NPFC

North Pacific Fisheries Commission

Stock assessment report for Pacific saury

EXECUTIVE SUMMARY

Data used in the assessment modeling

Data are included from the NPFC Convention Area and Members' Exclusive Economic Zones (EEZs). 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 180° 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.

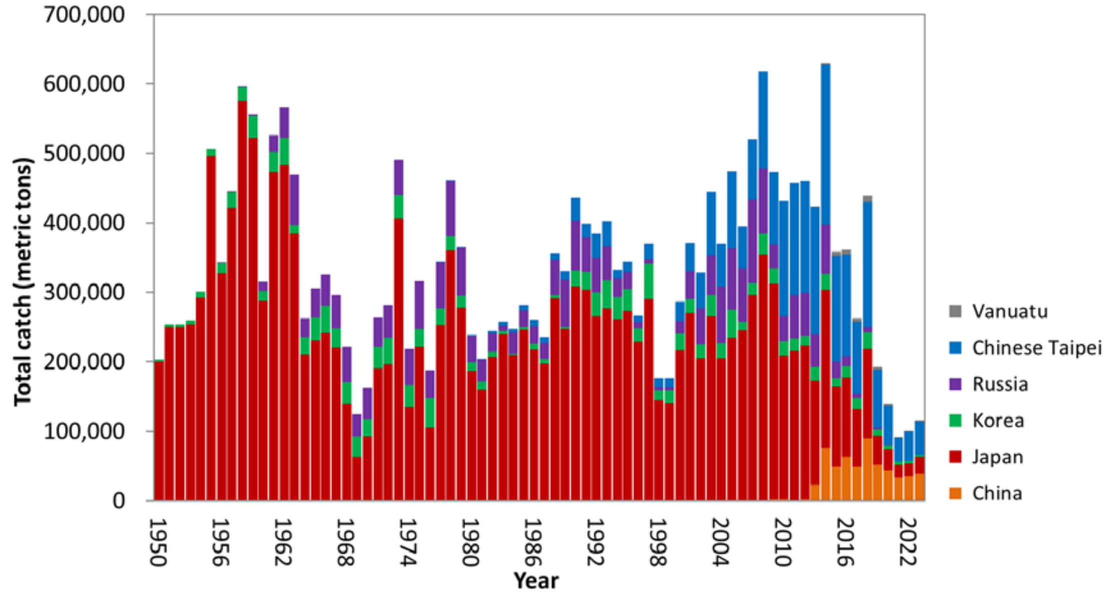


Figure 1. Time series of catch by Member during 1950-2023. The catch data for 1950-1979 are shown but not used in stock assessment modeling. Catch data in 2023 are preliminary (as of 2 December 2023) and not used in the assessment.

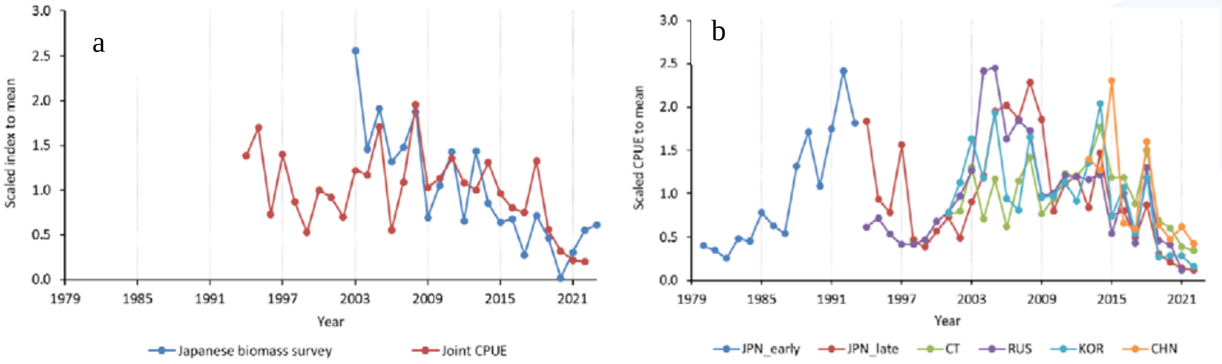


Figure 2. Time series of (a) Japanese survey biomass index and joint CPUE and (b) Member's standardized CPUE indices used in the assessment modeling.

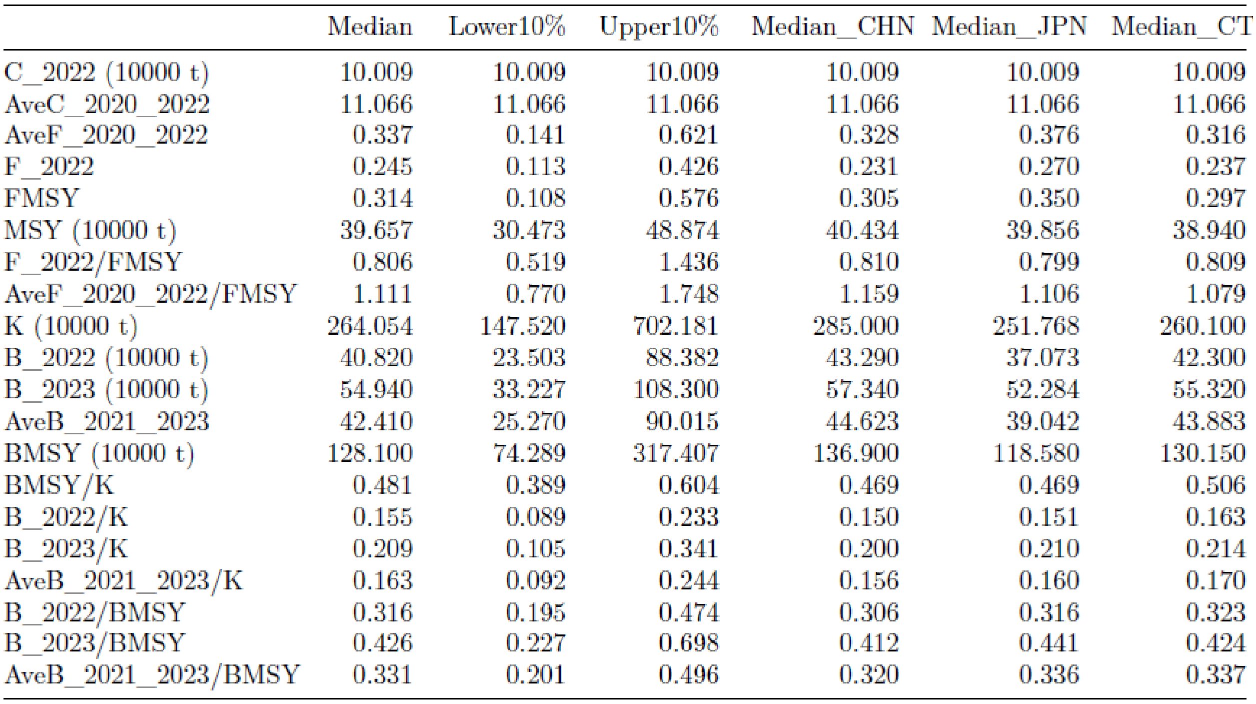
Brief description of specification of analysis and models

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 1980-2023. 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 intervals 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_2022 (10000 t)	10.009	10.009	10.009	10.009	10.009	10.009
AveC_2020_2022	11.066	11.066	11.066	11.066	11.066	11.066
AveF_2020_2022	0.337	0.141	0.621	0.328	0.376	0.316
F_2022	0.245	0.113	0.426	0.231	0.270	0.237
FMSY	0.314	0.108	0.576	0.305	0.350	0.297
MSY (10000 t)	39.657	30.473	48.874	40.434	39.856	38.940
F_2022/FMSY	0.806	0.519	1.436	0.810	0.799	0.809
AveF_2020_2022/FMSY	1.111	0.770	1.748	1.159	1.106	1.079
K (10000 t)	264.054	147.520	702.181	285.000	251.768	260.100
B_2022 (10000 t)	40.820	23.503	88.382	43.290	37.073	42.300
B_2023 (10000 t)	54.940	33.227	108.300	57.340	52.284	55.320
AveB_2021_2023	42.410	25.270	90.015	44.623	39.042	43.883
BMSY (10000 t)	128.100	74.289	317.407	136.900	118.580	130.150
BMSY/K	0.481	0.389	0.604	0.469	0.469	0.506
B_2022/K	0.155	0.089	0.233	0.150	0.151	0.163
B_2023/K	0.209	0.105	0.341	0.200	0.210	0.214
AveB_2021_2023/K	0.163	0.092	0.244	0.156	0.160	0.170
B_2022/BMSY	0.316	0.195	0.474	0.306	0.316	0.323
B_2023/BMSY	0.426	0.227	0.698	0.412	0.441	0.424
AveB_2021_2023/BMSY	0.331	0.201	0.496	0.320	0.336	0.337

