North Pacific Fisheries Commission

10th Meeting of the Small Scientific Committee on Pacific Saury REPORT

12-15 December 2022

February 2023

This paper may be cited in the following manner:

Small Scientific Committee on Pacific Saury. 2022. 10th Meeting Report. NPFC-2022-SSC PS10-Final Report. 62 pp. (Available at www.npfc.int)

2nd Floor Hakuyo Hall,
Tokyo University of Marine Science and Technology,
4-5-7 Konan, Minato-ku, Tokyo
108-8477, JAPAN

TEL +81-3-5479-8717
FAX +81-3-5479-8718
Email secretariat@npfc.int
Web www.npfc.int

North Pacific Fisheries Commission
10th Meeting of the Small Scientific Committee on Pacific Saury

12-15 December 2022
WebEx

REPORT

Agenda Item 1. Opening of the Meeting

1. The 10th Meeting of the Small Scientific Committee on Pacific Saury (SSC PS10) took place as a virtual meeting via WebEx, and was attended by Members from Canada, China, Japan, the Republic of Korea, the Russian Federation, Chinese Taipei, and Vanuatu. The Pew Charitable Trusts (Pew) attended as an observer. Dr. Larry Jacobson participated as an invited expert.

2. The meeting was opened by Dr. Toshihide Kitakado (Japan), the SSC PS Chair, who welcomed the participants. The Science Manager, Dr. Aleksandr Zavolokin, outlined the procedures for the meeting. Mr. Alex Meyer was selected as rapporteur.

Agenda Item 2. Adoption of Agenda

3. The agenda was adopted without revision (Annex A). The List of Documents and List of Participants are attached (Annexes B, C).

Agenda Item 3. Overview of the outcomes of previous NPFC meetings

3.1 SSC PS09

4. The Chair presented the outcomes and recommendations from the SSC PS09 meeting.

3.2 SWG MSE PS02

5. The Chair presented the outcomes and recommendations from the 2nd meeting of the joint SC-TCC-COM Small Working Group on Management Strategy Evaluation for Pacific saury (SWG MSE PS02).

Agenda Item 4. Review of the Terms of References of the SSC PS and existing protocols

4.1 Terms of References of the SSC PS

6. The SSC PS reviewed the Terms of References (ToR) of the SSC PS. With regard to paragraph 8, "To explore the design of the Management Strategy Evaluation framework," the SSC PS noted that this is now the task of the SWG MSE PS and that the role of the SSC PS is "to

provide support for the technical work related to the Management Strategy Evaluation". The SSC PS agreed to revise paragraph 8 accordingly and recommends that the SC endorse the revised ToR (Annex D).

4.2 CPUE Standardization Protocol

7. The SSC PS reviewed the catch-per-unit-effort (CPUE) Standardization Protocol and determined that no revisions are currently necessary.

4.3 Stock Assessment Protocol

8. The SSC PS reviewed the Stock Assessment Protocol and determined that no revisions are currently necessary.

Agenda Item 5. Member's fishery status including 2022 fishery

9. Korea presented its fisheries status (NPFC-2022-SSC PS10-IP01 (Rev. 1)). The Korean fishing vessels caught 3,438 MT of Pacific saury as of November 2022, which was a historical low. Annual catch has continued to decrease since 2018. The number of vessels operating has continued to decrease from 2015 to 2022. Accumulated catch remained low throughout the season apart from a slight increase between September and October. Nominal CPUE was 4.5 MT/vessel/day in 2021, a historical low. Fishing grounds were observed to be further south in 2022 compared to 2021. Over the fishing season, the fishing grounds move from east to west.

10. Chinese Taipei presented its fisheries status (NPFC-2022-SSC PS10-IP02). The catch recovered to around 180,000 tons in 2018 and has shown a declining trend since then. 93 vessels operated in 2021, compared to 87 in 2020. In 2022, the accumulated catch as of the end of November was 40,963 MT, compared to 34,040 MT for the same period last year. Vessels arrived in the fishing grounds earlier than in the previous year. Through November, seasonal catch in 2022 has been better than the previous year. From May to November 2022, the nominal CPUE has been about 1 MT/haul, which is slightly less than that of the same period in 2021. Compared to 2021, fishing grounds were observed to be further north in 2022. Over the fishing season, the fishing grounds move from east to west.

11. Japan presented its fisheries status (NPFC-2022-SSC PS10-IP03). In 2022, 113 vessels were registered, a decrease of 12 from the previous year. The annual catch as of November 2022 was 17,868 MT. The final annual catch for 2022 will be the lowest since 1950. The trend in 10-day catches has been similar to that in 2021. Previously, the peak catch was in October or September, but more recently it has been in November. Relative seasonal catch indicates that the high season has been getting shorter in recent years. Nominal CPUE was 0.51 MT/haul, the lowest since 2000. Most of the fishing grounds in 2022 were located on the high seas. In recent

years, the fishing grounds in August have moved south, and fishing grounds have moved eastward after 2019. As of the end of September, more than 70% of the fish caught in 2022 were age-1 fish.

12. Vanuatu presented its fisheries status (NPFC-2022-SSC PS10-IP04). Total annual catch peaked at 8,231 MT in 2018. Total catch in 2022 was 929 MT, the lowest after 2018. Vanuatu's Pacific saury fishery began in 2004. In total, it has authorized 16 vessels. The number of operating vessels was 4 from 2015 to 2021 and was 3 in 2022. The main fishing season has usually been from July to November. Looking at relative accumulated catch, fishing operations began later than previous years and catch increased from September. The largest abundance of catch was recorded from the end of September to the beginning of October. Nominal CPUE in 2022 was 5.7 MT/day. The main fishing grounds began in the east early in the season, before shifting to the west. Fishing grounds did not cross 165°E longitude in 2021 and 2022.

13. China presented its fisheries status (NPFC-2022-SSC PS10-IP05). As of December 2, total catch in 2022 was 35,443 MT. A total of 63 vessels have been operating in 2022, a decrease of 3 from 2021. Cumulative catch in 2022 has been lower than in 2021 in the early fishing season but is at a historically average level overall. The seasonal distribution of catches in 2022 has been similar to that of 2021, with the main season from September to November, but with catch much lower than in previous years. So far in 2022, nominal CPUE has been 6.21 MT/vessel/day, the lowest since 2013. The fishing grounds in 2022 have been more dispersed than in 2021.

14. Russia informed the SSC PS that it has not fished for Pacific saury this year. It reminded the SSC PS of the 2021 fisheries status information that it previously presented, namely that there continues to be a declining trend in catch and that the total catch in 2021 (610 MT) was the lowest since 1991.

15. The Science Manager presented the cumulative Pacific saury catches as of 3 December for 2022. The cumulative catch in the Convention Area by all Members was 94,623 MT. The total catch and trends in 2022 were similar to those in 2021, but almost 25% less than the total catch in 2020.

16. The SSC PS noted unusual fishing activity by some Members east of 170°E in June and July 2022 in addition to 2021. According to CMM 2021-08 for Pacific Saury, Members of the Commission are encouraged to take measures for fishing vessels flying their flags to refrain from fishing for Pacific saury in the areas east of 170°E from June to July. In relation to this, Japan presented the results of an analysis of the longitudinal distribution of age-0 Pacific saury in June and July under Agenda Item 8.1.

17. The SSC PS encouraged Members to provide up-to-date size frequency data from fisheries and the Japanese survey, even if it is preliminary and not highly precise, at future meetings. These data will be used to monitor recruitment variability and trends in size composition.

18. The SSC PS agreed to update the template for the submission of each Member's fisheries status information by adding new slides for presenting standardized effort (catch/stdCPUE), size and age compositions, size box compositions, and annual change of body length and/or size box compositions (indicating age compositions if possible) for the whole fishing season and for August to November (available on the website).

19. The SSC PS requested Japan and Chinese Taipei to present analyses of the monthly center of gravity of the Pacific saury stock as a coordinate based on the VAST output for the Japanese biomass survey and the joint CPUE standardization, respectively, for future meetings.

Agenda Item 6. Fishery-independent abundance indices

6.1 Review of any updates and progress

20. No updates were provided.

6.2 Review of plans of future biomass surveys

21. Japan informed the SSC PS that it plans to conduct its biomass survey with the usual area coverage and method in 2023.

22. The SSC PS expressed its appreciation to Japan for conducting the biomass survey in 2022, as well as for planning to do so again in 2023.

6.3 Recommendations for future work

23. The SSC PS encouraged Japan to conduct experiments on the calibration of the catchability coefficient so as to enable the use of an absolute abundance estimate, rather than a relative abundance estimate, as an abundance index in the Pacific saury stock assessment.

24. The SSC PS encouraged Japan to conduct analyses to confirm whether or not any vessel effects are occurring in the VAST model.

Agenda Item 7. Fishery-dependent abundance indices

7.1 Review of any updates and progress

25. No updates were provided.

7.2 Recommendations for future work

26. The SSC PS agreed to calculate and present the standardized effort (catch/stdCPUE) for individual Members' fisheries and for the combined fishery at future meetings.

Agenda Item 8. Biological information on Pacific saury

8.1 Review of any updates and progress

27. Japan presented a description of the longitudinal distribution of age-0 Pacific saury in June and July based on the VAST output using the Japanese survey data (NPFC-2022-SSC PS10-WP02). In the latest three years, the age-0 fish have mainly been distributed in the eastern region in June and July. Japan calculated cumulative percentages of age-0 biomass from west to east for all years. The age-0 biomass in the waters west of 170°E has been below 20% of the total biomass and has rapidly increased along the longitude east of 170°E in the last decade, except in 2017. Japan suggested that this supported the longitude of 170°E as the boundary for protecting most juvenile fish specified in the present CMM for Pacific saury.

8.2 Recommendations for future work

28. The SSC PS suggested that the spatial evaluation of age-0 survey catch should be extended in the next assessment to identify and quantify any benefits from potential season and area closures designed to protect age-0 fish. In particular, the effects on catch should be evaluated.

Agenda Item 9. Stock assessment using "provisional base models" (BSSPM)

9.1 Review of results and implications to management

29. China presented an updated stock assessment for Pacific saury using BSSPM (NPFC-2022-SSC PS10-WP03). The estimated median B_{2021} from the two base case scenarios was 266,250 (80%CI 124,400-426,500) and 622,750 (80%CI 165,500-1,173,000) MT, respectively. The median B_{2021}/B_{MSY} and F_{2021}/F_{MSY} over the two base case scenarios were 0.31 (80%CI 0.20-0.46) and 0.73 (80%CI 0.47-1.25), respectively. Over the two base case scenarios, large interannual variability was shown in biomass trajectory during the recent years. A decreasing biomass trend was found in 2019 and 2020, followed by an increase in 2021 and 2022. The probability of the population being in the yellow Kobe quadrant in 2021 was estimated to be greater than 79%.

30. Japan presented an updated stock assessment for Pacific saury using BSSPM (NPFC-2022-SSC PS10-WP04 (Rev. 2)). The 2022 median depletion level was only 25.1% (80%CI=14.1-39.4%) of the carrying capacity. Furthermore, B-ratio (=B/B_{msy}) and F-ratio (=F/F_{msy}) in 2021 were 0.288 (80%CI=0.191-0.406) and 0.740 (80%CI=0.468-1.140), respectively. For those three-year-average values, B-ratio over 2020-2022 and F-ratio over 2019-2021 were respectively 0.377 (80%CI=0.251-0.558) and 1.169 (80%CI=0.765-1.689). In addition, the

probability of the stock being in the green Kobe quadrant in 2021 was estimated to be nearly 0%, while the probability of being in the yellow Kobe quadrant was assessed to be greater than 80%. On the weight-of-evidence available now, the current Pacific saury stock is determined to be overfished. Based on the updated results, applying the formula from the total allowable catch (TAC) calculation used in the 2019 Commission meeting would give $F_{MSY}*B_{2022}$=229,000 MT. However, considering the current overfished population level and applying a simple discount exploitation rate depending on the current B-ratio, an appropriate catch would be $(B_{2022}/B_{MSY})*F_{MSY}*B_{2022}$=122,000 MT.

31. Chinese Taipei presented an updated stock assessment for Pacific saury in the North Pacific Ocean using BSSPM (NPFC-2022-SSC PS10-WP05). The ensemble time-series of biomass is estimated to have had an increasing pattern since 2000 with two peaks in 2003 and 2005, before dramatically decreasing over time and falling below B_{MSY} in 2009 – 2022. It should be noted that the models estimate the lowest biomass level in 2020 (median B_{2020}/B_{MSY} = 0.29, 80 percentile range 0.18 – 0.51) followed by a slight increase in 2021 and 2022 (median B_{2021}/B_{MSY} = 0.33, 80 percentile range = 0.19 – 0.56; median B_{2022}/B_{MSY} = 0.45, 80 percentile range = 0.23 – 0.77). In the most recent three years (2020 – 2022), the biomass was estimated to be below B_{MSY} (median $B_{2020\text{-}2022}/B_{MSY}$ = 0.36, 80 percentile range = 0.22 – 0.60). A steady increase in fishing mortality is estimated to have occurred from 2004 to 2018, but a decreasing trend in fishing mortality was found from 2019 to 2021. The recent average fishing mortality is estimated to be above F_{MSY} (median $F_{2019\text{-}2021}/F_{MSY}$ = 1.21, 80 percentile range = 0.71 – 2.16) while the fishing mortality in 2021 is less than F_{MSY} (median F_{2021}/F_{MSY} = 0.75, 80 percentile range = 0.43 – 1.45). The ensemble MCMC results from the two base cases indicated that the 2021 stock status is likely within the yellow quadrant (Prob [$B_{2021}<B_{MSY}$ and $F_{2021}<F_{MSY}$] = 72.82%)

32. The SSC PS reviewed the stock assessments presented by Members and aggregated the results, recognizing the agreement in trends among them (Annex E). Results of combined model estimates indicate that the stock declined with an interannual variability from near carrying capacity in the mid-2000's after a period of high productivity to current low levels. The results also indicated that B was below B_{MSY} (median average B/B_{MSY} during 2020-2022 = 0.368, 80%CI 0.232-0.564) and F was above F_{MSY} (average F/F_{MSY} during 2019-2021 = 1.192, 80%CI 0.757-1.883). The results further indicated that recent stock biomass remains at a historically low level in recent years. The biomass trend shows a small increase in recent years through 2021 and a marked increase in the Japanese biomass survey between 2021 and 2022. The harvest rate has also been declining from a peak in 2018 and was less than F_{MSY} during 2021. However, caution is required in interpreting these results, given historically low nominal CPUEs (see Annex E, Fig. 5) through 2022, relatively high fishing effort in 2021, and

variability inherent in fisheries-independent surveys.

9.2 Recommendations for future work

33. The SSC PS agreed to conduct further analyses to investigate the possible sources of the scale uncertainty shown by the retrospective analyses.

Agenda Item 10. New stock assessment models

10.1 Review of results

34. No updates were provided.

10.2 Recommendations for future work

35. The SSC PS agreed to work collaboratively towards the development of an age-structured model for use as the Pacific saury operating model and stock assessment model.

Agenda Item 11. Development and evaluation of an interim harvest control rule (HCR) as a short-term task

11.1 Management objectives, reference points and tuning criteria

11.2 Conditioning of operating models (OMs)

11.3 Possible/candidate HCR

11.4 Simulation platform

36. The SSC PS reviewed the outcomes of the SSC PS09 and SWG MSE PS02 meetings relating to management objectives, reference points, tuning criteria, conditioning of OMs, and possible/candidate HCR.

37. The Chair presented some preliminary simulation outcomes using some OMs based on the BSSPM to evaluate two possible HCRs (HCR1 and HCR2 out of three HCRs as discussed in SWG MSE PS02) for demonstration purposes. The work will be continued through conditioning the OMs based on the updated BSSPM assessment and further discussed in SWG MSE PS meetings.

38. The Chair informed the SSC PS that the Commission approved the allocation of funding for the development of a simulation platform using the Shiny application for the evaluation of HCR, as was proposed by the SWG MSE PS.

11.5 Recommendations for future work

39. The SSC PS agreed to continue to progress its work in line with the timeline and tasks agreed to at the SWG MSE PS02 meeting (SWG MSE PS02 Report, Annex F).

Agenda Item 12. Development of recommendations to improve conservation and management of Pacific saury stock

40. The SSC PS recommends that the SC consider and endorse the following rationale and approach in its scientific advice to the Commission:
    (a) The current annual TAC for 2021-2022 specified in CMM 2021-08 for Pacific saury (333,750 tons) based on historical catch is much larger than a TAC that would be based on the F_{MSY} catch approach (B_{2022}*F_{MSY} = 205,015 tons. The current biomass is much lower than B_{MSY} and the TAC for 2021-2022 did not reduce fishing mortality (F) in recent years. An HCR that reduces F when biomass is low may increase the probability of achieving long-term sustainable use of Pacific saury (i.e. higher long-term catch closer to MSY of around 403,000 tons). A reduction to the TAC for 2021-2022 would increase the probability of higher biomass and catch levels in the Pacific saury stock.
    (b) An HCR that reduces the target harvest rate and TAC when biomass falls below its target level may be appropriate for Pacific saury. This type of HCR is used in managing many fisheries around the world. For example, if an HCR that reduces F linearly when biomass is below B_{MSY} (see Annex E, Figure 8) is applied, the TAC calculated based on such an HCR (B_{2022}*F_{MSY}*(B_{2022}/B_{MSY}) = 101,885 tons could be similar with the current catch (98,000 tons, preliminary as of 17 December 2022).
    (c) Note, however, the performance of the above HCRs has not been evaluated by a formal MSE framework for Pacific saury. They were used as simple illustrations of common approaches used elsewhere.

Agenda Item 13. Review of the Work Plan of the SSC PS

41. The SSC PS reviewed, revised and endorsed the 2022-2026 SSC PS 5-Year Rolling Work Plan (NPFC-2021-SSC PS10-WP01 (Rev. 1)).

Agenda Item 14. Other matters

14.1 Observer Program

42. The Science Manager presented a summary of information regarding the existing scientific observer programs of Members and those of other RFMOs (NPFC-2018-SC03-WP03 (Rev. 1)) as of April 2018. For pelagic fisheries, there is no coordination in the Members' observer programs neither in terms of the type of observer program nor in coverage and data requirements. Russia, Korea and Chinese Taipei collect data on fishing vessels at sea by observers and electronic reporting system, respectively, while other Members carry out in-port scientific observations. Specifications for observer training, observer program design, number of observers and required data differ among Members. All "general" RFMOs (NAFO, NEAFC, SEAFO, SIOFA, SPRFMO) and CCAMLR have developed at least one observer program. Most of general RFMO OPs have been set up primarily to collect scientific data, but in three

of six cases, it includes compliance tasks with one general RFMO focusing on a compliance observer program. Almost all RFMOs for highly migratory species have observer programs with both science and compliance components, but with different balances. The SSC PS has previously developed a template for identification of scientific data which can be collected and/or validated by at-sea observers, fishermen, electronic reporting systems and other means, dividing the different types of data into four categories: data that can only be collected by observers at sea; data that can be collected by fishermen at sea; data which are preferably collected by observers, but a degree of cover can be achieved by other means; and data which can be collected equally well by other means.

43. The SSC PS considered the background information presented by the Science Manager and agreed to hold further discussions on the necessity of a regional scientific observer program and data gaps for the task of the SSC PS at its next meeting.

44. The SSC PS agreed that there may be important data that can be collected by an observer program and electronic monitoring programs, which will be useful for the stock assessment. Thus, the necessity and benefit of observer and electronic monitoring programs should be discussed more fully in future meetings.

14.2 Priority issues and timeline for next meeting

45. The SSC PS agreed on the following priorities for the next meeting:
    (a) Review standardized CPUE up to 2022.
    (b) Review the Japanese fishery-independent survey results up to 2023.
    (c) Update BSSPM analyses and provide recommendations to the SC/Commission.
    (d) Review progress on new assessment models and finalize a set of models and specification.
    (e) Review progress on development and evaluation of HCR as a short-term task.

14.3 Invited expert

46. The SSC PS expressed its appreciation for the continued valuable contributions of the invited expert, Dr. Larry Jacobson. The SSC PS recommends that Dr. Jacobson be invited to the next SSC PS meetings.

14.4 Other

47. No other issues were discussed.

Agenda Item 15. Recommendations to the Scientific Committee

48. The SSC PS recommends the following to the SC:
    (a) Endorse the revised Terms of Reference of the SSC PS (Annex D).

