Stock assessment of Chub Mackerel Pacific stock (2019)

Responsible Institute: National Research Institute of Fisheries Science

Summary

The stock biomass was estimated by cohort model considering abundance index. Although the biomass was high level above 3 million metric ton at 1970s, it declined below 2 million ton at 1980s, below a million ton at 1990s, downed 153,000 ton at 2001. It increased 700,000 ton by high recruitment of 2004, and continued to increase by relatively high recruitment and low fishing pressure. The biomass reached 3,411,000 ton at 2013 by extremely high recruitment of 2013. The biomass of 2018 was estimated at 5,595,000 ton by extremely high recruitment of 2018. The spawning biomass was at low level of below 100,000 ton until early 2000. It increased rapidly after 2015 by extremely high recruitment of 2013 and reached 1,185,000 ton at 2018. Fishing pressure (average of fishery coefficient at age) after 2000 were high at 2009 and 2010 but became low level after 2011.

For this population stock, we propose the Hockey Stick (HS) model of reproduction curve estimated by the least squares method and considering the autocorrelation of recruitment residuals as a candidate for the stock-recruitment relationship equation, SBmsy (1.54 million tons) as a candidate for the Target Reference Point. Following the reference, stock level at 2018 is below MSY. Although fishing pressure on the stock tends to decrease recently, it stayed over Fmsy after 1970. The status of spawning stock biomass was considered at “increasing” level by the transition between 2014 to 2018.

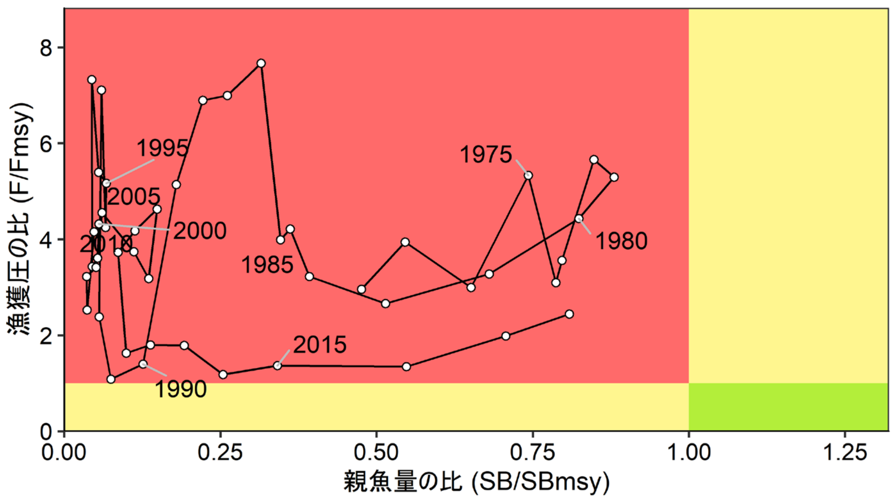
- Summary table of reference relating to MSY

References	**Values**
Regarding MSY	
SBmsy	1,545,000 tons
Fmsy	0.02, 0.05, 0.10, 0.18, 0.19, 0.35, 0.35 =0yr, 1yr, 2yr, 3yr, 4yr, 5yr, 6yr and above
%SPR(Fmsy)	54%
MSY	372,000 tons
SSB and Fishing pressure at 2018	
SB2018	1,185,000 tons
F2018	0.01, 0.02, 0.05, 0.44, 1.17, 1.07, 1.07 =0yr, 1yr, 2yr, 3yr, 4yr, 5yr, 6yr and above
%SPR(F2018)	38%
%SPR(F2016-F2018)	38%
Ratio to MSY	
SB2018/SBmsy	0.77
F2018/Fmsy	2.48

- S-R relationship assumption: Hockey stick (with autocorrelation)

- Summary of stock status

Status of current SSB	Below SBmsy
Status of F	Above Fmsy
Status of SSB	increasing



The relationship between SB/SBmsy and F/Fmsy.

The values of three years moving average were used for both SB and fishing intensity.

1. Data set

The data set used for the stock assessment is as follows.

Data set	Data source and research
Catch number by age and year	Landing at major ports (Hokkaido-Miyazaki [17] prefectures, JAFIC, Northern Purse Seine Fisheries Association) Length composition by month (NRIFS, Hokkaido-Miyazaki [17] prefectures, JAFIC); market measurement Length, weight, age, and maturity data by month (NRIFS, Hokkaido-Miyazaki [17] prefectures, JAFIC); market measurement, fisheries testing Mixing rate research of chub and blue mackerel by month and fisheries (NRIFS, Hokkaido-Miyazaki [17] Prefectures); at sample ports, market samples, and fisheries research
Index of the stock	
Recruitment index	Juvenile abundance index based on purse-seine fishing in the Joban waters in winter and spring (Ibaraki Prefecture) East Hokkaido-Sanriku Waters drift-net fishing survey CPUE (Hokkaido); drift net Transitional area larva/juvenile survey (May/June, NRIFS); mid water trawl* Mid water trawl survey at Northwestern Pacific(May-July, NRIFS); mid water trawl* Mid water trawl survey at Northwestern Pacific (September/October, NRIFS); mid water trawl*
SSB index	Izu Islands waters dip-net fishing CPUE (Kanagawa Prefecture) *
Spawning volume	Egg and larvae survey (NRIFS, Aomori-Miyazaki [18] prefectures); NORPAC net
Natural mortality	Assuming $M = 0.4$ per year (Honma et al., 1987)
Fishing effort index	Northern Pacific purse seine efforts (JAFIC, fisheries status survey by fishing ground) *

*: used as the tuning index for the cohort analysis. Details of each surveys are explained in Appendix 4 of this document.

2. Ecology of the species

1) Distribution and migration

Chub mackerel Pacific stock distributes from the coast of southern Japan to offshore waters of Kuril Islands (Fig. 2-1). It is considered that both adult and juvenile distributes far east from 170-degree East longitude line at high abundance period. At the low abundance period of 1990s-2000s, juvenile distributes from Japan to around 170-degree East, but adult distributes to 150-degree East due to the shrink of feeding ground. The feeding migration of adult expands northeast by the increase of stock abundance recently, and distribution of adult during summer to fall reach to 47-degree North, 166-degree East, east offshore of Kuril Island, after 2018.

Adult move to north (March to June) after spawning at Izu Islands area, and migrate to offshore of Sanriku and Hokkaido (summer to fall) for feeding (Meguro et al. 2002, Fig. 2-1). Larvae are widely distributing from Pacific side of southern Japan to Kuroshio extension and

Kuroshio-Oyashio transition area in spring. Larvae occurred at Kuroshio-Oyashio transition area and move to offshore of Kuril Island in summer and subadult down south in fall to offshore of Chiba and Ibaragi prefecture for wintering (Kawasaki 1968, Iizuka 1974, Nishida et al 2001, Kawasaki et al 2006). Portion of adult and subadult migrate to Kii strait, Bungo strait and Seto inland sea. It is considered that chub mackerel distributing in the Pacific is in one stock. Because of the occurrence of larvae originated upstream of Kuroshio current at the spawning ground of Izu Islands (Koizumi 1992), and spawning ground extended from offshore of southern Japan to northern Japan (Kuroda 1992).

2) Age and growth

It is known that the growth of chub mackerel changes by the level of recruitment and ocean environment (Watanabe and Yatsu 2004). There is no significant difference in growth between sex. The longevity was estimated at 7 or 8-year-old by age composition of catch, and maximum age was recorded at 11-year-old (Iizuka 2002). Fish age 6 and above are very rare in the catches in recent years. Average size (fork length) and weight of catch in 2018 are shown in Fig. 2-2 with comparison of those at 2011-2014 which did not show any slow growth. Average weight of 2018 was low comparing with those of 2011-2014 and 1970s, especially for age 5 (extremely high recruitment in 2013 year class). It is considered that density effect by the increasing abundance may cause for it. However, slower growth was observed at the high abundance period. It is considered that relatively lower temperature for living caused by expansion of the distribution far offshore, and poor condition of feeding ground may affect to it. It has been examined including affect by the feeding competition with Pacific sardine.

3) Reproduction

One female produces 50–90 thousand eggs several times during a spawning season (Kato and Watanabe, 2002). The maturity rate by age is known to be strongly affected by changes during growth (Watanabe and Yatsu, 2006). Main spawning grounds are found in waters around the Izu Islands but also in areas off the Pacific coast of southern Japan, including the Kinan area, Cape Muroto and Cape Ashizuri. Spawning is also observed in the Tohoku waters. A spawning season is from January to June. In the main spawning ground of Izu Islands, spawning occurs in March and April. In recent years, however, it shifts to May and June because of the high fraction of younger adult, which tend to lay eggs later season (Watanabe, 2010). March and April are the main spawning season recently. Figure 2-3 shows the maturity rate by age and year. The maturity rate of age 2 fish is expected to be lower in 2015 than in the period before 2014, due to the slow growth of the 2013 year class. Consequently, maturity rate by age after 2015 was used as the value of the period of high abundance.

4) Prey-predator relationships

Larvae feed on the eggs of copepods and nauplii, whereas juvenile prey on small zooplankton such as small copepods, noctilucines, cercariae, and salpae (Kato and Watanabe, 2002). The feeding behaviors of immature and adult fish differ depending on the waters and lifecycle, but they mainly prey on other fishes (e.g., anchovies and lantern fish), crustaceans (e.g., krill and copepods) and salpae. In the Sanriku waters, the main prey are mysid shrimp and anchovies.