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	146.700	0.163	1.123	0.562	0.545
1981	153.700	0.133	1.209	0.447	0.588
1982	165.132	0.148	1.311	0.492	0.641
1983	169.033	0.153	1.348	0.501	0.662
1984	172.600	0.143	1.373	0.468	0.675
1985	177.200	0.159	1.402	0.522	0.689
1986	178.100	0.146	1.397	0.484	0.689
1987	181.400	0.130	1.418	0.431	0.699
1988	186.000	0.192	1.448	0.638	0.714
1989	176.079	0.188	1.363	0.628	0.673
1990	173.523	0.251	1.340	0.845	0.660
1991	159.300	0.250	1.228	0.849	0.604
1992	151.500	0.253	1.171	0.867	0.572
1993	145.000	0.277	1.118	0.961	0.544
1994	135.100	0.246	1.044	0.862	0.503
1995	130.900	0.263	0.993	0.947	0.476
1996	121.800	0.219	0.911	0.805	0.436
1997	126.300	0.293	0.915	1.121	0.437
1998	113.500	0.155	0.821	0.598	0.392
1999	124.400	0.142	0.886	0.551	0.423
2000	140.074	0.204	1.018	0.768	0.486
2001	145.600	0.255	1.091	0.912	0.526
2002	151.000	0.218	1.156	0.747	0.563
2003	182.400	0.244	1.392	0.814	0.690
2004	167.100	0.221	1.277	0.738	0.632
2005	179.300	0.264	1.353	0.888	0.672
2006	155.488	0.254	1.184	0.847	0.584
2007	163.168	0.319	1.236	1.067	0.614
2008	159.200	0.388	1.190	1.312	0.594
2009	116.400	0.406	0.894	1.355	0.438
2010	117.900	0.365	0.890	1.232	0.440
2011	122.470	0.373	0.912	1.269	0.453
2012	108.500	0.424	0.825	1.419	0.407
2013	113.500	0.374	0.847	1.259	0.424
2014	104.500	0.602	0.798	1.971	0.398
2015	74.330	0.483	0.561	1.612	0.281
2016	67.220	0.538	0.509	1.786	0.254
2017	53.971	0.487	0.415	1.610	0.205
2018	59.390	0.734	0.450	2.397	0.226
2019	37.252	0.524	0.282	1.754	0.141
2020	30.510	0.458	0.233	1.530	0.115
2021	31.037	0.297	0.238	0.989	0.117
2022	40.820	0.245	0.316	0.806	0.155
2023	54.940		0.426		0.209

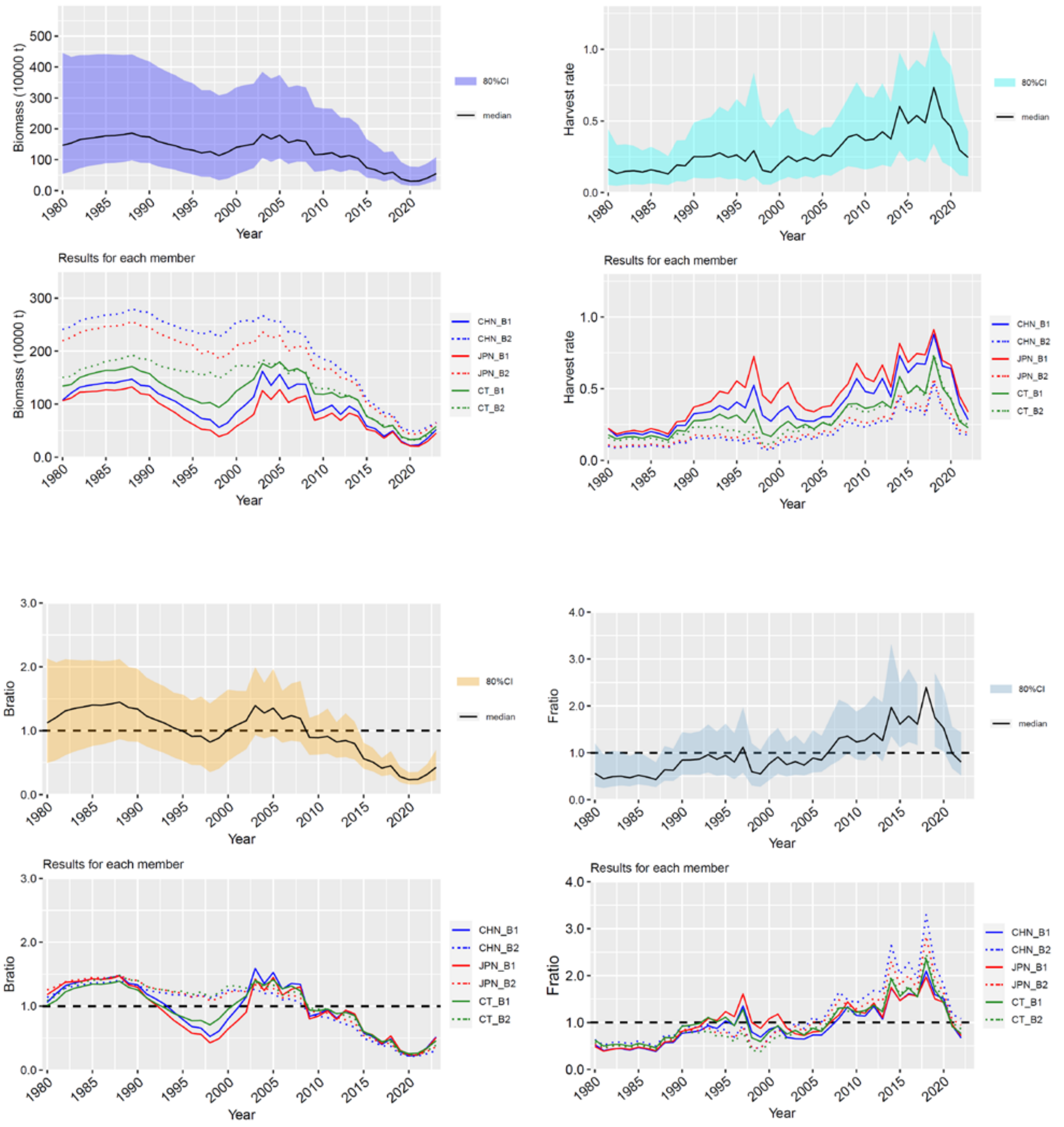


Figure 3. Time series of median estimated values of six runs for biomass, harvest rate, B-ratio, F-ratio and depletion level relative to K. The solid and shaded lines correspond to B1 and B2, respectively.

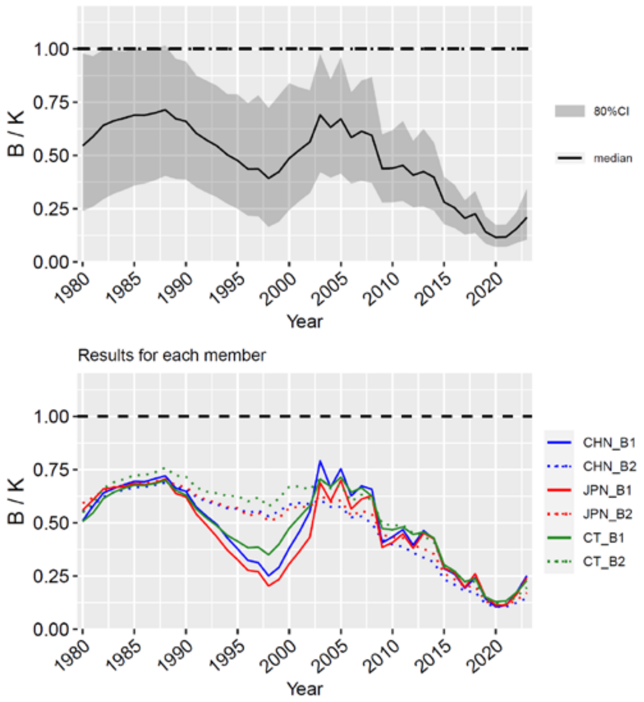


Figure 3 (Continued).