(b) Endorse the stock assessment report (Annex E).
(c) Endorse the SSC PS Work Plan (NPFC-2022-SSC PS10-WP01 (Rev. 1)).
(d) Allocate funds for the participation of an invited expert in the next SSC PS meetings.

Agenda Item 16. Adoption of the Report

49. The SSC PS10 report was adopted by consensus.

Agenda Item 17. Close of the Meeting

50. The meeting closed at 14:05 on 15 December 2022, Tokyo time.

Annexes:

Annex A – Agenda
Annex B – List of Documents
Annex C – List of Participants
Annex D – Revised Terms of Reference of the SSC PS
Annex E – Stock Assessment Report for Pacific Saury

Annex A

Agenda

Agenda Item 1. Opening of the Meeting

Agenda Item 2. Adoption of Agenda

Agenda Item 3. Overview of the outcomes of previous NPFC meetings
- 3.1 SSC PS09 meeting
- 3.2 SWG MSE PS02

Agenda Item 4. Review of the Terms of References of the SSC PS and existing protocols
- 4.1 Terms of References of the SSC PS
- 4.2 CPUE Standardization Protocol
- 4.3 Stock Assessment Protocol

Agenda Item 5. Member's fishery status including 2022 fishery

Agenda Item 6. Fishery-independent abundance indices
- 6.1 Review of any updates and progress
- 6.2 Review of plans of future biomass surveys
- 6.3 Recommendations for future work

Agenda Item 7. Fishery-dependent abundance indices
- 7.1 Review of any updates and progress
- 7.2 Recommendations for future work

Agenda Item 8. Biological information on Pacific saury
- 8.1 Review of any updates and progress
- 8.2 Recommendations for future work

Agenda Item 9. Stock assessment using "provisional base models" (BSSPM)
- 9.1 Review of results and implications to management
- 9.2 Recommendations for future work

Agenda Item 10. New stock assessment models
- 10.1 Review of results
- 10.2 Recommendations for future work

Agenda Item 11. Development and evaluation of an interim harvest control rule (HCR) as a short-term task
- 11.1 Management objectives, reference points and tuning criteria
- 11.2 Conditioning of operating models (OMs)
- 11.3 Possible/candidate HCR
- 11.4 Simulation platform
- 11.5 Recommendations for future work

Agenda Item 12. Development of recommendations to improve conservation and management of Pacific saury stock

Agenda Item 13. Review of the Work Plan of the SSC PS

Agenda Item 14. Other matters
- 14.1 Observer Program
- 14.2 Priority issues and timeline for next meeting
- 14.3 Invited expert
- 14.4 Other

Agenda Item 15. Recommendations to the Scientific Committee and SWG MSE PS

Agenda Item 16. Adoption of the Report

Agenda Item 17. Close of the Meeting

Annex B

List of Documents

MEETING INFORMATION PAPERS

Symbol	Title
NPFC-2022-SSC PS10-MIP01	Meeting Information
NPFC-2022-SSC PS10-MIP02	Provisional Agenda
NPFC-2022-SSC PS10-MIP03 (Rev. 1)	Annotated Indicative Schedule

WORKING PAPERS

Symbol	Title
NPFC-2022-SSC PS10-WP01	SSC PS Work Plan
NPFC-2022-SSC PS10-WP02	Updated summary of the longitudinal distribution of juvenile Pacific saury in response to NPFC CMM 2021-08
NPFC-2022-SSC PS10-WP03	Updates of stock assessment for Pacific saury in the North Pacific Ocean up to 2022
NPFC-2022-SSC PS10-WP04 (Rev. 2)	2022 updates on Pacific saury stock assessment in the North Pacific Ocean using Bayesian state-space production models
NPFC-2022-SSC PS10-WP05 (Rev. 1)	Updated stock assessment of Pacific saury (*Cololabis saira*) in the Western North Pacific Ocean through 2021

INFORMATION PAPERS

Symbol	Title
NPFC-2022-SSC PS10-IP01 (Rev. 1)	Korean Stick-held dip net Fishery Status up to 2022
NPFC-2022-SSC PS10-IP02	Chinese Taipei - Fishery status for Pacific saury
NPFC-2022-SSC PS10-IP03	Japan - Pacific saury fishing condition in 2022
NPFC-2022-SSC PS10-IP04	Vanuatu - Fishery Status for Pacific saury
NPFC-2022-SSC PS10-IP05	China - Fishery status for Pacific saury up to 2022

REFERENCE DOCUMENTS

Symbol	Stock assessment protocol for Pacific Saury
NPFC-2018-SC03-WP03 (Rev. 1)	Report on the existing observer programs of NPFC Members and those of other RFMOs
NPFC-2022-SSC PS09-Final Report	SSC PS09 Report

NPFC-2022-SWG MSE PS02-Final Report	SWG MSE PS02 Report
	Terms of Reference for the Small Scientific Committee on Pacific Saury (SSC PS)
	CPUE Standardization Protocol for Pacific Saury
	Stock assessment protocol for Pacific Saury

Annex C

List of Participants

CHAIR

Toshihide KITAKADO
kitakado@kaiyodai.ac.jp

CANADA

Chris ROOPER
chris.rooper@dfo-mpo.gc.ca

Janelle CURTIS
Janelle.Curtis@dfo-mpo.gc.ca

CHINA

Libin DAI
644318716@qq.com

Qiuyun MA
qyma@shou.edu.cn

Kai CAI
846977742@qq.com

Richard KINDONG
kindong@shou.edu.cn

JAPAN

Kazuhiro OSHIMA
oshima_kazuhiro28@fra.go.jp

Shuya NAKATSUKA
nakatsuka_shuya49@fra.go.jp

Taiki FUJI
fuji_taiki65@fra.go.jp

Takumi FUKUDA
takumi_fukuda720@maff.go.jp

Midori HASHIMOTO
hashimoto_midori91@fra.go.jp

Tsuyoshi KOGA
tsuyoshi_koga780@maff.go.jp

Hiroshi KUBOTA
kubota_hiroshi89@fra.go.jp

Hiroomi MIYAMOTO
miyamoto_hiroomi47@fra.go.jp

Shin-Ichiro NAKAYAMA
nakayama_shinichiro16@fra.go.jp

Miyako NAYA
naya_miyako88@fra.go.jp

Nanako SEKIGUCHI
caiziguankou9@gmail.com

Satoshi SUYAMA
suyama_satoshi77@fra.go.jp

Sayako TAKEDA
sayako_takeda590@maff.go.jp

Kyutaro YASUMOTO
kyutaro_yasumoto890@maff.go.jp

Kosuke YOSHIDA
kosuke_yoshida130@maff.go.jp

KOREA

Jae Bong LEE
leejb@korea.kr

Hyejin SONG
hyejinsong@korea.kr

Sanggyu SHIN
gyuyades82@gmail.com

RUSSIA

Oleg KATUGIN
oleg.katugin@tinro-center.ru

Dmitrii ANTONENKO
dmantonenko@yandex.ru

Emiliya CHERNIENKO
emilya.petrovna@gmail.com

Vladimir KULIK
vladimir.kulik@tinro-center.ru

CHINESE TAIPEI

Ren-Fen WU
fan@ofdc.org.tw

Yi-Jay CHANG
yjchang@ntu.edu.tw

Tung-hsieh CHIANG
chiangdon@ofdc.org.tw

Yun-Wei CHOU
pijhs101134@gmail.com

Wen-Bin HUANG
bruce@gms.ndhu.edu.tw

Jhen HSU
jhenhsu@ntu.edu.tw

Pin-Ying LI
pinying1028@ms1.fa.gov.tw

VANUATU

Jeyalda NGWELE
njeyalda@fisheries.gov.vu

Mei-Chin JUAN
meichin.mdfc@gmail.com

Kevin LIN
kevin.mdfc@msa.hinet.net

OBSERVERS

THE PEW CHARITABLE TRUSTS

Ashley WILSON
awilson@pewtrusts.org

INVITED EXPERT

Larry JACOBSON
larryjacobson6@gmail.com

RAPPORTEUR

Alex MEYER
meyer@urbanconnections.jp

SECRETARIAT

Robert DAY
rday@npfc.int

Alex ZAVOLOKIN
azavolokin@npfc.int

Judy DWYER
jdwyer@npfc.int

Yuko YOSHIMURA-TAKAMIYA
ytakamiya@npfc.int

Sungkuk KANG
skang@npfc.int

Natsuki HOSOKAWA
nhosokawa@npfc.int

Annex D

Revised Terms of Reference of the SSC PS

1. To review fishery data
    - Catch series
    - Age/size composition data
    - Others
2. To review fishery-dependent and fishery-independent indices
    - Review/update the existing CPUE Standardization Protocol
    - Review/update the indices
    - Evaluate the quality of the indices
    - Recommendation for future work
3. To review and update biological information/data
    - Stock structure
    - Growth
    - Reproduction and maturity schedule
    - Natural mortality
    - Migration pattern
    - Others
4. To update the stock assessment using “provisional base models” (i.e. Bayesian state-space production models)
    - Review the existing Stock Assessment Protocol
    - Simple update (including projection and evaluation of reference points as well as diagnosis)
    - Consideration of scenarios (for base and sensitivity)
    - Assessment of uncertainties and the implications for management
    - Evaluation/improvement (if necessary) of the models
    - Recommendation of the research for future work
5. To explore stock assessment models other than existing “provisional base models”
    - Data invention/availability (including the identification of potential covariates)
    - Initial (and continued) discussion on age-/size/stage-structure models
    - Identification of lack of information/data gaps and limitations
    - Recommendation of the research for future work
6. To facilitate data- and code- sharing processes
7. To review/improve the presentation of stock assessment results (including stock status summary reports in a format to be determined by the Working Group)
8. To support the technical work related to the Management Strategy Evaluation.

Annex E

Stock Assessment Report for Pacific Saury

Abstract:
This report presents the results of stock assessment of Pacific saury updated at the 10th Small Scientific Committee on Pacific saury meeting held virtually during December 12-15, 2022.

EXECUTIVE SUMMARY

Data used in the assessment modeling

Pacific saury (*Cololabis saira*) is widely distributed from the subarctic to the subtropical regions of the North Pacific Ocean. The fishing grounds are west of 180º E but 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. Appendix 1 shows data used for the updated stock assessment.

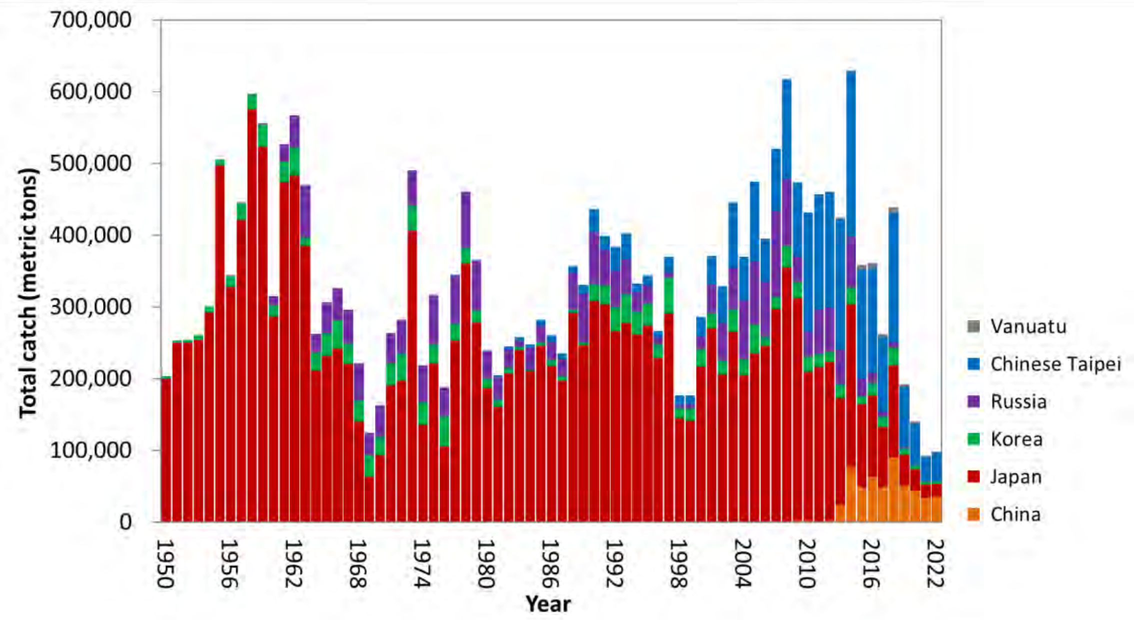


Figure 1. Time series of catch by Member during 1950-2022. The catch data for 1950-1979 are shown but not used in stock assessment modeling. Catch data in 2022 are preliminary (as of 17 December 2022) and not used in the assessment.

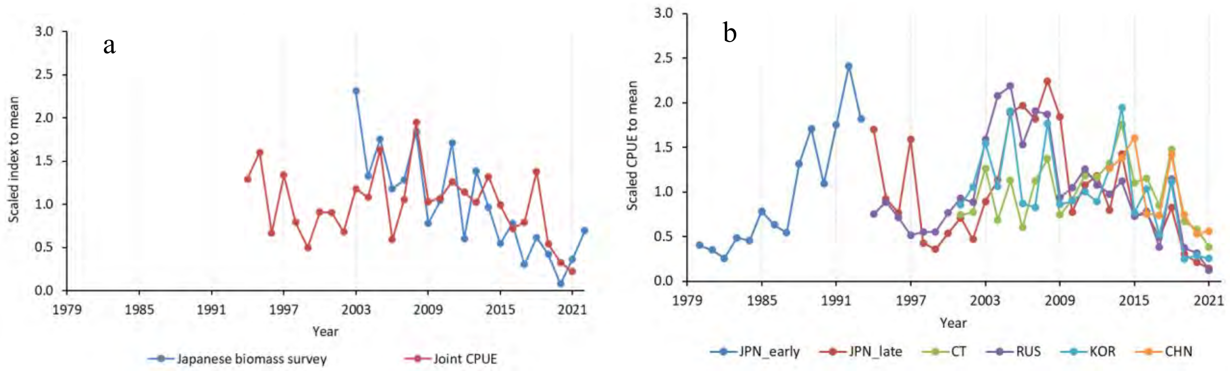


Figure 2. Time series of (a) Japanese survey biomass index and joint CPUE and (b) Member's standardized CPUE indices used in the assessment modeling.

Brief description of specification of analysis and models

A Bayesian state-space production model (BSSPM) used in previous stock assessments was employed as an agreed provisional stock assessment model for Pacific saury during 1980-2022. Scientists from three Members (China, Japan and Chinese Taipei) each conducted analyses following the agreed specification which called for two base case scenarios and two sensitivity scenarios (see Annex F, SSC PS09 report for more details). The two base case scenarios differ in using each Member's standardized CPUEs (base case B1) or standardized joint CPUEs (base case B2). For the two sensitivity cases with Japanese early CPUE (1980-1994), time-varying catchability was assumed to account for potential increases in catchability. A higher weight was given to the Japanese biomass survey estimates than to Members' CPUEs in B1 while comparable weights were given to the Japanese biomass survey estimates and the joint CPUEs in B2. 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 SSC PS considered the BSSPM results and noted the agreement in trends among Members' results for each base case model. However, there was a marked difference in the biomass level between B1 and B2 due to the different CPUE trends used. The SSC PS discussed and recognized that the results covered a wide range of uncertainties in data, model and estimation, and it therefore concluded the outcomes of MCMC runs could be aggregated over the 6 models (2 base case models x 3 Members) as in the previous assessments. 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/B_{MSY}), c) harvest rate (F), d) F-ratio (F/F_{MSY}) and e) B/K are shown in Figure 3. The Kobe plot with time trajectory using aggregated model outcomes is shown in Figure 4. Time series of median estimated values for biomass, harvest rate, B-ratio, F-ratio and depletion level relative to K are shown in Table 2.

Table 1. Summary of estimates of reference quantities. Median and credible interval for the aggregated results are presented. In addition, median values of Member's combined results (over B1 and B2) are shown.

	Median	Lower10%	Upper10%	Median_CHN	Median_JPN	Median_CT
C_2021 (10000 t)	9.221	9.221	9.221	9.221	9.221	9.221
AveC_2019_2021 (10000 t)	14.141	14.141	14.141	14.141	14.141	14.141
AveF_2019_2021	0.350	0.111	0.733	0.402	0.456	0.238
F_2021	0.213	0.071	0.467	0.241	0.287	0.149
FMSY	0.313	0.084	0.619	0.363	0.407	0.206
MSY	40.281	29.911	51.100	41.316	40.649	38.850
F_2021/FMSY	0.739	0.452	1.259	0.729	0.740	0.751
AveF_2019_2021/FMSY	1.192	0.757	1.883	1.203	1.169	1.211
K (10000 t)	281.400	142.200	919.083	249.200	224.579	398.200
B_2021 (10000 t)	43.260	19.750	129.400	38.260	32.149	61.950
B_2022 (10000 t)	65.500	36.900	162.000	62.190	56.264	82.035
AveB_2020_2022 (10000 t)	49.147	25.386	138.103	44.845	39.111	66.877
BMSY (10000 t)	131.800	70.360	409.910	118.800	104.432	186.400
BMSY/K	0.469	0.386	0.621	0.465	0.460	0.503
B_2021/K	0.151	0.088	0.240	0.149	0.147	0.159
B_2022/K	0.237	0.122	0.385	0.243	0.251	0.216
AveB_2020_2022/K	0.177	0.103	0.270	0.176	0.179	0.175
B_2021/BMSY	0.315	0.198	0.499	0.310	0.311	0.327
B_2022/BMSY	0.494	0.272	0.810	0.499	0.532	0.447
AveB_2020_2022/BMSY	0.368	0.232	0.564	0.364	0.377	0.360

Table 2. Time series of median estimated values for biomass, harvest rate, B-ratio, F-ratio and depletion level relative to K. The unit of biomass is 10,000 tons.

