meeting as an invited expert.

2. The meeting was opened by the TWG PSSA Chair, Dr. Toshihide Kitakado, who outlined the objectives and procedures for the meeting.

3. Japan welcomed the participants to Yokohama, pointed out that Pacific saury is an important species for the NPFC, and wished for the success of the meeting.

4. The Executive Secretary, Dr. Dae-Yeon Moon, reminded the participants that the Commission has tasked the TWG PSSA with providing a consensus stock assessment for Pacific saury by the beginning of 2019 and scientific guidance necessary for the development of harvest control rules for Pacific saury sufficient to prevent a declining trend of the stock. The Executive Secretary commended the participants for the good progress they achieved at the TWG PSSA03 meeting and for their hard work and cooperation to date. The Executive Secretary also thanked the United States, on behalf of the NPFC, for providing a voluntary contribution for funding the participation of the invited expert.

Agenda Item 2. Adoption of Agenda

5. The participants agreed to modify the titles of Agenda Item 6.4 and 6.4.4 to “Conclusion on the stock assessment of Pacific saury” and “Conclusion on the stock assessment results” respectively.

6. The revised Agenda was adopted (Annex A). The List of Documents and Participants List are attached (Annexes B, C).

Agenda Item 3. Overview of the outcomes of previous NPFC meetings relevant to Pacific saury

3.1 TWG PSSA03 meeting

7. The Chair summarized the outcomes and recommendations from the TWG PSSA03 meeting.

3.2 BRP/HCR/MSE workshop

8. The Chair of the Biological Reference Point/Harvest Control Rule/Management Strategy Evaluation Workshop, Mr. Luoliang Xu, summarized the outcomes and recommendations relevant to Pacific saury from the Workshop.

3.3 Progress of work on the joint CPUE standardization

9. Japan presented a preliminary joint CPUE standardization for Pacific saury with generalized linear models (GLM) and generalized additive models (GAM) on the assumption of lognormal distribution of errors (NPFC-2019-TWG PSSA04-WP01).

10. Russia presented a preliminary joint CPUE standardization for Pacific saury with GLM and GAM on the assumption of Tweedie with natural logarithm as a link function for distribution of errors (NPFC-2019-TWG PSSA04-WP03).

11. China presented a preliminary joint CPUE standardization for Pacific saury with spatial-GLM (NPFC-2019-TWG PSSA04-WP05).

12. China presented a preliminary joint CPUE standardization for Pacific saury with multiple indices (NPFC-2019-TWG PSSA04-WP06).

13. Chinese Taipei presented an evaluation of the spatio-temporal distribution and abundance of Pacific saury using Vector Autoregressive Spatio-Temporal (VAST) models.

14. The participants had some concerns about applying the VAST model to the CPUE data and agreed to discuss this issue further in a future meeting of the TWG PSSA. However, they agreed that it would be useful to apply such a spatio-temporal model to Japan’s biomass survey. Japan explained that it is already conducting such work and will present the results at a future meeting of the TWG PSSA.

15. The participants agreed to continue the joint CPUE standardization work and provide updates at the next TWG PSSA meeting as appropriate.

Agenda Item 4. Review of the Terms of Reference of the TWG PSSA

16. The participants reviewed the Terms of Reference of the TWG PSSA and determined that no revisions are currently necessary.

Agenda Item 5. Review of recent fishery status

17. China presented an update on the status of its fishery for Pacific saury with catch and CPUE data for 2018 (NPFC-2019-TWG PSSA04-IP01). Total catch has fluctuated from 2013 to 2018, and increased in 2018 compared to 2017. Fishing effort has declined since 2016.

18. Russia presented an update on the status of its fishery for Pacific saury (NPFC-2019-TWG PSSA04-WP07) with catch, CPUE and size composition data for 2018. Catch has been low in 2017 and 2018 compared to previous years. The number of vessels declined in 2018 compared to 2017. However, the catch per day per vessel has increased in 2018. In 2018, the fishing season began earlier than usual and was therefore longer. The average body length of caught Pacific saury was slightly larger in 2018 than in 2017.

19. Korea presented an update on the status of its fishery for Pacific saury with catch, CPUE and spatial distribution data for 2018 (NPFC-2019-TWG PSSA04-IP02). In 2018, total catch was 23,701 tons and 12 vessels fished for Pacific saury over 811 fishing days.

20. Japan presented an update on the status of its fishery for Pacific saury with catch, CPUE, spatial distribution, age composition and size composition data for 2018 (NPFC-2019-TWG PSSA04-IP03). Total catch in 2018 was 128,000 tons, over 99% of which was caught by stick-held dip nets. The fishing grounds were mainly offshore with one-third of catch caught in the high seas.

21. Chinese Taipei presented an update on the status of its fishery for Pacific saury with catch and CPUE data for 2018, and spatial distribution and size composition data for 2017 (NPFC-2019-TWG PSSA04-IP04). In 2018, total catch was 177,951 tons, an increase from 2017, and 83 vessels fished for Pacific saury over 6,235 fishing days. The average size of caught Pacific saury has declined over the 2015-2017 period. Fishing grounds have been expanding eastward in 2017.

Agenda Item 6. Review of results of the stock assessment using "provisional base models" (BSSPM)

6.1 Review of the Stock Assessment Protocol

22. The participants reviewed the Stock Assessment Protocol and determined that no revisions are currently necessary.

6.2 Review of the specification agreed in TWG PSSA03 meeting

23. The participants reviewed the specifications of the Bayesian state-space production model (BSSPM) for the updated stock assessment and template for stock status information and future projection as agreed in the TWG PSSA03 meeting (TWG PSSA03 report, Annexes F and G).

6.3 Review of stock assessment results

24. China presented its results of Pacific saury stock assessment (NPFC-2019-TWG PSSA04-WP08). The estimated median B_{2018} from the six base case scenarios (961,500-3,575,000 metric tons) was greater than the B_{2017} (583,800-1,950,000 metric tons). The median B_{2017}/B_{MSY} and F_{2017}/F_{MSY} from the six base case scenarios ranged from 0.23-0.69 and 0.59-1.17, respectively. The median B_{2018}/B_{MSY} from the six base case scenarios ranged from 0.88-1.40. Based on its diagnostics, China made the following research recommendations for future stock assessment: 1) Quantify the impact of changes in the input data on the assessment results since there were a few substantive changes in this assessment in addition to the modifications of model methods; 2) Explore random walk of time-varying catchability for other CPUE indices because the random walk catchability for the Japanese early CPUE performed better than the other tested patterns; 3) Conduct additional research for the estimated biomass index and the catchability of Japanese biomass index.

25. Chinese Taipei presented a stock assessment of Pacific saury in the Western North Pacific Ocean through 2018 (NPFC-2019-TWG PSSA04-WP09). Based on the results of its stock assessment, Chinese Taipei concluded that estimates of biomass have increased since 2000 with peaks in 2005 and 2008, and then dramatically decreased until 2017. There is a slight increasing trend in 2018 in all base cases. The median values of biomass depletion and the ratio of biomass to B_{MSY} in 2017 were estimated at 0.33 (80 percentile range 0.15 – 0.40) and 0.80 (80 percentile range 0.34 – 0.95), respectively. Recent fishing mortality is estimated to be below F_{MSY}. Sensitivity runs indicated slightly pessimistic results compared to the six base cases. Overall, the results of the sensitivity analysis confirmed the robustness of the base case model.

26. Japan presented the updated outcomes of its stock assessment for the Pacific saury using the BSSPM (NPFC-2019-TWG PSSA04-WP10). Based on the results of its stock assessment, Japan concluded that the stock status differed somewhat between 2017 and 2018, and the ranges of median B/K in 2017 and 2018 over the six base cases are respectively 0.196-0.268 and 0.338-0.491. Such a significant difference was also observed in B-ratio and F-ratio. Although Japan concluded in its previous stock assessment report in 2018 that the population status was overfished and subject to overfishing, the recent increase in the biomass estimated by the

Japanese survey drove the population status to a more optimistic condition as overfished but not subject to overfishing.

27. Russia demonstrated a different stock assessment model for Pacific saury in the western North Pacific Ocean using Just Another Bayesian Biomass Assessment (JABBA), as an example of the use of publicly available stock assessment software without using prior distributions for the survey or CPUE catchability coefficients (NPFC-2019-TWG PSSA04-WP04). Such approaches should be discussed further in the next assessment. A similar study with JABBA Select was recommended.

6.4 Conclusion on the stock assessment of Pacific saury

6.4.1 Stock biomass

6.4.2 Fishing mortality

6.4.3 Level of uncertainty

6.4.4 Conclusion on the stock assessment results

28. The participants reviewed the stock assessments presented by Members and aggregated the results (Annex D).

6.5 Recommendations for future work

6.5.1 Possible improvements of the models within BSSPM

29. The participants considered the following possible improvements that could be made to the models within the BSSPM:
    (a) Develop continuous production models.
    (b) Analyze the sensitivity of the models to each of the prior assumptions.
    (c) Perform a maximum likelihood estimation without assumed priors.
    (d) Examine each other's prior settings.
    (e) Further investigate the uncertainty in certain key parameters (i.e. catchability, intrinsic growth rates and shape).
    (f) Add histograms to Kobe plots in the template for stock status information.

6.5.2 Visual presentation of stock assessment results to SC and Commission

30. The participants agreed to include an Executive Summary in the stock assessment report to facilitate better understanding of the stock assessment results by managers. A draft of the Executive Summary is prepended to the stock assessment report (Annex D).

31. Because of the similarity in Members' stock assessment results, the participants agreed to include in the Executive Summary a direct aggregation of the results for all 18 models (six base cases by three Members) for ease of understanding. The results for each model are included in

the main body of the stock assessment report. The participants also noted that it may not always be advisable to aggregate stock assessment results, such as when Members' assessments show disagreement on key results.

32. The TWG PSSA agreed to provide the results of the retrospective analyses in graphic terms in the stock assessment report. No retrospective patterns were observed.

33. Hindcasting projections were included in the retrospective analyses for Japan. Results showed poor projection performance (see paragraph 38).

6.5.3 Facilitation of code-sharing processes

34. The participants reaffirmed the importance of working towards using a single, shared model code, which would enable more efficient stock assessments.

6.5.4 Others

35. No other future work was discussed.

Agenda Item 7. Implication for management of Pacific saury based on "provisional base models" (BSSPM)

7.1 Biological reference points

7.2 Review results of future projection

7.3 Risk analyses of alternative catch levels

7.4 Conclusion on the management advice

36. Based on combined model estimates, B was below B_{MSY} (average B/B_{MSY} during 2016-2018 = 0.82) and F was below F_{MSY} (average F/F_{MSY} during 2015-2017 = 0.82). Results indicate that the stock declined from near carrying capacity in the mid-2000's after a period of high productivity to current levels. Exploitation rates were increasing slowly during this period but remained lower than F_{MSY}. Point estimates indicate that stock biomass fell to the lowest value since 1980 (B/B_{MSY} = 0.63) in 2017, then increased to B_{MSY} in 2018. Biomass estimates show long-term fluctuations and interannual variability.

37. Several years of new data will be required to detect changes in stock condition because individual assessment model estimates and survey observations are highly uncertain. It would therefore be reasonable to wait perhaps three years before carrying out another benchmark assessment. A limited set of current model scenarios could be updated more frequently, and survey data should be monitored annually although individual year-to-year changes will be difficult to interpret.

38. The participants noted that the BSSPM model projections for Pacific saury were not useful and likely to be misinterpreted because Pacific saury is a short-lived species and production models like the BSSPM do not explicitly carry information about recent age structure, recruitment strength, growth rates or other factors that might be used to predict short-term changes in the stock. The participants decided that the projections should not be included in the main body of the report due to their misleading nature. The TWG PSSA's ability to improve the accuracy of the future projections may increase when an age-structured assessment model is developed for Pacific saury and other projection procedures are considered.

Agenda Item 8. Review and update of biological information/data

39. Japan presented a review of available information on growth, maturation and mortality for future stock assessment and management of Pacific saury (NPFC-2019-TWG PSSA04-WP02).

40. The participants reaffirmed the importance of biological information for the Pacific saury stock assessment, especially as the TWG PSSA moves towards the development of age-structured models and MSE analyses.

41. Japan provided supplementary information on the geographical distribution change over time of Pacific saury because some Members pointed out the importance to clarify distribution by age.

42. The participants encouraged Japan to submit a working paper on the ecology and biology of Pacific saury to a future TWG PSSA meeting.

43. The participants recommended that the TWG PSSA conduct simulation studies to evaluate the existing and alternative survey designs, in light of the changes in the spatial dynamics of the Pacific saury stock and fisheries in recent years. The TWG plans to review any progress on spatial/temporal model-based survey biomass estimation and variance of the current survey catchability estimate prior to the next assessment. Japan agreed to internally discuss the possibility of making survey data available to the Members and associated conditions.

44. The participants encouraged Japan to present the plans for its 2019 biomass survey at the upcoming SSC PS04 meeting.

45. Japan encouraged scientists from other Members to participate in Japan's biomass survey (refer to the NPFC Circular #012/2019 Invitation to Japanese Biomass Survey for Pacific saury, distributed on 5 March 2019).

Agenda Item 9. Exploration of stock assessment models other than existing "provisional base models"

9.1 Data invention/availability (including the identification of potential covariates)

46. The participants reviewed the table of each Member's data availability for size composition and catch/CPUE data for Pacific saury that was compiled at the TWG PSSA02 meeting (Annex E).

9.2 Initial discussion on age/size/stage-structured models

47. The participants agreed to review a preliminary application of age-structured models to Pacific saury or existing approaches to other short-lived stocks. It will be important to maintain the existing BSSPM as the benchmark model, while new models are considered. It may be desirable to use both the BSSPM and the age-structured model in future.

48. The participants considered the recommendation by the BRP/HCR/MSE workshop to develop age-structured models for Pacific saury stock assessment and agreed that this is the direction the TWG PSSA should work towards.

9.3 Identification of information/data gaps and limits

49. The participants agreed to continue discussion towards the identification of information/data gaps and limits when appropriate.

9.4 Recommendations for future work

50. The participants considered the following as possible future work:
    (a) Further investigate the natural mortality of Pacific saury.
    (b) Conduct simulation studies to evaluate the existing and alternative designs of the Japanese biomass survey.

51. The participants encouraged any scientist from the Members to develop an age-structured model and present a preliminary demonstration at a future TWG PSSA meeting.