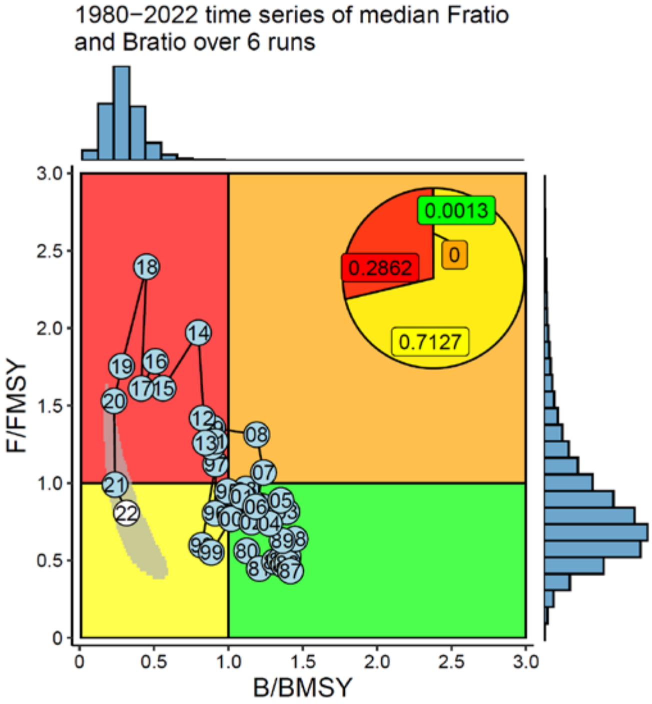


Figure 4. Kobe plot with time trajectory. The data are aggregated across 6 model results (2 base-case models by 3 Members).

Current stock condition and management advice

Summary of stock status

Results of all Members' and 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. Combined results show that average B was below B_{MSY} during 2021-2023 (median average B/B_{MSY} during 2021-2023 = 0.331, 80%CI=0.201-0.496) and average F was above F_{MSY} (average F/F_{MSY} during 2020-2022 = 1.111, 80%CI= 0.770-1.748). Thus, stock biomass remained at low levels in recent years. The evidence is mixed but biomass may have increased modestly during 2022-2023 based on unstandardized CPUE for 2023 and higher recruitment that may be evident in the Japanese fishery size composition data. There was an increase in the Japanese biomass survey between 2021 and 2023. Ignoring the 2020 survey result (as the 2020 survey was incomplete), the Japanese survey varied without trend at historically low levels during 2015-2023. Standardized CPUE declined to low levels in 2022 but nominal data for 2023 show higher catch rates in 2023 for most Members (Figure 5). Effective fishing effort in the entire fishery remains high with decreases by most Members offset by increases in fishing effort for other Members. Harvest rates declined from a peak in 2018 and were lower but near F_{MSY} during 2021-2022. Reductions in harvest rate and increases in nominal CPUE during 2022-2023 are positive signs but data and recent estimates are variable, CPUE, survey data and biomass are still low, and fishing effort remains high. As described below, management approaches that reduce exploitation at current low biomass levels are more likely to take advantage of any recent increases in stock productivity and help rebuild the fishery and Pacific saury population.

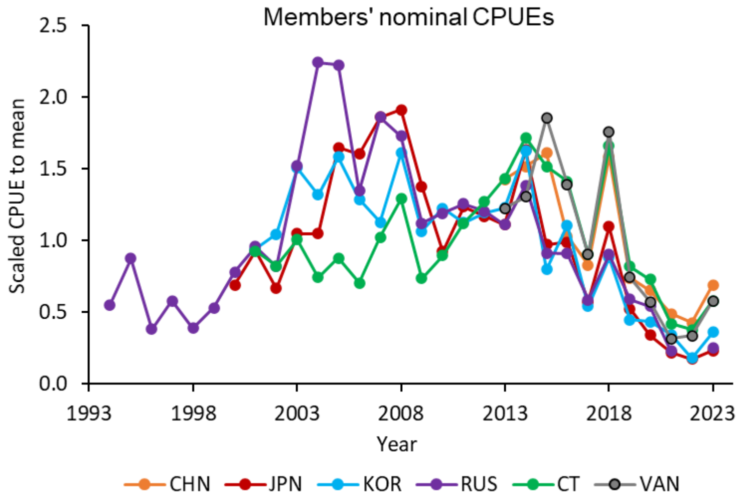


Figure 5. Time series of Member's nominal CPUE indices. Data in 2023 are preliminary (as of November 2023).

The retrospective patterns were modest or not identified and reduced from the previous assessment. There was some scale uncertainty that was examined by Members and determined to be the result of differing prior assumptions. Fortunately, the trends in relative exploitation and relative biomass were robust and consistent.

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 previous stock 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 6). 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 (Figure 7). 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 2024 (B_{2023}*F_{MSY}*(B_{2023}/B_{MSY}) = 73,490 tons) that is smaller to the 2023 catch (102,003 tons, preliminary as of 2 December 2023). Results for the original approach yield TAC for 2024 (B_{2023}*F_{MSY} = 172,512 tons), which is substantially higher than recent catches.

The current annual catch limit for 2023-2024 specified in CMM 2023-08 for Pacific saury (250,000 tons) based on historical catch is much larger than a TAC that would be based on the F_{MSY} catch approach 172,512 tons. The current biomass is much lower than B_{MSY} and the TAC for 2023-2024 may not reduce fishing mortality in those 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 396,570 tons). A reduction to the TAC for 2023-2024 would increase the probability of higher biomass and catch levels in the Pacific saury stock.

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. Note the performance of the above HCRs is in the process of being evaluated.

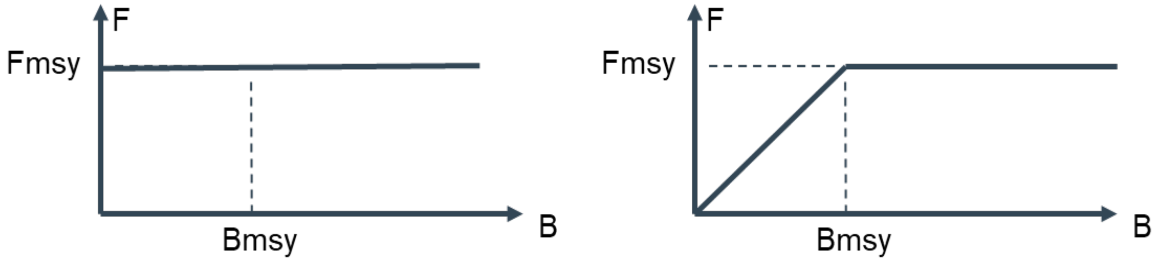


Figure 6. Shapes of harvest rates used in the 2019 Commission meeting for setting the TAC for 2020 (left) and a standard HCR (right).

Figure 7. 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 2023 is a preliminary number as of 2 December 2023. 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.

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) 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.

3) 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.