Year	Biomass	HarvestRate	Bratio	Fratio	Depletion
1980	157.678	0.151	1.197	0.524	0.571
1981	167.400	0.122	1.291	0.415	0.614
1982	177.300	0.138	1.376	0.461	0.658
1983	181.800	0.142	1.409	0.473	0.676
1984	184.700	0.134	1.422	0.447	0.683
1985	188.600	0.149	1.447	0.498	0.695
1986	188.600	0.138	1.436	0.464	0.691
1987	191.800	0.123	1.450	0.414	0.698
1988	197.056	0.181	1.481	0.613	0.714
1989	188.700	0.175	1.397	0.602	0.676
1990	185.474	0.235	1.379	0.805	0.664
1991	171.300	0.233	1.274	0.803	0.613
1992	164.900	0.233	1.230	0.807	0.590
1993	159.400	0.252	1.194	0.879	0.569
1994	151.300	0.220	1.137	0.774	0.536
1995	147.519	0.233	1.100	0.838	0.516
1996	138.900	0.192	1.022	0.704	0.478
1997	143.700	0.258	1.026	0.978	0.479
1998	129.800	0.136	0.914	0.526	0.427
1999	141.000	0.125	0.970	0.493	0.453
2000	157.200	0.182	1.099	0.699	0.513
2001	161.700	0.229	1.165	0.838	0.548
2002	165.100	0.199	1.213	0.703	0.575
2003	196.220	0.227	1.452	0.768	0.703
2004	174.200	0.212	1.287	0.720	0.622
2005	187.100	0.253	1.367	0.869	0.663
2006	161.752	0.244	1.194	0.829	0.575
2007	169.900	0.306	1.253	1.037	0.606
2008	172.155	0.359	1.236	1.248	0.604
2009	127.900	0.369	0.939	1.262	0.451
2010	127.100	0.338	0.924	1.167	0.447
2011	133.195	0.343	0.948	1.206	0.463
2012	112.500	0.409	0.828	1.392	0.398
2013	119.329	0.355	0.866	1.219	0.424
2014	111.200	0.566	0.821	1.889	0.403
2015	76.535	0.469	0.563	1.589	0.275
2016	72.586	0.498	0.528	1.704	0.260
2017	57.634	0.456	0.429	1.538	0.206
2018	63.360	0.693	0.469	2.295	0.230
2019	42.200	0.456	0.310	1.562	0.151
2020	38.040	0.367	0.279	1.271	0.134
2021	43.260	0.213	0.315	0.739	0.151
2022	65.500		0.494		0.237

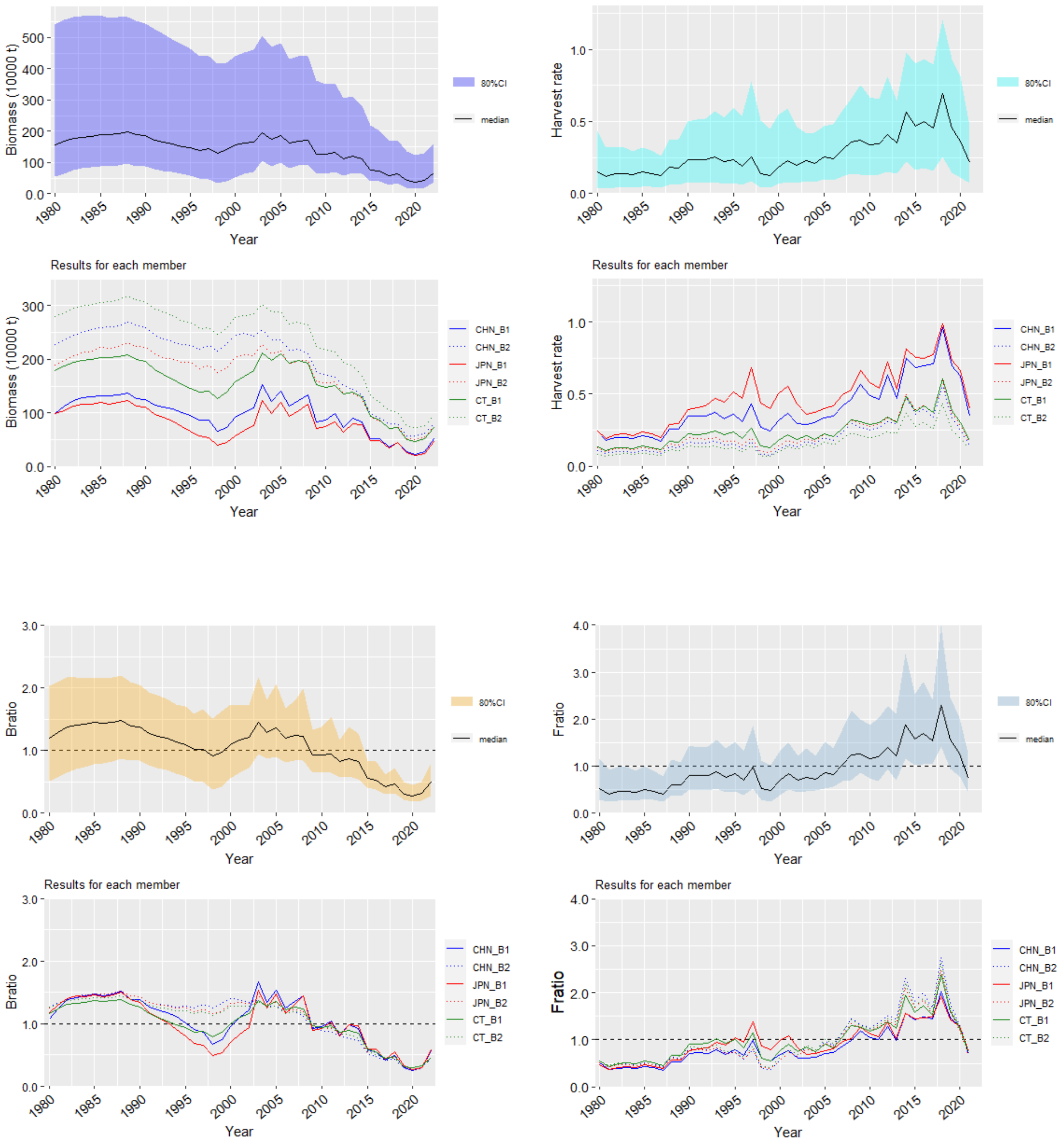


Figure 3. Time series of median estimated values of six runs for biomass, harvest rate, B-ratio, F-ratio and depletion level relative to K. The solid and shaded lines correspond to B1 and B2, respectively.

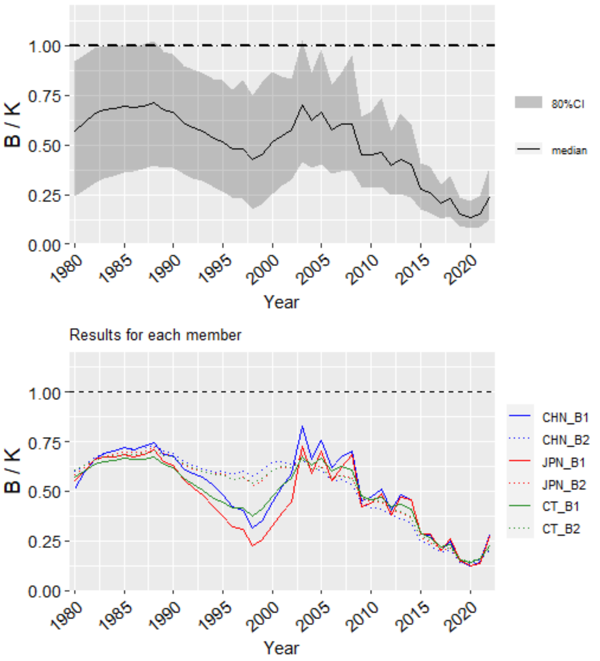


Figure 3 (Continued).

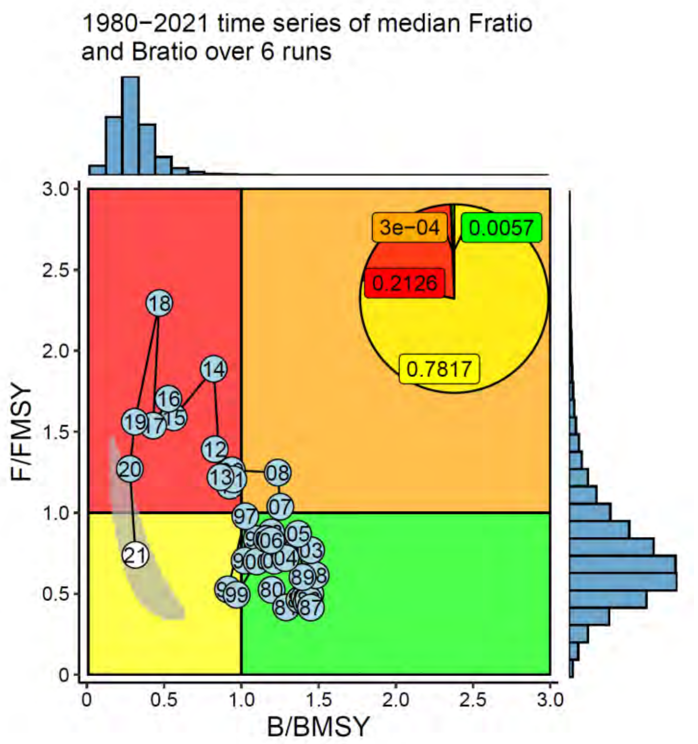


Figure 4. Kobe plot with time trajectory. The data are aggregated across 6 model results (2 base-case models by 3 Members).

Current stock condition and management advice

Summary of stock status

Results of combined model estimates indicate that the stock declined with an interannual variability from near carrying capacity in the mid-2000's after a period of high productivity to current low levels. The results also indicated that B was below B_{MSY} (median average B/B_{MSY} during 2020-2022 = 0.368, 80%CI=0.232-0.564) and F was above F_{MSY} (average F/F_{MSY} during 2019-2021 = 1.192, 80%CI= 0.757-1.883). The results further indicated that recent stock biomass remains at a historically low level in recent years. The biomass trend shows a small increase in recent years through 2021 and a marked increase in the Japanese biomass survey between 2021 and 2022. The harvest rate has also been declining from a peak in 2018 and was less than F_{MSY} during 2021. However, caution is required in interpreting these results, given historically low nominal CPUEs (see Fig. 5) through 2022, relatively high fishing effort in 2021, and variability inherent in fisheries-independent surveys.

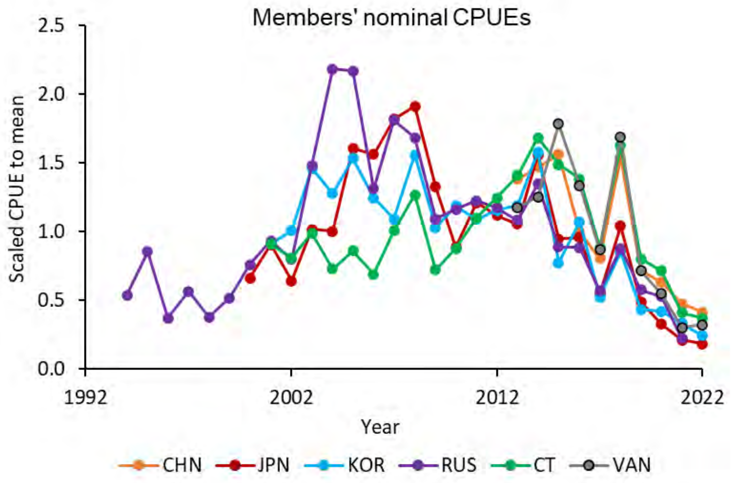


Figure 5. Time series of Member's nominal CPUE indices. Data in 2022 are preliminary (as of November 2022).

Robustness to scale uncertainty

Retrospective analyses for base case models in this assessment show considerable scale uncertainty with the magnitude (but not trend) of biomass and fishing mortality estimates changing substantially in some models as the terminal year in the model was reduced sequentially from 2022 to 2018. Members agreed that there was little or no retrospective pattern in trend because the overall trends in biomass and fishing mortality were relatively consistent (see Figure 3). Poor retrospective patterns estimate dramatic changes in recent trends when the terminal year is changed, as demonstrated in Figure 6 showing retrospective patterns for other species. However, the scale uncertainty surprised some Members and was a concern because unscaled biomass estimates are used in TAC calculations. It also seemed possible that uncertain scale in biomass estimates would make TAC calculations uncertain and affect conclusions about stock biomass and fishing mortality. Ensuing discussion and some calculations led the group to conclude that TAC advice based on BSSPM results are relatively unaffected by scale uncertainty.

Scale uncertainty is common in stock assessment modeling based on forward projecting models like the BSSPM that do not converge to stable historical biomass levels. Scale uncertainty is exacerbated for Pacific saury because the model is biomass based (so that mortality and growth are confounded), there are only two age groups, age zero saury are not fully selected by either the survey or fishery, and growth and natural mortality change rapidly. Scale uncertainty for Pacific saury is probably inevitable until reliable estimates of survey selectivity are developed. A new age-structured assessment model currently under development may help as well.

Stock status for Pacific saury in this assessment based on the BSSPM model is described in terms of robust biomass and fishing mortality ratio trends to avoid problems with scale uncertainty. The biomass ratio B/B_{MSY} can be expressed as true B times an error divided by true B_{MSY} times an error. The two errors tend to be similar and cancel in the ratio so that B/B_{MSY} and true B/true B_{MSY} are similar, and the status measure is robust. The tendency to robust trend estimation has always been evident in Pacific saury assessments because the trends estimated in models fit by members with different assumptions tend to be similar. The robustness property applies to Kobe plots and similar means for status determination because the comparison is F/F_{MSY} to F_{MSY} and B/B_{MSY} to B_{MSY}.

TAC calculations like TAC = F_{MSY} * B are robust to scale uncertainty because errors in estimates of productivity and biomass tend to cancel in the product of F_{MSY} and B. In practical terms, scale uncertainty means that assessment scientists cannot determine if the stock is larger and less productive or smaller and more productive. Fishing mortality and productivity are related in simple Schaefer surplus production models because $F_{MSY} = r/2$ where r is the intrinsic rate of productivity which is the maximum rate of population growth. Reported catch C = F * B is not affected by scale uncertainty. If the estimated biomass estimates are too large, then the model must underestimate fishing mortality and productivity to obtain the observed catch, so the stock appears to be relatively large and unproductive. Similarly, if the estimated biomass is too small, then the model must overestimate fishing mortality and productivity so that the stock appears to be smaller and more productive.

The over (or under) estimation of biomass tends to be cancelled out by an under (or over) estimation of F_{MSY}. The SSC PS demonstrated this pattern by calculating TAC = F_{MSY} x B based on estimates from two base models by three Member. The TAC results were more similar than the original biomass estimates, which had substantially different scales (Table 3). TAC calculated from any harvest control rule based on F_{MSY} (e.g. with the target F reduced when $B/B_{MSY} < 1$) should also be robust.

Robust trend estimation and robust TAC calculations based on model biomass estimates are not related to predicting future trends in the Pacific saury fishery. Robust properties to scale uncertainty do not alleviate any other problems that may exist in the model. Rather, robust means that similar results will be obtained from results with different scales.

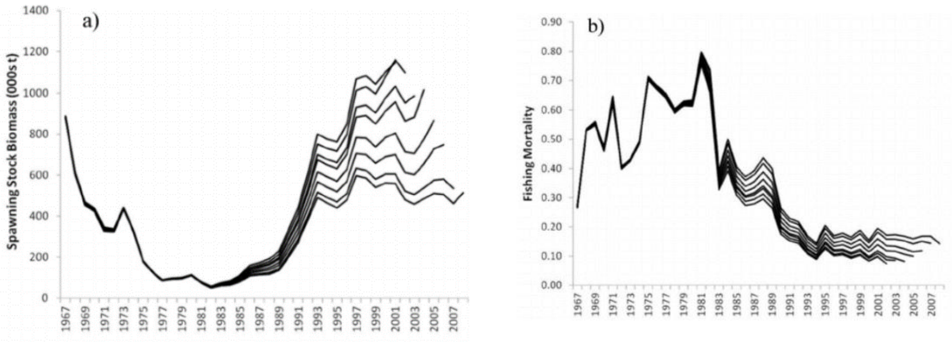


Figure 6. Retrospective patterns in stock assessment results (not Pacific saury).

Management advice

The Commission has responsibility for choosing the TAC and the TAC approach for the Pacific saury fishery. The method used by the Commission in 2019 to set the 2020 TAC for saury was F_{MSY} * B, which is a standard approach used previously in many fisheries. However, it was noted in the last assessment that the original method is seldom used in modern fishery management because it maintains a high (F_{MSY}) fishing mortality level as stock biomass becomes low, as is currently the case for Pacific saury. Simulation studies for many fisheries show better performance (higher average catch and less frequent low biomass conditions) using harvest control rules such as a new standard approach now used in many fisheries. The newer standard reduces fishing mortality in a simple linear fashion when stock size falls below B_{MSY} to help rebuild stocks at low biomass and increase catches (Figure 7). It gives the same F and same TAC for stocks at biomass levels B_{MSY} and higher (the original and new approaches are identical when stock biomass is at least B_{MSY}). The new approach is generally regarded as better on technical grounds at maintaining productive stock levels, avoiding low biomass conditions and obtaining relatively high long-term catch. Both approaches are based on the same underlying reference points (F_{MSY} and B_{MSY}) that are estimable for Pacific saury in the BSSPM and likely future models. Both approaches use robust trend-based stock status measures and reference points.

TAC calculations were carried out in this assessment for illustrative purposes using the original and newer standard approaches. Such calculations may serve as a means for communication between scientists and managers, provide another approach to calculate TAC on an interim manner, or as a basis for further work. Results show that the newer approach results in TAC for 2023 (101,885 tons) that is close to the 2022 catch (98,000 tons, preliminary as of 17 December 2022) and better matches current surplus production in the stock. Results for the original approach yield TAC for 2023 (205,015 tons), which is substantially higher than recent catches.

The current annual TAC for 2021-2022 specified in CMM 2021-08 for Pacific saury (333,750 tons) based on historical catch is much larger than a TAC that would be based on the F_{MSY} catch approach (B_{2022}*F_{MSY} = 205,015 tons). The current biomass is much lower than B_{MSY} and the TAC for 2021-2022 did not reduce fishing mortality in recent years. A harvest control rule that reduces F when biomass is low may increase the probability of achieving long-term sustainable use of Pacific saury (i.e. higher long-term catch closer to MSY of around 403,000 tons). A reduction to the TAC for 2021-2022 would increase the probability of higher biomass and catch levels in the Pacific saury stock.

An HCR that reduces the target harvest rate and TAC when biomass falls below its target level may be appropriate for Pacific saury. This type of HCR is used in managing many fisheries around the world. For example, if an HCR that reduces F linearly when biomass is below B_{MSY} (Figure 8) is applied, the TAC calculated based on such an HCR (B_{2022}*F_{MSY}*(B2022/B_{MSY}) = 101,885 tons) could be similar with the current catch (98,000 tons, preliminary as of 17 December 2022).

Note, however, the performance of the above HCRs has not been evaluated by a formal MSE framework for Pacific saury. They were used as simple illustrations of common approaches used elsewhere.

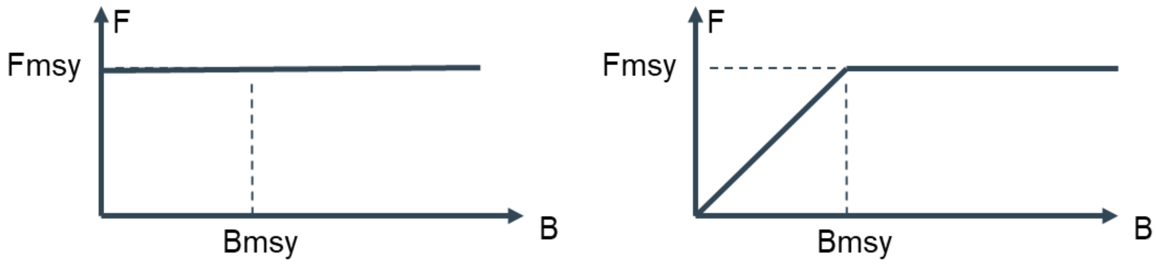


Figure 7. Shapes of harvest rates used in the 2019 Commission meeting for setting the TAC for 2020 (left) and a standard HCR (right).

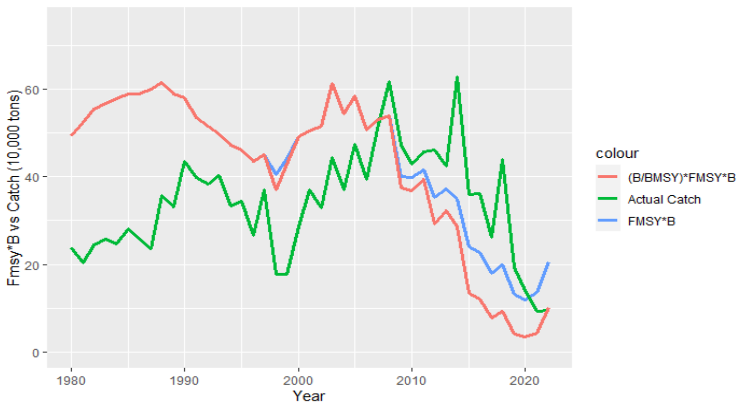


Figure 8. Median time series of F_{MSY}*B, min(1, B/B_{MSY})*F_{MSY}*B, and the actual catch. The first calculation was used by the Commission in 2019 and the second calculation is a common HCR used elsewhere that reduces F when biomass falls below B_{MSY}. Note that the catch in 2022 is a preliminary number as of 17 December 2022. Note that these two calculations are the same when B > B_{MSY}. Also the second calculation is shown as an example application of an HCR.

The HCR used in the second calculation above is a relatively simple approach widely used in many fisheries, but only one example from the range of potential harvest control rules of the same or other types. The SWG MSE PS is currently evaluating options that would work well for short lived Pacific saury.

Table 3. Summary of results for application of TAC calculations as an example manner.

	Base case 1			Base case 2			Aggregated
	CHN	JP	CT	CHN	JP	CT	over 6 runs
Fmsy	0.49	0.52	0.25	0.21	0.26	0.16	0.313
B2022	51.78	46.5	72.59	79.17	74.8	95.12	65.5
B2022/Bmsy (=c)	0.57	0.58	0.46	0.42	0.48	0.43	0.494
Fmsy*B2022	25.37	24.18	18.15	16.63	19.45	15.22	20.50
c*Fmsy*B2022	14.46	14.02	8.35	6.98	9.34	6.54	10.13

Special comments regarding the procedures and stock assessment results

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

1) Standardized CPUE data were assumed to change more slowly than biomass and were down-weighted relative to the Japanese survey in the first base case (B1), which used CPUE from individual Members. In B1, a single non-linear parameter was used for the CPUEs for each Member. Model results support this decision.