Agenda Item 10. Other matters

10.1 Initial discussion on Management Strategy Evaluation

52. The participants agreed that it would be premature to hold discussions on Management Strategy Evaluation (MSE) at the current meeting and that such discussions would be more appropriate after the development of an age-structured model. They recognized that, under its Terms of Reference, the TWG PSSA is expected to explore the design of the MSE framework and MSE will therefore continue to be a standing agenda item at future TWG PSSA meetings.

10.2 Priorities for next meetings

53. The participants recognized the following as priorities for the next TWG PSSA meetings:
    (a) Conduct a stock assessment update with base case model 2 (q_biomass=1).
    (b) Further investigate improvements to the BSSPM.
    (c) Develop an age-structured model.
    (d) Continue joint CPUE work to incorporate broader spatial and temporal coverage.
    (e) Update the biomass estimate using the existing method.
    (f) Explore the possibility of developing a spatio-temporal model for the biomass estimate.
    (g) Further investigate the coefficient of variation for the catchability coefficient in the Japanese survey. This variance should be included in the variance of the biomass data. If possible, refine the catchability estimate for the survey.
    (h) Develop a longer-term roadmap for work related to Pacific saury stock assessment.

10.3 Selection of TWG PSSA Chair for next biennium

54. The participants agreed to extend the term of the current Chair, Dr. Toshihide Kitakado, for two more years.

10.4 Other

55. Canada informed the participants that the North Pacific Marine Science Organization (PICES) will hold a workshop on 16 October 2019 in Victoria, Canada on the influence of environmental changes on the potential for species distribution shifts and subsequent consequences for estimating abundance of Pacific saury and encouraged Members to attend the workshop.

56. The participants recommended that the SC draft rules to address submission, revision and treatment of scientific papers before and during meetings, and submit the rules to the Commission for consideration. Members should be encouraged to bring attention to any changes in data or results detected before/during/after meetings to the TWG PSSA as soon as possible.

Agenda Item 11. Recommendations to the Small Scientific Committee on Pacific Saury

57. The TWG PSSA recommended the following to the SSC PS:
    (a) The participants agreed to continue the joint CPUE standardization work.
    (b) The participants recommended that the SSC PS endorse the stock assessment report (Annex D).
    (c) The participants agreed to use the current stock assessment models (BSSPM) as a benchmark and continue to improve them.
    (d) The participants agreed to continue biological research related to the stock assessment of Pacific saury.

(e) The participants agreed to continue work towards the development of age-structured models as new stock assessment models as well as the potential operating model for MSE.

(f) The participants recommended considering sharing more data for improving the current stock assessment and developing future ones.

(g) The participants recognized the contribution by the invited expert in facilitating the work of the TWG PSSA and recommended inviting Dr. Larry Jacobson (or an expert with similar qualifications and experience) to also attend the next TWG PSSA meetings.

Agenda Item 12. Adoption of the Report

58. The report was adopted by consensus.

Agenda Item 13. Close of Meeting

59. The meeting closed at 12:15 on 9 March 2019.

Annexes:

Annex A – Agenda

Annex B – List of Documents

Annex C – List of Participants

Annex D – Stock Assessment Report for Pacific Saury

Annex E – Data availability on size composition and catch/CPUE for Pacific saury

Annex A

Agenda

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Agenda Item 2. Adoption of Agenda

Agenda Item 3. Overview of the outcomes of previous NPFC meetings and intersessional activities relevant to Pacific saury

- 3.1 TWG PSSA03 meeting
- 3.2 BRP/HCR/MSE workshop
- 3.3 Progress of work on the joint CPUE standardization

Agenda Item 4. Review of the Terms of References of the TWG PSSA

Agenda Item 5. Review of recent fishery status

Agenda Item 6. Review of results of the stock assessment using "provisional base models" (BSSPM)

- 6.1 Review of the Stock Assessment Protocol
- 6.2 Review of the specification agreed in TWG PSSA03 meeting
- 6.3 Review of stock assessment results
- 6.4 Conclusion on the stock assessment of Pacific saury
  - 6.4.1 Stock biomass
  - 6.4.2 Fishing mortality
  - 6.4.3 Level of uncertainty
  - 6.4.4 Conclusion on the stock assessment results
- 6.5 Recommendations for future work
  - 6.5.1 Possible improvements of the models within BSSPM
  - 6.5.2 Visual presentation of stock assessment results to SC and Commission
  - 6.5.3 Facilitation of code-sharing processes
  - 6.5.4 Others

Agenda Item 7. Implication for management of Pacific saury based on "provisional base models" (BSSPM)

- 7.1 Biological reference points
- 7.2 Review results of future projection
- 7.3 Risk analyses of alternative catch levels
- 7.4 Conclusion on the management advice

Agenda Item 8. Review and update of biological information/data

Agenda item 9. Exploration of stock assessment models other than existing "provisional base models"

- 9.1 Data invention/availability (including the identification of potential covariates)
- 9.2 Initial discussion on age/size/stage-structured models
- 9.3 Identification of information/data gaps and limits
- 9.4 Recommendations for future work

Agenda item 10. Other matters

- 10.1 Initial discussion on Management Strategy Evaluation
- 10.2 Priorities for next meeting
- 10.3 Selection of TWG PSSA Chair for next biennium
- 10.4 Other

Agenda Item 11. Recommendations to the Small Scientific Committee on Pacific Saury

Agenda Item 12. Adoption of Report

Agenda Item 13. Close of the Meeting

Annex B

List of Documents

MEETING INFORMATION PAPERS

Document number	Title
NPFC-2019-TWG CMSA02-MIP01 (Rev. 2)	Meeting Notice and Information
NPFC-2019-TWG PSSA04-MIP02	Provisional Agenda
NPFC-2019-TWG PSSA04-MIP03	Provisional Annotated Agenda
NPFC-2019-TWG PSSA04-MIP04 (Rev. 1)	Indicative Schedule

REFERENCE DOCUMENTS

Document number	Title
NPFC-2018-TWG PSSA03-Final Report	Report of the 3rd meeting of TWG PSSA
	Terms of Reference for TWG PSSA
	Data availability for PSSA
	Stock Assessment Protocol for Pacific Saury

WORKING PAPERS

Document number	Title
NPFC-2019-TWG PSSA04-WP01	Preliminary Joint CPUE standardization for the Pacific saury with generalized linear and generalized additive models on the assumption of lognormal distributions
NPFC-2019-WS BRP_HCR_MSE01 (Rev. 1)	Review of target and limit reference points
NPFC-2019-TWG PSSA04-WP02	Available information of growth, maturation and mortality for future stock assessment and management of Pacific saury, Cololabis saira
NPFC-2019-TWG PSSA04-WP03	Preliminary joint CPUE standardization for the Pacific saury in the Northwest Pacific Ocean
NPFC-2019-TWG PSSA04-WP04	Alternative stock assessment of Pacific saury in the western North Pacific Ocean using JABBA
NPFC-2019-TWG PSSA04-WP05	CPUE standardization for Pacific saury fishery in North Pacific using GLM and spatial-GLM model

NPFC-2019-TWG PSSA04-WP06	Comparison of joint CPUE standardization based on various scenarios for Pacific saury (Cololabis saira) in the Northwestern Pacific Ocean
NPFC-2019-TWG PSSA04-WP07	Russian fishery for Pacific saury in 2018
NPFC-2019-TWG PSSA04-WP08	North Pacific Ocean Pacific Saury (Cololabis saira) 2019 Stock Assessment Update Report
NPFC-2019-TWG PSSA04-WP09	Stock assessment of Pacific saury (Cololabis saira) in the Western North Pacific Ocean through 2018
NPFC-2019-TWG PSSA04-WP10	Outcomes of the stock assessment for the Pacific saury – 2019 update with the BSSPM

INFORMATION PAPERS

Document number	Title
NPFC-2019-TWG PSSA04-IP01	Pacific saury fishery in China in 2018
NPFC-2019-TWG PSSA04-IP02	Catch and CPUE of the Korean Pacific saury fishery
NPFC-2019-TWG PSSA04-IP03	Status of Japanese Pacific saury fishery in 2018
NPFC-2019-TWG PSSA04-IP04	Updated Fishery Report of Chinese Taipei to 2018

Annex C

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Annex D

Stock Assessment Report for Pacific Saury

Abstract:
This document reports the results of the stock assessments conducted at the 4th meeting of the Technical Working Group on Pacific saury stock assessment (TWG PSSA), held at Yokohama during March 6-9, 2019.

EXECUTIVE SUMMARY

Data

Pacific saury (*Cololabis saira*) is widely distributed from the subarctic to the subtropical regions of the North Pacific Ocean. While their fishing grounds are limited to west of 180E, the main fishing grounds differ among Members (China, Japan, Korea, Russia, Chinese Taipei, and Vanuatu). Figure 1 shows the historical catches of Pacific saury by Member. Figure 2 shows CPUE and Japanese survey biomass indices used in the stock assessment.

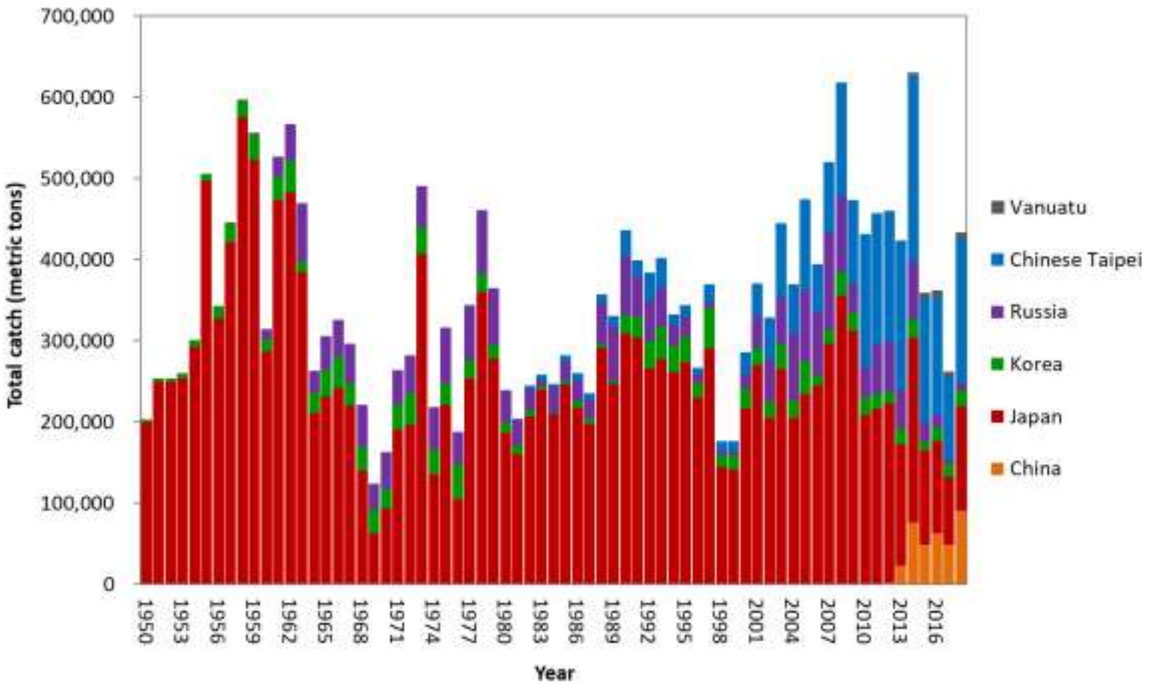


Figure 1. Time series of catch by Member. The catch data for 1950-1979 and 2018 are shown in the figure but were not used in stock assessment modeling.

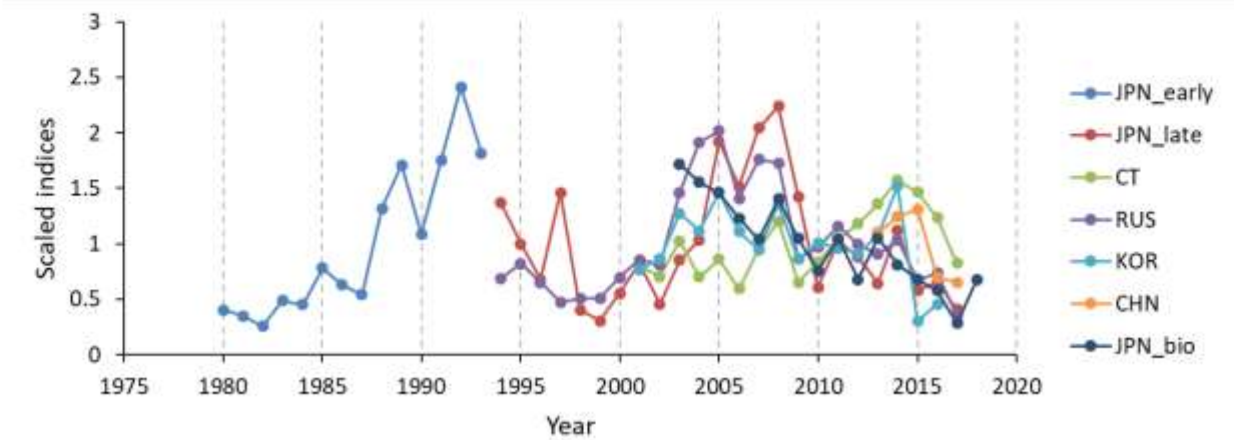


Figure 2. Time series of CPUE and Japanese survey biomass indices (JPN_bio). Survey data for 2018 were used in assessment modeling but CPUE data for 2018 were not.

Brief description of specification of analysis and models

A Bayesian state-space production model which was used in the previous stock assessments was employed for 1980-2018 as an agreed provisional stock assessment model to assess Pacific saury. Scientists from three Members (China, Japan and Chinese Taipei) each conducted analyses following the agreed specification for six base case models as well as six sensitivity case models (see Annex F, TWG PSSA03 report for more details). The six base case models covered three different assumptions of prior distribution for catchability (q) of the Japanese biomass survey index 1) q from 0.1 to 1; 2) q fixed at 1; and 3) q from 0.1 to 3[1] and two scenarios where the Japanese early CPUE was either used or not used. For the three base case scenarios that used the Japanese early CPUE, time-varying catchability was assumed because of the stated increase of catchability between 1980 and 1994. A higher weight was given for the Japanese biomass survey estimates compared to that for the Members' CPUEs. The CPUE data were modeled as nonlinear indices of biomass. Members used similar approaches with some differences in the assumption of the time-varying catchability and prior distributions for the free parameters in the model.