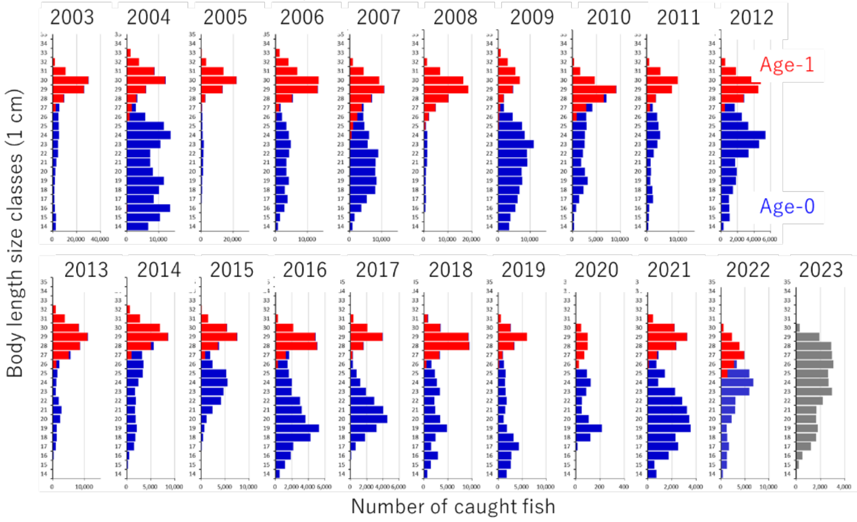
4) The 2020 biomass index from the Japanese survey has large uncertainties due to incomplete survey coverage and complicates interpretation of recent trends. It may be better to disregard the 2020 observation when evaluating recent trends visually.

5) 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. 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.

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

7) Time series of size and age composition data from the Japanese survey and fishery (Figures 8 and 9) 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

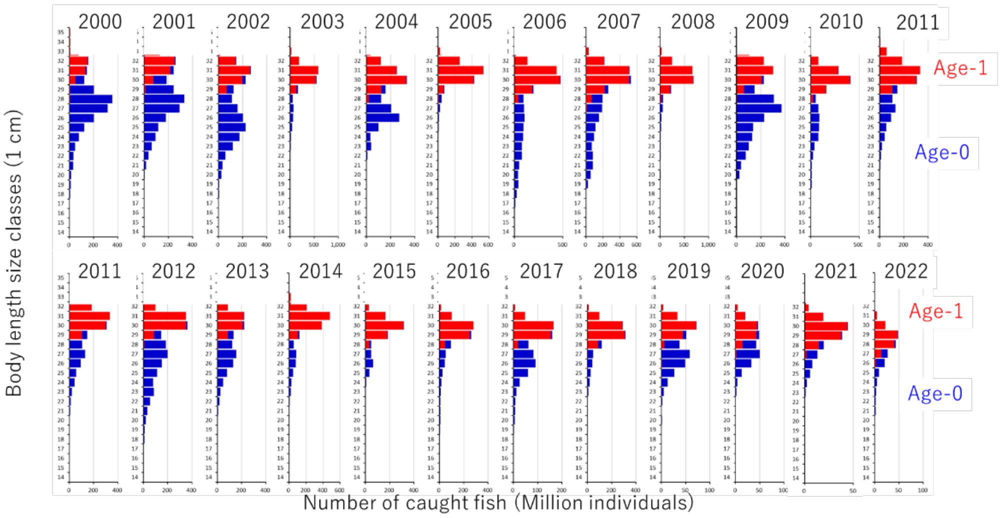


Figure 8. Time series of age and length composition of samples taken from the Japanese survey and commercial fishery (August-November) in Japan.

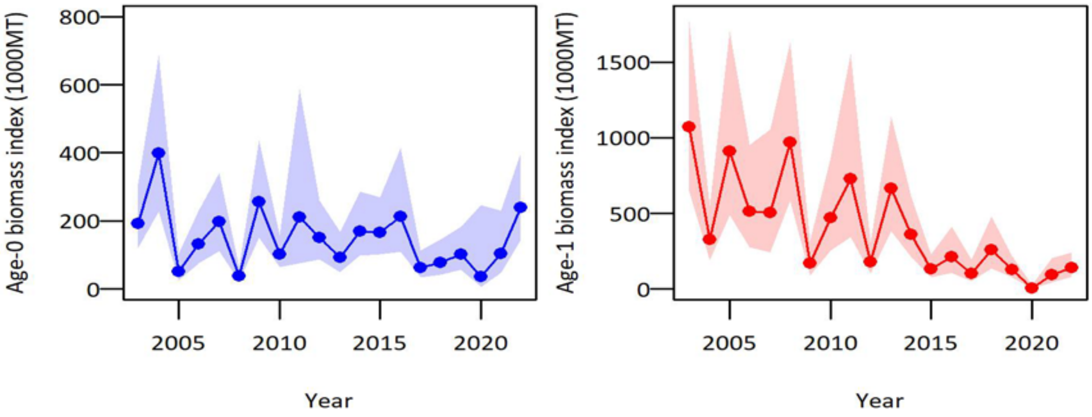


Figure 9. Time series of Japanese survey biomass index by age.

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

Western North Pacific

In Japan, the stick-held dip net fishery for Pacific saury was developed in the 1940s. Since then, the stick-held dip net gears have become the dominant fishing 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 18 thousand tons were recorded in 2008 and 2022, 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 610 tons in 2021.

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).

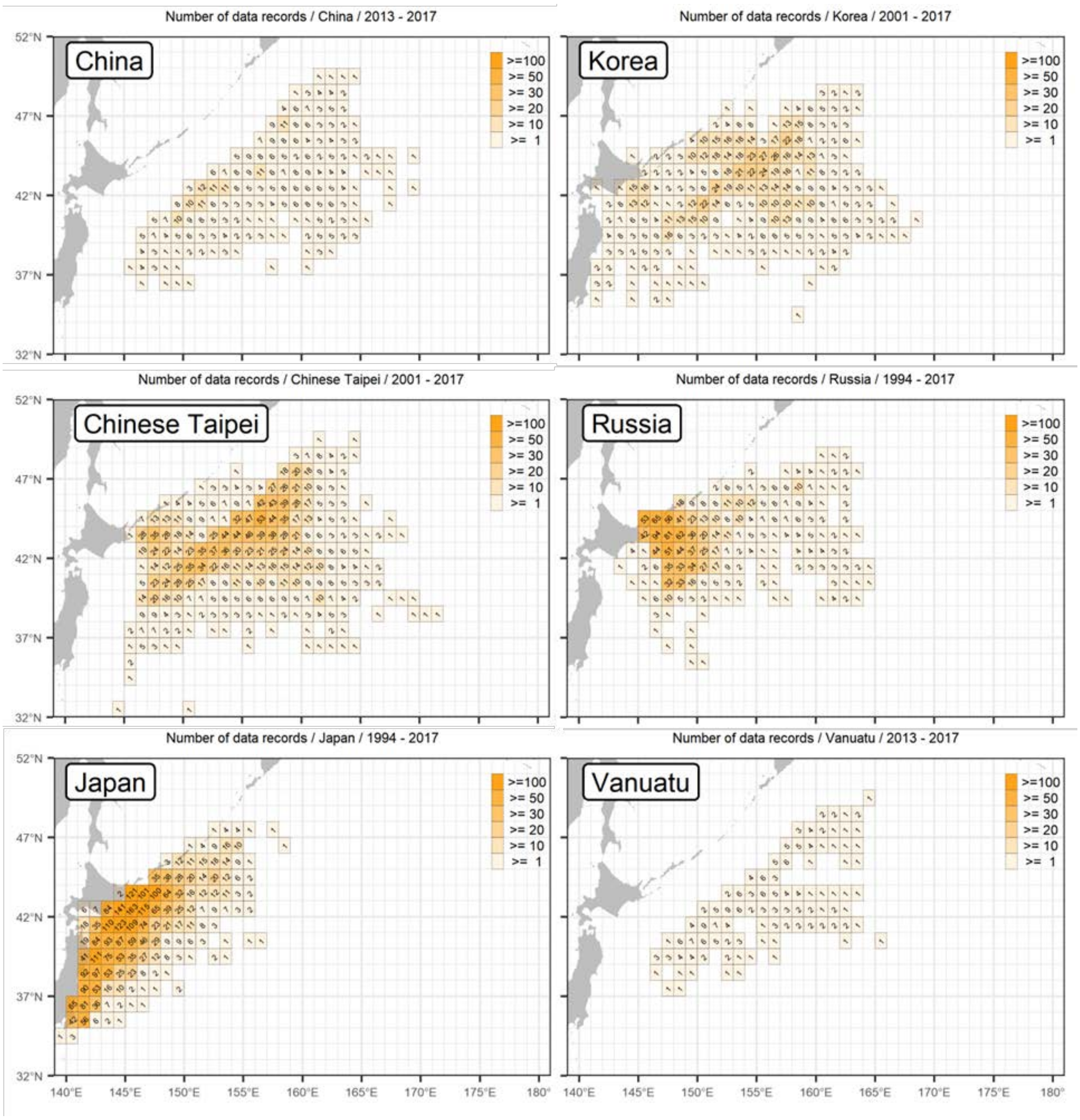


Figure 1 (a). Main fishing grounds for Pacific saury by fishing members in the western North Pacific Ocean during 1994-2017. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index