2) Retrospective analyses have shown that BSSPM model projections are not suitable for use by managers and they have therefore been omitted by most Members (See discussion in the 2019 assessment (NPFC-2019-SSC PS04-Final Report)). Projections are problematic because recruits and older Pacific saury are not distinguished in the model, environmental effects are important but not predictable and because the species is short-lived.

3) The 2020 biomass index from the Japanese survey has large uncertainties due to incomplete survey coverage. Potential Covid-19 effects on CPUE and catches were not considered in this assessment but may be important. Members should consult fishermen regarding possible impacts of COVID-19 on the fishery.

4) The relative importance of fishing and environmental factors on the population dynamics of Pacific saury is unknown and an important area for research. However, changing environmental conditions may have contributed to the decline and current low stock size of Pacific saury. However oceanographic or biological factors responsible for changes in productivity have not yet been determined. Development of modeling procedures to incorporate environmental change is an important area for future research. The work should include refinements to stock assessment models to better reflect and estimate environmental effects on recruitment and biology. This work should be coordinated among Members and folded into the development of age-structured and improved BSSPM models.

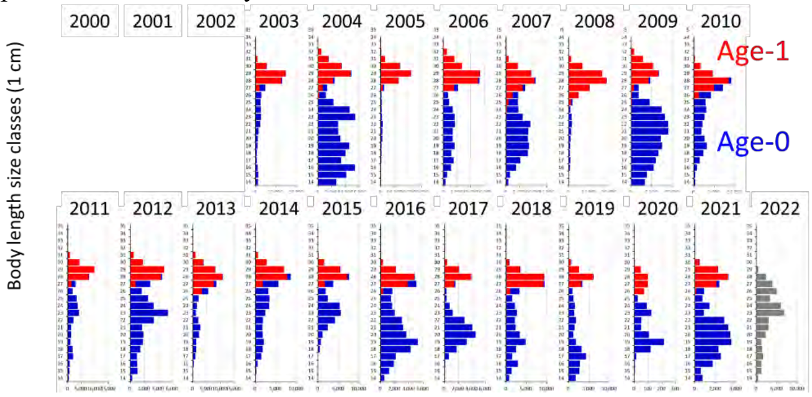
5) The Commission should consider defining overfishing and overfished status and identify actions taken when such conditions occur in the future.

6) In the next assessment, the geographic area to which data and assessment estimates apply (Convention Area, Members' EEZ or both) should be described.

7) Nominal CPUE trends (Figure 5) and standardized CPUEs (Figure 2) used in assessment modeling were similar. Preliminary catch (around 98,000 mt as of 17 December 2022) and preliminary nominal CPUE in 2022 for each Member were at the lowest levels historically. CPUE declines more slowly than stock biomass as demonstrated in all BSSPM results for Pacific saury. Thus, the decline in stock biomass was probably greater than the decline in CPUE.

8) Time series of size and age composition data from the Japanese survey and fishery (Figures 9 and 10) showed the occurrence of weak year classes (i.e. 2005, 2008) consistently. Such consistency will facilitate application of new age and/or size structured model.

(a) Japanese biomass survey



(b) Japanese commercial fishery between August and November

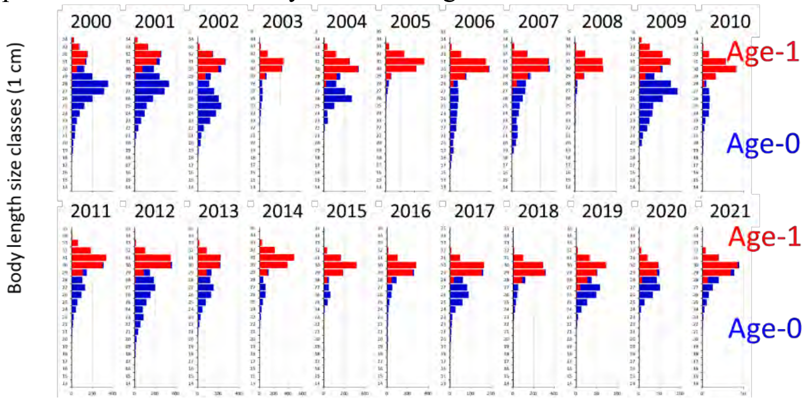


Figure 9. Time series of age and length composition of samples taken from the Japanese survey and commercial fishery (August-November) in Japan.

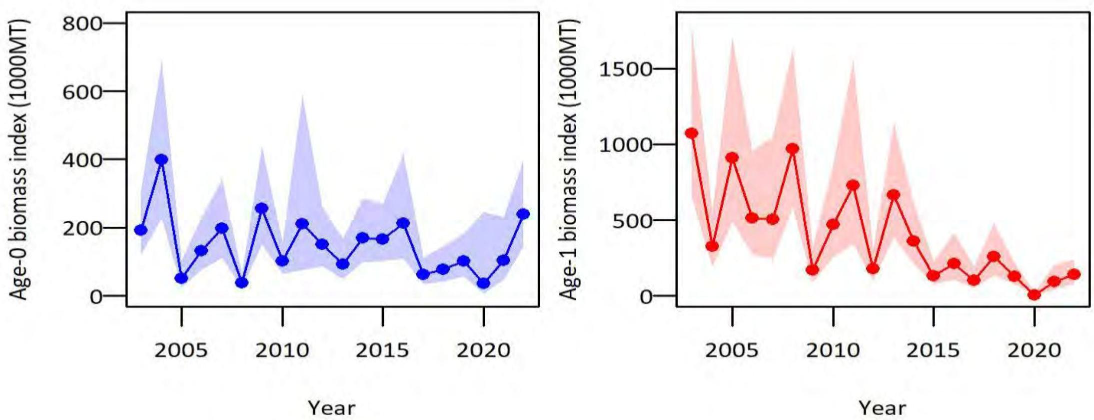


Figure 10. Time series of Japanese survey biomass index by age.

9) In this assessment, trends in effective annual fishing effort were calculated as catch divided by standardized CPUE (nominal CPUE was used for Vanuatu because standardized CPUE was not available, Figure 11). Standardized CPUE is theoretically the catch rate for a single type of vessel operating across the range of the fishery during the fishing season. Standardized CPUE = catch / standardized fishing effort so

standardized fishing effort = catch / standardized CPUE. Thus, the effort calculation measures the amount of fishing effort theoretically required for a representative type of vessel in each year to take the observed catch. Results for the entire fishery show that effort increased beginning in 1994 and has been variable and relatively high since about 2000 despite strong trends in fishing effort by individual members. In particular, declines in Japanese and Russian fishing effort have been offset by increases in fishing effort by China since 2015, Korea since 2011, Chinese Taipei since 2001 and, to a lesser extent, Vanuatu since 2011.

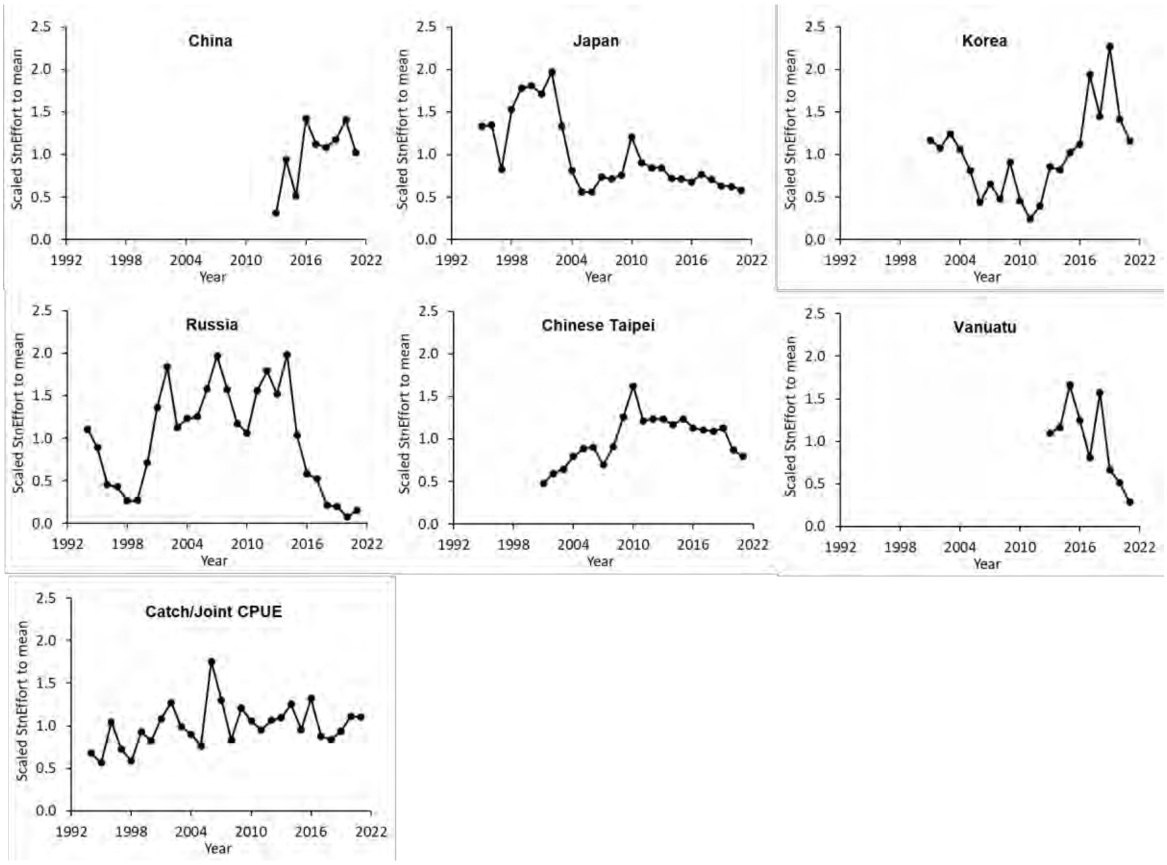


Figure 11. Time series of standardized efforts for the total fishery and Members' fishery calculated by a simple formula of Catch/standardized CPUE. Note that the effort for Vanuatu is the nominal effort.

STOCK ASSESSMENT REPORT FOR PACIFIC SAURY

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 the Kuril Islands to eastward to the 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

Pacific 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 160°E) 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

<u>Western North Pacific</u>

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 technique to catch Pacific saury in the northwest Pacific Ocean. Since 1995, more than 97% of Japan's total catch is caught by the stick-held dip net. The annual catch of Pacific saury for stick-held dip net fishery has fluctuated. Maximum and minimum catches of 355 thousand tons and 30 thousand tons were recorded in 2008 and 2020, respectively.

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 2.4 thousand tons in 2019 and about 750 tons in 2020.

China commenced its exploratory saury fishing using stick-held dip nets 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.

Chinese Taipei's Pacific saury fishery can date back to 1975 and had its first commercial catch in 1977. Over the past decade, the number of active Pacific saury fishing vessels has been increasing from 68 to 91 and the catch has fluctuated between 39,750 tons and 229,937 tons since 2001. Aside from Pacific saury fishery, most of the Pacific saury fishing vessels also conduct flying squid jigging operations in the Northwest Pacific Ocean.

Vanuatu commenced its development of Pacific saury fishery by using stick-held dip net in the high seas in 2004. Currently there are four vessels operating in the Northwest Pacific targeting saury, but the total accumulative number of its authorized Pacific saury fishing vessels from 2004 to 2020 is 16. 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 around 300 kg of saury were captured by Canadian commercial fisheries over 17 years from 1997-2013 (Wade and Curtis 2015; NPFC-2022-SSC PS09-IP01). 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 United States' 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)

Historically, Japanese and Russian vessels operated mainly within their own EEZs, but they have shifted into the Convention Area in recent years. Chinese, Korean and Chinese Taipei vessels operate mainly in the high seas of the North Pacific (Figure 1).

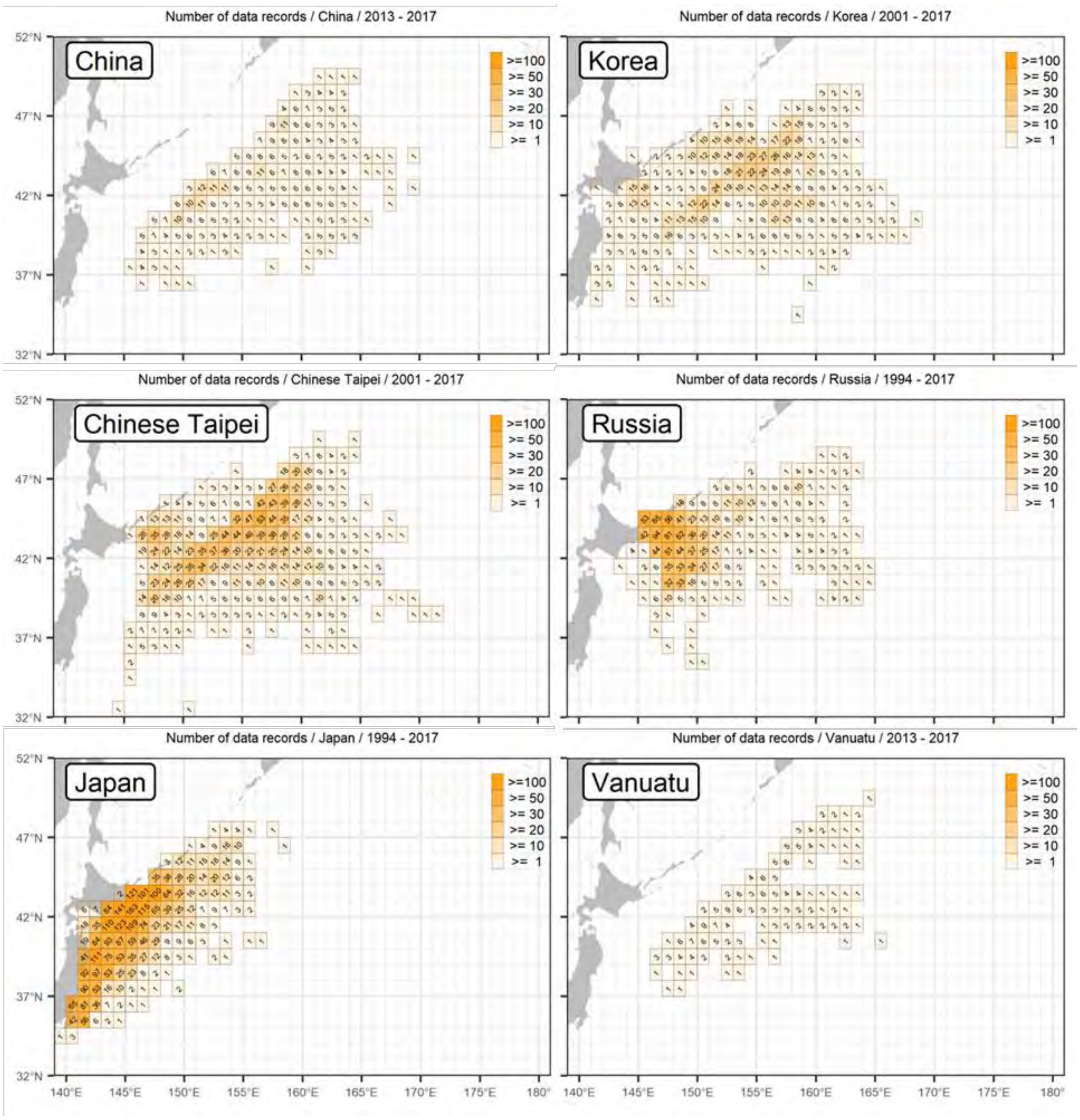


Figure 1 (a). Main fishing grounds for Pacific saury by fishing members in the western North Pacific Ocean during 1994-2017. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index

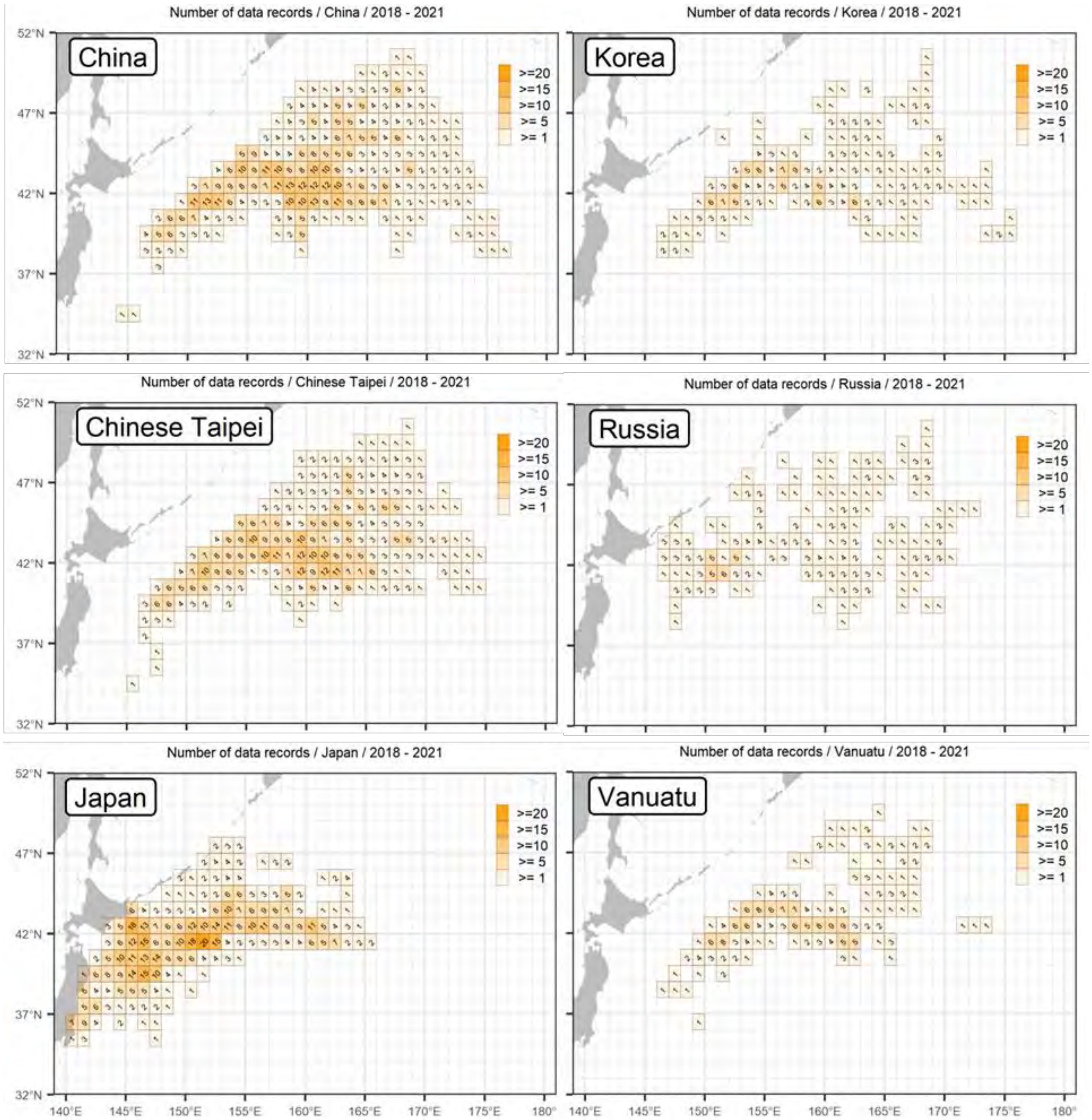


Figure 1 (b). Main fishing grounds for Pacific saury by fishing members in the western North Pacific Ocean during 2018-2021. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index