Before the 1980s, when stock abundances were high, chub mackerel were often observed to be eaten by large fishes such as the mackerel shark, blue shark, pomfret, albacore, and skipjack tuna (Kawasaki 1965 and Nagasawa 1999), as well as the minke whale (Kasamatsu and Tanaka, 1992). In the 1990s, the lower abundance period, predation of minke whales was not reported (Tamura et al., 1998). From the research report of baleen whale predations, composition of anchovy decreased in the stomach contents after 2012, but mackerels and sardine increased. Especially in the case of sei whale, main prey item was shift from anchovy in early 2000s to mackerel and sardine in late 2000s (Tamura et al 2016), it still continued after 2010 (Konishi et al. 2016). The abundance of mackerels seems to increase enough to be main prey items for whales.

3. Fisheries on the species

1) Outline of fisheries

The major fisheries for chub mackerel are purse seine, set net and dip-net fishing, and stick-held dip-net fishing. Purse seine operates all over the year with main fishing season from September to February next year in offshore waters of Joban and Sanriku coast. The major fishing ground of Eastern Hokkaido water in 1980s of stock rich period which was disappeared from 1990s to 2000s, was recovered after 2012. Smaller purse seine operates all over the year at the Pacific coast south from Chiba prefecture. Set net fishery was conducted most of Japanese coast and large catch was reported from Sanriku coast. Dip-net and stick-held dip-net fishing (firelight mackerel fishing) which targets spawning shoals (age 2 to 4 fish) are mainly conducted from January to June in the Izu Islands waters. The species are also caught by line fishing all over Japan.

2) History of catch

The catch was summed from July to June next year of fishing season, the stock abundance was estimated as the abundance of the first day of July. Chub mackerel catch was estimated using the mixed rate of sampling at fishing ports and official statistics which is classified with chub and blue mackerel together.

The chub mackerel fishery was first developed by line fishing at the Tsugaru-Hachinohe fishing ground in 1951, and expanded in 1954 (Miyazawa, 1994). Afterward, dip net fishing was developed at Izu Island fishing ground in 1958 and it started at commercial level from 1975. The catch increased from 227,000 tons in 1964 to 1,207,000 tons in 1978 by the entry of purse seine fishery (Fig. 3-1, Table 3-1).

After 1979, however, the annual catch decreased around 30,000 tons in 1990 and 1991. Between 1992 and 2003, the catch largely fluctuated from 50,000 to 400,000 tons. During the period of 2004–2008, the catches were relatively stable at 180,000–250,000 tons, supported by the highly recruitment in 2004 and 2007. Then, it decreased slightly to 100,000–130,000 tons between 2009 and 2012, due to the decrease of fishing efforts, an increase in bycatch of blue mackerel, and changes in fishing grounds. The catch increased to 282,000 tons in 2014 by high recruitment in 2013.

The catches between 2015-2017 ranged from 330,000 to 332,000 tons. It slightly decreased at 2018 to 298,000 tons.

Russia also caught chub mackerel between 1966 and 1988, with the catch in the peak between 1972 and 1979 ranging from 120,000 to 240,000 tons (Fig. 3-1, Table 3-1). Recently, China and Russia catch chub mackerel at the high sea of North Pacific and 200 EEZ, respectively. They reported their catch to the North Pacific Fisheries Commission (NPFC). Since both countries reported chub mackerel catch with mix of blue mackerel as mackerels, the catches of both countries were estimated assuming the same mixed rate of chub and blue mackerels caught by Japanese purse seine operated during July to December at the North Pacific (Fig. 3-1, Table 3-1). The mixed rates of chub mackerel were estimated 79% for 2014, 91% for 2015, 98% for 2016, 99% for 2017, and 99.5% for 2018. It is considered that estimated value based on fishing year is same as statistics summarized by calendar year, because fishing season is concentrated between July to October (see Appendix 5).

Age composition of catch was shown in Figure 3-2. Juvenile fish (age 0 to 1) were main components of the catches between 1990 to 2004, but proportion of age 2 fish increased after strong recruitment of 2004 (Fig. 3-2, Appendix 6). It is considered that the survival rate after recruitment increased after 2004 due to the decrease of fishing pressure to juvenile fish (see section below). By the extreme high recruitment of 2013, the proportion of 2013 year class increased after 2014.

3) Annual fishing effort by fisheries

Fishing effort of purse seine fishery tends to increase following the intensity of recruitment. After 1992, it increased following strong recruitments of 1992 and 1996, then decreased. It increased again with strong recruitment of 2004, then it decreased (Fig. 3-3). The increase of fishing effort for 2004-year class was supposed to be regulated by the fishery management following stock rebuilding plan (Ichinokawa et al. 2015, Ichinokawa et al. 2016). It is considered that the fishing pressure was continued to be controlled by fishery management measure after 2000s. It is also considered that negative effects of Tohoku earthquake in March 2011, the change of fleet composition to improve business management, and mind change of fisher men from “mass catch and cheap price” to “appropriate catch and fordable price” contributed to reduce fishing efforts. The fishing efforts revealed to increase in 2012 to 2015 due to the decrease of negative effect of Tohoku earthquake, but it has decreased again after 2016.

4. Stock status

1) Stock assessment methods

We estimated the numbers at age by years 1970-2018 using the tuning-VPA method (cohort analysis) which applies the Pope’s approximation formula (Pope, 1972) (Table 4-1, Appendices 1,2,3 and 6). The fishing season was defined as from July to the following June. The natural mortality coefficient (*M*) was set at 0.4 per year (Honma et al. 1987). As for the tuning indices of the VPA, we used four indices which was considered to reflect the changes in SSB and recruitment, and the fishing mortality (terminal *F*) in 2018 which is the most recent year was estimated

(Appendix Table 2-1).

2) Changes in the biomass indices

The spawning biomass of mackerels in the Pacific waters peaked in the 1960s and mid-1970s, with the number of eggs reaching one quadrillion in total. Although the spawning biomass remained at low levels in the late 1980s, recent years have seen another increase as the SSB increases (Figure 4-1, Egg/Juvenile/Larva database; Oozeki *et al.* 2007). The spawning biomass of chub mackerel, which was first differentiated from that of blue mackerel in 2005, was estimated to be 322 trillion eggs in 2007, a huge increase from 39 trillion eggs in 2005. The spawning biomass fluctuated thereafter, with an increase of 347 trillion eggs in 2017, 583 trillion eggs in 2018, 550 trillion eggs between January and June in 2019, which increased up to the high levels seen in the 1970s. The indices of recruitment shown in Figure 4-2 which are obtained from various surveys, show high values in 2004, 2007, 2009, 2013, 2016 and 2018. These values reflect high level of recruitment, and the value in 2018 was the highest for most indices. Figure 4-3 shows the change in CPUE and the abundance indices for the northern purse-seine fishery, which is the major fishery of the stock. These changes reflect the trends in biomass, and was high in 1992 and 1996 when exceptionally high level of cohorts occurred and the years that followed. CPUE has remained at high levels since 2005, after the 2004 cohorts which showed high recruitment. Since 2013, after the high level of cohorts in 2012 became the target of fishing, the CPUE increased even more, and showed very high value in 2017. CPUE in 2018 decreased probably because of the increase in Japanese sardine which resulted in an increase of bycatch of this species.

3) Trends in biomass and fishing pressure

Biomass was at a high level of three to five million tons during the fishing season of 1970 to 1979; however, due to the decrease in recruitment by the low recruitment per spawning (RPS) in 1979 and 1980 together with high fishing pressure, the biomass decreased to 1.932 million tons in 1980 (Figure 4-4, 4-6, Table 4-1, Appendix 6). The biomass was almost stable at around 1.455-1.816 million tons during 1981 to 1986; however, since 1987, biomass even decreased due to the decrease in recruitment by the low RPS and high fishing pressure resulting in 215 thousand tons in 1990. Biomass increased after the high recruitment in 1992 and 1996 and then decreased due to high fishing pressure, and the biomass was at the lowest level of 153 thousand tons in 2001. From 2004 onwards, biomass increased with the high recruitment in 2004 together with decreasing fishing pressure. And due to the extremely high recruitment in 2013, the biomass even increased to 3.411 million tons in 2013. Thereafter, the biomass even increased due to the high recruitment in 2018, resulting in an estimated 5.595 million tons, which was the highest biomass since 1970. However, it must be cautioned that age 0 and one year old which has high uncertainty in the estimated amount of recruitment consist the majority of the biomass in 2018 (Figure 4-4).

The SSB was at a high level of 657 thousand to 1.401 million tons during 1970 to 1980; however, due to the decrease in recruitment and high fishing pressure during 1979 and 1980, the SSB decreased to 737 thousand tons in 1981, 567 thousand tons in 1982 (Figure 4-5, 4-6, Table 4-1,

Appendix 6). Thereafter, SSB remained around 450 thousand tons till 1985; however, due to the decrease in recruitment and high fishing pressure since 1986, SSB decreased to 97 thousand tons in 1990. Since then, it remained at a low level of around less than 100 thousand tons, resulting at a lowest level of 44 thousand tons in 2002. After that, due to the high recruitment in 2004, SSB increased to 296 thousand tons in 2006, and despite of the drop in 2010, SSB increased rapidly since 2015 due to extremely high recruitment in 2013 and SSB was estimated to be 1.185 million tons in 2018. Since 2013, biomass of elder parous fish aged ≥4 years, which are thought to deliver larvae with higher survival rate are increasing (Figure 4-5).

The RPS was fairly stable during 1970-1985 when the SSB was more than 450 thousand tons, and the recruitment was at a high level of more than 3 billion individuals despite of some yearly fluctuations (Figure 4-5, 4-6, Table 4-1). The RPS was extremely low in 1987-1989, 1998 and 2006 when the SSB was lower than 450 thousand tons. On the other hand, the RPS was extremely high in 1992, 1996, 2004 and 2013, resulting in large yearly fluctuations. In order to avoid low recruitment level, and to gain better recruitment in years when the environment is favorable for reproduction, it is important to sufficiently increase the SSB for the sake of recovery of this stock.