Summary of stock assessment results

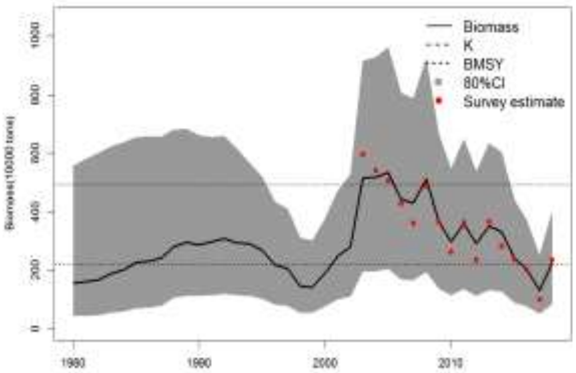
The results of the six base case models by the three stock assessment groups were averaged with equal weight to account for uncertainty in time-varying catchability in the models and differences in assumptions of prior distributions. The stock assessment results for each Member were similar, so outcomes of MCMC runs were aggregated over for the 18 models (6 base case models x 3 Members). The aggregated results for assessing the overall median values and their associated 80% credible intervals are shown in Table 1. The graphical presentations for times series of a) biomass (B), b) B-ratio (=B/Bmsy), c) exploitation rate (F), d) F-ratio (F/Fmsy) and e) B/K are shown in Figure 3. The Kobe plot with time trajectory using aggregated model outcomes is shown in Figure 4.

Table 1. Summary of estimates of reference quantities. Median values and ranges are reported.

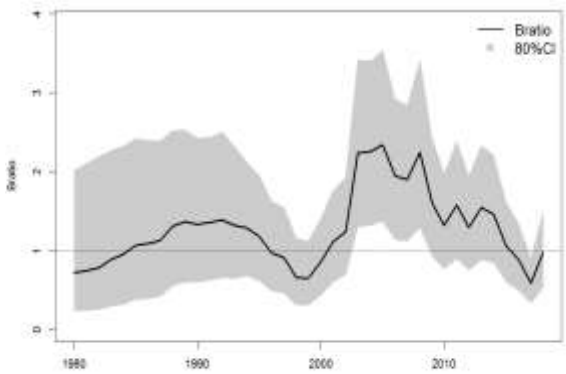
	Aggregated	Lower 10%	Upper 10%	China	Japan	Chinese Taipei
C2017 (10,000tons)	26.2			26.2	26.2	26.2
Ave C2015-2017 (10,000tons)	32.8			32.8	32.8	32.8
Ave F2015-2017	0.18	0.10	0.49	0.18	0.19	0.15
F2017	0.20	0.11	0.54	0.21	0.23	0.16
FMSY	0.25	0.11	0.45	0.27	0.26	0.24
MSY (10,000tons)	49.3	32.4	81.2	54.9	49.4	44.8
F2017 / FMSY	0.81	0.42	1.77	0.84	1.09	0.61
Ave F2015-2017 / FMSY	0.82	0.41	1.78	0.74	0.94	0.78
K (10,000tons)	490.3	244.2	930.1	497.3	468.1	504.4
B2017 (10,000tons)	129.7	51.0	249.4	126.6	114.4	175.1
B2018 (10,000tons)	222.5	82.6	395.6	221.8	209.0	246.6
Ave B2016-2018 (10,000tons)	184.8	70.1	334.8	181.8	172.3	223.3
BMSY (10,000tons)	219.7	111.1	419.4	218.5	206.6	232.6
BMSY / K	0.44	0.39	0.53	0.42	0.43	0.46
B2017 / K	0.27	0.15	0.40	0.25	0.23	0.33
B2018 / K	0.44	0.24	0.64	0.44	0.41	0.47
B2016-2018 / K	0.38	0.21	0.53	0.37	0.34	0.42
B2017 / BMSY	0.63	0.34	0.95	0.57	0.51	0.80
B2018 / BMSY	1.04	0.58	1.55	1.00	0.91	1.16
B2016-2018 / BMSY	0.82	0.47	1.22	0.83	0.75	0.90

[1] The third assumption on prior distribution catchability used in Chinese Taipei's report was q > 1.

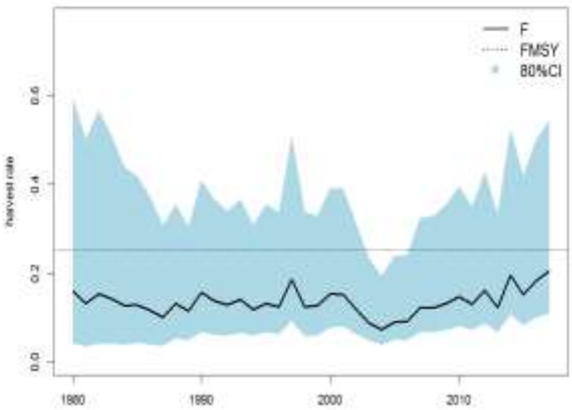
(a) Biomass (B)



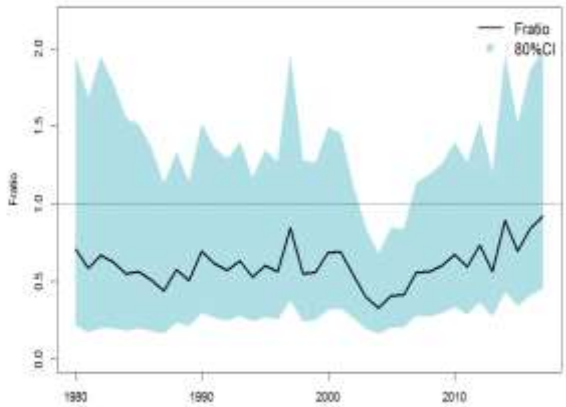
(b) B-ratio (B/Bmsy)



(c) Exploitation rate (F)



(d) F-ratio (F/Fmsy)



(e) B/K

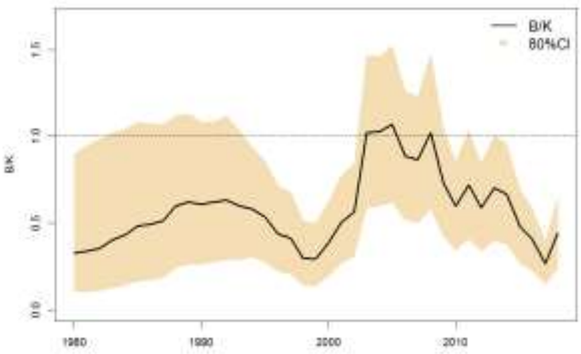


Figure 3. Time series plots for five key reference quantities: a) biomass (B), b) B-ratio (=B/Bmsy), c) exploitation rate (F), d) F-ratio (F/Fmsy), and e) B/K. The red dots in figure (a) show the survey biomass index by Japan, which was used in the model for the estimation of biomass. The data are aggregated across 18 model results (6 base-case models by 3 Members).

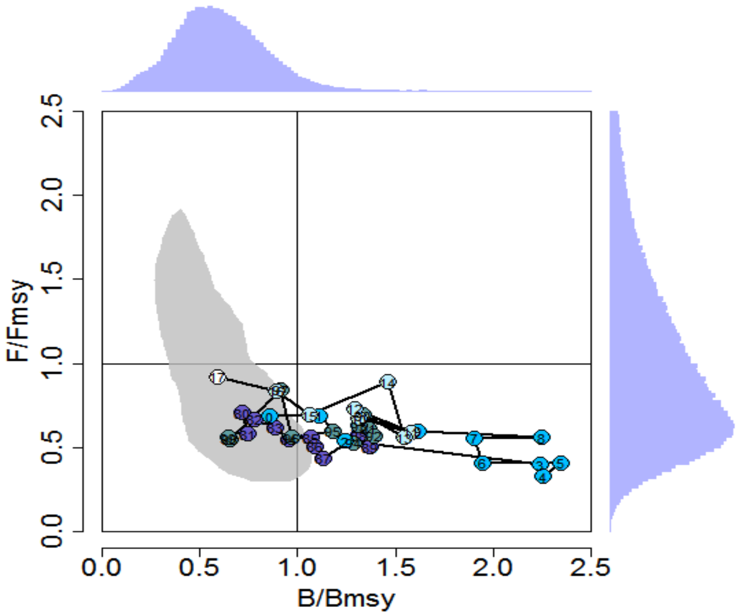


Figure 4. Kobe plot with time trajectory. The data are aggregated across 18 model results (6 base-case models by 3 Members).

Current stock condition

Based on combined model estimates, B was below Bmsy (average B/Bmsy during 2016-2018 = 0.82) and F was below Fmsy (average F/Fmsy during 2015-2017 = 0.82). Results indicate that the stock declined from near carrying capacity in the mid-2000's after a period of high productivity to current levels. Exploitation rates were increasing slowly during this period but remained lower than Fmsy. Point estimates indicate that stock biomass fell to the lowest value since 1980 (B/Bmsy = 0.63) in 2017, then increased to Bmsy in 2018. Biomass estimates show long-term fluctuations and interannual variability.

Special comments regarding the procedures and stock assessment results

The TWG PSSA worked collaboratively to produce this consensus stock assessment, which includes significant technical improvements.

1) CPUE data were assumed to change more slowly than biomass and were down-weighted relative to the Japanese survey.
2) Retrospective analyses showed that BSSPM model projections for Pacific saury were less useful than expected and the TWG agreed results were likely to be misinterpreted. The issue was discussed and further explained in the report. Additional research or age-structured assessment modelling may be required to provide projection results for use by managers, to enhance projection capability and support potential MSE (Management Strategy Evaluation) work.
3) Several issues related to prior distributions for catchability in the Japanese survey used in modeling merit attention. Additional field studies to estimate catchability would be useful. The TWG noted that the upper bound in base case models 3 and 6 may not constrain the BSSPM sufficiently and result in biomass estimates that are too low. The TWG was pleased to learn of tentative plans for participation of scientists from other Members in the Japanese survey.
4) The TWG plans to review any progress on spatial/temporal model-based survey biomass estimation and variance of the current survey catchability estimate prior to the next assessment. Japan agreed to internally discuss the possibility of making survey data available to the Members and associated conditions.

5) Certain other key parameter estimates (i.e. intrinsic growth rate and shape) reach the upper bound of their prior ranges in some models indicating that these parameters and suitable priors in stock assessment modelling should be investigated before the next assessment.
6) It may be possible to increase efficiency of stock assessment work by reducing duplicate work by Members. For example, CPUE standardization and assessment modeling might be done by single subgroups. The time saved could be used to develop harvest control rules and implement age-structured models, for example.
7) Three independent assessment model computer programs were used in this assessment to fit the same model. It would be easier to maintain computer code and ensure correct calculations if one program were used by all Members, particularly as more complicated age-structured models are introduced.
8) This executive summary for Pacific saury stock assessment results is an attempt to enhance communication with managers, other scientists and interested persons who may not want to read the full assessment report with complete technical details. Such reports are typically short and include agreed sets of tables and figures in standard formats. The NPFC should discuss the format of the executive summary with respect to information requirements and effective communication.
9) Because of the similarity in outcomes, the TWG agreed to aggregate Members' stock assessments for communicating results in 2019. This may not be advisable in future years.
10) Members report that the fishing grounds have shifted further offshore over the last decade. Japanese survey results indicate possible changes in spatial distribution of Pacific saury habitat. Potential effects on productivity are unknown.

1. INTRODUCTION

1.1 Distribution

Pacific saury (*Cololabis saira* Brevoort, 1856) has a wide distribution extending in the subarctic and subtropical North Pacific Ocean from inshore waters of Japan and Kuril Islands to 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).

1.2 Migration

Saury migrates extensively between the northern 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 in offshore regions (east of 160E) also migrate westward toward the coast of Japan after October every year (Suyama et al. 2012).

1.3 Population structure

Genetic evidence suggests there are no distinct stocks 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).

1.4 Spawning season and grounds

The spawning season of Pacific saury is relatively long, beginning in September and ending in June of the following year (Watanabe and Lo 1989). Pacific saury spawns over a vast area from the Japanese coastal waters to eastern offshore waters (Baitaliuk et al. 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).

1.5 Food and feeding

The Pacific saury larvae 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 on 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 whales *Balaenoptera acutorostrata* (Konishi et al. 2009) and sea birds (Ogi 1984).

1.6 Age and growth

Based on analysis of daily otolith increments, Pacific saury reaches 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). There is some variation in growth rate depending on the hatching month during this long spawning season (Kurita et al. 2004) and 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 in June and July when Japanese research surveys are conducted and reach over 29 cm in the fishing season between August and December (Suyama et al. 2006).

1.7 Reproduction

The minimum size of maturity of Pacific saury has been estimated at about 25 cm in the field (Hatanaka 1956) or rearing experiments (Nakaya et al. 2010). In rare cases, saury have been found to mature at 22 cm (Sugama 1957; Hotta 1960). Under rearing experiments, Pacific saury begins spawning 8 months after hatching, and spawning activity continues for about 3 months (Suyama et al. 2016). Batch fecundity is about 1,000 to 3,000 eggs per saury (Kosaka 2000).

2. FISHERY

2.1 Overview of fisheries

Western North Pacific

In Japan, the stick-held dip net fishery for Pacific saury was developed in the 1940s. Since then, the stick-held dip net gears have become the dominant fishing technic to catch Pacific saury in the northwest Pacific Ocean. More than 97% of Japan's total catch is caught by the stick-held dip net. Since 1995, the annual catch of Pacific saury for stick-held dip net fishery has varied. Maximum and minimum catches of 347 thousand tons and 84 thousand tons were recorded in 2008 and 2017, respectively. The 2018 annual catch of this fishery was 128,457 tons in the national waters and in the NPFC Convention Area.

Pacific saury fisheries in Korea have been operated with gillnet since the late 1950s in Tsushima Warm Current region. Korean stick-held dip net fishery started from 1985 in the Northwest Pacific Ocean. The largest catch of 50 thousand tons was recorded in 1997 (Gong and Suh 2013).

Russian fishery for Pacific saury has been conducted using stick-held dip nets in the northwest Pacific Ocean in the area that includes national waters (mainly within the Russian EEZ) and adjacent NPFC Convention Areas. Russian catch statistics for saury fishery exists, beginning from 1956, and standardized CPUE indices from that fishery were calculated since 1994. Saury fishery traditionally occurred from August to November; however, in recent years, the onset of fishing for saury shifted to the early summer period. Peak catch of saury of over 100 thousand tons was in 2007. Since then, the annual catch has been decreasing, and was about 8 thousand tons in 2018.