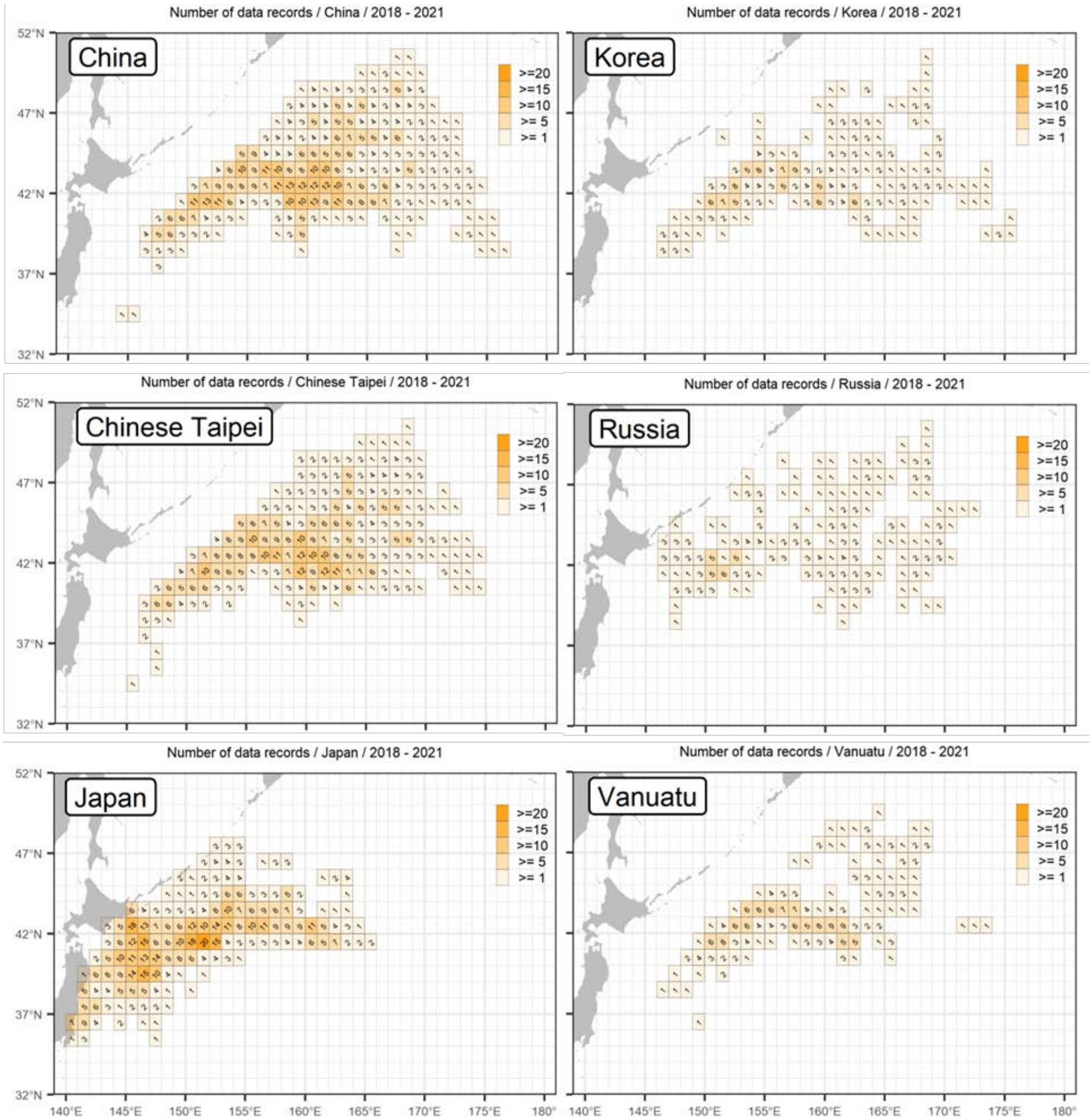


Figure 1 (b). Main fishing grounds for Pacific saury by fishing members in the western North Pacific Ocean during 2018-2021. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index