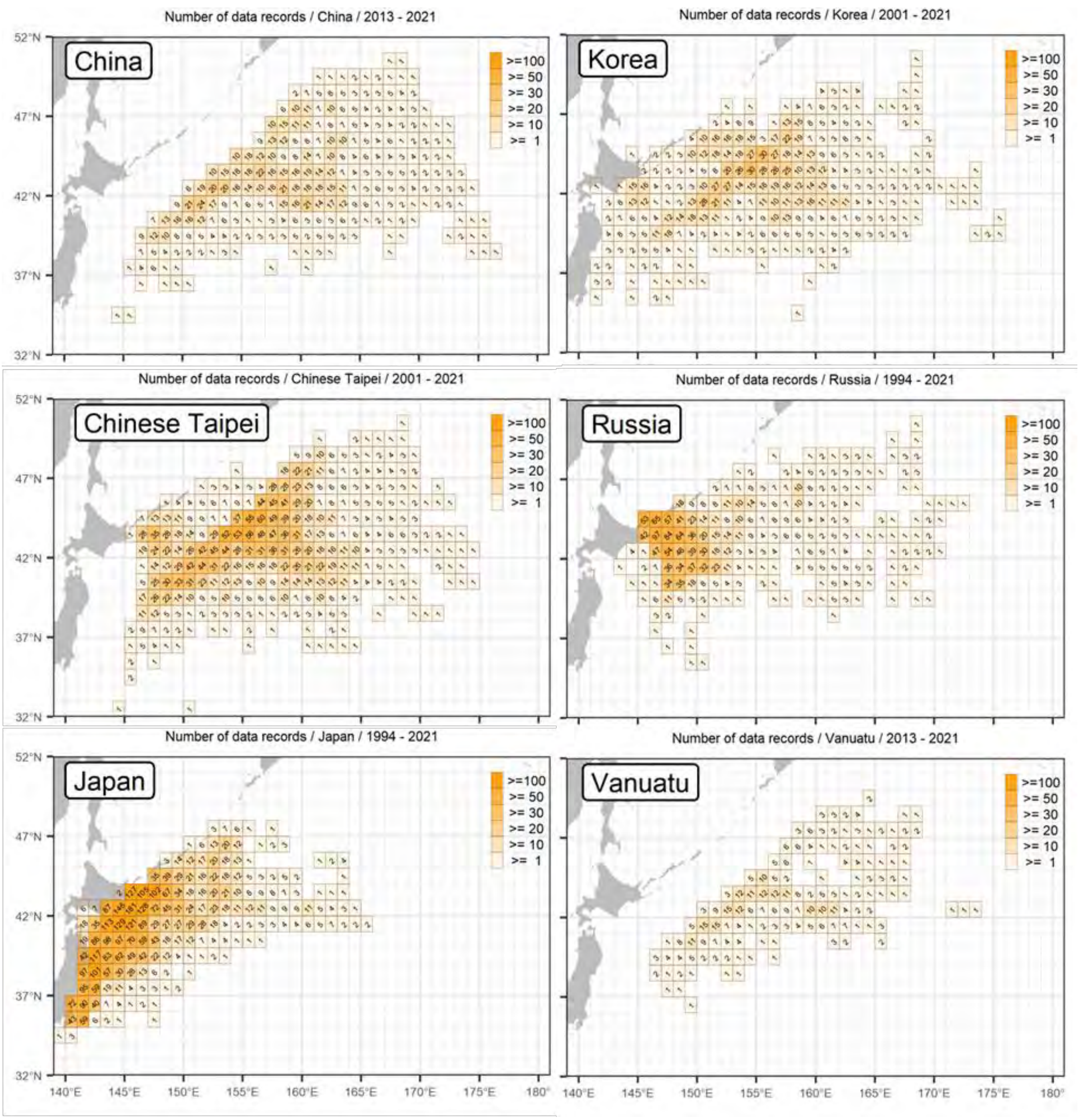


Figure 1 (c). Main fishing grounds for Pacific saury by fishing members in the western North Pacific Ocean during 1994-2021. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index

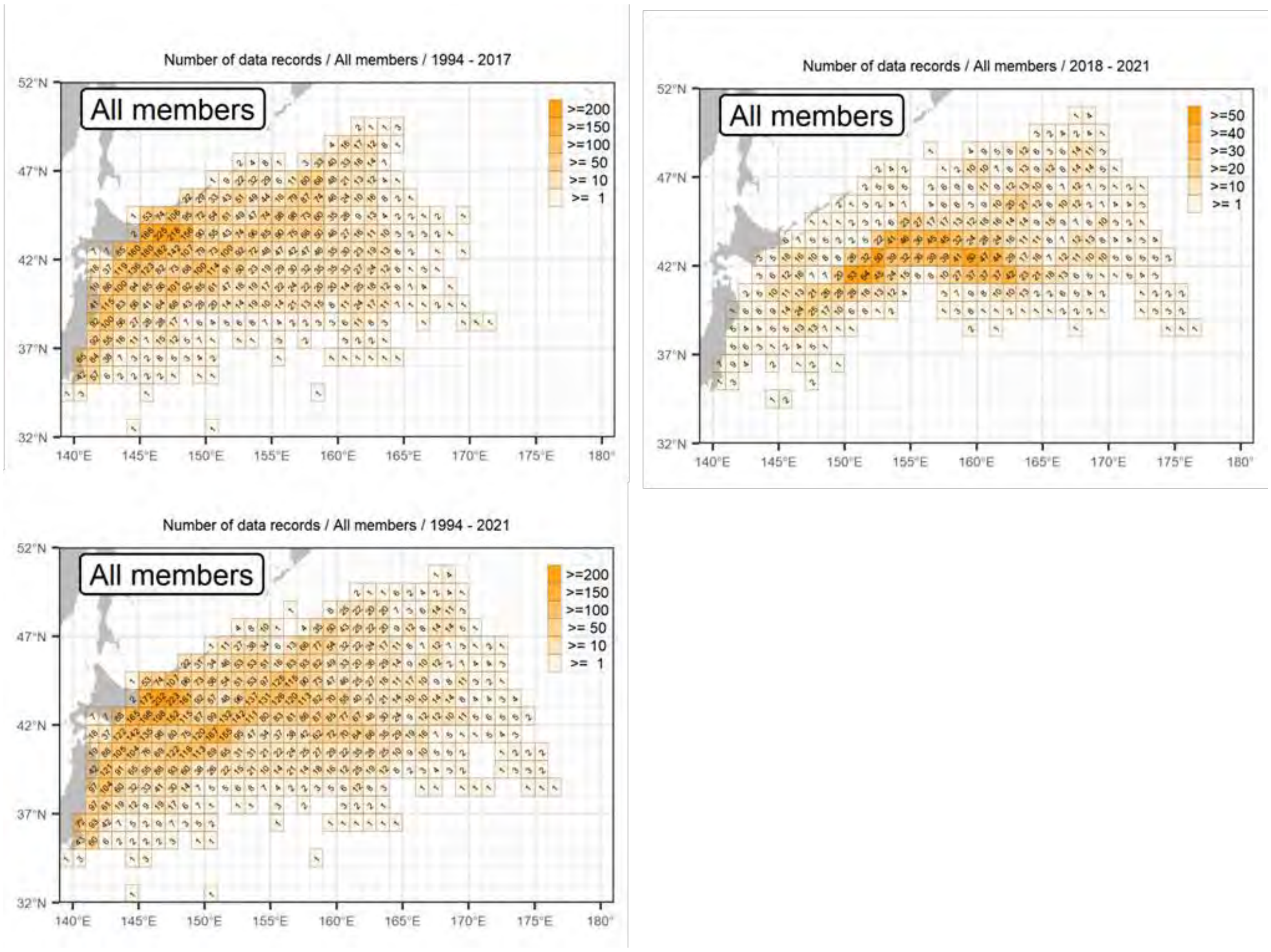


Figure 1 (d). Main fishing grounds for Pacific saury in the western North Pacific Ocean. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index

2.2 Catch records

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

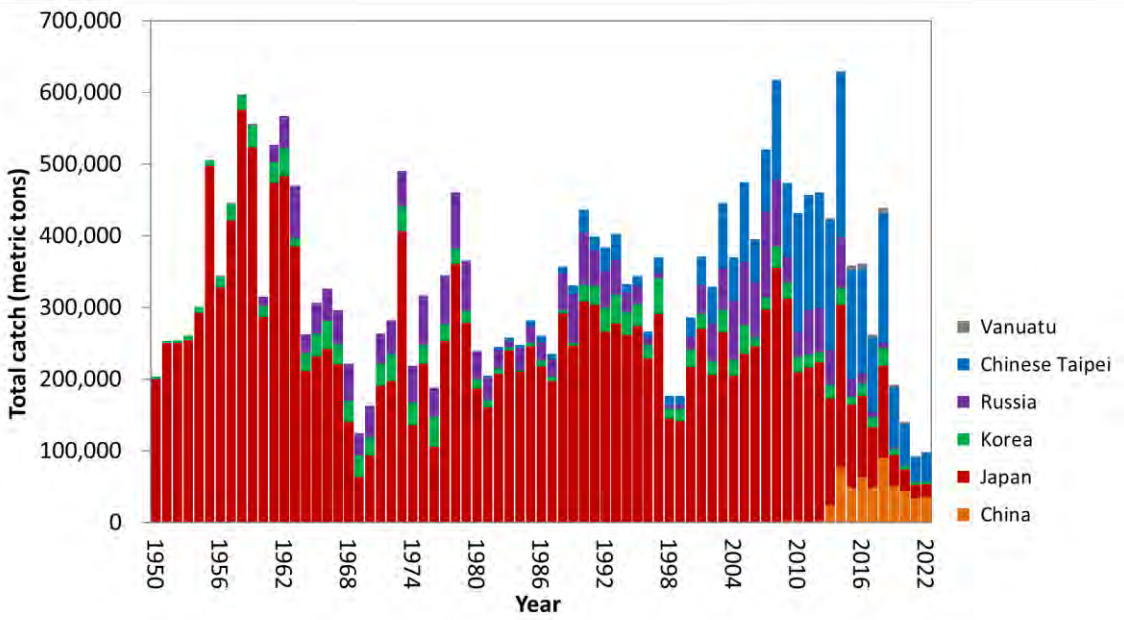


Figure 2. Time series of catch by Member during 1950-2022. The catch data for 1950-1979 are shown but not used in stock assessment modeling. Catch data in 2022 are preliminary (as of 17 December 2022) and not used in the assessment.

3. SPECIFICATION OF STOCK ASSESSMENT

A Bayesian state-space production model (BSSPM) used in previous stock assessments was employed as an agreed provisional stock assessment model for Pacific saury during 1980-2022. Scientists from three Members (China, Japan and Chinese Taipei) each conducted analyses following the agreed specification which called for two base case scenarios and two sensitivity scenarios (see Annex F, SSC PS09 report for more details). The two base case scenarios differ in using each Member's standardized CPUEs (base case B1) or standardized joint CPUEs (base case B2). For the two sensitivity cases with Japanese early CPUE (1980-1994), time-varying catchability was assumed to account for potential increases in catchability. A higher weight was given to the Japanese biomass survey estimates than to Members' CPUEs in B1 while comparable weights were given to the Japanese biomass survey estimates and the joint CPUEs in B2. 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.

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*

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 the 3 members)

The multiple biomass indices are modelled as follows:

Survey biomass estimate

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

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

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

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 Member-specific differences in preferred assumptions 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-2020-SSC PS06-WP08 and NPFC-2020-SSC PS06-WP10; for the non-uniform priors used in Chinese Taipei, see document NPFC-2020-SSC PS06-WP17.

3.2 Agreed scenarios

Table 1. Definition of scenarios

	Base case (NB1)	**Base case (NB2)**	**Sensitivity case (NS1)**	**Sensitivity case (NS2)**
Initial year	1980	1980	1980	1980
Biomass survey	$I_{t,bio} = q_{bio}\, B_t e^{v_{t,bio}}$ $v_{t,bio} \sim N(0, cv_{t,bio}^2 + \sigma^2)$ $q_{bio} \sim$ U(0,1) (2003-2022)	Same as left	Same as left	Same as left
CPUE	CHN(2013-2021) JPN_late(1994-2021) KOR(2001-2021) RUS(1994-2021) CT(2001-2021) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ σ_f^2=$c \cdot (ave(cv_{t,bio}^2) + \sigma^2)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey (*c* = 5)	Joint CPUE (1994-2021) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma^2)$	CHN(2013-2021) JPN_early(1980-1993, time-varying *q*) JPN_late(1994-2021) KOR(2001-2021) RUS(1994-2021) CT(2001-2021) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ σ_f^2=$c \cdot (ave(cv_{t,bio}^2) + \sigma^2)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey (*c* = 6)	JPN_early(1980-1993, time-varying *q*) $I_{t,JE} = q_{t,JE} B_t^b e^{v_{t,JE}}$ $v_{t,JE} \sim N(0, \sigma_{JE}^2)$ σ_{JE}^2=$c\ ave(cv_{t,joint}^2 + \sigma^2)$ Joint CPUE (1994-2021) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma^2)$
Hyper-depletion / stability	A common parameter for all fisheries with a prior distribution, *b* ~ *U*(0, 1)	*b* ~ *U* (0, 1)	A common parameter for all fisheries but JPN_early, with a prior distribution, *b* ~ *U*(0, 1) [*b* for JPN_early is fixed at 1]	*b* ~ *U* (0, 1) for joint CPUE. [*b* for JPN_early is fixed at 1]
Prior for other than q_{bio}	Own preferred options	Own preferred options	Own preferred options	Own preferred options

Table 2. Description of symbols used in the stock assessment

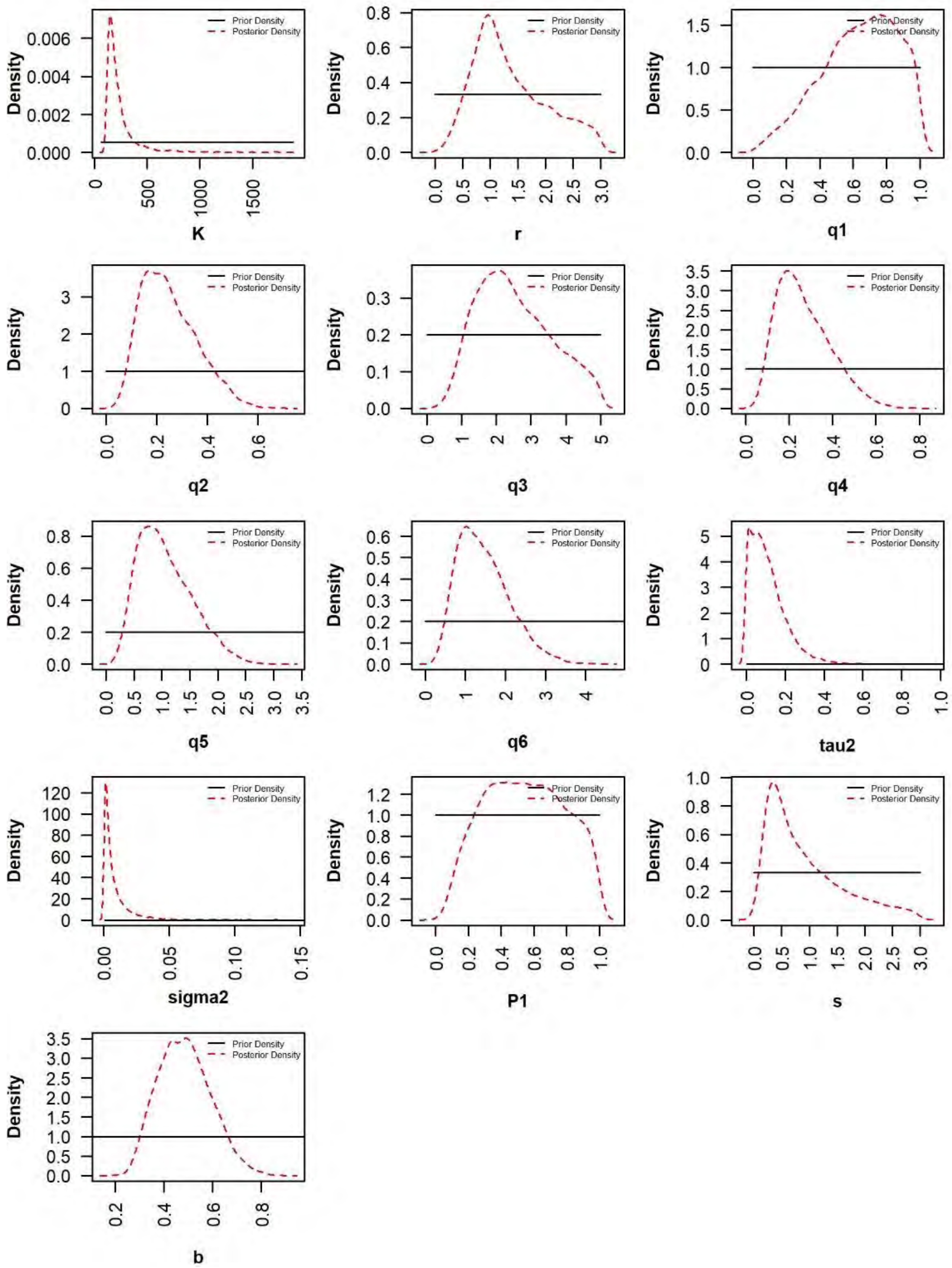
Symbol	Description
C_{2021}	Catch in 2021
$AveC_{2019\text{-}2021}$	Average catch for a recent period (2019–2021)
$AveF_{2019\text{-}2021}$	Average harvest rate for a recent period (2019–2021)
F_{2021}	Harvest rate in 2021
F_{MSY}	Annual harvest rate producing the maximum sustainable yield (MSY)
MSY	Equilibrium yield at F_{MSY}
F_{2021}/F_{MSY}	Average harvest rate in 2021 relative to F_{MSY}
$AveF_{2019\text{-}2021}/F_{MSY}$	Average harvest rate for a recent period (2019–2021) relative to F_{MSY}
K	Equilibrium unexploited biomass (carrying capacity)
B_{2021}	Stock biomass in 2021 estimated in the model
B_{2022}	Stock biomass in 2022 estimated in the model
$AveB_{2020\text{-}2022}$	Stock biomass for a recent period (2020–2022) estimated in the model
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_{2021}/K	Stock biomass in 2021 relative to K[a]
B_{2022}/K	Stock biomass in 2022 relative to K[a]
$B_{2020\text{-}2022}/K$	Stock biomass in the latest time period (2020-2022) relative to the equilibrium unexploited stock biomass[a]
B_{2021}/B_{MSY}	Stock biomass in 2021 relative to B_{MSY}[a]
B_{2022}/B_{MSY}	Stock biomass in 2022 relative to B_{MSY}[a]
$B_{2020\text{-}2022}/B_{MSY}$	Stock biomass for a recent period (2020–2022) relative to the stock biomass that produces maximum sustainable yield (MSY) [a]

[a]calculated as the average of the ratios.