China commenced its exploratory saury fishing using stick-held dip net in the high seas in 2003, but only started to develop this fishery in 2012. The fishing seasons mainly cover the period from June-November.

The Pacific saury fishery of Chinese Taipei was first developed in 1975 by a research vessel, thereafter two commercial fishing vessels started operating in the Northwest Pacific Ocean in the next year. Between the 1980s and the early 1990s, the Pacific saury caught by some fishing fleets including trawlers, drift net fishing vessels, squid jiggers and tuna longliners. The number of fishing vessels reached 43 in 1985, 1986, and 1989. However, only the squid jiggers harvest the Pacific saury after 1996. Since the Pacific saury fishing season is mainly in the second half of the year, most fishing vessels typically fish for Atlantic shortfin squid (*Illex argentinus*) in the Southwest Atlantic Ocean for the first 4 or 5 months of the year. After the end of squid fishing season, the fishing vessels return to homeport to change fishing gear and then proceed to harvest Pacific saury in the Northwest Pacific Ocean. Before 2005, most of the fishing vessels engaged in the Pacific saury fishery also conducted neon flying squid jigging operations in the Northwest Pacific Ocean. After then, as the catch of Pacific saury exceeded that of neon flying squid, the fishing vessels changed their fishing practices to target Pacific saury only.

Vanuatu commenced its development of Pacific saury fishery by using stick-held dip net at the high seas in 2013. Currently there are four vessels operating in the Northwest Pacific targeting saury. The fishing season mainly covers the period from July to November each year.

Eastern North Pacific

Although Pacific saury occur in the Canada EEZ, there is no targeted fishery for the species. There is no historical record of Canadian participation in international fisheries for saury. Domestic fisheries sometimes capture saury as bycatch in pelagic and bottom trawls and there are a handful of records from other gear types including commercial longlines. The most recently compiled estimates indicate only 224 kg of saury were captured by Canadian commercial fisheries over 17 years from 1997-2013 (Wade and Curtis 2015). There are also records of saury catches from research trawls (surface, pelagic and bottom trawls) in Canadian waters, but the catches have been minimal.

Management plans developed by the National Marine Fisheries Service currently prohibit targeted fishing on marine forage species including the Pacific saury. In the 1950's to mid-1970's there were sporadic attempts to commercially fish for Pacific saury off of California with limited success using purse seines and light attraction (Kato 1992). Catches from 1969-1972 averaged 450 tons. Currently landings are only "occasionally" reported as bycatch in fisheries on the US west coast. Landings of Pacific saury as bycatch on the US west coast averaged 5.5 kg per year from 2011-2015 (NOAA Fisheries National Bycatch Report Database System, https://www.st.nmfs.noaa.gov/, accessed March 8, 2019)

While Japanese and Russian vessels operate mainly within their EEZ, Chinese, Korean and Chinese Taipei vessels operate mainly in the high seas of the North Pacific (Figure 1).

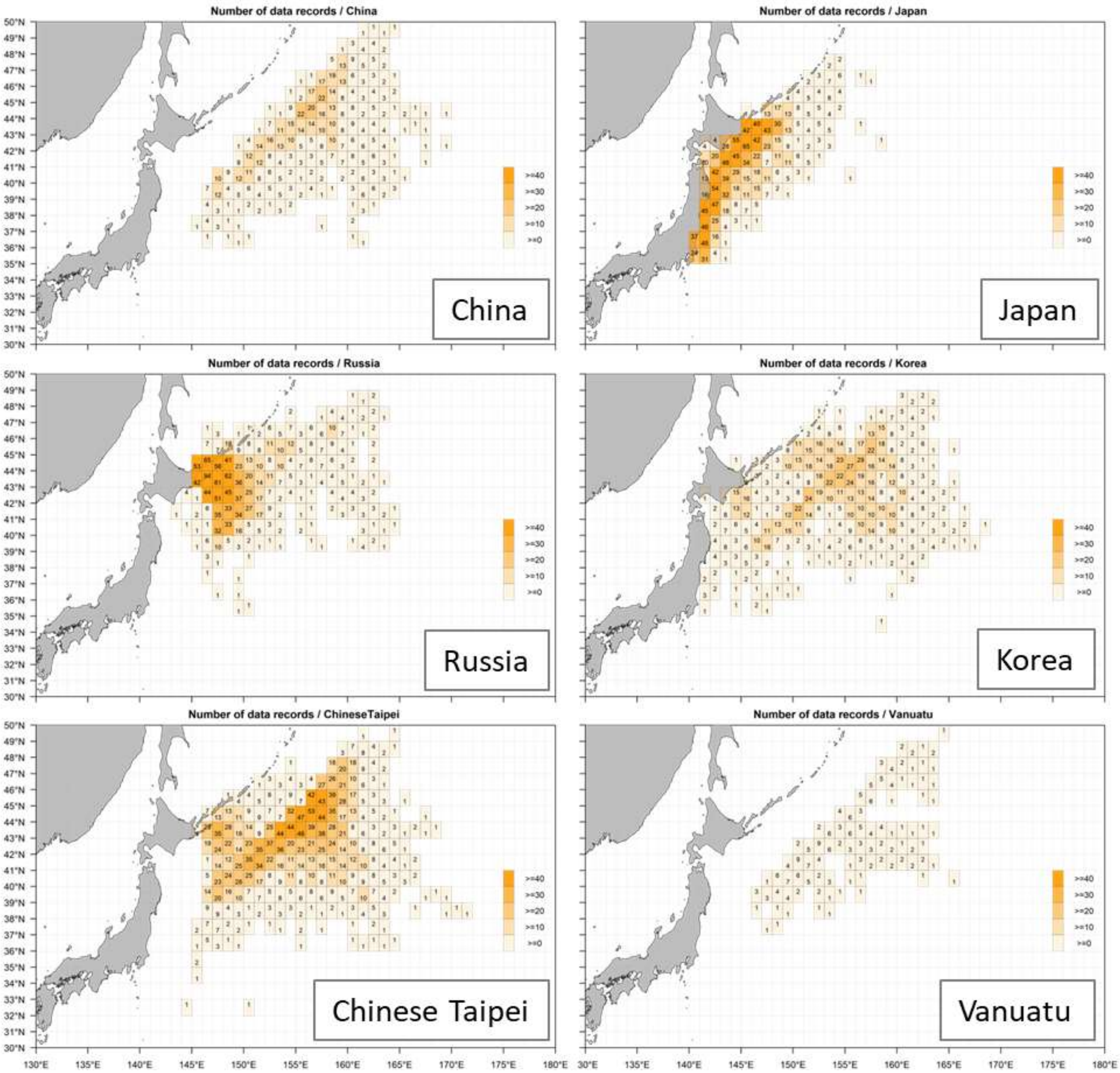


Figure 1. Main fishing grounds for Pacific saury by fishing members in the Western North Pacific Ocean. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index (NPFC-2018-TWG PSSA03-WP02, NPFC-2018-TWG PSSA03-WP03, NPFC-2018-TWG PSSA03-WP04, NPFC-2018-TWG PSSA03-WP06b, NPFC-2018-TWG PSSA03-WP08, and NPFC-2018-TWG PSSA03-WP12; available at www.npfc.int).

2.2 Catch records

Figure 2 shows the historical catches of Pacific saury by Member.

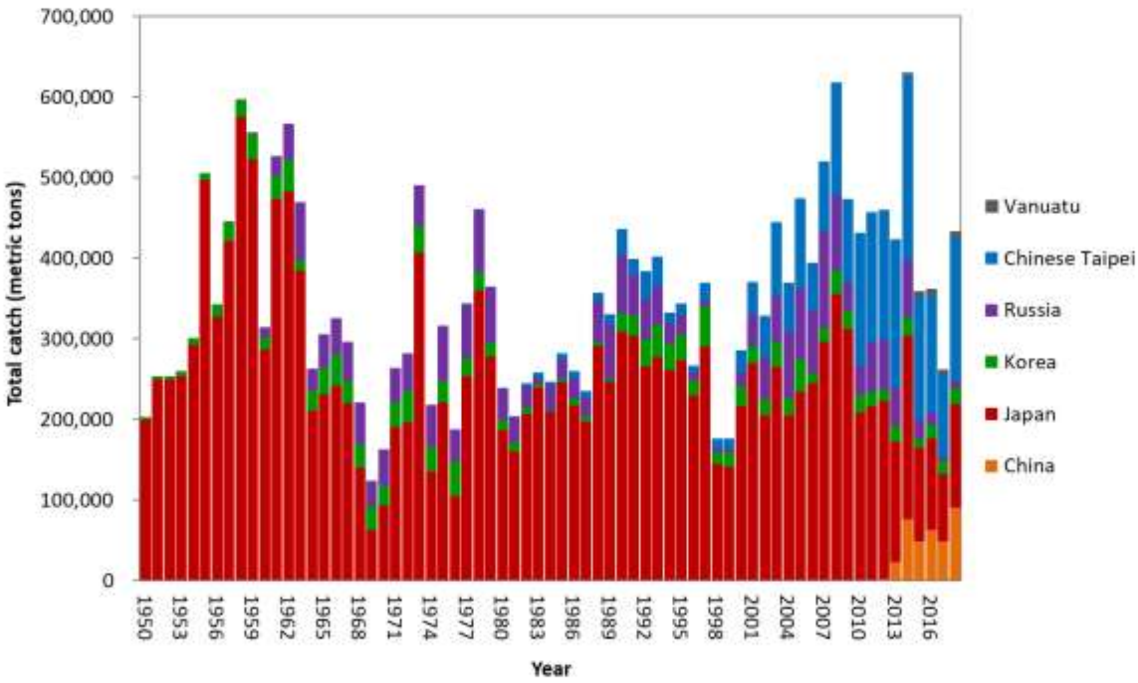


Figure 2. Time series of catch by Member.

3. SPECIFICATION OF STOCK ASSESSMENT

A Bayesian state-space production model which was used in the previous stock assessments was employed for 1980-2018 as an agreed provisional stock assessment model to assess Pacific saury. Scientists from three Members (China, Japan and Chinese Taipei) each conducted analyses following the agreed specification for six base case models as well as six sensitivity case models (see Annex F, TWG PSSA03 report for more details). The six base case models covered three different assumptions of prior distribution for catchability (q) of the Japanese biomass survey index 1) q from 0.1 to 1; 2) q fixed at 1; and 3) q from 0.1 to 3[2] and two scenarios where the Japanese early CPUE was either used or not used. For the three base case scenarios that used the Japanese early CPUE, time-varying catchability was assumed because of the stated increase of catchability between 1980 and 1994. A higher weight was given for the Japanese biomass survey estimates compared to that for the Members' CPUE. The CPUE data were modeled as nonlinear indices of biomass. Members used similar approaches with some differences in the assumption of the time-varying catchability and prior distributions for the free parameters in the model. Details are given in the following sections.

3.1 Bayesian state-space production model

The population dynamics is modelled by the following equations:

$$B_t = \{B_{t-1} + B_{t-1} f(B_{t-1}) - C_{t-1}\} e^{u_t}, \quad u_t \sim N(0, \tau^2)$$

$$f(B_t) = r\left[1 - \left(\frac{B_t}{K}\right)^z\right]$$

where

B_t : the biomass at the beginning of year t

C_t : the total catch of year t

[2] The third assumption on prior distribution catchability used in Chinese Taipei's report was q > 1.

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 (shape parameter; different symbols were used by 3 members)

The multiple biomass indices are modelled as follows:

Survey biomass estimate

$$I_{t,biomass} = q_{biomass} B_t \, exp(\, v_{t,biomass}), \qquad \text{where} \;\; v_{t,biomass} \sim N\left(0, \sigma^2_{biomass}\right)$$

where

$q_{biomass}$: the relative bias in biomass estimate
$v_{t,biomass}$: the observation error term in year *t* for survey biomass estimate
$\sigma^2_{biomass}$: the observation error variance for survey biomass estimate

CPUE series

$$I_{t,f} = q_f B_t^b \, exp(\, v_{t,f}), \qquad \text{where} \;\; v_{t,f} \sim N\left(0, \sigma_f^2\right)$$

where

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

q_f : the catchability coefficient for biomass index *f*

b: the hyper-stability/depletion parameter
$v_{t,f}$: the observation error term in year *t* for biomass index *f*
σ_f^2: the observation error in year *t* for biomass index *f*

For the estimation of parameters, Bayesian methods were used with different own preferred assumption for the prior distributions for the free parameters. MCMC methods were employed for simulating the posterior distributions. For the assumptions of uniform priors used in China and Japan, see documents NPFC-2019-TWG PSSA04-WP10 (Rev. 1) and NPFC-2019-TWG PSSA04-WP08 (Rev. 1); for the non-uniform priors used in Chinese Taipei, see document NPFC-2019-TWG PSSA04-WP09 (Rev. 1).