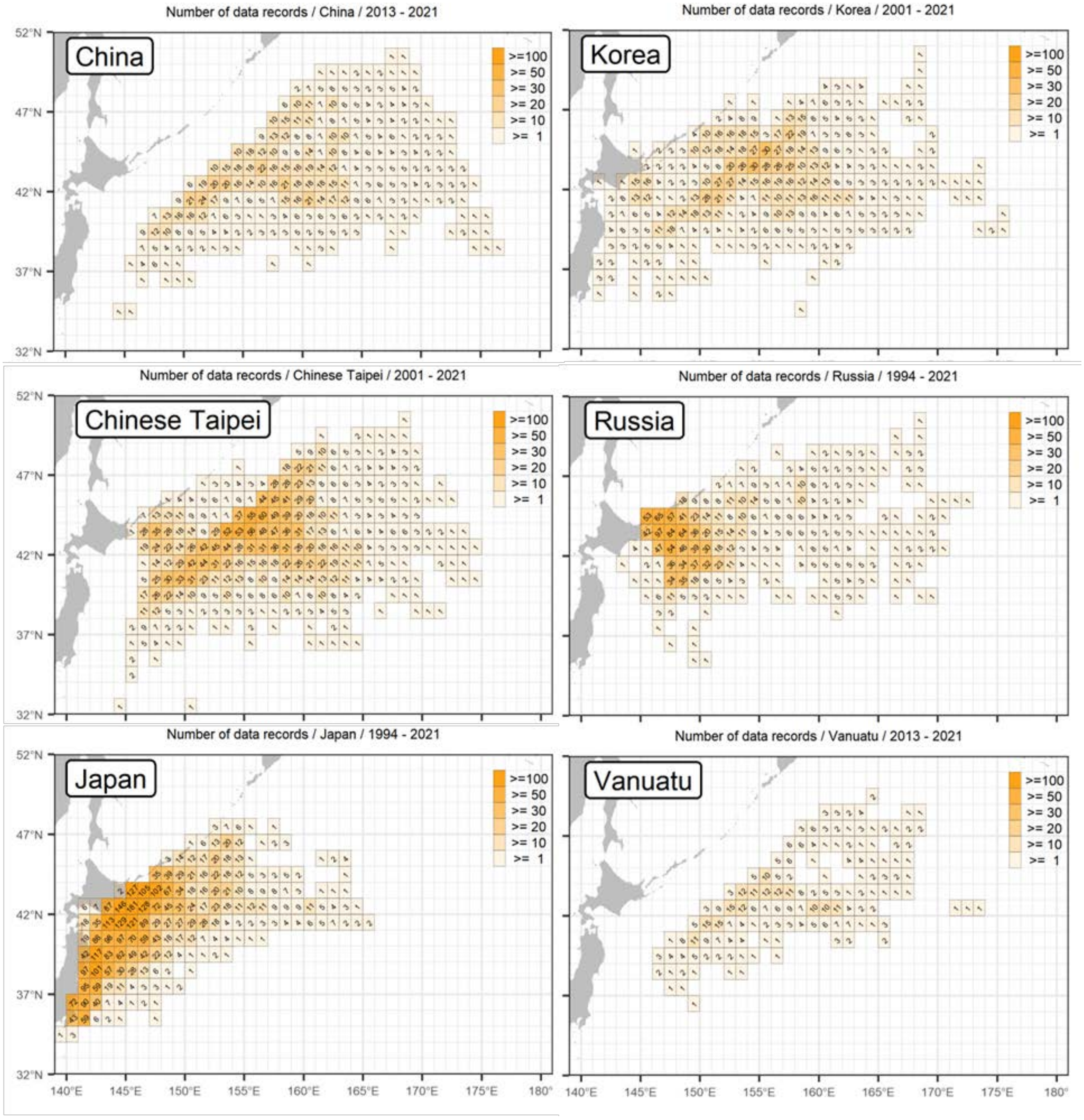
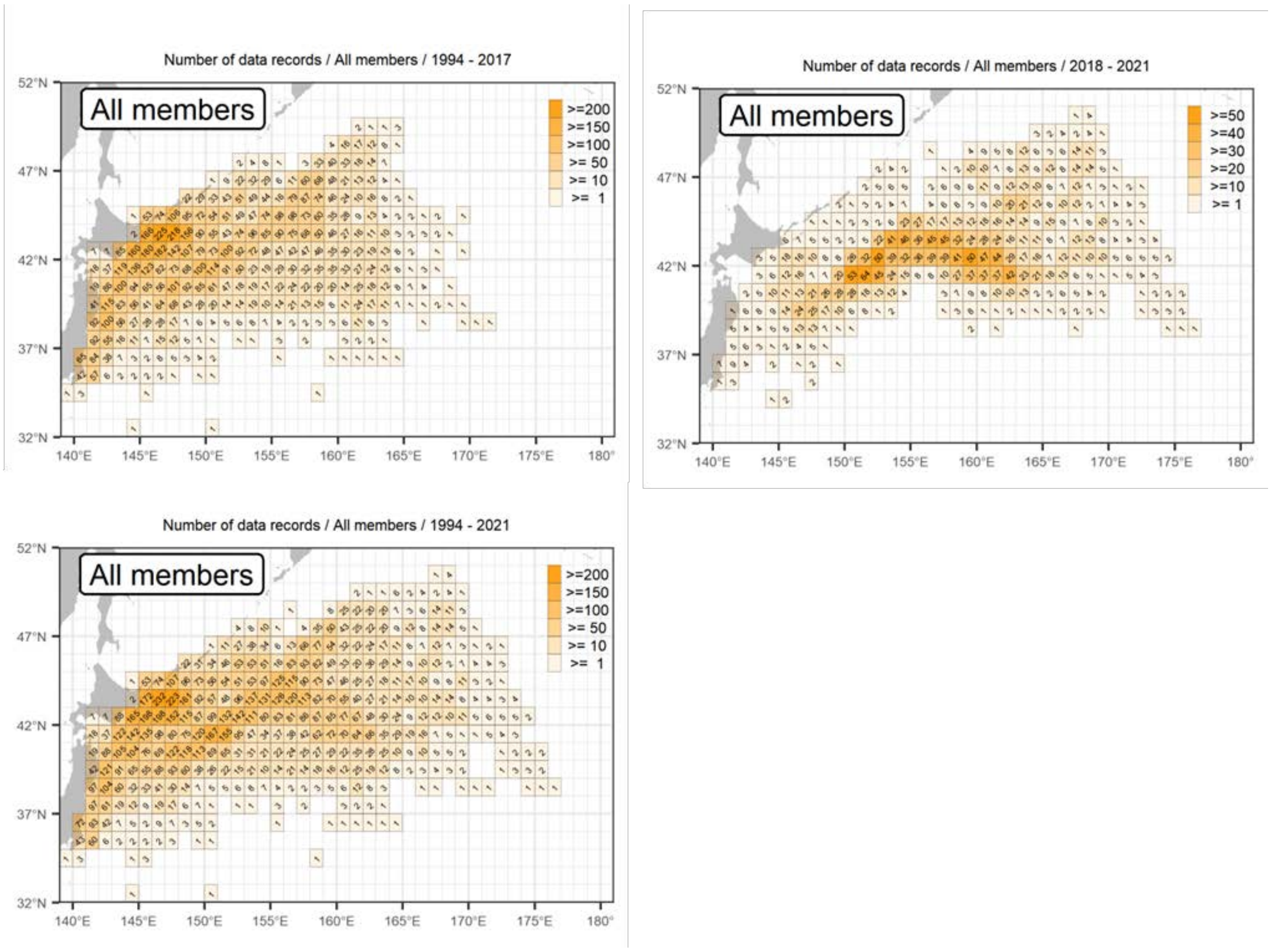


Figure 1 (c). Main fishing grounds for Pacific saury by fishing members in the western North Pacific Ocean during 1994-2021. The legend shows the number of data records. This figure is based on the data shared by the Members for the development of a joint CPUE index


Number of data records / All members / 1994 - 2017

Number of data records / All members / 2018 - 2021

Number of data records / All members / 1994 - 2021

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.

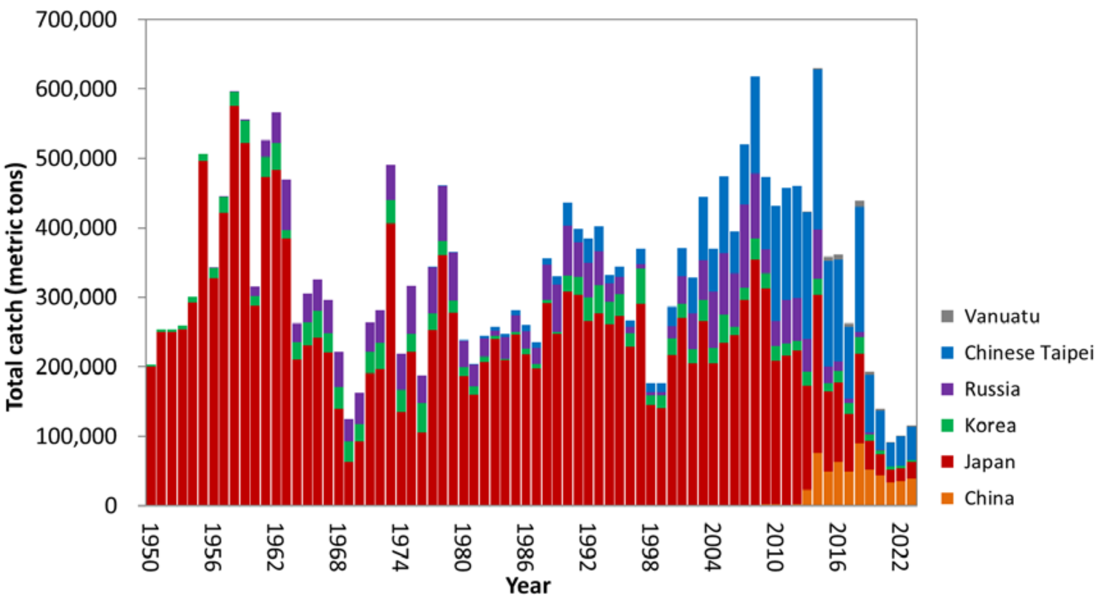


Figure 2. Time series of catch by Member during 1950-2023. The catch data for 1950-1979 are shown but not

used in stock assessment modeling. Catch data in 2023 are preliminary (as of 2 December 2023) 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 1980-2023. 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-2023-SSC PS12-WP05 and NPFC-2023-SSC PS12-WP09; for the non-uniform priors used in Chinese Taipei, see document NPFC-2023-SSC PS12-WP06.