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)

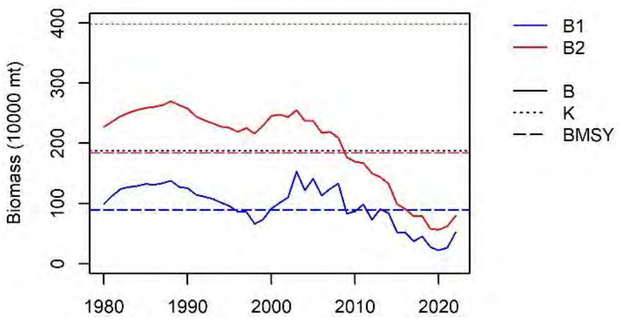


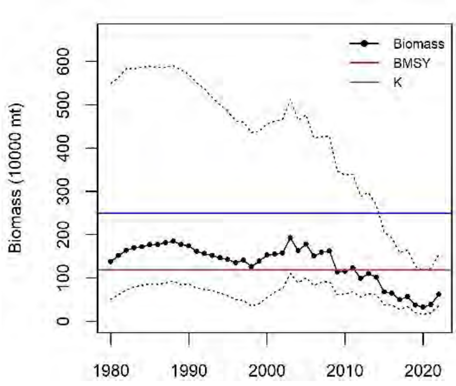
4.1.2 Summary of estimates of parameters and reference points

	Base case 1	Base case 2	Over all 2
C2021	9.22	9.22	9.22
AveC2019-2021	14.14	14.14	14.14
AveF2019-2021	0.57	0.24	0.40
F2021	0.35	0.15	0.24
F_{MSY}	0.49	0.21	0.36
MSY	43.89	38.11	41.32
F2021/F_{MSY}	0.71	0.76	0.73
AveF2019-2021/F_{MSY}	1.16	1.26	1.20
K	187.70	398.20	249.20
B2021	26.63	62.28	38.26
B2022	51.78	79.17	62.19
AveB2020-2022	33.74	66.36	44.85
B_{MSY}	89.28	184.10	118.80
B_{MSY}/K	0.47	0.46	0.46
B2021/K	0.14	0.15	0.15
B2022/K	0.28	0.20	0.24
B2020-2022/K	0.18	0.17	0.18
B2021/B_{MSY}	0.30	0.32	0.31
B2022/B_{MSY}	0.57	0.42	0.50
B2020-2022/B_{MSY}	0.38	0.35	0.36

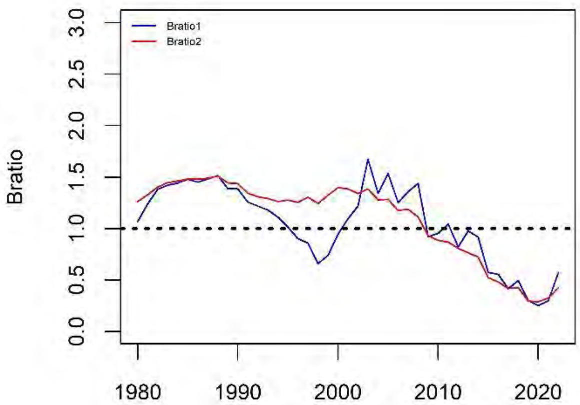
4.1.3 Time series plots for base case models and aggregated results

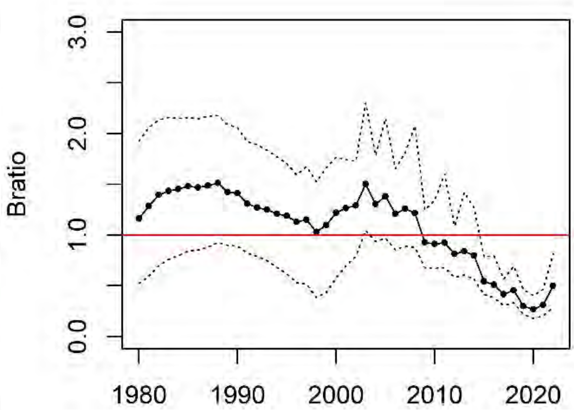
(a) Biomass



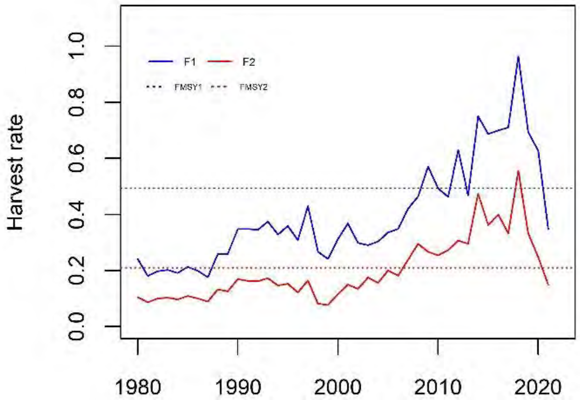


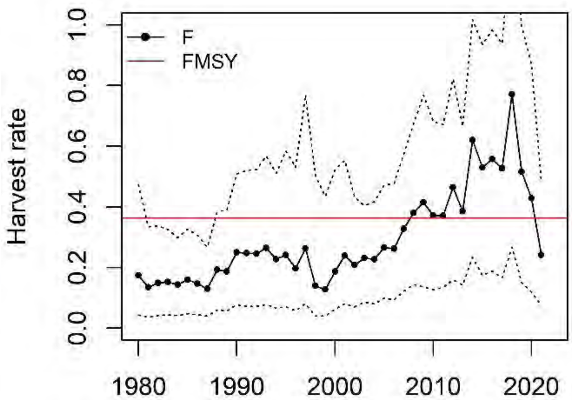
(b) B-ratio (B/B_{MSY})



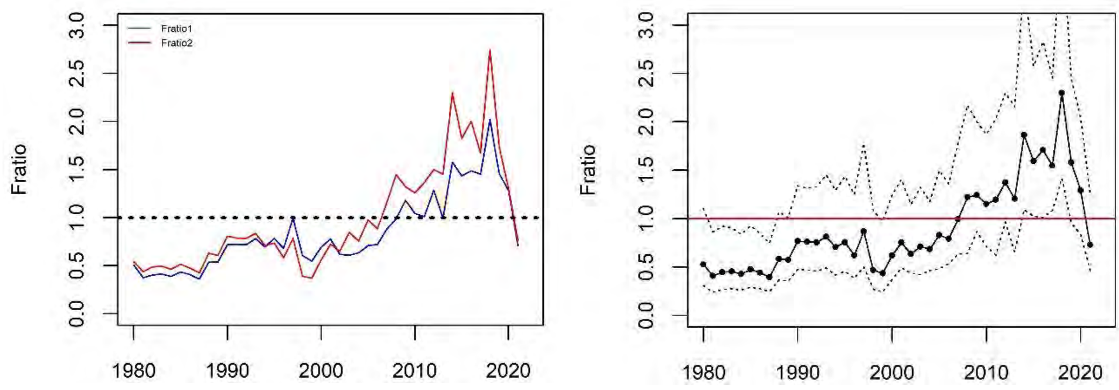


(c) Exploitation rate (F)

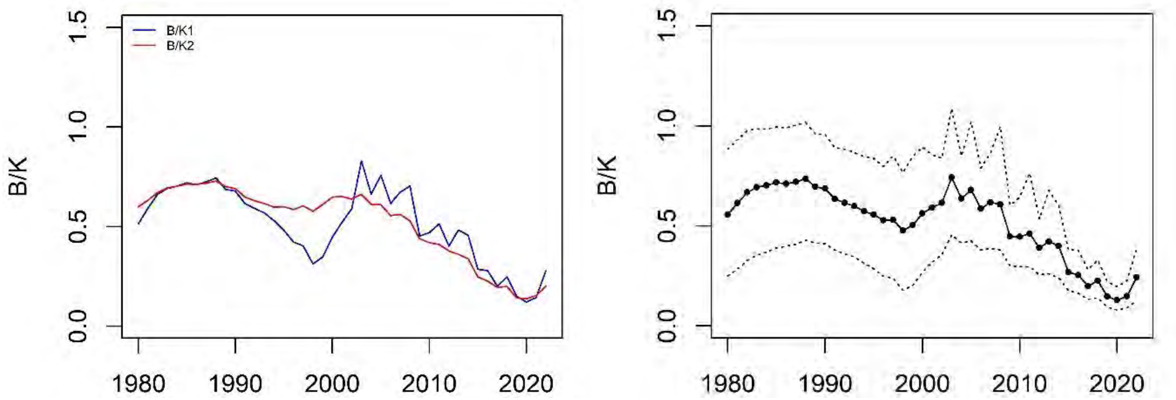




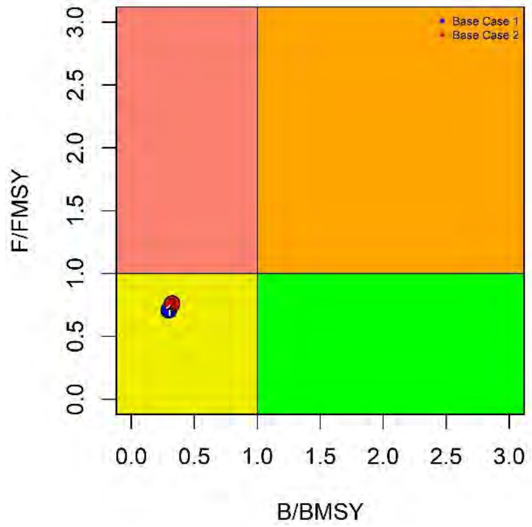
(d) F-ratio (F/F_{MSY})

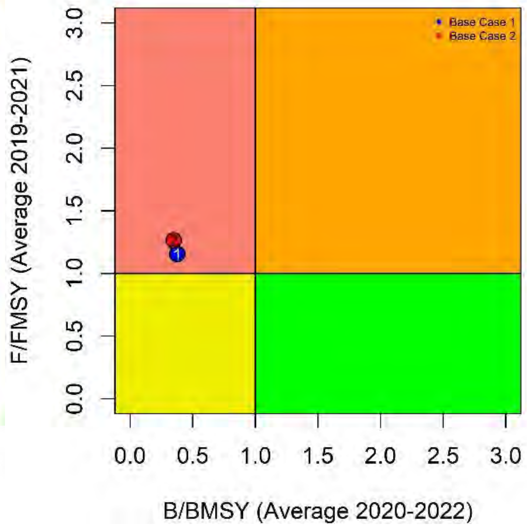


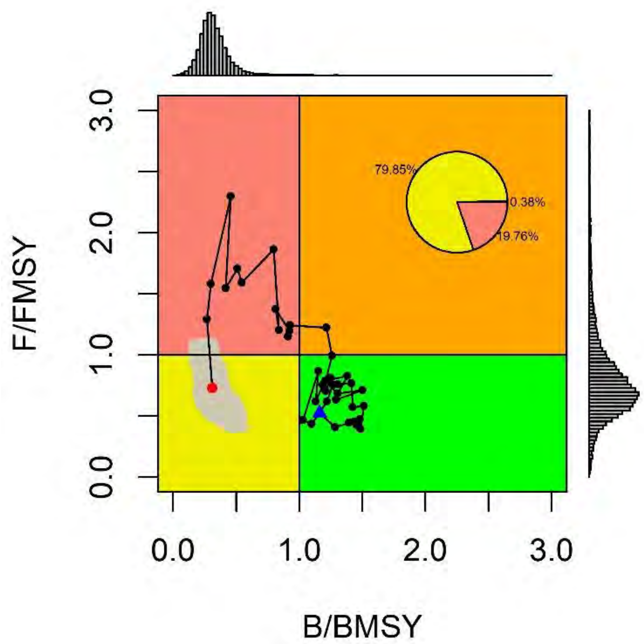
(e) B/K



4.1.4 Kobe plots

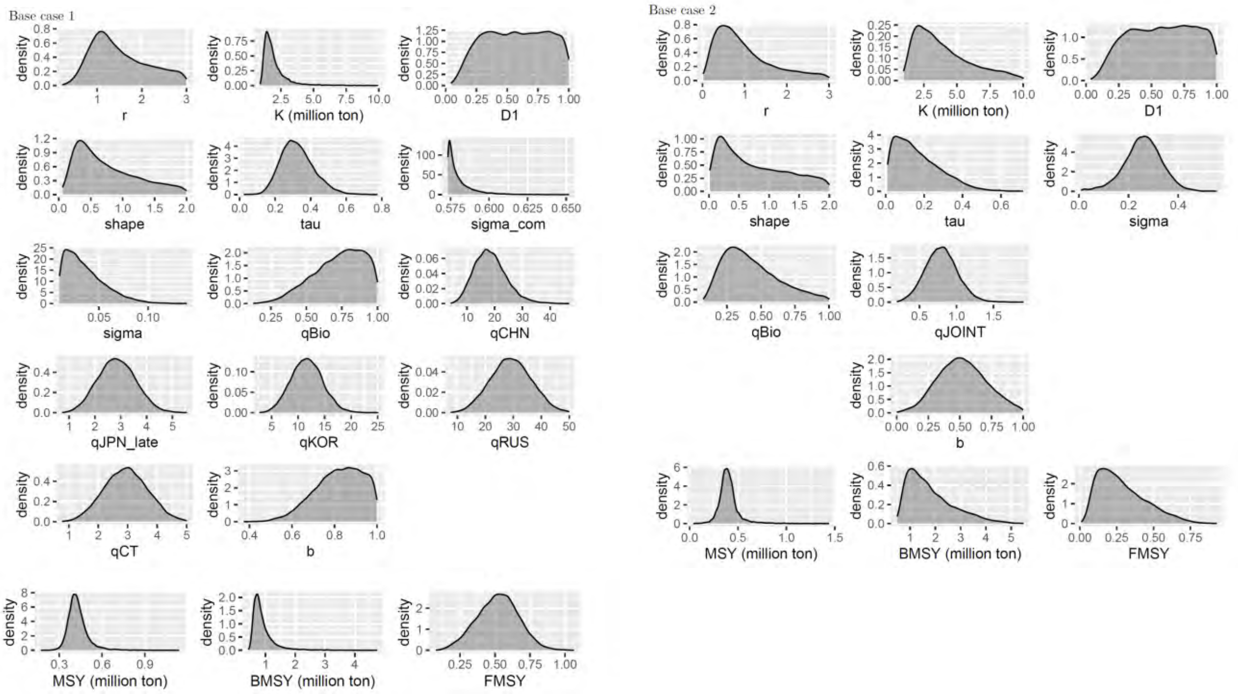






4.2 JAPAN

4.2.1 Prior and posterior distributions for Base case models



Note: Prior for each free parameter is assumed to be uniform over the shown horizontal range.

4.2.2 Summary of estimates of parameters and reference points

Over the two base cases.

	Mean	Median	Lower10th	Upper10th
C_2020	0.140	0.140	0.140	0.140
AveC_2018_2020	0.257	0.257	0.257	0.257
AveF_2018_2020	0.526	0.515	0.290	0.775
F_2020	0.378	0.355	0.188	0.595
FMSY	0.368	0.357	0.179	0.563
MSY (million ton)	0.415	0.405	0.339	0.498
F_2020/FMSY	1.097	1.033	0.641	1.625
AveF_2018_2020/FMSY	1.543	1.480	0.973	2.187
K (million ton)	2.915	2.421	1.548	4.949
B_2020 (million ton)	0.455	0.393	0.235	0.742
B_2021 (million ton)	0.545	0.480	0.284	0.868
AveB_2019_2021	0.498	0.433	0.274	0.792
BMSY (million ton)	1.336	1.144	0.751	2.189
BMSY/K	0.469	0.463	0.398	0.552
B_2020/K	0.168	0.161	0.094	0.248
B_2021/K	0.205	0.195	0.108	0.314
AveB_2019_2021/K	0.185	0.179	0.106	0.269
B_2020/BMSY	0.358	0.339	0.212	0.526
B_2021/BMSY	0.440	0.412	0.238	0.673
AveB_2019_2021/BMSY	0.396	0.378	0.238	0.574

Base case 1

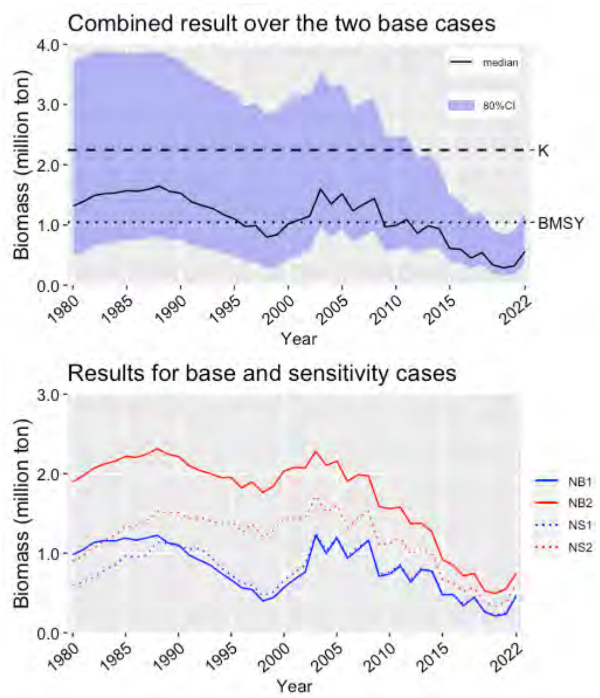
	Mean	Median	Lower10th	Upper10th
C_2021	0.092	0.092	0.092	0.092
AveC_2019_2021	0.141	0.141	0.141	0.141
AveF_2019_2021	0.606	0.609	0.374	0.831
F_2021	0.405	0.399	0.243	0.574
FMSY	0.519	0.524	0.324	0.704
MSY (million ton)	0.429	0.419	0.358	0.508
F_2021/FMSY	0.806	0.768	0.542	1.113
AveF_2019_2021/FMSY	1.205	1.167	0.844	1.596
K (million ton)	1.978	1.712	1.246	2.975
B_2021 (million ton)	0.257	0.231	0.161	0.379
B_2022 (million ton)	0.514	0.465	0.332	0.748
AveB_2020_2022	0.335	0.302	0.224	0.481
BMSY (million ton)	0.908	0.800	0.605	1.309
BMSY/K	0.468	0.460	0.408	0.544
B_2021/K	0.138	0.136	0.085	0.193
B_2022/K	0.279	0.272	0.171	0.396
AveB_2020_2022/K	0.181	0.180	0.117	0.246
B_2021/BMSY	0.295	0.288	0.191	0.406
B_2022/BMSY	0.597	0.575	0.382	0.839
AveB_2020_2022/BMSY	0.387	0.377	0.263	0.518

Base case 2

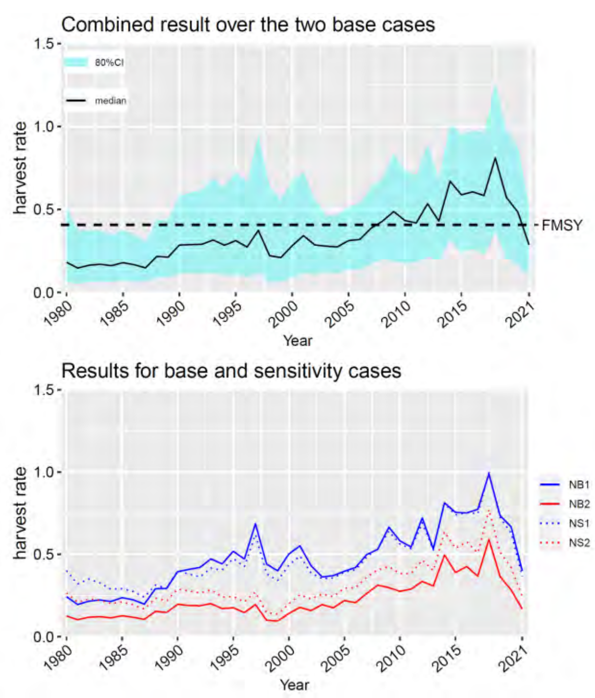
	Mean	Median	Lower10th	Upper10th
C_2021	0.092	0.092	0.092	0.092
AveC_2019_2021	0.141	0.141	0.141	0.141
AveF_2019_2021	0.322	0.275	0.126	0.589
F_2021	0.196	0.168	0.080	0.352
FMSY	0.288	0.255	0.106	0.525
MSY (million ton)	0.402	0.390	0.302	0.504
F_2021/FMSY	0.759	0.700	0.399	1.165
AveF_2019_2021/FMSY	1.218	1.173	0.664	1.785
K (million ton)	3.980	3.448	1.718	7.268
B_2021 (million ton)	0.646	0.549	0.262	1.148
B_2022 (million ton)	0.879	0.748	0.409	1.510
AveB_2020_2022	0.706	0.602	0.307	1.234
BMSY (million ton)	1.812	1.588	0.839	3.177
BMSY/K	0.466	0.459	0.391	0.553
B_2021/K	0.170	0.160	0.097	0.253
B_2022/K	0.244	0.223	0.125	0.393
AveB_2020_2022/K	0.189	0.178	0.107	0.284
B_2021/BMSY	0.366	0.340	0.219	0.539
B_2022/BMSY	0.526	0.478	0.277	0.837
AveB_2020_2022/BMSY	0.407	0.377	0.242	0.606