As a sensitivity test on *M*, we used 0.3 and 0.5 as alternatives to the base value of 0.4 and estimated the biomass, SSB and recruitment for the most recent year 2018 (Figure 4-7). The biomass ranged from 81% to 128%, SSB from 93% to 110% and recruitment from 72% to 143% compared to the base value, resulting in higher value as *M* increases.

Average *F* among all ages (simple average of *F* at age) fluctuated widely among years at a range of 0.16 and 1.34, and show low levels since 2011 (Figure 4-8, Appendix 6). *F* for young age fish (0-2 years old) were especially high when the 1992 and 1996 cohort entered the fishing target, but remain low since 2010. The fishing ratio was high at a level of more than 40% in 1986, 1988 and 1989 which resulted in a large decrease in biomass (Figure 4-9, Table 4-1, Appendix 6). Thereafter, the fishing ratio was at a very high level of 56% in 1993, high level of 33-51% until 2001, resulting at a lowest level of biomass in 2001. The fishing ratio was at a low level of 19-36 % during 2002 to 2010, thereafter, at a level of 6-13% since 2011 which had the influence of the Tohoku earth quake which occurred in March 2011.

Item	Value	Remarks
SB2018	1.185 million tons	SSB in 2018
F2018	（age 0, 1, 2, 3, 4, 5, 6+） = （0.01, 0.02, 0.05, 0.44, 1.17, 1.07, 1.07）	
U2018	9%	Fishing ratio in 2018

4) Yield per recruitment（YPR）, spawning per recruitment（SPR）and current fishing pressure

In order to compare the fishing pressure considering the influence of selectivity, Figure 4-10 shows the %SPR (ratio of SPR which assumes no fishing divided by the SPR with current catch) calculated by converting the *F* value of each year. The lower the fishing pressure, the higher the %SPR. The %SPR was extremely low during 1993 to 1997, which suggests high fishing pressure on juveniles during this period. After 2011, %SPR remains at a high level of about 40%, which suggests that the fishing pressure on juvenile fishes are not high.

Figure 4-11 shows the relationship between YPR and %SPR for the current fishing pressure. As for the selectivity in *F*, we use the selectivity which was used to estimate *F* that gives MSY (*Fmsy*) which was suggested at the ‘Research Institute meeting on Reference points for the Pacific Stock of Chub Mackerel’ held in April, 2019. *Fmsy* corresponds to 54% in %SPR. Current fishing pressure (F2016-F2018) is higher than *Fmsy*, but is lower than F30%SPR.

Item	Value	Remarks
%SPR（F2018）	38%	%SPR in 2018
%SPR（F2016-2018）	38%	%SPR corresponding to current fishing pressure (F2016-F2018)

5) Stock-recruitment relationship

Figure 4-12 shows the Stock-recruitment (S-R) relationship between SSB (in biomass) and recruitment (in numbers). According to the ‘Research Institute meeting on Reference points for the Pacific Stock of Chub Mackerel’ mentioned above, it is suggested to use the Hockey-Stick functional response type for the S-R relationship of this stock (Nishijima *et al.* 2019). Parameters for the S-R relationship is estimated based on the SSB and recruitment which are estimated by the stock assessment conducted in 2018, and as for the optimization method, least-squares method is used. The model also considers auto-correlation between the residuals of the recruitment. Estimated parameters for the S-R relationship are shown in the Table below.

S-R relationship	Optimization method	Auto-correlation	a	b	S.D.	ρ
Hockey-Stick (HS) type	Least square	Yes	0.00758	1,056,000	0.837	0.375

Here, parameter a is the steepness (numbers / g) of the HS S-R curve from the origin to the break point, and b is the SSB (ton) at the break point.

6) Level of SSB and fishing pressure that will achieve MSY under the current environmental condition.

The table below shows the SSB and *F* that will achieve MSY (SBmsy, Fmsy) under the current environmental condition since 1970, which was suggested at the ‘Research Institute meeting on Reference points for the Pacific Stock of Chub Mackerel’ suggested above (Nishijima *et al.* 2019).

Item	Suggested value	Remarks
SBmsy	1.545 million tons	SSB that will obtain MSY
Fmsy	（age 0, 1,2,3,4,5,6+） = （0.02, 0.05, 0.10, 0.18, 0.19, 0.35, 0.35）	
%SPR（Fmsy）	54%	%SPR corresponding to Fmsy
MSY	372 thousand tons	MSY

7) Stock status, stock trend and level of fishing pressure

Figure 4-13 and Appendix 7 shows a Kobe-plot which shows the relationship between SSB and its corresponding fishing pressure. F/Fmsy shows the yearly ratio between F and F under the current selectivity that gives Fmsy which was converted to %SPR. It is regarded that the fishing pressure of this stock for the entire period has been always above the level that gives MSY. The fishing pressure in 2018 was 2.48 times larger than Fmsy. Moreover, the SSB for the entire period is considered to be lower than the SBmsy. The SSB in 2018 was 0.77 times the SBmsy.

Item	Value	Remarks
SB2018/ SBmsy	0.77	Ratio between the SSB that gives MSY and the SSB in 2018
F2018/ Fmsy	2.48	Ratio between the fishing pressure that gives MSY and the fishing pressure in 2018 *

* Ratio between *F* in 2018 and *F* under the current selectivity that gives Fmsy which was converted to %SPR.

Level of SSB	below SBmsy
Level of *F*	above Fmsy
Trends in SSB	Increasing

5. Stock assessment summary

Biomass of this stock was at a high level of 3 million tons in the 1970s; however, dropped to 2 million tons in the 1980s, further dropping to 1 million tons in the 1990s, resulting in 153 thousand tons in 2001. Thereafter, due to the high recruitment in 2004, biomass exceeded 700 thousand tons, and together with the fairly high recruitment and reduction in fishing pressure, biomass began to increase from the low levels in the early 2000s. And due to the extremely high recruitment in 2013, biomass in 2013 was 3.411 million tons. Thereafter, due to the extremely high recruitment in 2018, the biomass even increased, and was estimated to be 5.595 million tons in 2018. SSB increased from the lowest level of less than 100 thousand tons in the early 2000s, and due to the extremely high recruitment in 2013, SSB rapidly increased after 2015 and was estimated to be 1.185 million tons in 2018.

Since 1970, SSB has been lower than SBmsy for the entire period. In spite of the decrease in fishing pressure in recent years, *F* has been always higher than the Fmsy for the entire period since

1970. Trends in SSB is considered to be increasing based on the recent five-year trends (2014-2018).

6. Other matters

Since the North Pacific Fisheries Commission (NPFC) received information on catch of mackerels in the 200 EEZ of Russia and the high sea of the North Pacific Ocean from China and Russia, we included the catch by these countries in the assessment. However, since the details of the catch by China and Russia is not known enough, many assumptions were made for the assessment. Information on age composition of the catch is important to get more reliable stock assessment results, and it is important to ask to report this information as well.

On the other hand, for investigating fishing effort by foreign vessels and to understand the behavior of the foreign vessels in the Northwest Pacific Ocean, a research started since 2016 using the satellite data at night time (Appendix 5). There are some surveys that estimate catch by foreign vessels including Illegal Unreported and Unregulated (IUU) fishing (Oozeki *et al*. 2018); however, these values are not yet used in this assessment since calculation of the biomass requires high accuracy in catch. It is important to continue collecting information on such.

Kawai *et al*. (2002) noted that the fishing pressure on juvenile fish was low during the high level of stock biomass in the 1970s, and if we had fished similarly, stock should have recovered in the 1990s. In the stock assessment report until 2005, it is indicated an obvious increase in F for the juveniles aged 0 and 1 fish since 1993 (Figure 4-8), and suggests that catching a huge amount of these juveniles are not practical, and the biological optimum age of this stock entering fishery is concluded to be 3.5 years old. Watanabe *et al*. (2012) considered the effectiveness of various harvesting scenarios by fishing season and area using a stock-dynamics model and suggested that it was most effective to restrict wintering area of juvenile. In recent years, the F of the juveniles is decreasing (Figure 4-8). It is desirable to keep reducing F of the juveniles for sustainable use of the stock.

Several recent studies show that the amount of recruitment depends on the survival rate during the period from egg to larva, when survival rate is affected by the condition of spawners (e.g. whether it has spawned before or not, nutritional condition, experienced temperature before spawning) which in turn affect the quality of the egg (Yoneda *et al*. 2010, 2013). Also, the survival rate is affected by the growth rate which depends on the experienced environment during the larval period (Takahashi *et al*. 2010, Yoneda *et al*. 2013).

There is a high correlation between the recruitment and the growth rate of juvenile migrating to the north. When there is high recruitment, the percentage of hatching individuals in April is high, which is the peak period of spawning, and vice versa, thus it is considered that the survival rate of the hatched individuals in April determine the amount of recruitment (Kamimura *et al*. 2015). The spawning in April results in producing high quality eggs in terms of the composition of the parental fish and experienced water temperature compared to those in May-June. The start of feeding of those hatched in April coincides with the blooming season which gives advantage in surviving of the larvae. Annual fluctuations in the experienced environment after hatching which greatly affects the initial survival rate is generally large, and if the experienced water temperature is same as that in the spawning grounds (about 18°C), growth rate of the larvae decreases and the delay in metamorphosis occur thus the survival rate decreases. On the other hand, if the larvae immediately get transported to the Kuroshio current area where the water temperature is around 20°C, the survival rate increases and the recruitment becomes high (Takahashi et al. 2010, 2012, Yoneda *et al*. 2013). It is expected that precise estimation of recruitment will become possible in the future by systematically analyzing the relationship between the environment and biological characteristics.