3.2 Agreed scenarios

Table 1. Definition of scenarios

Case	Relative bias in biomass estimate	Fishery dependent index	Variance component	Hyper-stability
Base case 1 (B1)	U~(0.1, 1)	A1	V1	H1
Base case 2 (B2)	1 (unbiased)	A1	V1	H1
Base case 3 (B3)	U~(0.1, 3)	A1	V1	H1
Base case 4 (B4)	U~(0.1, 1)	A2	V2	H2
Base case 5 (B5)	1 (unbiased)	A2	V2	H2
Base case 6 (B6)	U~(0.1, 3)	A2	V2	H2
Sensitivity case 1 (S1)	U~(0.1, 1)	A1	V3	H3
Sensitivity case 2 (S2)	1 (unbiased)	A1	V3	H3
Sensitivity case 3 (S3)	U~(0.1, 3)	A1	V3	H3
Sensitivity case 4 (S5)	U~(0.1, 1)	A2	V3	H3
Sensitivity case 5 (S5)	1 (unbiased)	A2	V3	H3
Sensitivity case 6 (S6)	U~(0.1, 3)	A2	V3	H3

A1: With JPN early CPUE (1980-1993) with assumptions of time-varying *q*

A2: Without JPN early CPUE (1980-1993)

V1: Variances of CPUEs are assumed to be common and 6 times of that of biomass

V2: Variances of CPUEs are assumed to be common and 5 times of that of biomass

V3: Variances of CPUEs are assumed to be separate free parameters

H1: b is a common parameter for all fisheries but JPN_early, with a prior distribution, *b* ~ U(0, 1) [*b*_JPN_early=1]

H2: *b* is a common parameter for all fisheries, with a prior distribution, *b* ~ U(0, 1)

H3: *b*=1

Table 2. Description of symbols used in the stock assessment

Symbol	Description
C_{2017}	Catch in 2017
$AveC_{2015\text{-}2017}$	Average catch for a recent period (2015–2017)
$AveF_{2015\text{-}2017}$	Average harvest rate for a recent period (2015–2017)
F_{2017}	Harvest rate in 2017
F_{MSY}	Annual harvest rate producing the maximum sustainable yield (MSY)
MSY	Equilibrium yield at FMSY
F_{2017}/F_{MSY}	Average harvest rate in 2017 relative to FMSY
$AveF_{2015\text{-}2017}/F_{MSY}$	Average harvest rate for a recent period (2015–2017) relative to FMSY
K	Equilibrium unexploited biomass (carrying capacity)
B_{2017}	Stock biomass in 2017 estimated in the model
B_{2018}	Stock biomass in 2018 estimated in the model[b]
$AveB_{2016\text{-}2018}$	Stock biomass for a recent period (2016–2018) estimated in the model[b]
B_{MSY}	Stock biomass that will produce the maximum sustainable yield (MSY)
B_{MSY}/K	Stock biomass that produces the maximum sustainable yield (MSY) relative to the equilibrium unexploited biomass[a]
B_{2017}/K	Stock biomass in 2017 relative to K[a]
B_{2018}/K	Stock biomass in 2018 relative to K[a,b]
$B_{2016\text{-}2018}/K$	Stock biomass in the latest time period (2016-2018) relative to the equilibrium unexploited stock biomass[a,b]
B_{2017}/B_{MSY}	Stock biomass in 2017 relative to BMSY[a]
B_{2018}/B_{MSY}	Stock biomass in 2018 relative to BMSY[a,b]
$B_{2016\text{-}2018}/B_{MSY}$	Stock biomass for a recent period (2016–2018) relative to the stock biomass that produces maximum sustainable yield (MSY) [a,b]

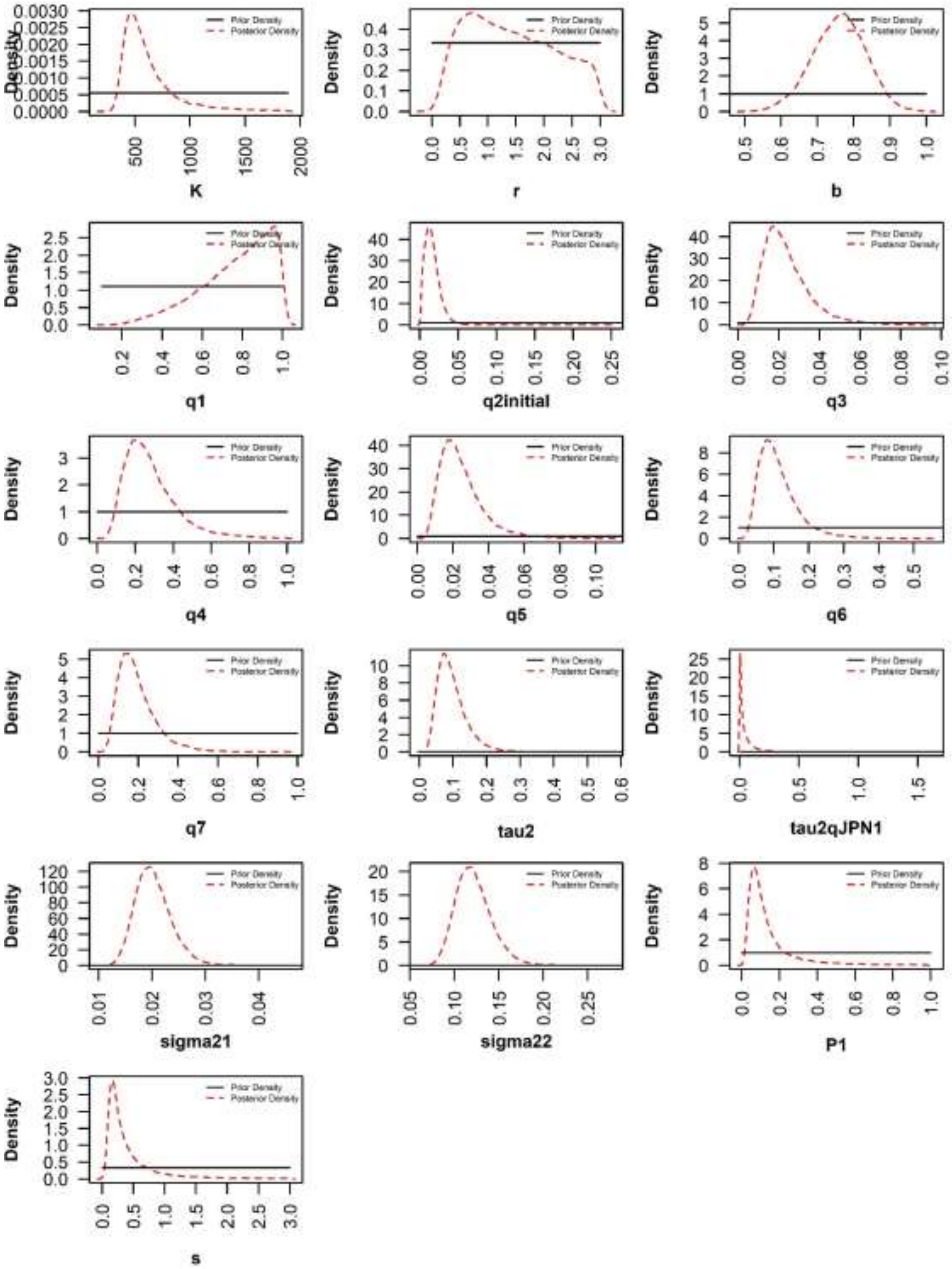
[a]calculated as the average of the ratios,

[b]Japanese biomass survey available but no CPUE available in 2018.

4. RESULTS by CHINA, JAPAN and CHINESE TAIPEI

4.1 CHINA

4.1.1 Prior and posterior distributions for Base case model 1 (as an illustrative example)

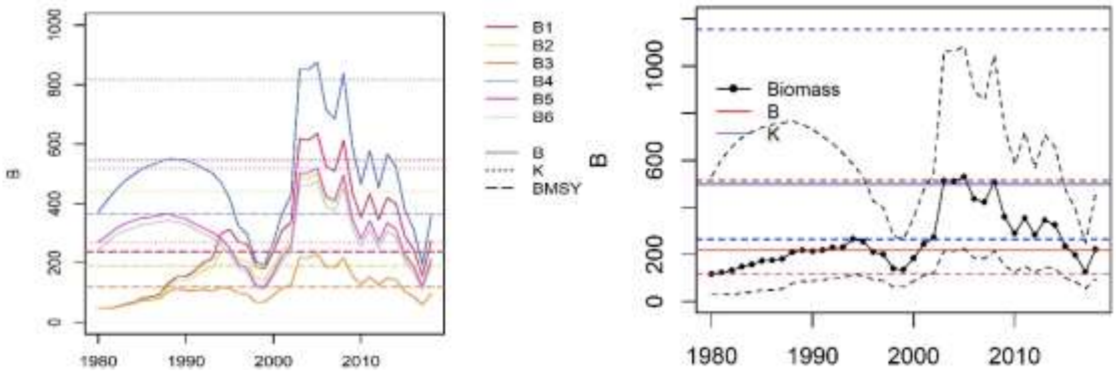


4.1.2 Summary of estimates of parameters and reference points

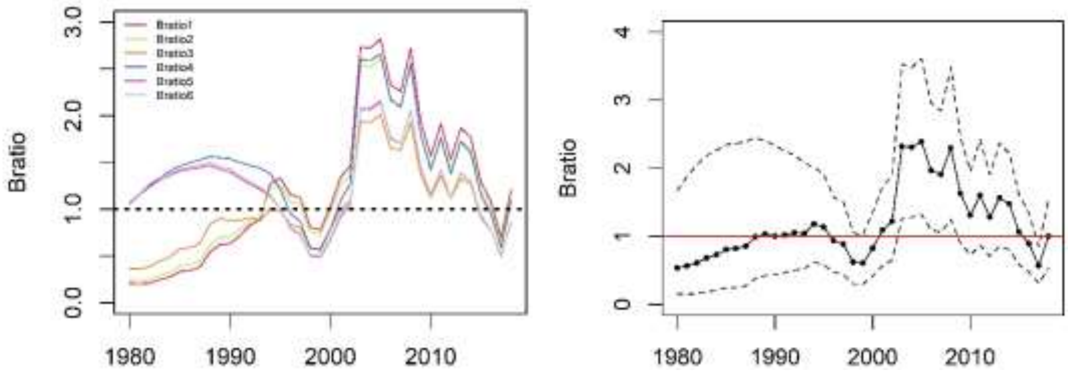
	Base case 1	Base case 2	Base case 3	Base case 4	Base case 5	Base case 6	Overall
C2017	26.18	26.18	26.18	26.18	26.18	26.18	26.18
AveC2015-2017	32.75	32.75	32.75	32.75	32.75	32.75	32.75
AveF2015-2017	0.15	0.18	0.41	0.12	0.19	0.21	0.18
F2017	0.17	0.21	0.45	0.13	0.22	0.24	0.21
FMSY	0.27	0.30	0.37	0.19	0.21	0.24	0.27
MSY	64.65	57.06	44.80	66.50	52.78	51.92	54.86
F2017/FMSY	0.59	0.71	1.17	0.69	1.04	1.07	0.84
AveF2015-2017/FMSY	0.52	0.63	1.06	0.59	0.91	0.94	0.74
K	547.70	441.50	268.10	816.70	517.10	539.00	497.30
B2017	157.00	125.00	58.38	195.00	118.40	109.20	126.60
B2018	272.70	214.60	96.15	357.50	211.40	193.20	221.80
AveB2016-2018	223.38	178.70	80.23	288.30	173.30	158.67	181.83
BMSY	234.50	190.10	119.20	365.40	239.40	240.40	218.50
BMSY/K	0.41	0.41	0.43	0.43	0.43	0.43	0.42
B2017/K	0.30	0.28	0.23	0.27	0.23	0.23	0.25
B2018/K	0.52	0.48	0.38	0.49	0.40	0.40	0.44
B2016-2018/K	0.43	0.40	0.32	0.40	0.33	0.33	0.37
B2017/BMSY	0.69	0.65	0.51	0.59	0.49	0.50	0.57
B2018/BMSY	1.20	1.12	0.85	1.09	0.88	0.88	1.00
B2016-2018/BMSY	1.00	0.94	0.72	0.89	0.72	0.72	0.83

4.1.3 Time series plots for base case models and aggregated results

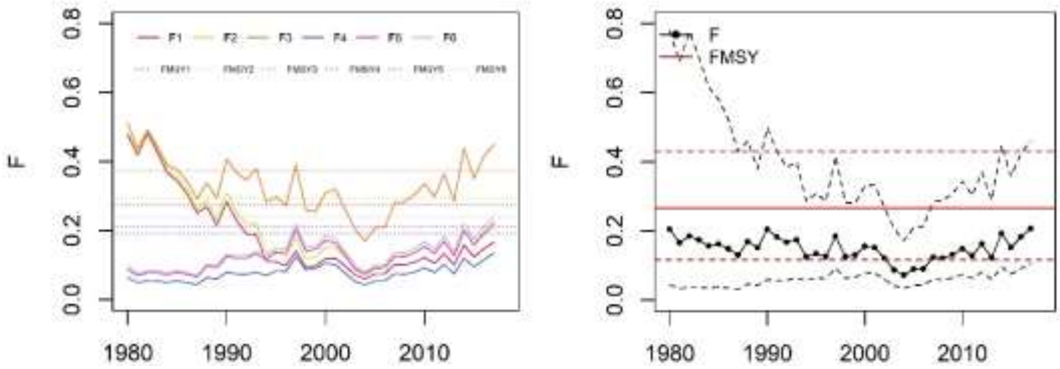
(a) Biomass



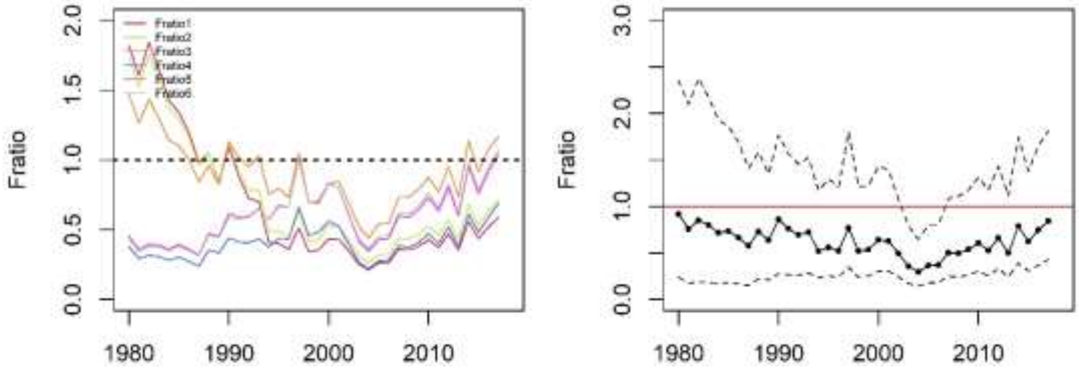
(b) B-ratio (B/Bmsy)



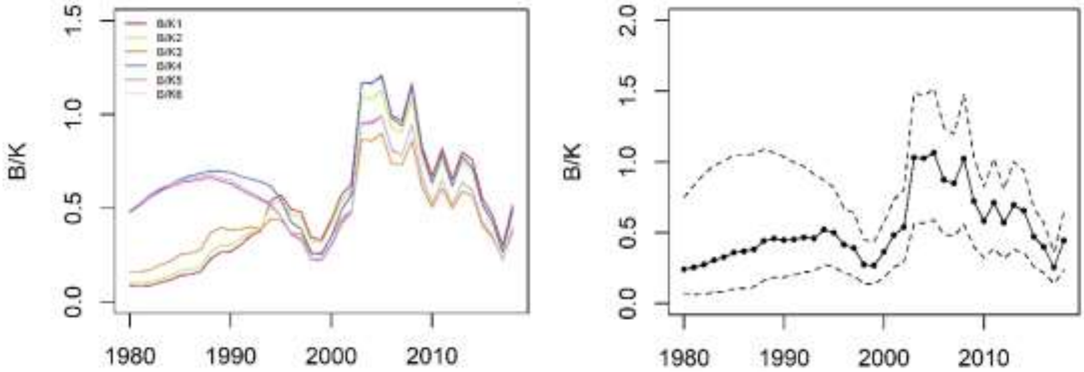
(c) Exploitation rate (F)