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	$I_{t,bio} = q_{bio}\ B_t e^{v_{t,bio}}$ $v_{t,bio} \sim N\big(0, cv_{t,bio}^2 + \sigma_{\square}^2\big)$ q_{bio} ~ U(0,1) (2003-2023)	Same as left	Same as left	Same as left
CPUE	CHN(2013-2022) JPN_late(1994-2022) KOR(2001-2022) RUS(1994-2022) CT(2001-2022) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ σ_f^2=$c \cdot (ave(cv_{t,bio}^2) + \sigma_{\square}^2)$, where $ave(cv_{t,bio}^2)$ is computed except for 2020 survey (*c* = 5)	Joint CPUE (1994-2022) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma_{\square}^2)$	CHN(2013-2022) JPN_early(1980-1993, time-varying *q*) JPN_late(1994-2022) KOR(2001-2022) RUS(1994-2022) CT(2001-2022) $I_{t,f} = q_f B_t^b e^{v_{t,f}}$ $v_{t,f} \sim N(0, \sigma_f^2)$ σ_f^2=$c \cdot (ave(cv_{t,bio}^2) + \sigma_{\square}^2)$, 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=$c\ ave(cv_{t,joint}^2 + \sigma_{\square}^2)$ Joint CPUE (1994-2022) $I_{t,joint} = q_{joint} B_t^b e^{v_{t,joint}}$ $v_{t,joint} \sim N(0, cv_{t,joint}^2 + \sigma_{\square}^2)$
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_{2022}	Catch in 2022
$AveC_{2020\text{-}2022}$	Average catch for a recent period (2020–2022)
$AveF_{2020\text{-}2022}$	Average harvest rate for a recent period (2020–2022)
F_{2022}	Harvest rate in 2022
F_{MSY}	Annual harvest rate producing the maximum sustainable yield (MSY)
MSY	Equilibrium yield at F_{MSY}
F_{2022}/F_{MSY}	Average harvest rate in 2022 relative to F_{MSY}
$AveF_{2020\text{-}2022}/F_{MSY}$	Average harvest rate for a recent period (2020–2022) relative to F_{MSY}
K	Equilibrium unexploited biomass (carrying capacity)
B_{2022}	Stock biomass in 2022 estimated in the model
B_{2023}	Stock biomass in 2023 estimated in the model
$AveB_{2021\text{-}2023}$	Stock biomass for a recent period (2021–2023) 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_{2022}/K	Stock biomass in 2022 relative to K[a]
B_{2023}/K	Stock biomass in 2023 relative to K[a]
$B_{2021\text{-}2023}/K$	Stock biomass in the latest time period (2021-2023) relative to the equilibrium unexploited stock biomass[a]
B_{2022}/B_{MSY}	Stock biomass in 2022 relative to B_{MSY}[a]
B_{2023}/B_{MSY}	Stock biomass in 2023 relative to B_{MSY}[a]
$B_{2021\text{-}2023}/B_{MSY}$	Stock biomass for a recent period (2021–2023) relative to the stock biomass that produces maximum sustainable yield (MSY) [a]

[a] calculated as the average of the ratios.

4 SOME AGGREGATED RESULTS FOR VISUALIZATION PURPOSE

4.1 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.

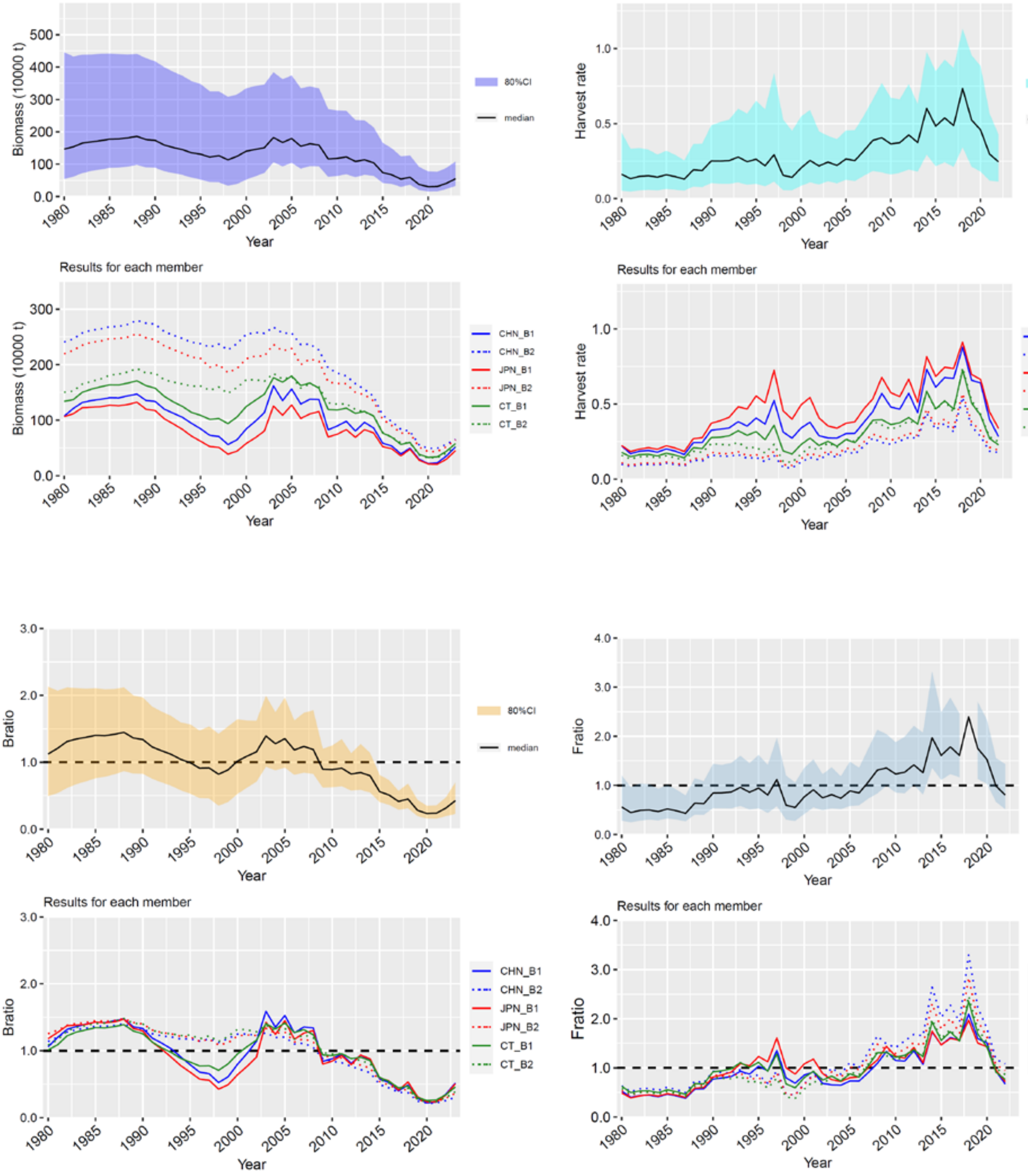


Figure 3. Time series of median estimated values of six runs for biomass, harvest rate, B-ratio, F-ratio and depletion level relative to K. The solid and shaded lines correspond to B1 and B2, respectively.

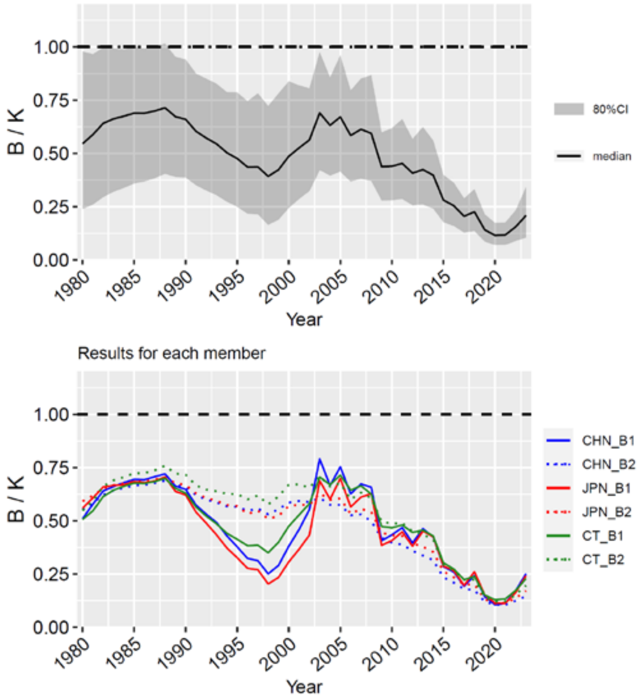


Figure 3 (Continued).