Recent breeding experiments have revealed that multiparous fish (having delivered offspring multiple times) spawn eggs that are better in quality than those of first-time spawners (spawning for the first time), resulting in higher survival rate of hatched larvae (Yoneda et al., 2013). Moreover, elder multiparous fish migrate faster to southern spawning grounds (Watanabe, 2010), mature faster in the spawning season (in preparation for spawning), and tend to spawn earlier (March to April). April is the time of year with the greatest concentration of spawning individuals (Watanabe, 2010) and is thus considered to be the original spawning season for this stock in the absence of human interventions. Coinciding with spring blooms that increase the amount of food and given that not many warm-water predators (e.g. skipjacks) have arrived yet, April must be the best time for larvae and juveniles to grow. Accordingly, it is important to increase and sustain elder spawner biomass to boost recruitment and maintain it above certain level. To achieve it, it is important to maintain elder spawners by the stock assessment and management considering age composition of adult fish.

7. References

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（Authors : Ryuji Yukami、Shota Nishijima、Sayoko Isu、Yasuhiro Kamiura、Sho Furuichi、Ryosuke Watanabe）

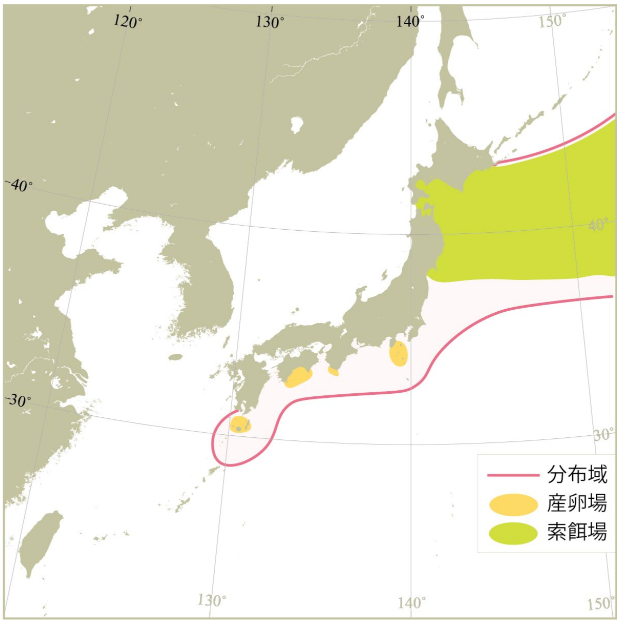


Figure 2-1. Distribution and migration of chub mackerel Pacific stock.

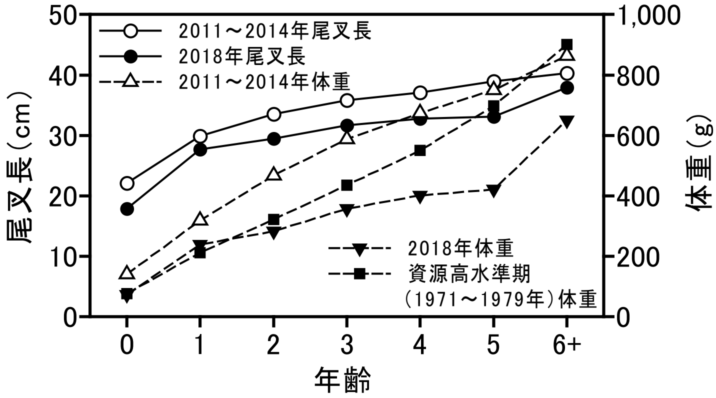


Figure 2-2. Relationship between age and length (fork length), and between age and weight.

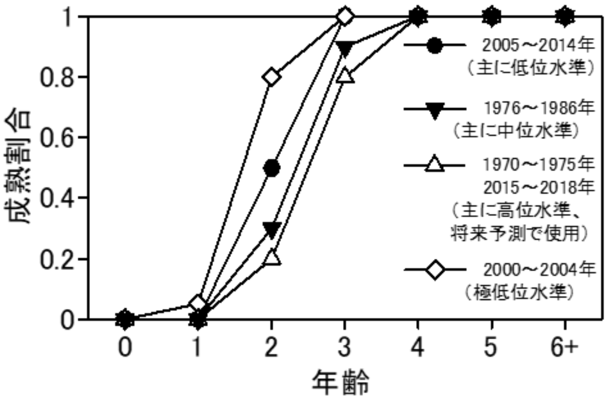


Figure 2-3. Maturity rate by age.

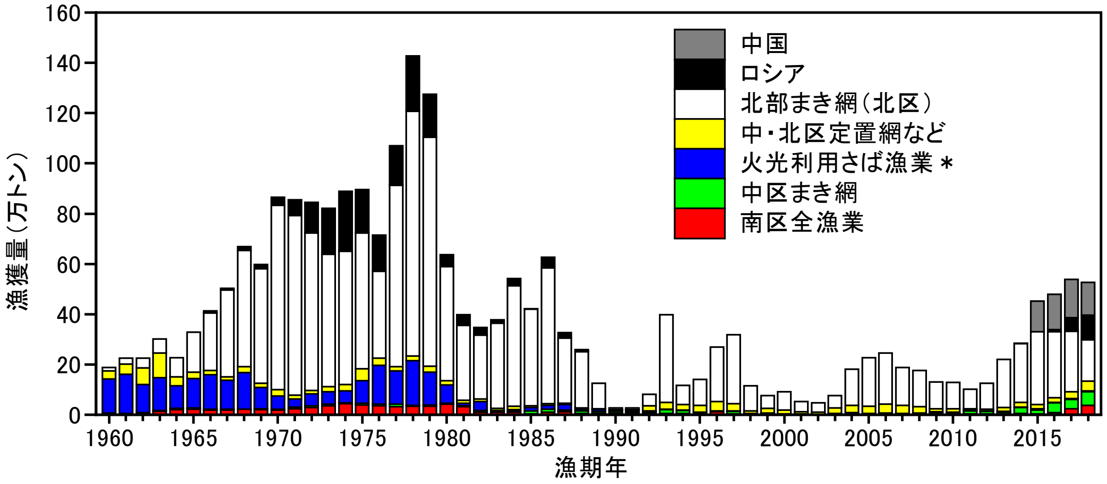


Figure 3-1. Annual catches of chub mackerel by fisheries. (Grey: China, black: Russia, white: purse seine for the northern area, yellow: middle/northern fixed shore net, blue: mackerel fishing using firelight, green: middle area purse seine net, red: southern-area all fisheries).

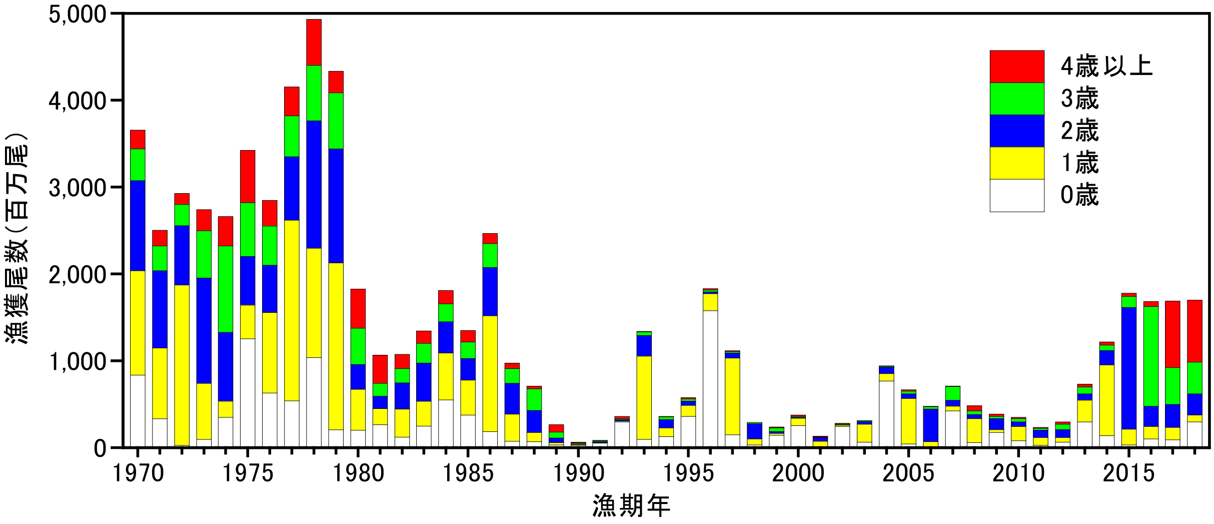


Figure 3-2. Annual age composition in catch. (Red: above 4 years old, green: 3 years old, blue: 2 years old, yellow: 1 year old, white: age 0).

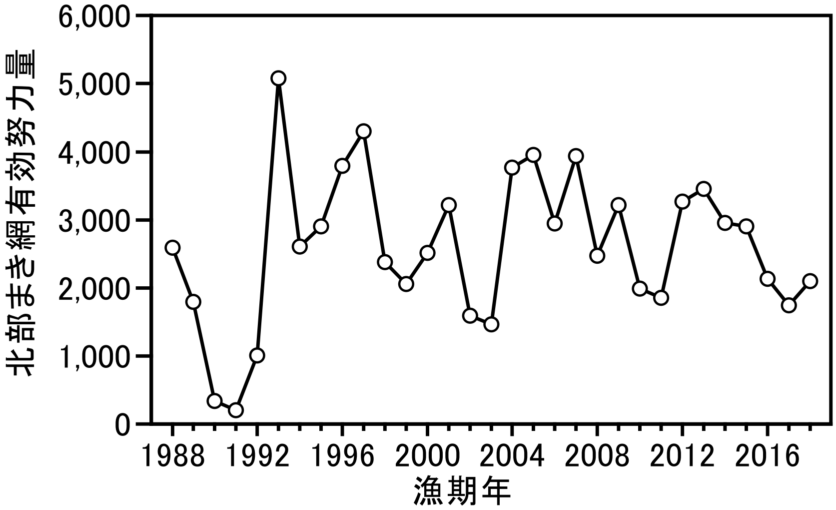


Figure 3-3. Annual effective effort on chub mackerel by purse seine fishery. (source: JAFIC. Appendix 4).