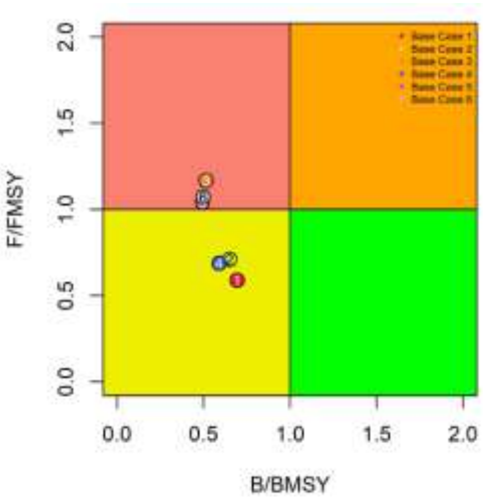
(d) F-ratio (F/Fmsy)

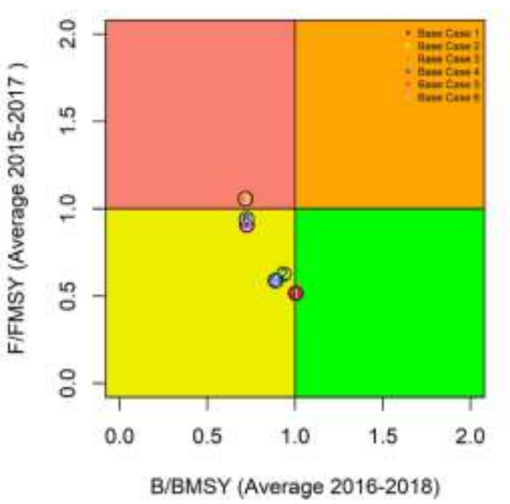


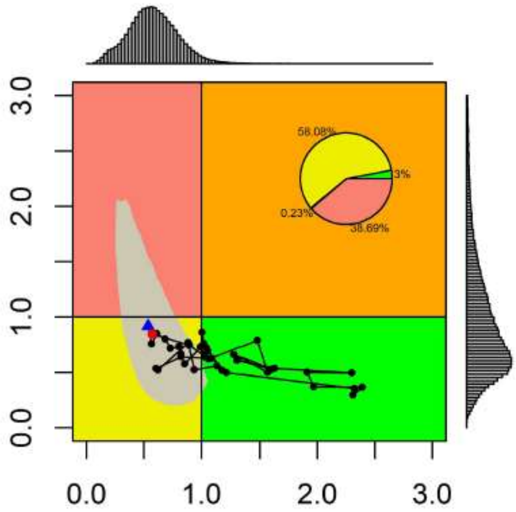
(e) B/K



4.1.4 Kobe plots

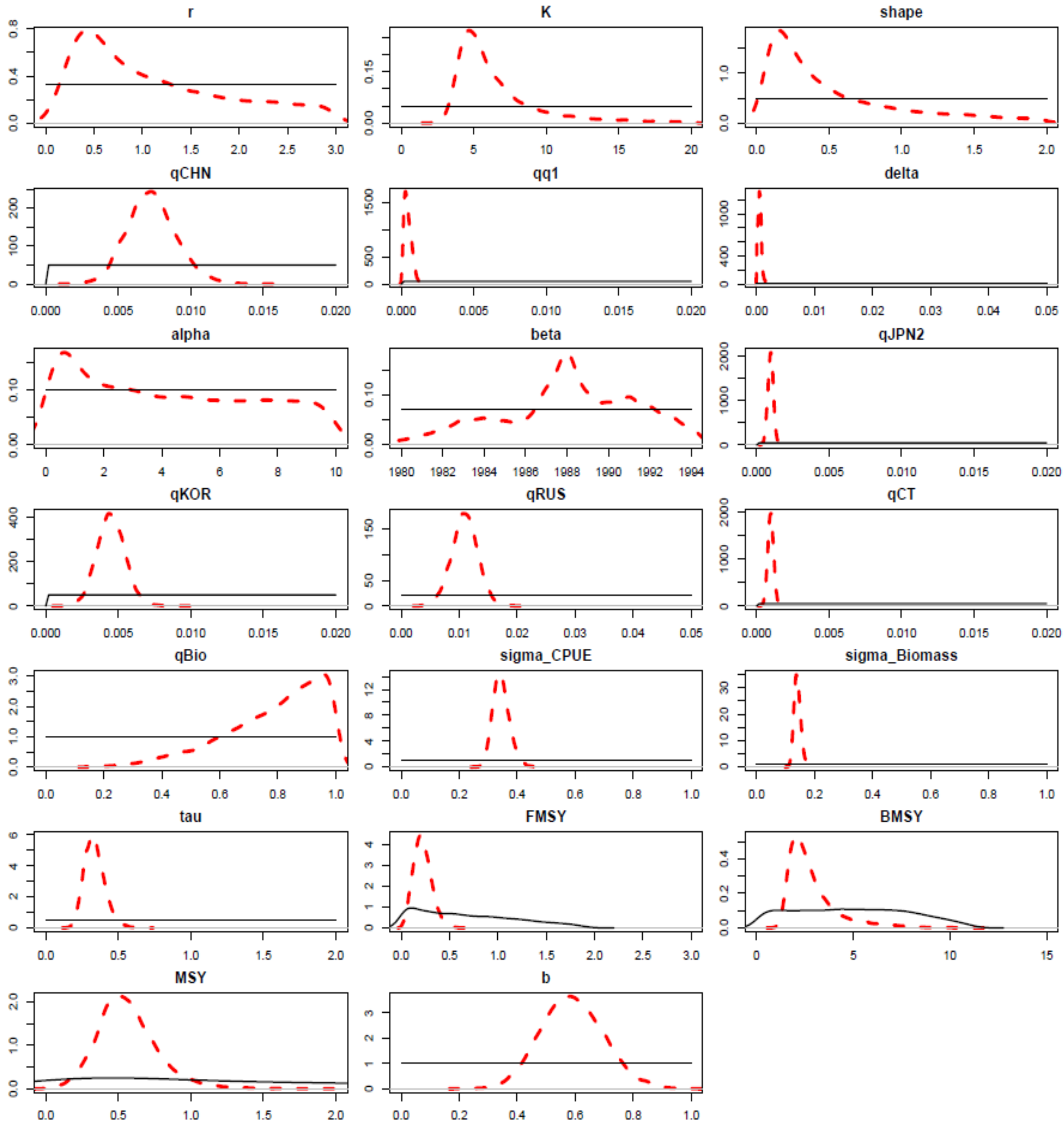






4.2 JAPAN

4.2.1 Prior and posterior distributions for Base case model 1 (as an illustrative example)

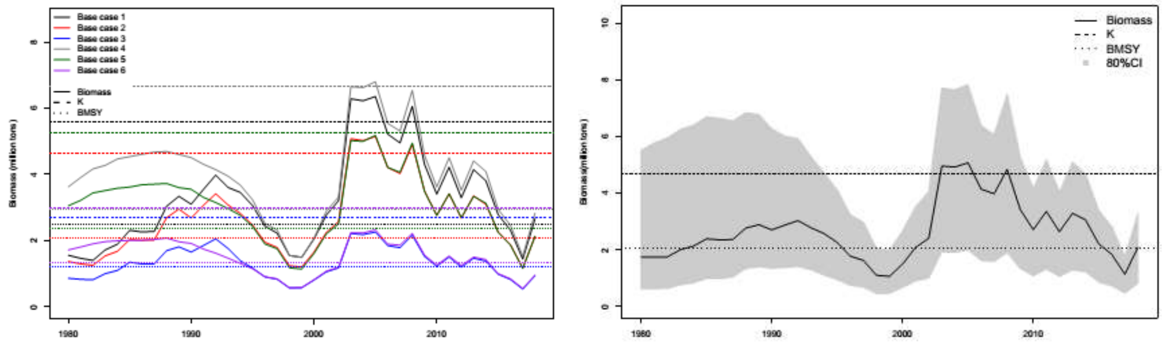


4.2.2 Summary of estimates of parameters and reference points

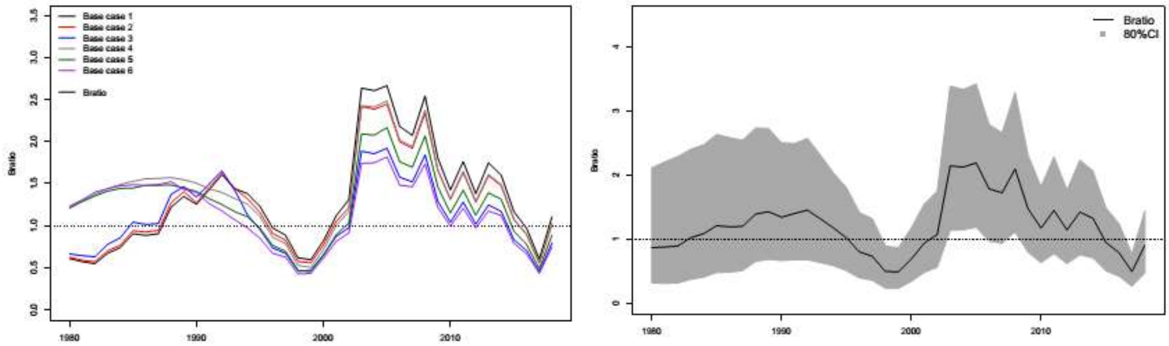
	Base 1	Base 2	Base 3	Base 4	Base 5	Base 6	Overall
C2017	26.18	26.18	26.18	26.18	26.18	26.18	26.18
Ave C2015-2017	32.75	32.75	32.75	32.75	32.75	32.75	32.75
Ave F2015-2017	0.16	0.19	0.44	0.15	0.19	0.42	0.19
F2017	0.18	0.22	0.49	0.17	0.22	0.47	0.23
FMSY	0.21	0.23	0.35	0.2	0.21	0.34	0.26
MSY	54.29	50.34	43.49	60.15	53.39	45.21	49.4
F2017 / FMSY	0.83	0.96	1.35	0.81	1.06	1.38	1.09
Ave F2015-2017 / FMSY	0.71	0.83	1.19	0.69	0.91	1.23	0.94
K	557.95	464	270.75	665.15	524.1	299.3	468.1
B2017	144.4	117.2	53.58	152.8	116.4	55.68	114.4
B2018	266.25	213.1	94.28	283.05	213.3	96.03	209
Ave B2016-2018	211.93	173.7	76.39	226.05	173.17	78.37	172.27
BMSY	248.6	208.1	121.5	295.7	236.7	132.7	206.6
BMSY / K	0.42	0.42	0.43	0.42	0.43	0.43	0.43
B2017 / K	0.27	0.25	0.2	0.25	0.22	0.2	0.23
B2018 / K	0.49	0.45	0.36	0.46	0.4	0.34	0.41
B2016-2018 / K	0.4	0.37	0.3	0.37	0.33	0.28	0.33
B2017 / BMSY	0.6	0.56	0.45	0.56	0.49	0.43	0.5
B2018 / BMSY	1.11	1.02	0.8	1.03	0.89	0.75	0.91
B2016-2018 / BMSY	0.9	0.83	0.66	0.84	0.73	0.62	0.75

4.2.3 Time series plots for base case models and aggregated results

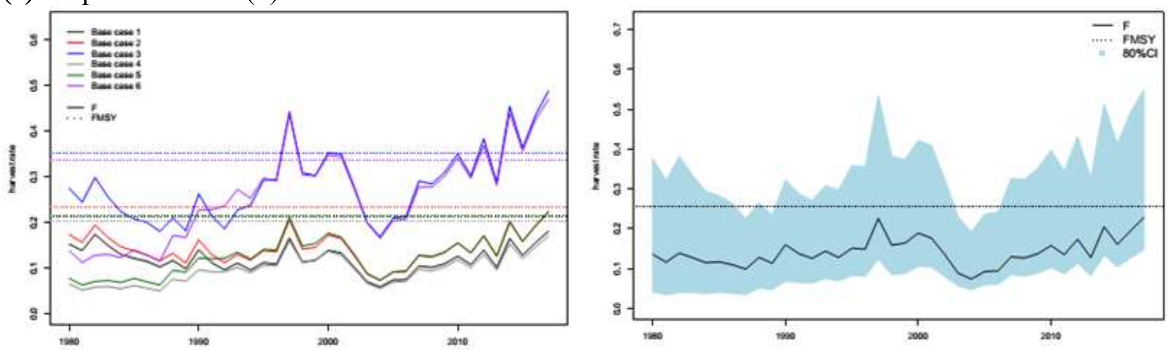
(a) Biomass



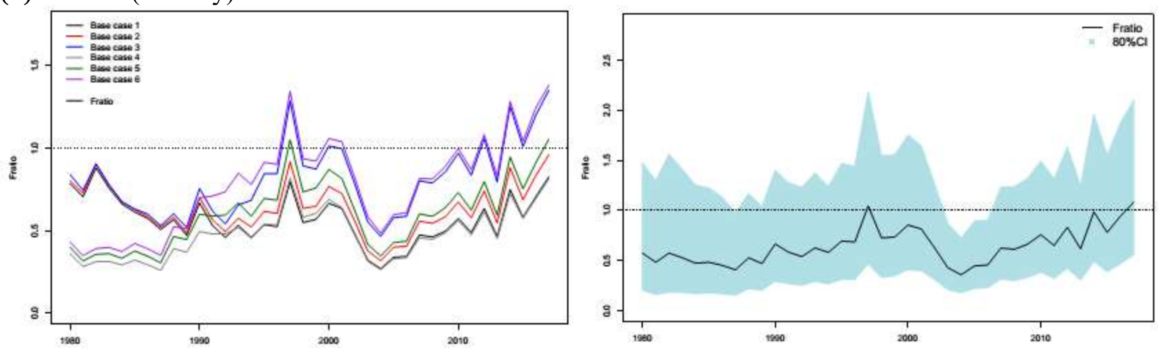
(b) B-ratio (B/Bmsy)