4.2.3 Time series plots for base case models and aggregated results

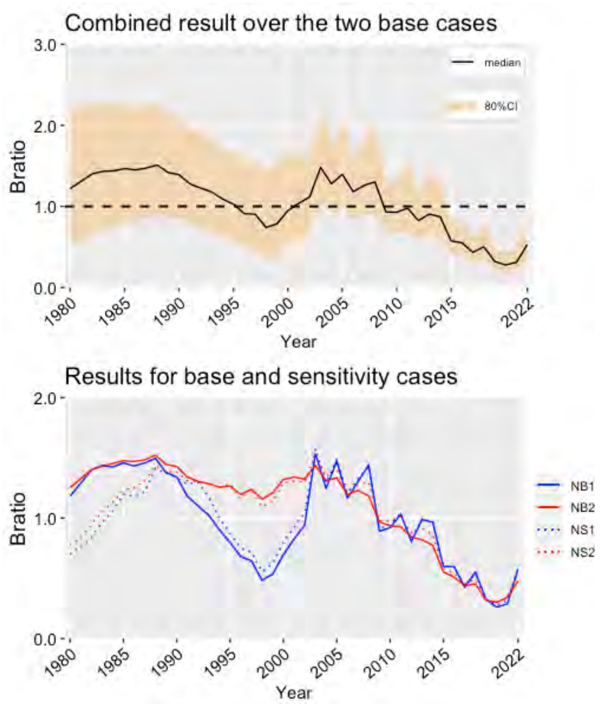
(a) Biomass



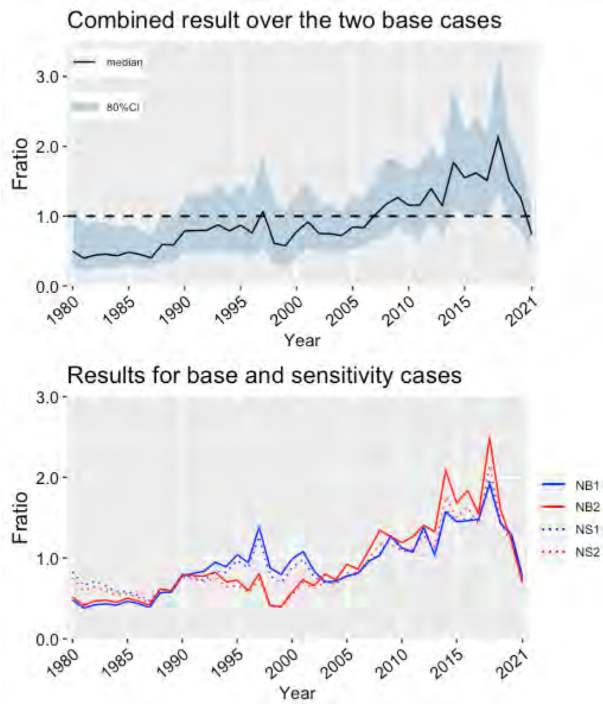
(b) Harvest rate



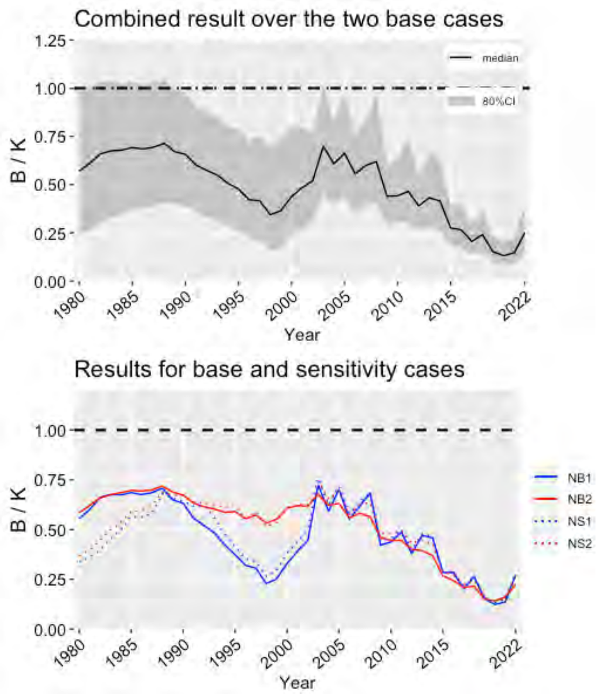
(c) B-ratio



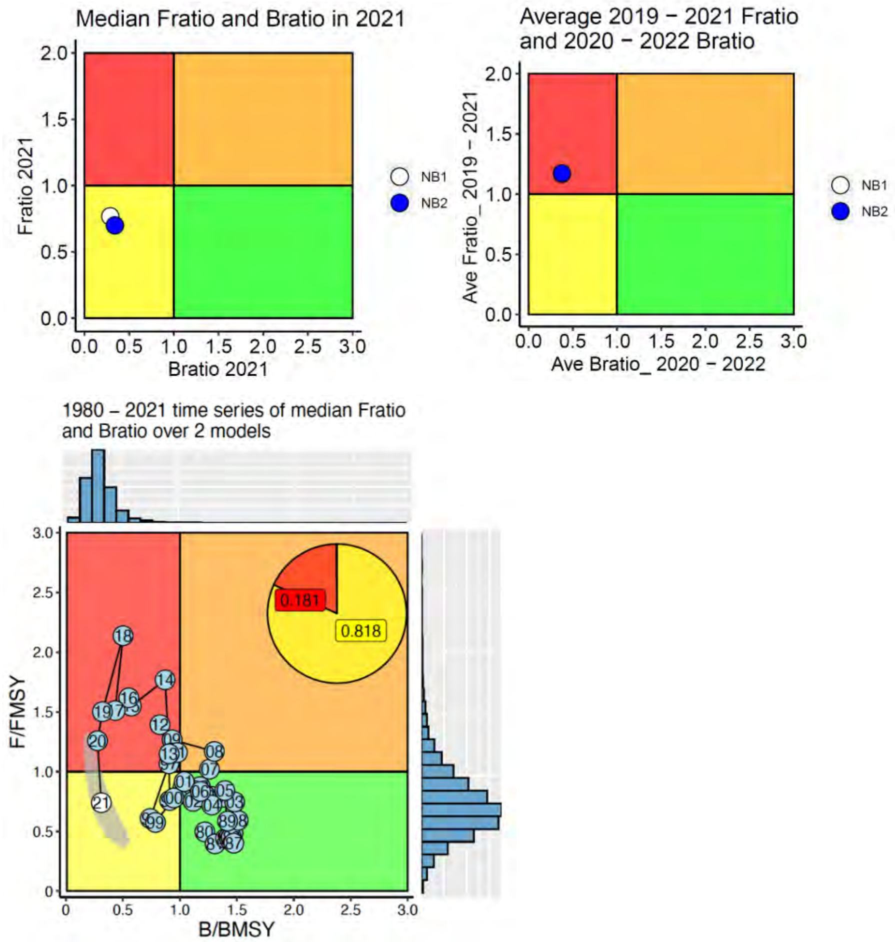
(d) F-ratio



(e) Depletion level relative to *K*

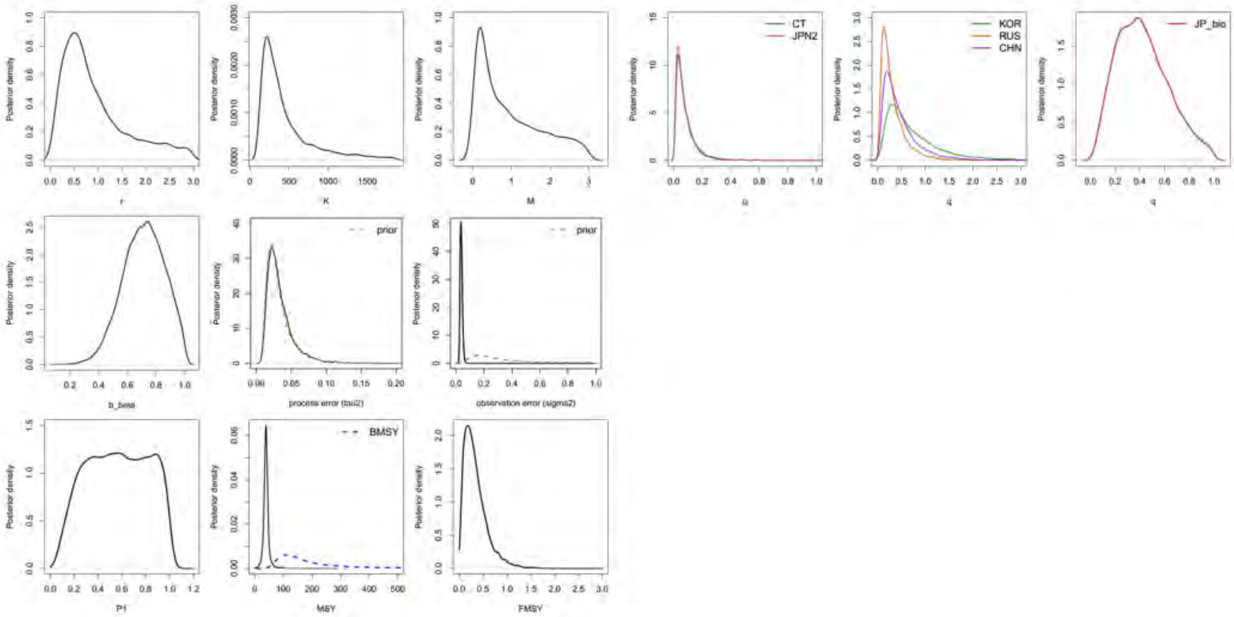


4.2.4 Kobe plots



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

(a) Base case1

	Mean	Median	Lower 10th	Upper 10th
$Catch_{2021}$	9.22	9.22	9.22	9.22
$F_{2019-2021}$	0.32	0.29	0.11	0.57
F_{2021}	0.20	0.18	0.07	0.35
F_{MSY}	0.27	0.25	0.09	0.48
MSY	39.83	39.03	29.72	48.79
F_{2021}/F_{MSY}	0.87	0.74	0.47	1.25
$F_{2019-2021}/F_{MSY}$	1.37	1.20	0.78	1.90
K	461.13	334.05	168.60	979.08
B_{2021}	69.86	51.39	26.69	126.30
B_{2022}	95.83	72.59	40.91	165.99
$B_{2020-2022}$	76.86	57.03	30.93	137.56
B_{MSY}	212.03	155.50	86.45	425.58
B_{MSY}/K	0.48	0.47	0.39	0.59
B_{2021}/K	0.17	0.16	0.09	0.25
B_{2022}/K	0.24	0.23	0.12	0.37
$B_{2020-2022}/K$	0.18	0.18	0.10	0.28
B_{2021}/B_{MSY}	0.35	0.32	0.20	0.51
B_{2022}/B_{MSY}	0.50	0.46	0.26	0.75
$B_{2020-2022}/B_{MSY}$	0.39	0.36	0.22	0.56

(b) Base case2

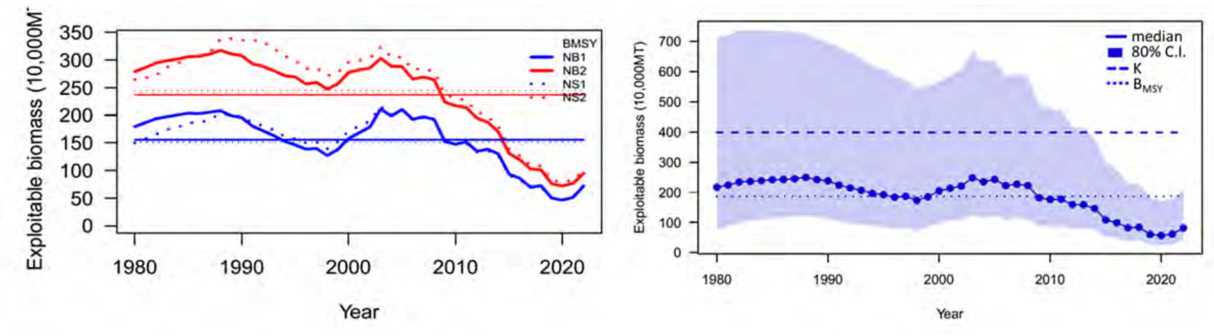
	Mean	Median	Lower 10th	Upper 10th
$Catch_{2021}$	9.22	9.22	9.22	9.22
$F_{2019-2021}$	0.24	0.19	0.06	0.51
F_{2021}	0.15	0.12	0.04	0.30
F_{MSY}	0.21	0.16	0.05	0.44
MSY	38.69	38.56	23.23	50.81
F_{2021}/F_{MSY}	1.57	0.76	0.39	1.68
$F_{2019-2021}/F_{MSY}$	2.35	1.22	0.66	2.47
K	668.95	513.95	192.71	1447.90
B_{2021}	111.16	77.03	30.72	219.30
B_{2022}	133.06	95.12	43.84	252.99
$B_{2020-2022}$	116.93	81.91	34.34	228.55
B_{MSY}	310.02	237.25	97.47	645.28
B_{MSY}/K	0.48	0.47	0.38	0.60
B_{2021}/K	0.18	0.16	0.08	0.29
B_{2022}/K	0.23	0.21	0.09	0.38
$B_{2020-2022}/K$	0.19	0.17	0.08	0.31
B_{2021}/B_{MSY}	0.37	0.33	0.18	0.61
B_{2022}/B_{MSY}	0.48	0.43	0.21	0.80
$B_{2020-2022}/B_{MSY}$	0.40	0.36	0.19	0.65

(c) Joint estimates of the base cases 1 and 2

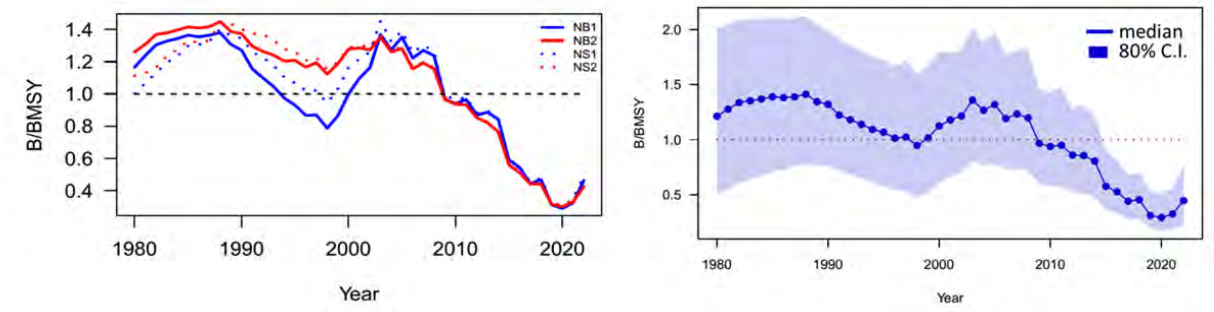
	Mean	Median	Lower 10th	Upper 10th
$Catch_{2021}$	9.22	9.22	9.22	9.22
$F_{2019-2021}$	0.28	0.24	0.08	0.55
F_{2021}	0.17	0.15	0.05	0.33
F_{MSY}	0.24	0.21	0.06	0.46
MSY	39.26	38.85	26.61	49.79
F_{2021}/F_{MSY}	1.22	0.75	0.43	1.45
$F_{2019-2021}/F_{MSY}$	1.86	1.21	0.71	2.16
K	565.04	398.25	177.80	1274.00
B_{2021}	90.51	61.96	28.19	176.10
B_{2022}	114.45	82.04	42.16	212.07
$B_{2020-2022}$	96.89	66.88	32.23	185.61
B_{MSY}	261.02	186.40	90.58	563.27
B_{MSY}/K	0.62	0.47	0.20	1.12
B_{2021}/K	0.17	0.16	0.08	0.27
B_{2022}/K	0.23	0.22	0.10	0.37
$B_{2020-2022}/K$	0.19	0.18	0.09	0.29
B_{2021}/B_{MSY}	0.36	0.33	0.19	0.56
B_{2022}/B_{MSY}	0.49	0.45	0.23	0.77
$B_{2020-2022}/B_{MSY}$	0.39	0.36	0.20	0.60

4.3.3 Time series plots for base case models and aggregated results

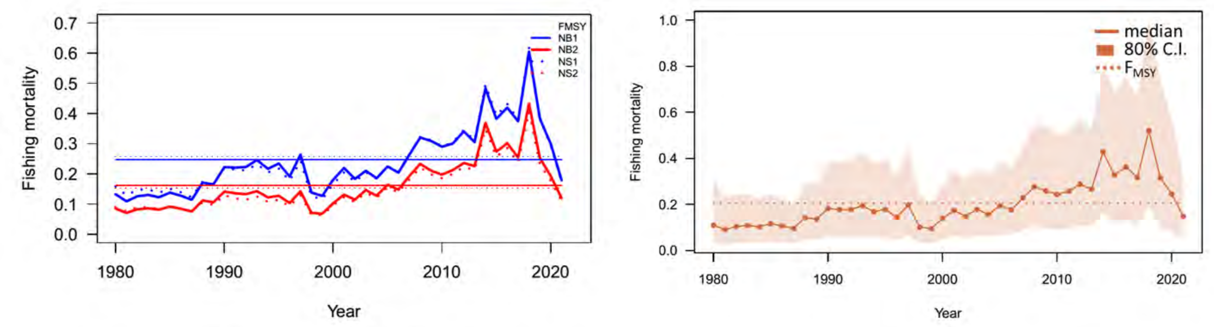
(a) Biomass



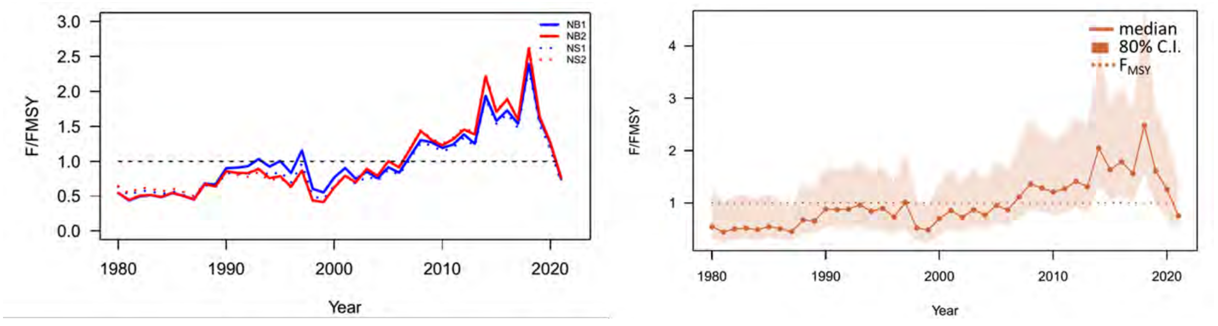
(b) B-ratio (B/B_{MSY})



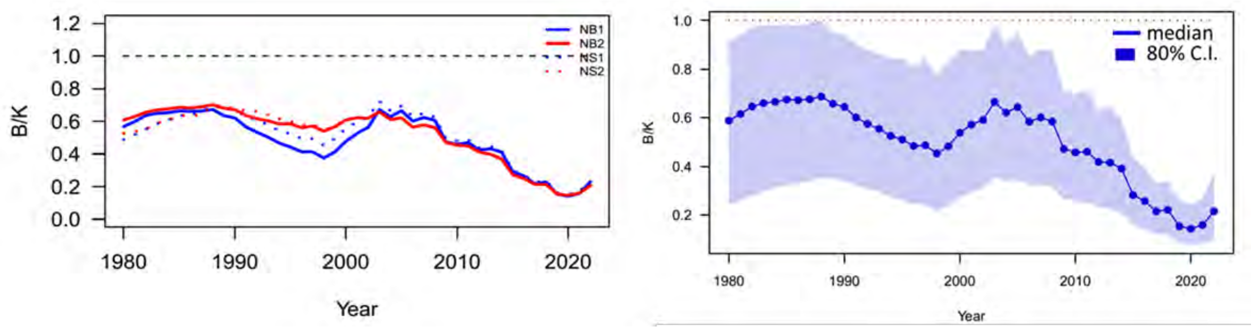
(c) Exploitation rate (F)



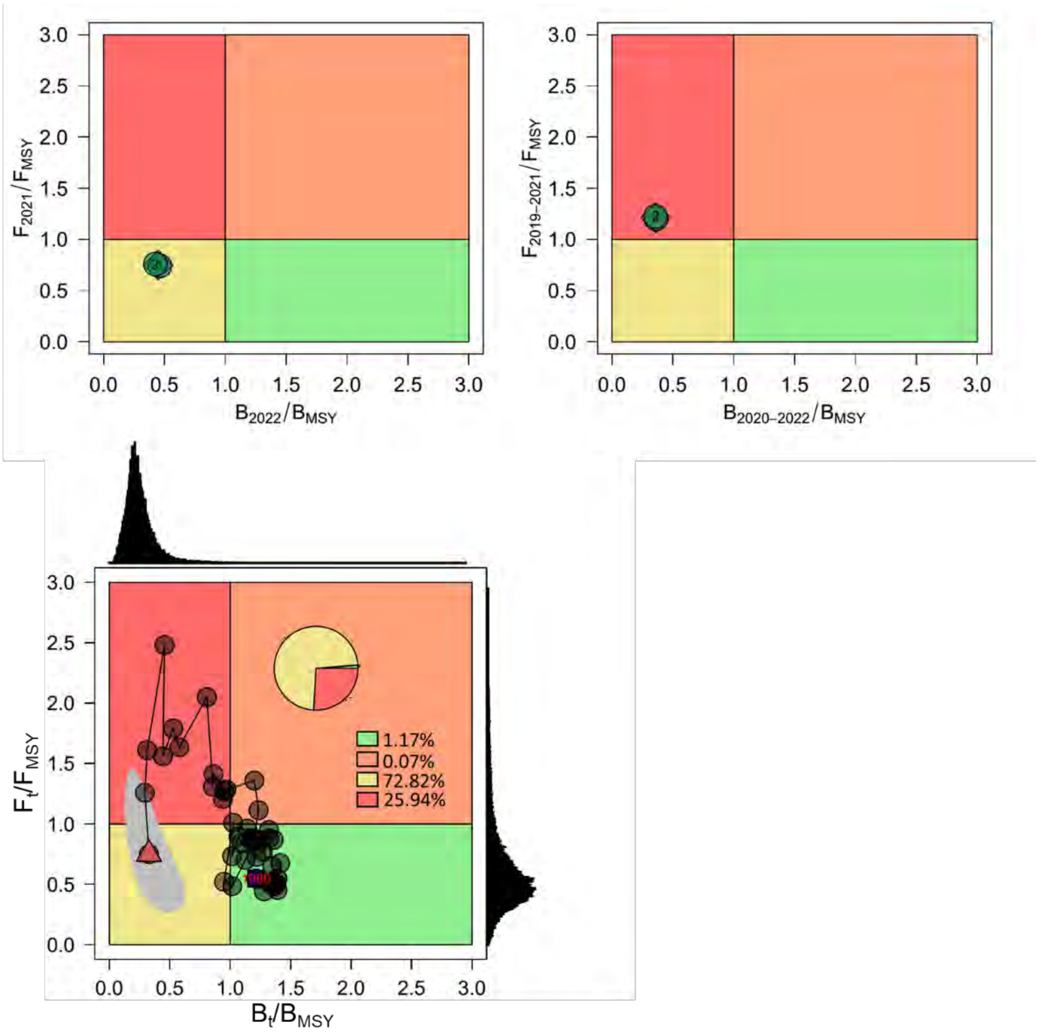
(d) F-ratio (F/F_{MSY})



(e) B/K



4.3.4 Kobe plots



5 SOME AGGREGATED RESULTS FOR VISUALIZATION PURPOSE

5.1 Visual presentation of results

The graphical presentations for times series of biomass (B), B-ratio (B/B_{MSY}), exploitation rate (F), F-ratio (F/F_{MSY}) and B/K are shown in Figure 3.