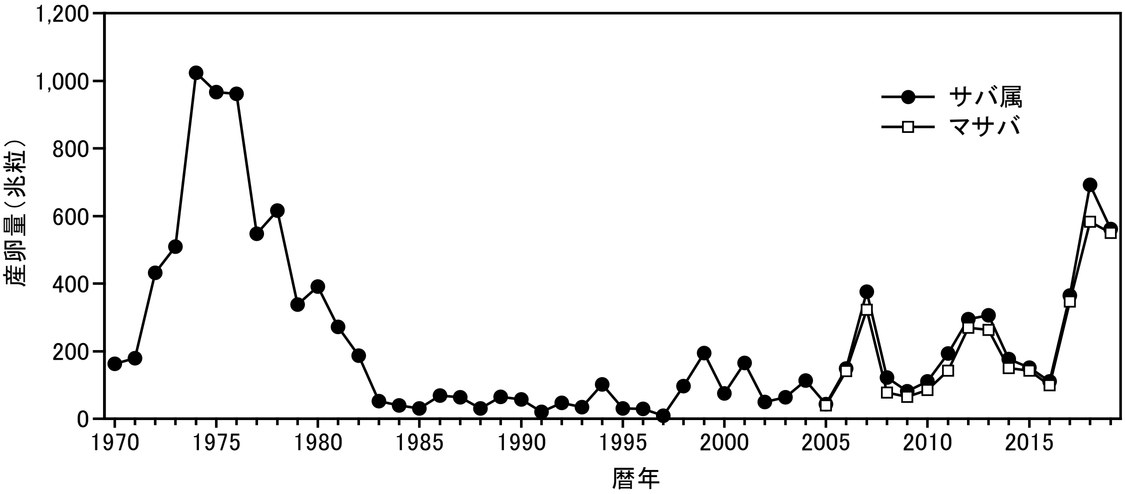


Figure 4-1. Spawning eggs of mackerels in the Pacific waters off Japan. The chub mackerel is plotted separately after 2005. Values for 2019 is for January to June.

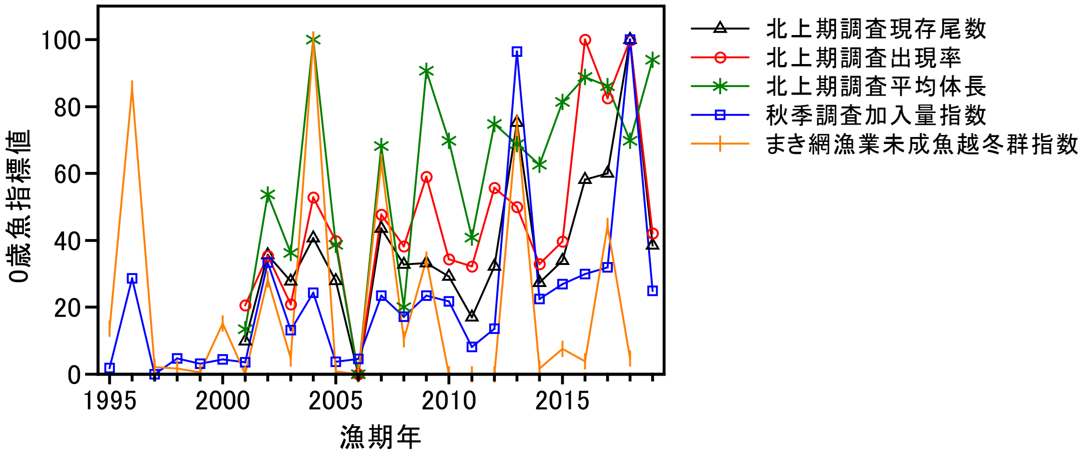


Figure 4-2. Fluctuations in the recruitment index in various surveys (Appendix 4; relative values with the index maximum and minimum set at 100 and 0, respectively). (Black triangle: existing numbers during the northing survey, red circle: occurrence during the northing survey, green: average length during the northing survey, blue square: recruitment index from the autumn survey, orange cross: index of juvenile going through the winter obtained from purse-seine fishery). (Y-axis: index for 0 years old, X-axis: fishing year).

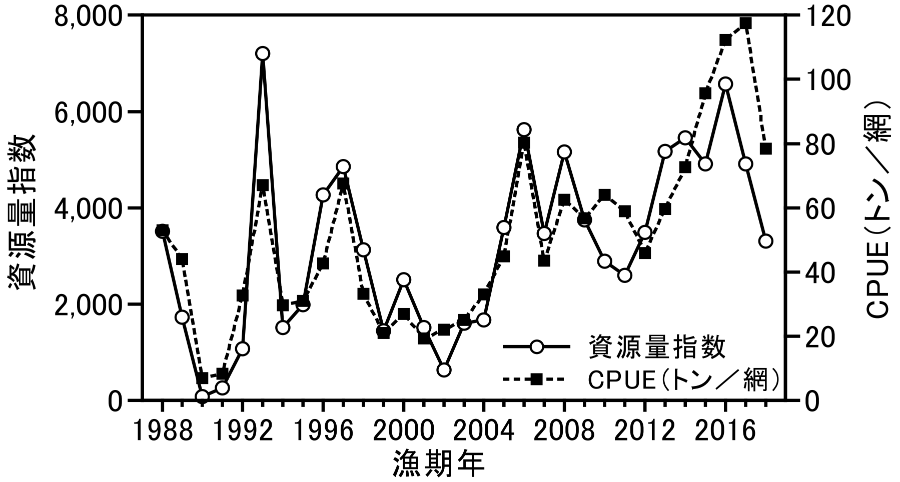


Figure 4-3. Fluctuations in CPUE for mackerels in North Pacific purse-seine fishery and indices of abundance (courtesy of Japan Fisheries Information Service Center (JAFIC), Appendix 4). (white circle with solid line is index of abundance, left y-axis is abundance index, x-axis is fishing year).

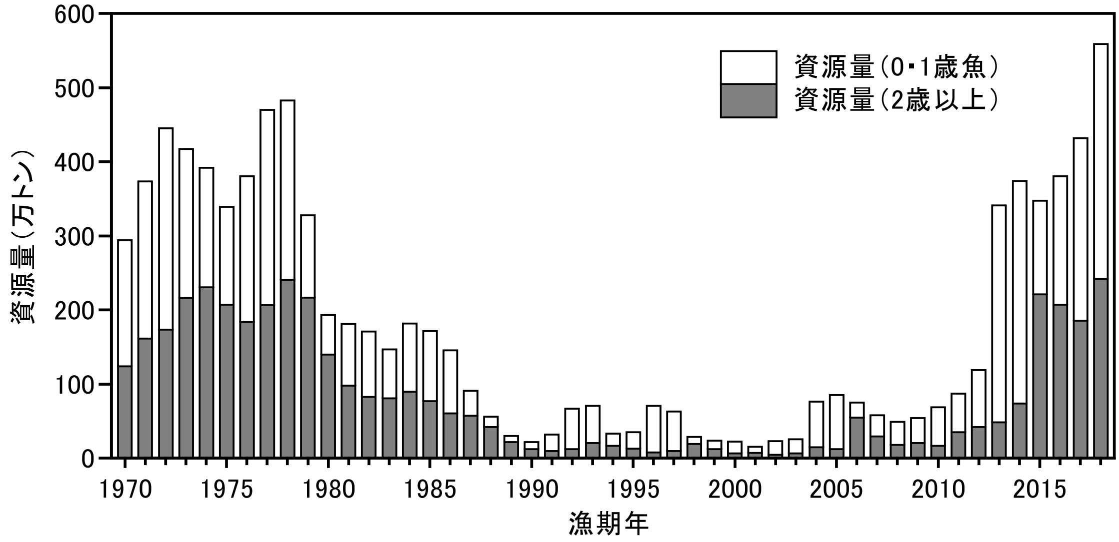


Figure 4-4. Fluctuations in abundance (biomass) of chub-mackerel. The white part of the bar plot shows the biomass for age 0-1 fishes, and the black part of the bar plot shows those of ages 2+. Y-axis is biomass (ten thousand tons), x-axis is fishing year.

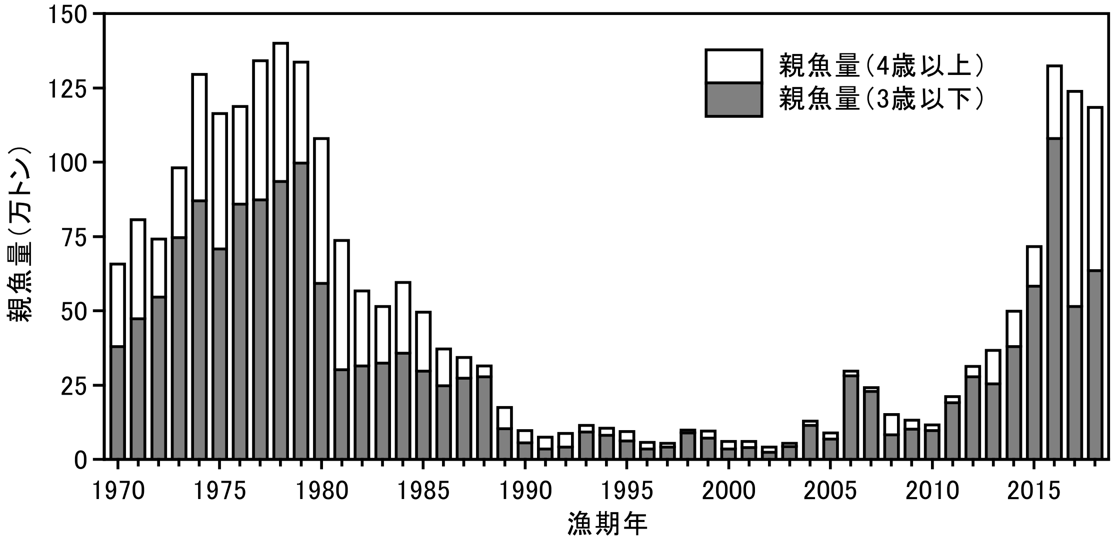


Figure 4-5. Fluctuations in SSB. The white part of the bar plot shows SSB over age 4, and the black part of the bar plot shows those SSB under age 3. Y-axis is the SSB (ten thousand tons), x-axis is the fishing year.