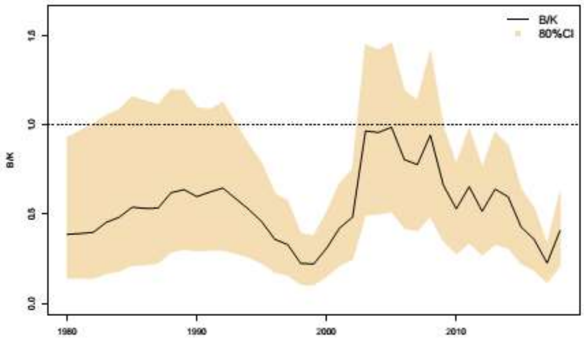
(c) Exploitation rate (F)

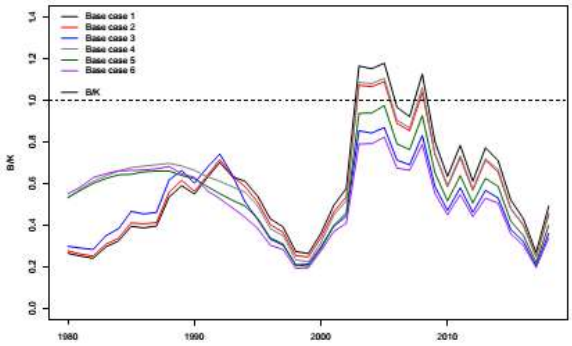


(d) F-ratio (F/Fmsy)

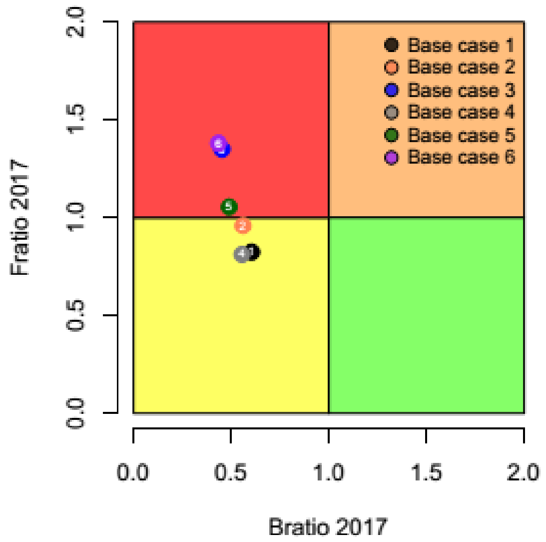


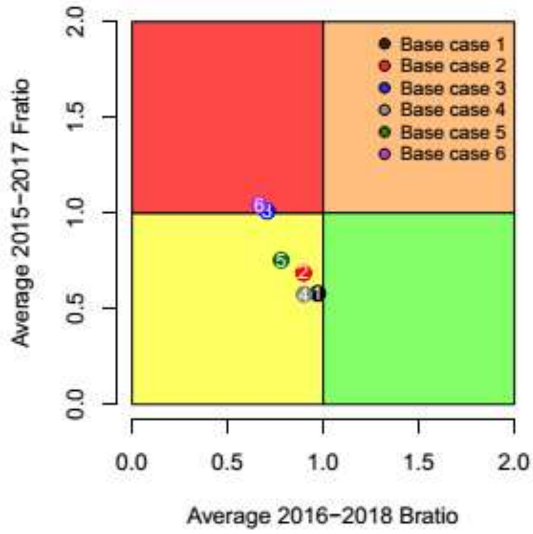
(e) B/K

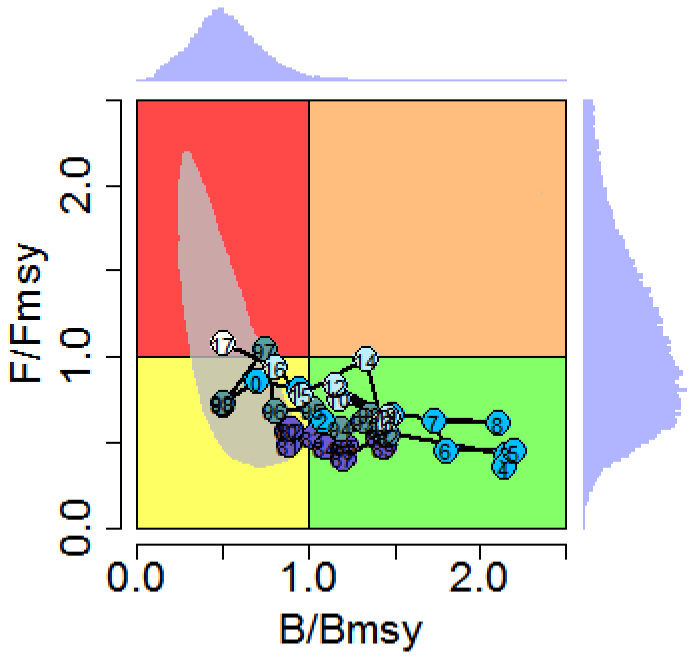

B/K
80%CI
B/K
1980
1990
2000
2010


Base case 1
Base case 2
Base case 3
Base case 4
Base case 5
Base case 6
B/K
B/K
1980
1990
2000
2010

4.2.4 Kobe plots

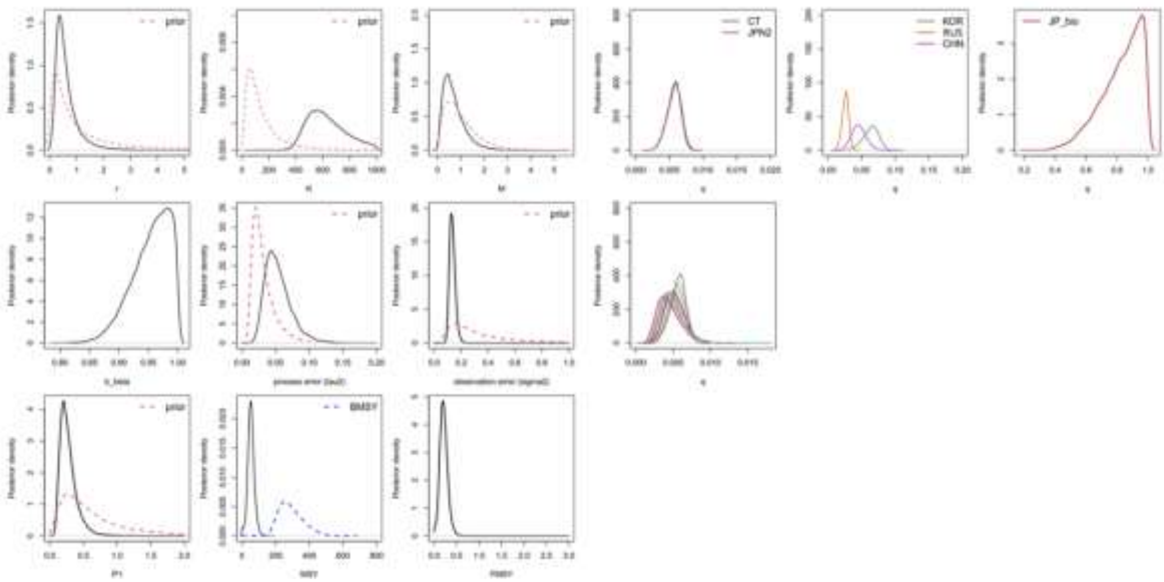






4.3 CHINESE TAIPEI

4.3.1 Prior and posterior distributions for Base case model 1 (as an illustrative example)

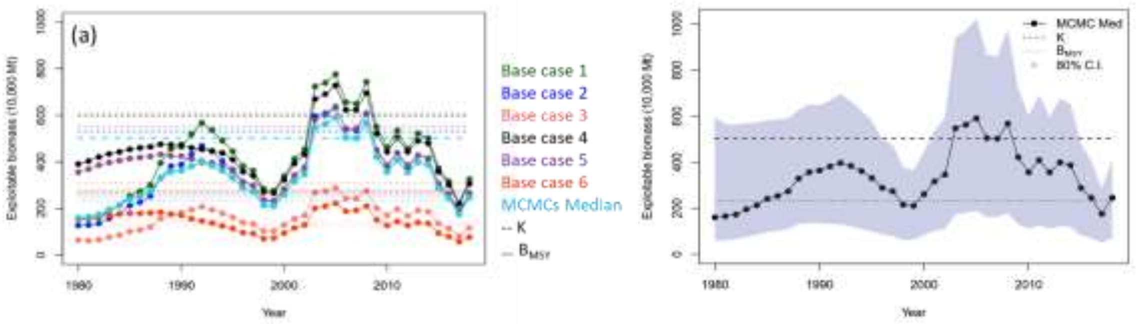


4.3.2 Summary of estimates of parameters and reference points

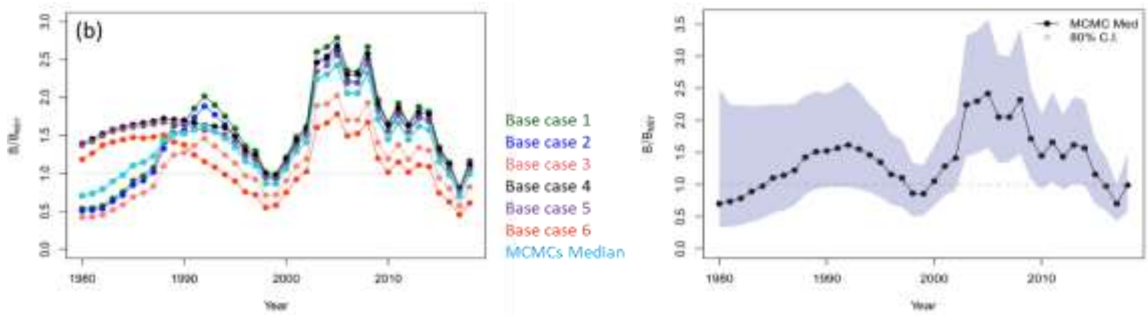
	Base case1	Base case2	Base case3	Base case4	Base case5	Base case6	Overall
				Median			
C_{2017} (mt)	261,789	261,789	261,789	261,789	261,789	261,789	261,789
Ave $C_{2015\text{-}2017}$ (mt)	327,453	327,453	327,453	327,453	327,453	327,453	327,453
Ave F2015-2017	0.12	0.14	0.36	0.12	0.14	0.57	0.15
F_{2017}	0.13	0.15	0.38	0.13	0.15	0.61	0.16
F_{MSY}	0.21	0.23	0.36	0.18	0.19	0.39	0.24
MSY	52.91	50.68	42.72	45.87	44.63	40.19	44.75
F_{2017}/F_{MSY}	0.6	0.67	1.11	0.71	0.77	1.69	0.84
Ave $F_{2015\text{-}2017}/F_{MSY}$	0.56	0.63	0.98	0.67	0.75	1.46	0.78
K	606.7	530.9	308.5	597.4	550.4	266.6	504.4
B_{2017}	222.2	183.1	81.98	220.2	191.5	57.2	175.10
B_{2018}	324.4	266.6	117.3	304.7	264.8	76.18	246.60
Ave $B_{2016\text{-}2018}$	273.3	224.85	99.64	262.45	228.15	66.69	222.13
B_{MSY}	280.3	247.4	143.2	277	256.6	126	231.90
B_{MSY}/K	0.46	0.47	0.46	0.46	0.47	0.47	0.46
B_{2017}/K	0.37	0.35	0.27	0.38	0.36	0.22	0.33
B_{2018}/K	0.54	0.51	0.39	0.52	0.49	0.29	0.47
$B_{2016\text{-}2018}$ /K	0.48	0.45	0.35	0.47	0.45	0.27	0.44
B_{2017}/B_{MSY}	0.8	0.75	0.57	0.81	0.77	0.46	0.70
B_{2018} $/B_{MSY}$	1.17	1.09	0.82	1.12	1.06	0.61	0.99
Ave $B_{2016\text{-}2018}/B_{MSY}$	1.03	0.97	0.73	1.02	0.96	0.56	0.96

4.3.3 Time series plots for base case models and aggregated results

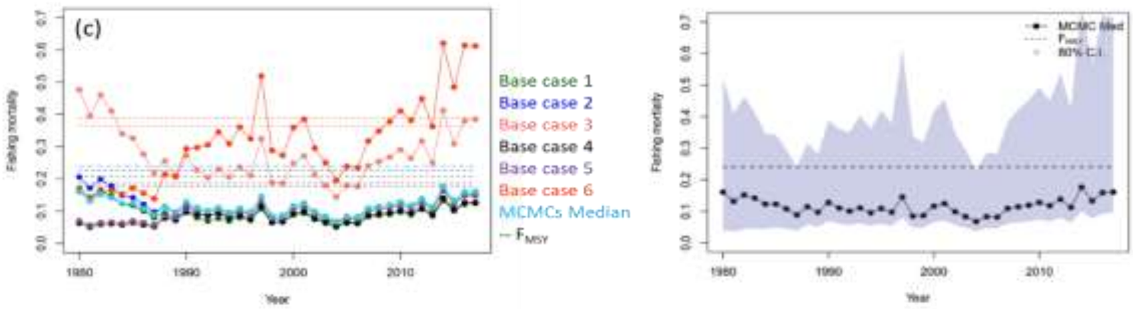
(a) Biomass



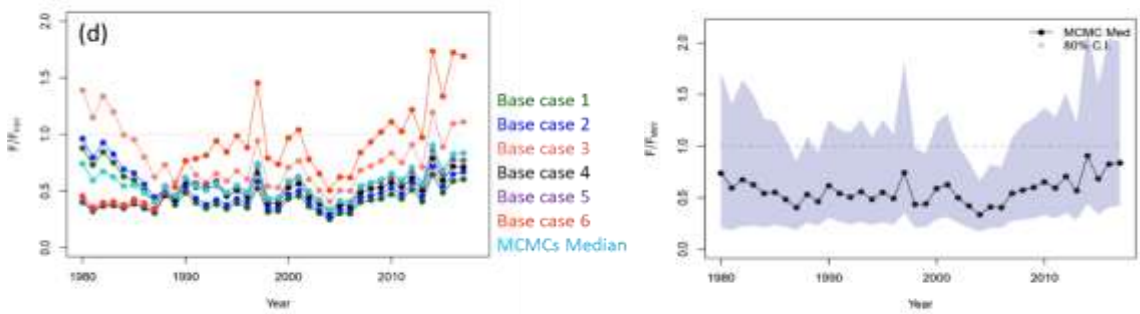
(b) B-ratio (B/Bmsy)