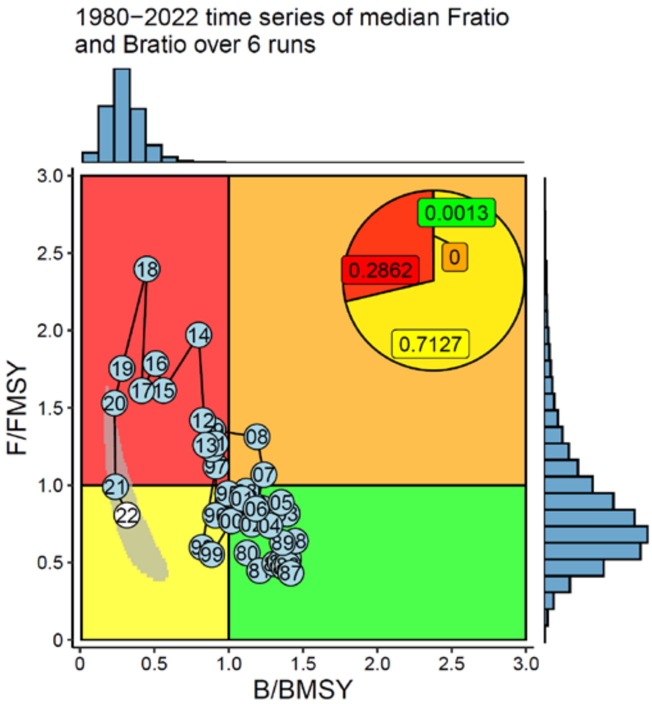
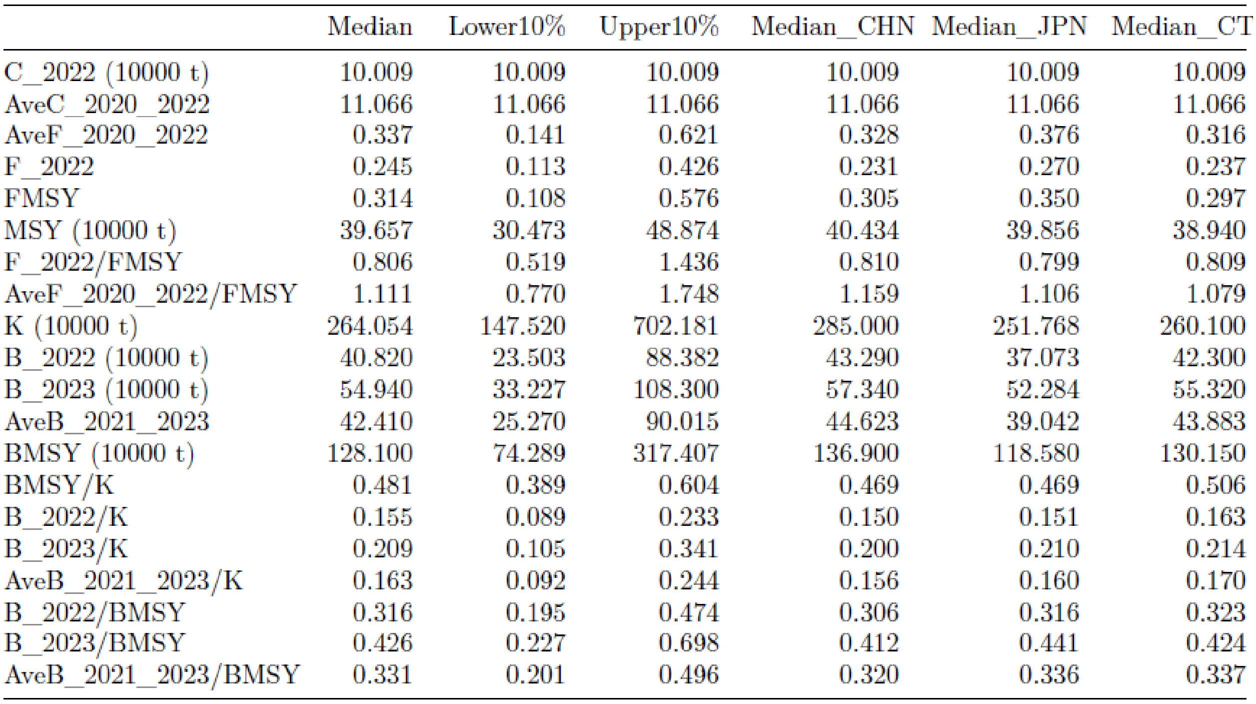


Figure 4. Kobe plot with time trajectory. The data are aggregated across 6 model results (2 base-case models by 3 Members).

4.2 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_2022 (10000 t)	10.009	10.009	10.009	10.009	10.009	10.009
AveC_2020_2022	11.066	11.066	11.066	11.066	11.066	11.066
AveF_2020_2022	0.337	0.141	0.621	0.328	0.376	0.316
F_2022	0.245	0.113	0.426	0.231	0.270	0.237
FMSY	0.314	0.108	0.576	0.305	0.350	0.297
MSY (10000 t)	39.657	30.473	48.874	40.434	39.856	38.940
F_2022/FMSY	0.806	0.519	1.436	0.810	0.799	0.809
AveF_2020_2022/FMSY	1.111	0.770	1.748	1.159	1.106	1.079
K (10000 t)	264.054	147.520	702.181	285.000	251.768	260.100
B_2022 (10000 t)	40.820	23.503	88.382	43.290	37.073	42.300
B_2023 (10000 t)	54.940	33.227	108.300	57.340	52.284	55.320
AveB_2021_2023	42.410	25.270	90.015	44.623	39.042	43.883
BMSY (10000 t)	128.100	74.289	317.407	136.900	118.580	130.150
BMSY/K	0.481	0.389	0.604	0.469	0.469	0.506
B_2022/K	0.155	0.089	0.233	0.150	0.151	0.163
B_2023/K	0.209	0.105	0.341	0.200	0.210	0.214
AveB_2021_2023/K	0.163	0.092	0.244	0.156	0.160	0.170
B_2022/BMSY	0.316	0.195	0.474	0.306	0.316	0.323
B_2023/BMSY	0.426	0.227	0.698	0.412	0.441	0.424
AveB_2021_2023/BMSY	0.331	0.201	0.496	0.320	0.336	0.337

5 CONCLUDING REMARKS

See the Executive Summary.

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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					4.13		0.747		1.39	0.29
1995	343743					2.11		0.869		1.70	0.30
1996	266424					1.77		0.646		0.73	0.29
1997	370017					3.52		0.501		1.40	0.30
1998	176364					1.05		0.501		0.87	0.32
1999	176498					0.87		0.568		0.53	0.35
2000	286186					1.28		0.822		1.00	0.32
2001	370823					1.65	7.84	0.947	1.57	0.92	0.19
2002	328362					1.11	11.28	1.172	1.63	0.70	0.18
2003	444642	1348.7	23.9			2.04	16.32	1.526	2.67	1.22	0.18
2004	369400	769.8	20.5			2.72	11.78	2.914	1.45	1.17	0.18
2005	473907	1012.2	30.7			4.40	19.33	2.963	2.39	1.71	0.16
2006	394093	696.6	30.0			4.55	9.45	1.975	1.27	0.55	0.15
2007	520207	782.0	36.9			4.19	8.12	2.231	2.35	1.09	0.17

2008	617509	989.6	26.5			5.15	16.56	2.083	2.90	1.96	0.19
2009	472177	367.4	20.0			4.18	9.60	1.175	1.57	1.03	0.17
2010	429808	554.9	26.4			1.80	9.75	1.224	1.94	1.13	0.17
2011	456263	756.4	35.3			2.52	11.32	1.467	2.51	1.36	0.20
2012	460544	346.4	21.1			2.72	9.19	1.442	2.47	1.08	0.17
2013	423790	758.8	26.6	14.02		1.89	13.61	1.407	2.80	1.00	0.16
2014	629576	448.7	21.7	12.77		3.31	20.42	1.479	3.62	1.31	0.14
2015	358883	337.2	21.4	23.10		1.69	7.41	0.652	2.42	0.96	0.18
2016	361688	358.1	24.4	6.57		1.81	10.76	1.208	2.43	0.80	0.15
2017	262640	145.7	27.3	5.97		1.12	5.40	0.525	1.82	0.75	0.16
2018	435881	378.9	28.7	16.05		1.96	11.89	1.577	3.07	1.33	0.17
2019	195251	247.5	23.4	6.40		0.70	2.75	0.558	1.41	0.56	0.16
2020	139779	12.1	115.7	4.80		0.48	2.85	0.497	1.23	0.32	0.18
2021	92117	161.2	27.0	6.21		0.33	2.83	0.141	0.79	0.22	0.18
2022	100085	290.6	20.4	4.24		0.27	1.62		0.71	0.20	0.16
2023		323.7	26.3								