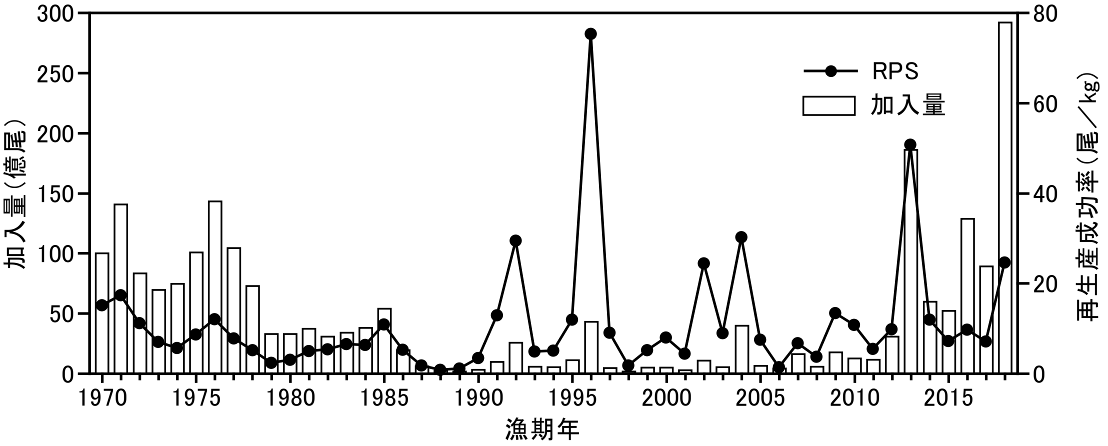


Figure 4-6. Fluctuations in recruitment and recruitment per spawning (RPS). White bar plot shows recruitment. Left y-axis is recruitment (100 million in numbers), right y-axis is the RPS (numbers/kg).

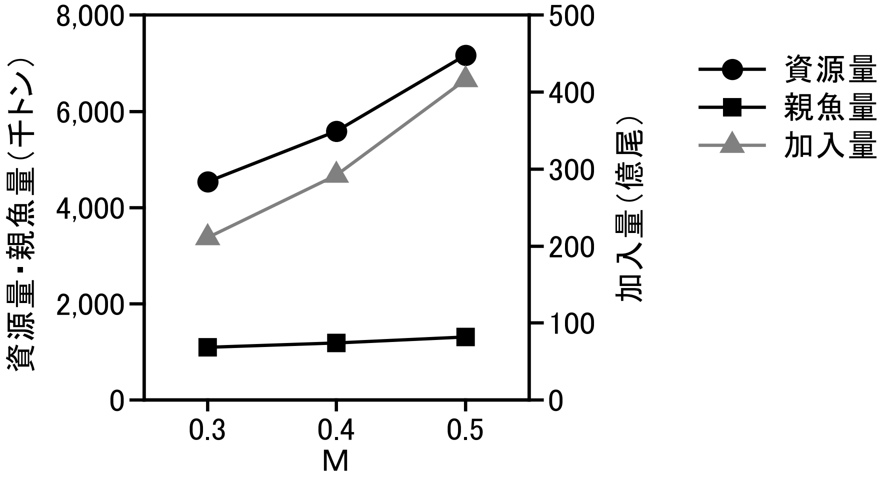


Figure 4-7. Biomass, SSB and recruitment for 2018 depending on the value of *M*. black circle represents the biomass, square represents SSB and triangle represents the recruitment. Left y-axis is the biomass and SSB (thousand tons), right y-axis is the recruitment (100 million in numbers).

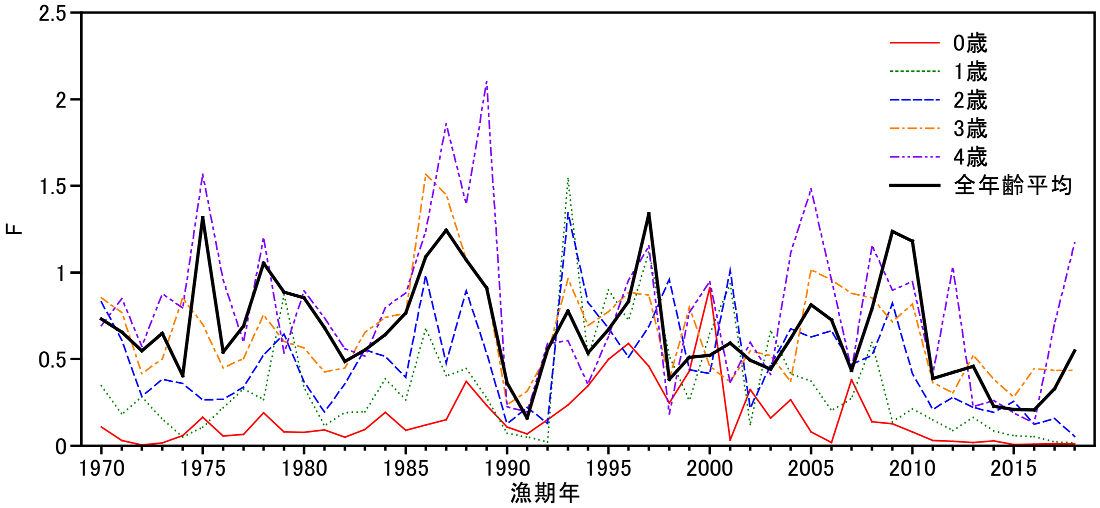


Figure 4-8. Fluctuations in *F* at age. The black solid line shows the average of all ages.

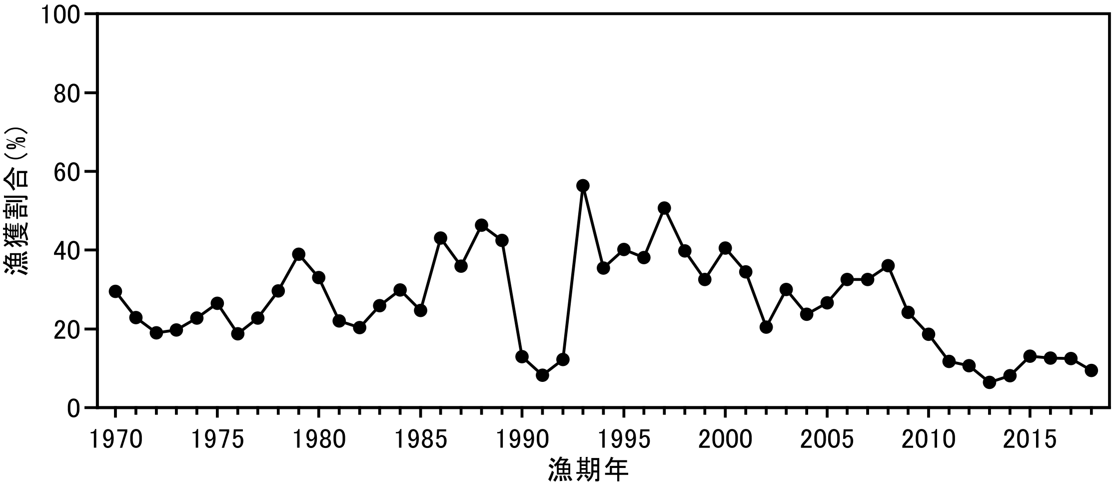


Figure 4-9. Fluctuations in catch proportion. Y-axis is the catch proportion (%).

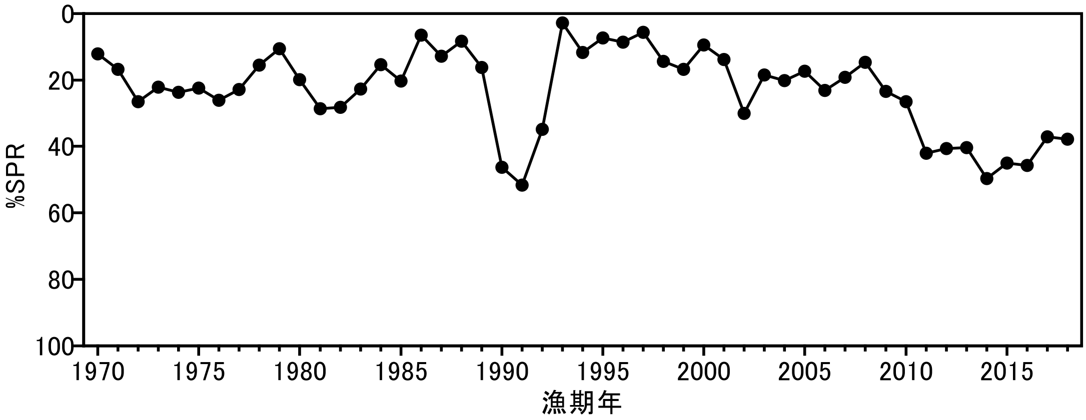


Figure 4-10. Fluctuations in %SPR by years. %SPR shows the ratio of SSB when no fishing to the SSB when there is fishing, and %SPR becomes low with high *F* and vice versa.