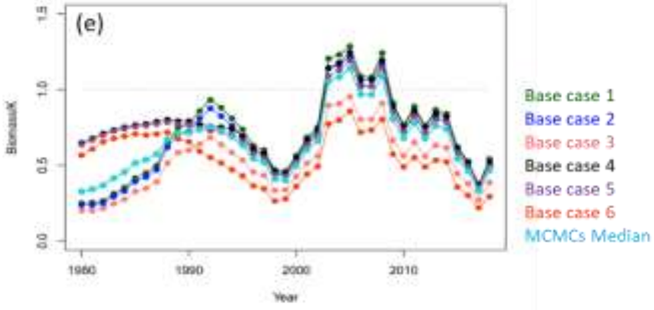
(c) Exploitation rate (F)

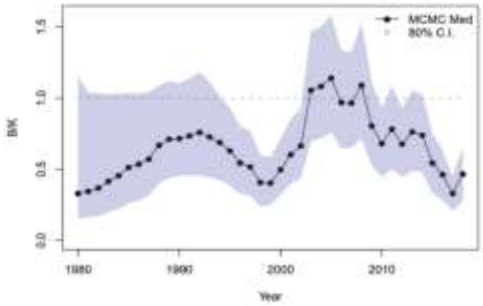


(d) F-ratio (F/Fmsy)

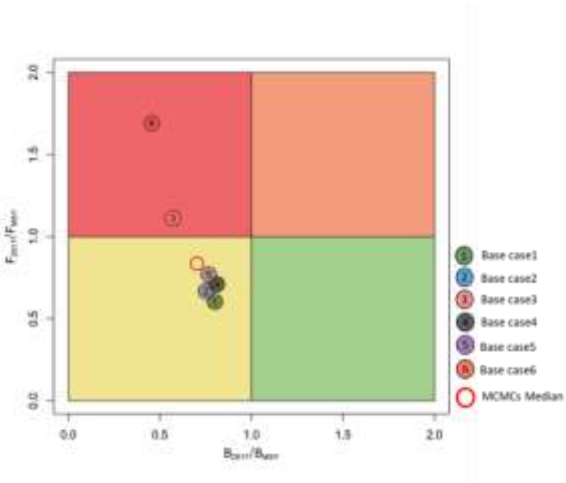


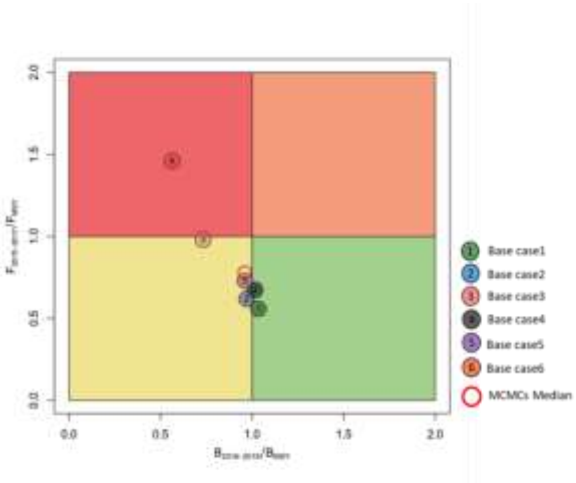
(e) B/K

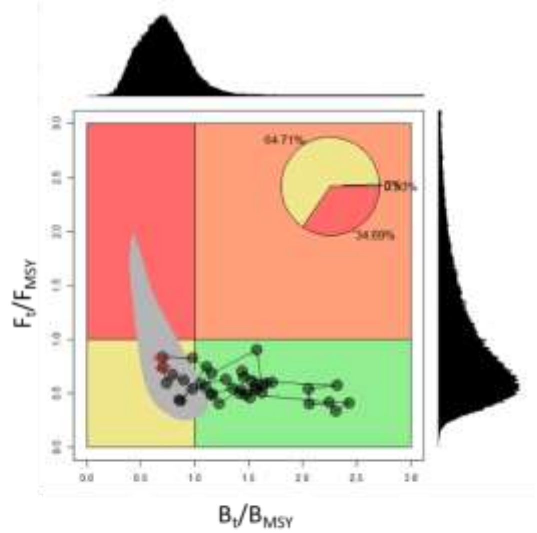

(e)
Biomass/K
Year
Base case 1
Base case 2
Base case 3
Base case 4
Base case 5
Base case 6
MCMCs Median


MCMC Med
80% C.I.
B/K
Year

4.3.4 Kobe plots





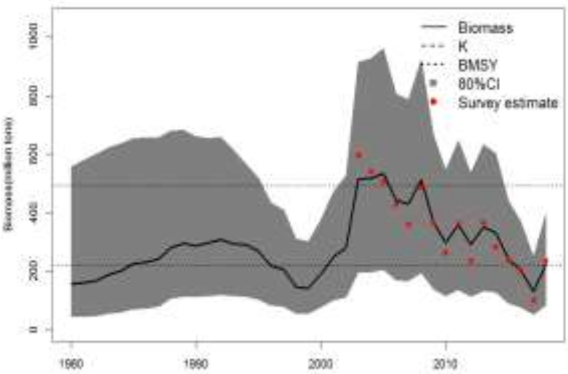


5 AGGREGATED RESULTS

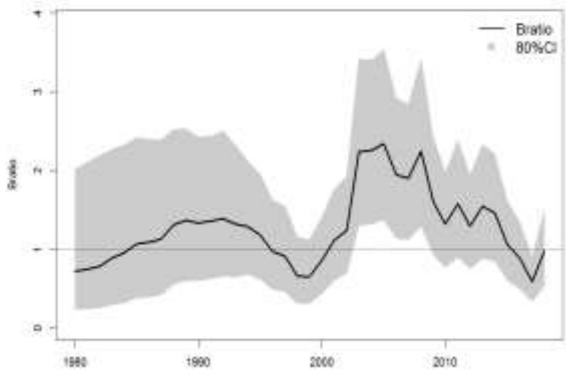
5.1 Visual presentation of results

The graphical presentations for times series of a) biomass (B), b) B-ratio (=B/Bmsy), c) exploitation rate (F), d) F-ratio (F/Fmsy) and e) B/K are shown in Figure 3.

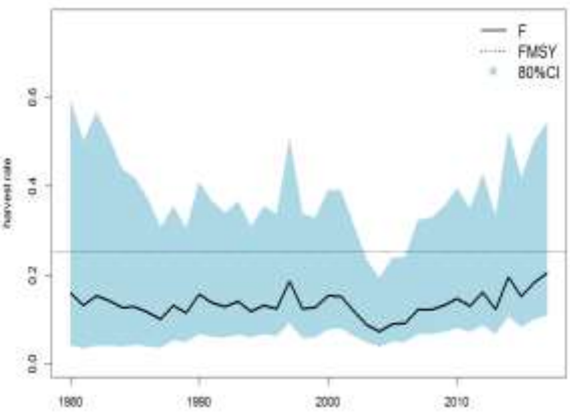
(a) Biomass (B)



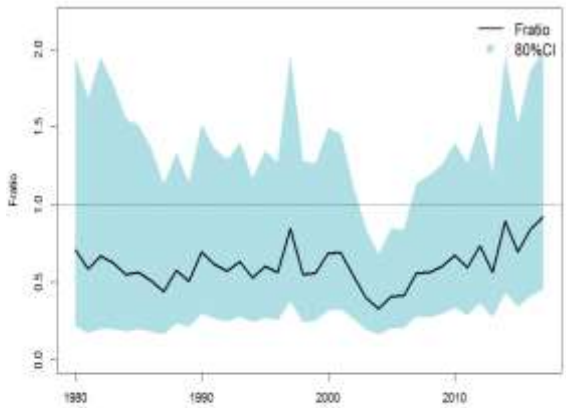
(b) B-ratio (B/Bmsy)



(c) Exploitation rate (F)



(d) F-ratio (F/Fmsy)



(e) B/K

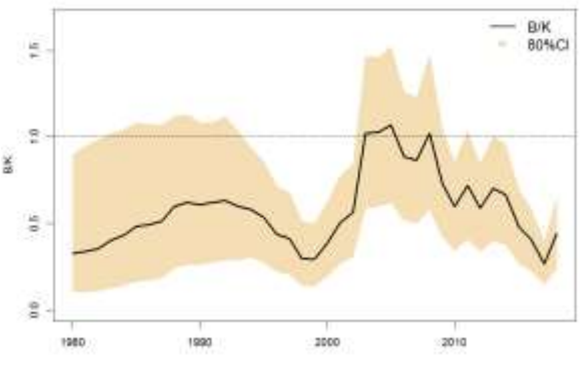


Figure 3. Time series plots for five key reference quantities: a) biomass (B), b) B-ratio (=B/Bmsy), c) exploitation rate (F), d) F-ratio (F/Fmsy) and e) B/K. The red dots in figure (a) are the biomass indices by Japan.

The Kobe plot with time trajectory using aggregated model outcomes is shown in Figure 4.

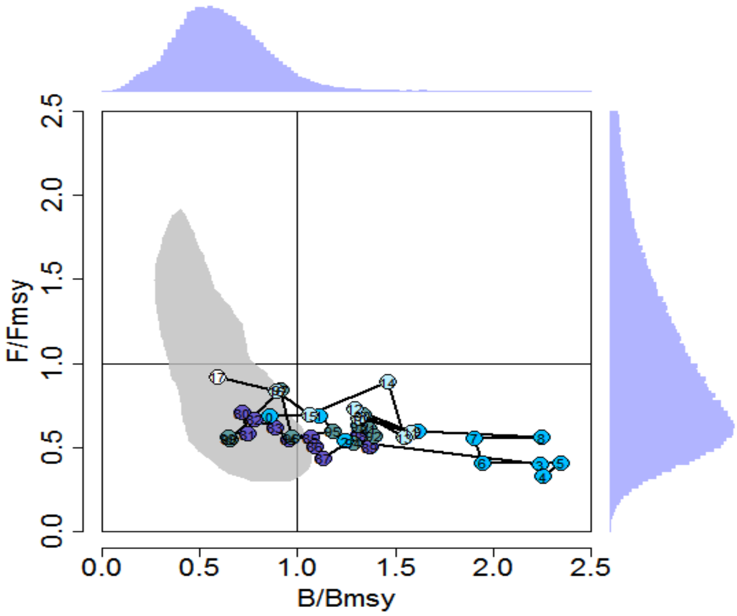


Figure 4. Kobe plots with time trajectory.

5.2 Summary table

Table 3. Summary of estimates of reference quantities. Median values and ranges are reported.

	Aggregated	Lower 10%	Upper 10%
C2017 (10,000tons)	26.2		
Ave C2015-2017 (10,000tons)	32.8		
Ave F2015-2017	0.18	0.10	0.49
F2017	0.20	0.11	0.54
FMSY	0.25	0.11	0.45
MSY (10,000tons)	49.3	32.4	81.2
F2017 / FMSY	0.81	0.42	1.77
Ave F2015-2017 / FMSY	0.82	0.41	1.78
K (10,000tons)	490.3	244.2	930.1
B2017 (10,000tons)	129.7	51.0	249.4
B2018 (10,000tons)	222.5	82.6	395.6
Ave B2016-2018 (10,000tons)	184.8	70.1	334.8
BMSY (10,000tons)	219.7	111.1	419.4
BMSY / K	0.44	0.39	0.53
B2017 / K	0.27	0.15	0.40
B2018 / K	0.44	0.24	0.64
B2016-2018 / K	0.38	0.21	0.53
B2017 / BMSY	0.63	0.34	0.95
B2018 / BMSY	1.04	0.58	1.55
B2016-2018 / BMSY	0.82	0.47	1.22

6 CONCLUDING REMARKS

Based on combined model estimates, B was below Bmsy (average B/Bmsy during 2016-2018 = 0.82) and F was below Fmsy (average F/Fmsy during 2015-2017 = 0.82). Results indicate that the stock declined from near carrying capacity in the mid-2000's after a period of high productivity to current levels. Exploitation rates were increasing slowly during this period but remained lower than Fmsy. Point estimates indicate that stock biomass fell to the lowest value since 1980 (B/Bmsy = 0.63) in 2017, then increased to Bmsy in 2018. Biomass estimates show long-term fluctuations and interannual variability.

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Data availability on size composition and catch/CPUE for Pacific saury
(developed at TWG PSSA02, Dec 2017, and adopted by SC03, Apr 2018)

Length composition	China	Japan	Korea	Russia	Chinese Taipei	Vanuatu
Size category	1cm bin	a) Com fish: 1cm bin b) Survey: 1cm bin	a) Catch by size group (3 classes) b) 1cm	a) Catch by size group (3 classes) b) Catch by size group (5 classes) c) 1cm	a) Catch by size group (5 classes) b) Catch by size group (6 classes) c) 1cm	a) Catch by size group (5 classes)? b) Catch by size group (6 classes)?
Period of data	2013-	a) 1950- b) 2003-	a) 2001-2015 b) 2001-	a) 1956- b) 1960- c) 2003-	a) 2001-2008 b) 2009- c) 2006-	To be checked
Sampling fraction	little	a) 5,000 (/yr) b) 100 (/sampling station)	a) 20-100%* b) a little	a), b), c) sample size 3,700-56,700	a), b) 100%* c) sample size 360-400 (/yr)	To be checked
Spatial coverage	Fishing grounds in CA	a) mostly in NW b) Lat 38-48N & Long 143E-165W	a),b) Fishing grounds in CA	a), b), c) Mostly in fishing grounds in Russian EEZ	a), b), c) Fishing area in CA	To be checked
Temporal coverage	By month (Aug-Oct)	a) by day (Aug-Dec) b) by sampling occasion (Jun)	a),b) By month in fishing season (May-Dec)	a), b) by year c) by month (Aug-Nov)	a), b) by month (Jun-Dec) c) by month (Oct-Nov)	To be checked
Comment			*from log book		*from log book	
Catch/CPUE	China	Japan	Korea	Russia	Chinese Taipei	Vanuatu
Spatial coverage	By 1-deg grid in CA	NW and CA (1-deg grid)	By 1-deg grid in CA	NW and CA (1-deg grid)	By 1-deg grid in CA	By 1-deg grid in CA?
Temporal coverage	By month (Aug-Dec)	By month (Aug-Dec)	By month (May-Dec)	By month (Aug-Nov)	By month (Jun-Dec)	By month (Aug-Nov)?