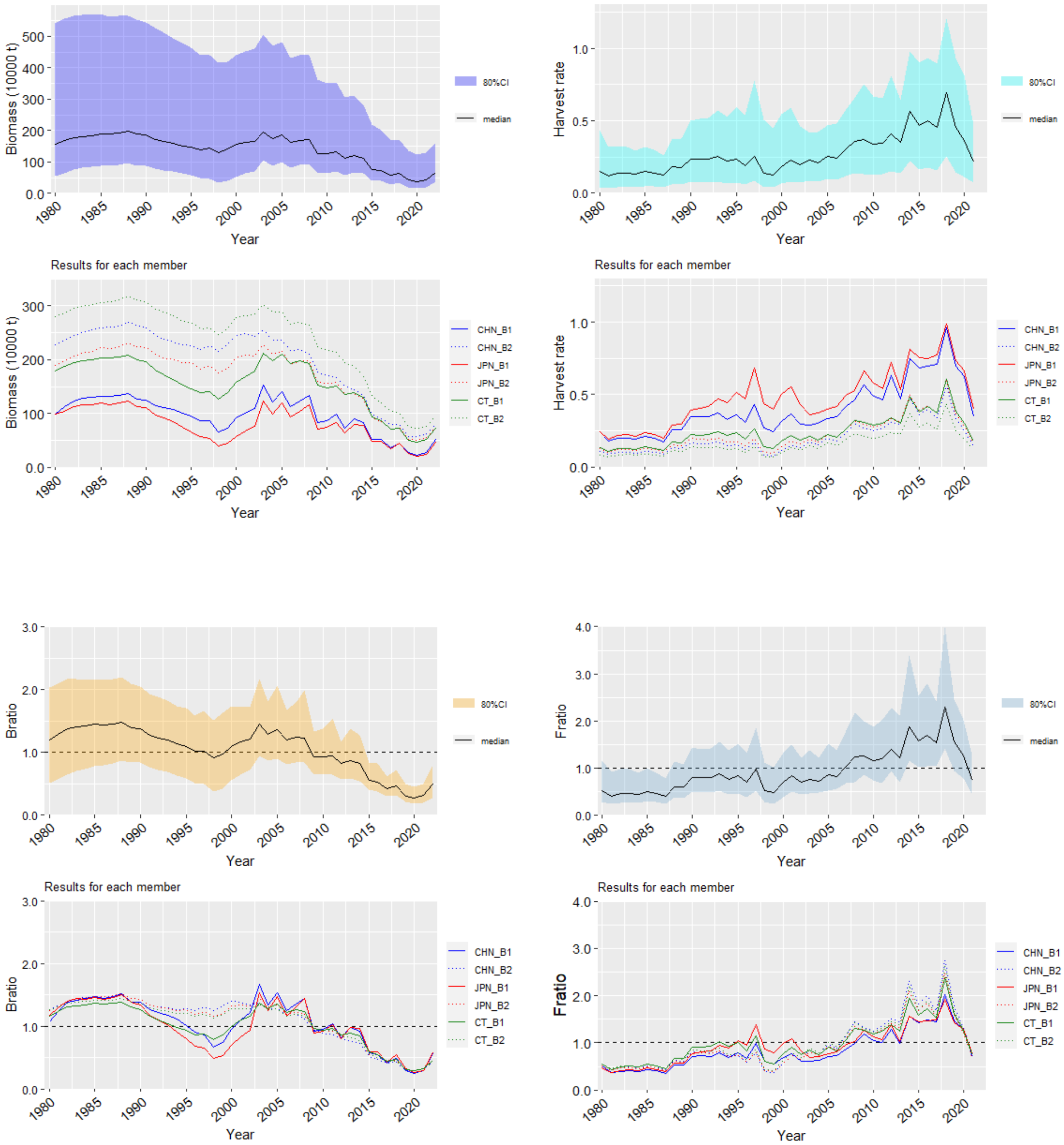


Figure 3. Time series of median estimated values of six runs for biomass, harvest rate, B-ratio, F-ratio and depletion level relative to K. The solid and shaded lines correspond to B1 and B2, respectively.

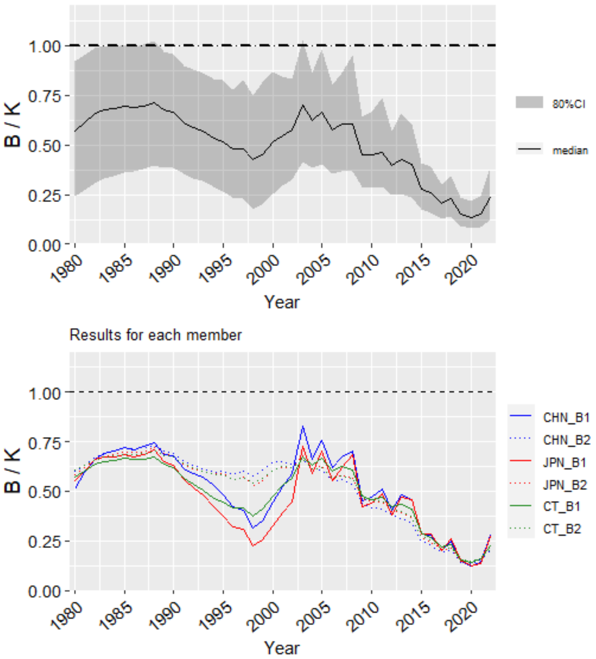


Figure 3 (Continued).

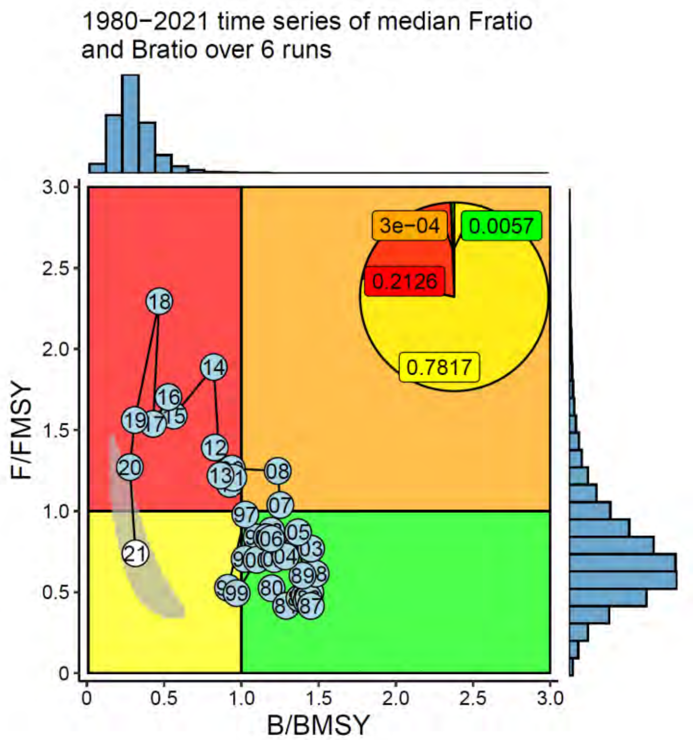


Figure 4. Kobe plot with time trajectory. The data are aggregated across 6 model results (2 base-case models by 3 Members).

5.2 Summary table

Table 3. Summary of estimates of reference quantities. Median and credible interval for the aggregated results are presented. In addition, median values of Member's combined results (over B1 and B2) are shown.

	Median	Lower10%	Upper10%	Median_CHN	Median_JPN	Median_CT
C_2021 (10000 t)	9.221	9.221	9.221	9.221	9.221	9.221
AveC_2019_2021 (10000 t)	14.141	14.141	14.141	14.141	14.141	14.141
AveF_2019_2021	0.350	0.111	0.733	0.402	0.456	0.238
F_2021	0.213	0.071	0.467	0.241	0.287	0.149
FMSY	0.313	0.084	0.619	0.363	0.407	0.206
MSY	40.281	29.911	51.100	41.316	40.649	38.850
F_2021/FMSY	0.739	0.452	1.259	0.729	0.740	0.751
AveF_2019_2021/FMSY	1.192	0.757	1.883	1.203	1.169	1.211
K (10000 t)	281.400	142.200	919.083	249.200	224.579	398.200
B_2021 (10000 t)	43.260	19.750	129.400	38.260	32.149	61.950
B_2022 (10000 t)	65.500	36.900	162.000	62.190	56.264	82.035
AveB_2020_2022 (10000 t)	49.147	25.386	138.103	44.845	39.111	66.877
BMSY (10000 t)	131.800	70.360	409.910	118.800	104.432	186.400
BMSY/K	0.469	0.386	0.621	0.465	0.460	0.503
B_2021/K	0.151	0.088	0.240	0.149	0.147	0.159
B_2022/K	0.237	0.122	0.385	0.243	0.251	0.216
AveB_2020_2022/K	0.177	0.103	0.270	0.176	0.179	0.175
B_2021/BMSY	0.315	0.198	0.499	0.310	0.311	0.327
B_2022/BMSY	0.494	0.272	0.810	0.499	0.532	0.447
AveB_2020_2022/BMSY	0.368	0.232	0.564	0.364	0.377	0.360

6 CONCLUDING REMARKS

See the Executive Summary.

REFERENCES

Baitaliuk A.A., Orlov, A.M., & Ermakov, Y.K. 2013. Characteristic features of ecology of the Pacific saury *Cololabis saira* (Scomberesocidae, Beloniformes) in open waters and in the northeast Pacific Ocean. Journal of Ichthyology 53(11): 899-913.

Chow S., Suzuki N., Brodeur R.D., Ueno Y. 2009. Little population structuring and recent evolution of the Pacific saury (*Cololabis saira*) as indicated by mitochondrial and nuclear DNA sequence data. J Exp Mar Biol Ecol 369:17–21.

Fukushima S. 1979. Synoptic analysis of migration and fishing conditions of saury in northwest Pacific Ocean. Bull. Tohoku Reg. Fish. Res. Lab. 41, 1-70.

Gong Y., Suh Y.S. 2013. Effect of climate-ocean changes on the abundance of Pacific saury. J Environ Biol. 34(1): 23-30.

Hotta H. 1960. On the analysis of the population of the Pacific saury (*Cololabis saira*) based on the scales and the otolith characters, and their growth. Bull Tohoku Reg Fish Res Lab 16: 41–64.

Hubbs C.L., Wisner R.L. 1980. Revision of the sauries (Pisces, Scomberesocidae) with descriptions of two new genera and one new species. Fish Bull US 77: 521–566.

Kato S. 1992. Pacific saury. In W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.). Californias living marine resources and their utilization. California Sea Grant Extension Publication UCSGEP-92-12, Davis, CA. P. 199-201.

Konishi K., Tamura T., Isoda T., Okamoto R., Hakamada T., Kiwada H., Matsuoka K. 2009. Feeding strategies and prey consumption of three baleen whale species within the Kuroshio-Current extension. J North Atl Fish Sci 42: 27-40.

Kosaka S. 2000. Life history of the Pacific saury *Cololabis saira* in the northwest Pacific and considerations on resource fluctuations based on it. Bulletin of Tohoku National Fisheries Research Institute 63: 1–96.

Kurita Y., Nemoto Y., Oozeki Y., Hayashizaki K., Ida H. 2004. Variations in patterns of daily changes in otolith increment widths of 0+ Pacific saury, *Cololabis saira*, off Japan by hatch date in relation to the northward feeding migration during spring and summer. Fish Oceanogr 13(Suppl. 1): 54–62.

Nakaya M., Morioka T., Fukunaga K., Murakami N., Ichikawa T., Sekiya S., Suyama S. 2010. Growth and maturation of Pacific saury *Cololabis saira* under laboratory conditions. Fish Sci 76: 45–53.

Nihira A. 1988. Predator－Prey interaction Between Albacore Thunnus alalunga (Bonne terre) and Pacific Saury *Cololabis saira*,　in the area of Emperor seamount Chain in the North Western Pacific Ocean.　Bull. Ibaraki Pref. Fish. Exp. Stat. 26: 125-136.

Odate K. 1977. On the feeding habits of the Pacific saury, *Cololabis saira* (Brevoort). Bull. Tohoku Reg. Fish. Res. Lab. 38: 75–88.

Ogi H. 1984. Feeding ecology of the Sooty Shearwater in the western subarctic North Pacific Ocean. Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships, ed.by D.N. Nettleship et al. Canadian Wildlife Service Special Publication, Ottawa, 78-84.

Parin N.V. 1968. Scomberesocidae (Pisces, Synentognathi) of the eastern Atlantic Ocean. Atlantide Rep. 10: 275-290.

Sato T. and Hirakawa H. 1976. Studies on food habit of coho salmon in the Northwestern Pacific Ocean. Bull. Fukushima Pref. Fish. Exp. Stat. 4: 25-31.

Sugama K. 1957. Analysis of population of the saury (*Cololabis saira* Brevoort) on the basis of character of otolith-I. Bull Hokkaido Reg Fish Res Lab 16: 1–12.

Suyama S., Sakurai Y., Meguro T., and Shimazaki K. 1992. Estimation of the age and growth of Pacific saury *Cololabis saira* in the central North Pacific Ocean determined by otolith daily growth increments. Nippon Suisan Gakkaishi 58: 1607-1614.

Suyama S., Kurita Y., Ueno Y. 2006. Age structure of Pacific saury *Cololabis saira* based on observations of the hyaline zones in the otolith and length frequency distributions. Fish Sci 72: 742–749.

Suyama S., Nakagami M., Naya M., Ueno Y. 2012a. Migration route of Pacific saury *Cololabis saira* inferred from the otolith hyaline zone. Fisheries Science 78(6): 1179-1186.

Suyama S., Nakagami M., Naya M., Ueno Y. 2012b. Comparison of the growth of age-1 Pacific saury *Cololabis saira* in the Western and the Central North Pacific. Fisheries science 78(2): 277-285.

Suyama S., Shimizu A., Isu S., Ozawa H., Morioka T., Nakaya M., Nakagawa T.,·Murakami N., Ichikawa T., Ueno Y. 2016. Determination of the spawning history of Pacific saury *Cololabis saira* from rearing experiments: identification of post-spawning fish from histological observations of ovarian arterioles. Fisheries Science 82(3): 445-457.

Wade J., and Curtis J.M.R. 2015. A review of data sources and catch records for Pacific Saury (*Cololabis saira*) in Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 3058: iv + 20 p.

Watanabe Y., Butler J.L., Mori T. 1988. Growth of Pacific saury, *Cololabis saira*, in the northeastern and northwestern Pacific Ocean. Fish Bull US 86: 489–498.

Watanabe Y., Lo N.C.H. 1989. Larval production and mortality of Pacific saury, *Cololabis saira*, in the northwestern Pacific Ocean. Fish Bull US 87: 601–613.

Appendix 1

Updated total catch, CPUE standardizations and biomass estimates for the stock assessment of Pacific saury

Year	Total catch (metric tons)	Biomass JPN (VAST, 1000 metric tons)	CV (%)	CPUE CHN (metric tons/ vessel/ day)	CPUE JPN_early (metric tons/ net haul)	CPUE JPN_late (metric tons/ net haul)	CPUE KOR (metric tons/ vessel/ day)	CPUE RUS (metric tons/ vessel/ day)	CPUE CT (metric tons/ net haul)	Joint CPUE (VAST)	CV (%)
1980	238510				0.72						
1981	204263				0.63						
1982	244700				0.46						
1983	257861				0.87						
1984	247044				0.81						
1985	281860				1.4						
1986	260455				1.13						
1987	235510				0.97						
1988	356989				2.36						
1989	330592				3.06						
1990	435869				1.95						
1991	399017				3.13						
1992	383999				4.32						
1993	402185				3.25						
1994	332509					3.91		16.97		1.29	0.35
1995	343743					2.12		20.10		1.60	0.36
1996	266424					1.76		16.10		0.67	0.35
1997	370017					3.65		11.69		1.34	0.36
1998	176364					0.98		12.47		0.79	0.37
1999	176498					0.82		12.57		0.50	0.39
2000	286186					1.24		17.30		0.91	0.37
2001	370823					1.63	7.75	21.09	1.57	0.90	0.29
2002	328362					1.08	9.59	20.02	1.63	0.68	0.28
2003	444642	1263.3	22.5			2.05	14.03	35.92	2.67	1.18	0.28
2004	369400	725.7	20.4			2.61	9.61	47.06	1.45	1.08	0.28
2005	473907	962.7	30.9			4.32	17.32	49.53	2.38	1.63	0.27
2006	394093	644.9	27.4			4.52	7.89	34.60	1.27	0.59	0.27
2007	520207	700.5	29.9			4.17	7.50	43.16	2.37	1.05	0.27
2008	617509	1007.1	26.1			5.15	16.04	42.40	2.90	1.95	0.28
2009	472177	427.8	21.9			4.22	7.80	21.29	1.57	1.03	0.28
2010	429808	570.8	27.1			1.78	8.13	23.66	1.93	1.07	0.27
2011	456263	938.2	36.3			2.47	9.08	28.46	2.50	1.26	0.29
2012	460544	330.4	20.2			2.72	8.08	24.47	2.47	1.14	0.27
2013	423790	756.4	25.3	11.39		1.83	11.52	22.13	2.80	1.02	0.27
2014	629576	528.6	21.8	12.47		3.28	17.64	25.35	3.72	1.32	0.27
2015	358883	299.5	19.2	14.49		1.68	6.97	16.48	2.33	0.99	0.28
2016	361688	425.2	25.2	6.81		1.74	9.38	17.76	2.44	0.72	0.27

2017	262639	164.7	25.5	6.66		1.13	4.71	8.59	1.79	0.79	0.27
2018	439079	336.8	26.7	12.78		1.89	10.08	25.92	3.12	1.38	0.28
2019	192377	231.4	21.4	6.71		0.70	2.27	8.47	1.41	0.54	0.27
2020	139646	44.5	112.0	4.81		0.49	2.61	7.20	1.23	0.33	0.29
2021	92206	200.9	31.6	5.04		0.33	2.31	2.82	0.81	0.22	0.28
2022		380.6	19.8								