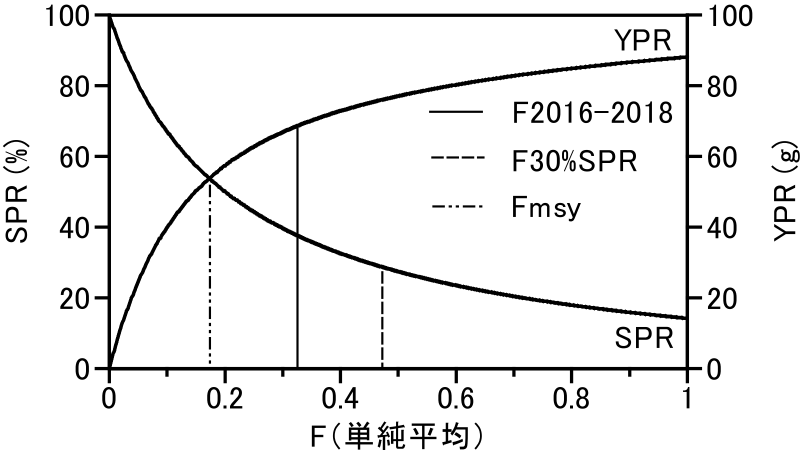


Figure 4-11. Relationship between the fishing mortality (F, simple average) and %SPR, YPR.

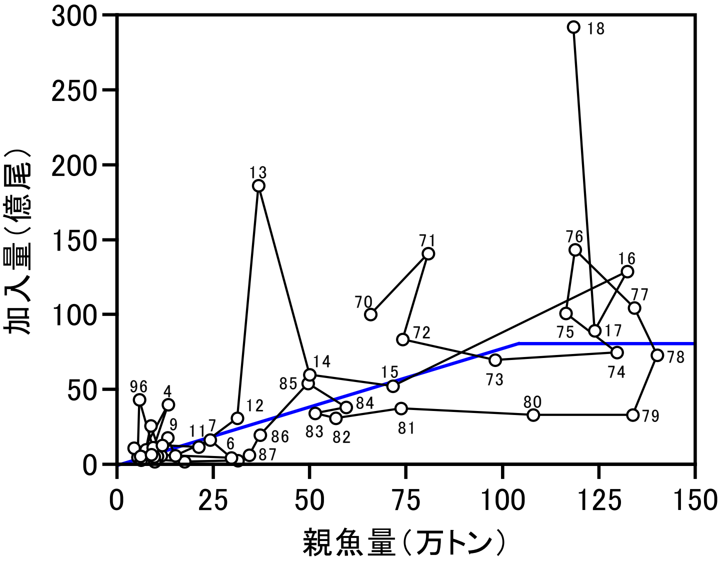


Figure 4-12. Relationship between SSB and recruitment. The blue line shows the S-R relationship suggested at the ‘Research Institute meeting on Reference points’ held in April 2019.

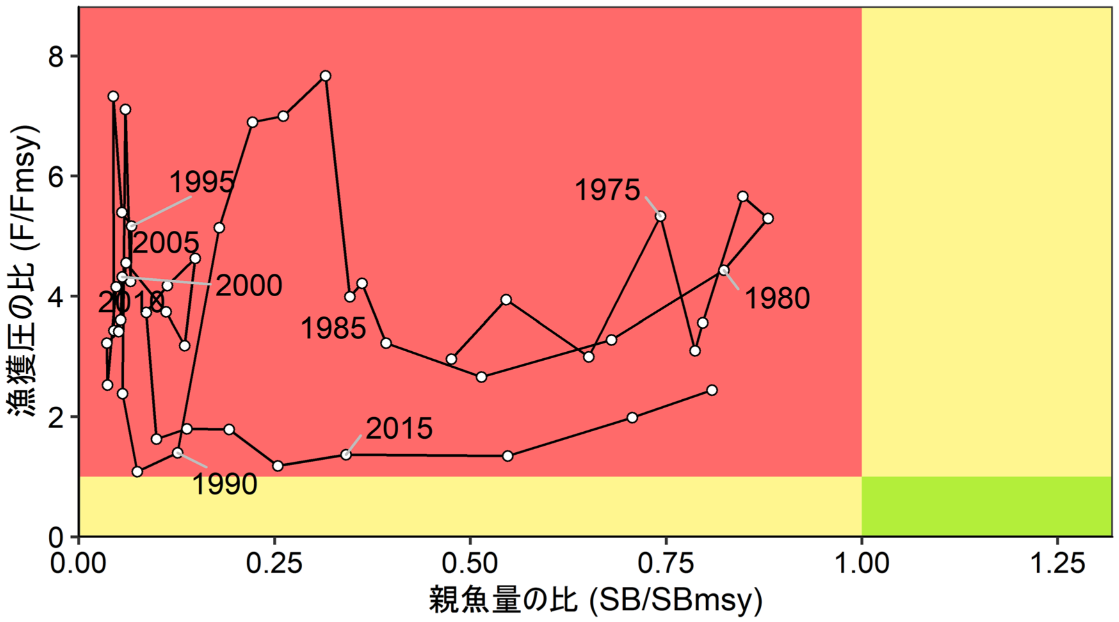


Figure 4-13. Relationship between the SSB and F that gives MSY (SBmsy, Fmsy) to the current SSB and F (Kobe plot). The *F* and SSB is the three-year moving average. The value in 2015 is the average of 2013 to 2015.

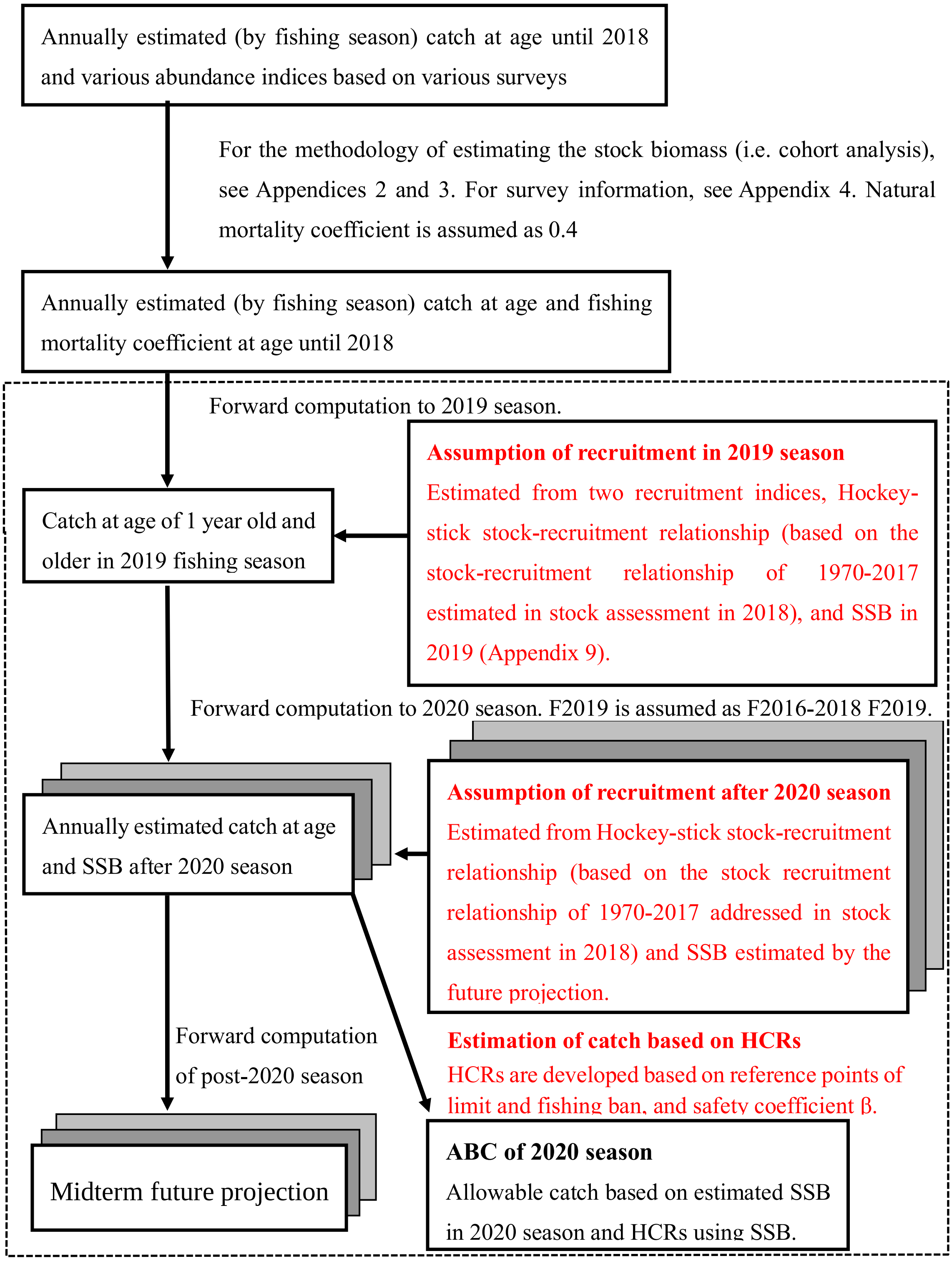
Table 3-1. Annual chub mackerel catch by country, region and fisheries (ton). The captions in the table below are from the left: Fishing year (July through following June), Total, Total of Japan catches, Russia, China, Northern purse-seine fishery, Fixed-net etc., Mackerel fishing using firelight, Middle-area purse-seine fishery, All types of fishing.

漁期年 7月～ 翌年6月	合計	日本 合計	太平洋北・中区						南区 全漁業
			ロシア	中国	北区 まき網	定置網 等	火光利用 サバ漁業*	中区 まき網	
1970	865,471	833,471	32,000	-	733,494	25,319	52,415	4,072	18,171
1971	855,109	793,109	62,000	-	715,905	14,115	31,986	7,253	23,849
1972	845,177	722,572	122,604	-	626,753	12,463	47,507	7,414	28,435
1973	821,531	638,536	182,996	-	527,106	20,188	49,180	7,308	34,753
1974	889,406	649,406	240,000	-	529,706	24,345	47,244	4,535	43,577
1975	896,611	722,805	173,806	-	540,113	46,915	89,945	6,370	39,461
1976	715,078	570,435	144,643	-	345,519	29,261	154,132	5,468	36,055
1977	1,070,984	912,950	158,034	-	722,035	15,933	133,046	9,250	32,686
1978	1,427,837	1,207,487	220,350	-	974,295	17,734	177,393	3,942	34,123
1979	1,275,041	1,104,013	171,028	-	911,006	23,234	130,929	4,347	34,497
1980	637,015	589,399	47,616	-	454,159	15,900	73,075	3,342	42,924
1981	398,394	356,046	42,348	-	298,344	11,811	9,855	4,036	32,001
1982	347,229	317,275	29,954	-	254,320	10,854	35,196	6,325	10,580
1983	378,130	364,628	13,502	-	338,760	8,299	915	6,147	10,506
1984	542,636	513,119	29,517	-	479,173	13,738	4,723	5,473	10,011
1985	422,432	419,724	2,708	-	384,355	5,959	14,196	11,457	3,758
1986	626,925	585,023	41,902	-	540,716	6,263	16,253	12,343	9,448
1987	326,549	305,635	20,914	-	259,765	5,214	21,442	7,658	11,555
1988	258,616	250,914	7,703	-	223,576	5,053	7,095	9,851	5,338
1989	125,291	125,291	-	-	101,051	1,747	8,420	7,610	6,463
1990	27,767	27,767	-	-	7,886	3,615	2,088	6,784	7,395
1991	26,385	26,385	-	-	5,321	1,958	4,924	5,129	9,052
1992	81,493	81,493	-	-	46,727	20,165	2,505	4,766	7,329
1993	397,959	397,959	-	-	348,663	27,732	1,596	15,202	4,766
1994	117,336	117,336	-	-	76,263	23,039	1,757	12,011	4,267
1995	140,569	140,569	-	-	104,151	25,503	1,591	4,862	4,461
1996	269,122	269,122	-	-	217,419	35,861	43	3,655	12,145
1997	318,407	318,407	-	-	275,169	27,874	1,661	9,579	4,124
1998	114,796	114,796	-	-	99,789	10,079	436	3,052	1,440
1999	76,512	76,512	-	-	51,193	18,581	43	3,515	3,181
2000	91,192	91,192	-	-	72,102	15,236	0	2,275	1,579
2001	52,896	52,896	-	-	40,432	8,616	0	1,390	2,458
2002	46,745	46,745	-	-	35,753	8,492	44	1,476	979
2003	75,559	75,559	-	-	48,429	21,822	84	920	4,304
2004	181,144	181,144	-	-	143,135	29,665	189	6,257	1,898
2005	226,256	226,256	-	-	193,026	27,596	388	1,769	3,477
2006	245,091	245,091	-	-	202,515	35,291	2,950	2,492	1,842
2007	188,373	188,373	-	-	151,563	31,996	721	1,690	2,402
2008	176,360	176,360	-	-	144,864	25,159	1,065	2,701	2,571
2009	130,228	130,228	-	-	106,561	12,442	939	5,792	4,494
2010	127,877	127,877	-	-	103,747	14,642	2,540	4,127	2,821
2011	102,020	102,020	-	-	78,163	5,369	2,772	13,048	2,668
2012	125,645	125,645	-	-	102,865	7,611	2,105	9,020	4,044
2013	220,671	220,671	-	-	191,576	7,730	2,766	16,018	2,581
2014	301,802	282,318	36	19,449	233,560	23,936	2,939	17,620	4,263
2015	452,584	329,777	423	122,384	289,416	15,689	4,506	17,294	2,872
2016	479,957	330,043	9,101	140,812	262,463	39,720	1,605	18,122	8,133
2017	539,260	332,271	53,135	153,854	240,934	37,916	2,910	26,739	23,771
2018	526,573	298,331	98,373	129,868	165,279	54,697	3,797	37,417	37,141

Table4-1. Results of the cohort-analysis. The captions in the table are from the left: fishing year, catch (thousand tons), biomass (thousand tons), SSB (thousand tons), recruitment (million in numbers), catch proportion (%), and RPS (numbers/kg).

漁期年	漁獲量（千トン）	資源量（千トン）	親魚量（千トン）	加入量（百万尾）	漁獲割合（%）	再生産成功率（尾／kg）
1970	865	2,938	657	9,998	29	15.2
1971	855	3,737	807	14,084	23	17.5
1972	845	4,454	741	8,345	19	11.3
1973	822	4,171	981	6,958	20	7.1
1974	889	3,917	1,296	7,462	23	5.8
1975	897	3,391	1,164	10,095	26	8.7
1976	715	3,803	1,188	14,344	19	12.1
1977	1,071	4,699	1,341	10,460	23	7.8
1978	1,428	4,826	1,401	7,283	30	5.2
1979	1,275	3,276	1,337	3,291	39	2.5
1980	637	1,932	1,079	3,302	33	3.1
1981	398	1,810	737	3,725	22	5.1
1982	347	1,706	567	3,084	20	5.4
1983	378	1,464	514	3,397	26	6.6
1984	543	1,816	595	3,805	30	6.4
1985	422	1,713	496	5,410	25	10.9
1986	627	1,455	371	1,962	43	5.3
1987	327	909	343	630	36	1.8
1988	259	558	314	263	46	0.8
1989	125	295	175	199	42	1.1
1990	28	215	97	342	13	3.5
1991	26	320	74	965	8	13.0
1992	81	665	87	2,581	12	29.5
1993	398	705	114	565	56	4.9
1994	117	332	105	536	35	5.1
1995	141	350	94	1,126	40	12.0
1996	269	705	57	4,321	38	75.4
1997	318	628	54	489	51	9.1
1998	115	288	98	176	40	1.8
1999	77	235	96	504	33	5.3
2000	91	225	64	514	41	8.1
2001	53	153	63	276	35	4.4
2002	47	228	44	1,071	20	24.5
2003	76	252	60	545	30	9.0
2004	181	763	132	4,001	24	30.2
2005	226	849	89	666	27	7.5
2006	245	752	296	418	33	1.4
2007	188	579	241	1,636	33	6.8
2008	176	490	151	566	36	3.8
2009	130	538	132	1,769	24	13.4
2010	128	689	117	1,266	19	10.9
2011	102	868	212	1,161	12	5.5
2012	126	1,185	312	3,097	11	9.9
2013	221	3,411	367	18,632	6	50.8
2014	302	3,738	499	5,992	8	12.0
2015	453	3,476	715	5,211	13	7.3
2016	480	3,807	1,323	12,958	13	9.8
2017	539	4,327	1,238	8,927	12	7.2
2018	527	5,595	1,185	29,212	9	24.6

Appendix 1. The workflow of stock assessment



Annually estimated (by fishing season) catch at age until 2018 and various abundance indices based on various surveys

For the methodology of estimating the stock biomass (i.e. cohort analysis), see Appendices 2 and 3. For survey information, see Appendix 4. Natural mortality coefficient is assumed as 0.4

Annually estimated (by fishing season) catch at age and fishing mortality coefficient at age until 2018

Forward computation to 2019 season.

Assumption of recruitment in 2019 season

Estimated from two recruitment indices, Hockey-stick stock-recruitment relationship (based on the stock-recruitment relationship of 1970-2017 estimated in stock assessment in 2018), and SSB in 2019 (Appendix 9).

Catch at age of 1 year old and older in 2019 fishing season

Forward computation to 2020 season. F2019 is assumed as F2016-2018 F2019.

Assumption of recruitment after 2020 season

Estimated from Hockey-stick stock-recruitment relationship (based on the stock recruitment relationship of 1970-2017 addressed in stock assessment in 2018) and SSB estimated by the future projection.

Annually estimated catch at age and SSB after 2020 season

Forward computation of post-2020 season

Estimation of catch based on HCRs

HCRs are developed based on reference points of limit and fishing ban, and safety coefficient β.

Midterm future projection

ABC of 2020 season

Allowable catch based on estimated SSB in 2020 season and HCRs using SSB.

NOTE : Workflows in the dashed box are developed based on the discussions of stock-recruitment relationship and reference points (written in red) at the Committee of Stock Management Policy (http://www.jfa.maff.go.jp/j/press/sigen/190612.html, [in Japanese])

Appendix 2. Methodology of stock estimation

Catch at age, biomass, fishing mortality coefficient, and total catch are estimated by the cohort analysis using the equation by Pope (1972) (Appendix 6). Fishing season is defined as July to June of the following year. In the stock assessment, biological and fisheries events are assumed to occur in certain months: spawning in June, recruitment of young in July, and fishing in December, when is the middle of the fishing season. Natural mortality coefficient (M) is assumed as 0.4 year^{-1} based on Homma et al. (1987). Catch at age is estimated for major fisheries in the region between Miyazaki prefecture to the Pacific coast of Hokkaido prefecture as well as catches by foreign vessels. The age frequencies of catch by People's Republic of China and the Russian Federation after 2014 are assumed to be the same as that of Northern purse seine fishery from July to December, which operates near the area where Chinese and Russian vessels operate. Age of 6 and older are considered as 6+ years old based on the method by Hiramatsu (1999).

Catch at age is calculated based on equations (1) – (3),

$$N_{a,y} = N_{a+1,y+1}\exp(M) + C_{a,y}\exp\left(\frac{M}{2}\right) \qquad \text{if } a \leq 4 \qquad (1)$$

$$N_{5,y} = \frac{C_{5,y}}{C_{5,y} + C_{6+,y}} N_{6+}\exp(M) + C_{5,y}\exp\left(\frac{M}{2}\right) \qquad (2)$$

$$N_{6+,y} = \frac{C_{6+,y}}{C_{5,y} + C_{6+,y}} N_{6+}\exp(M) + C_{6+,y}\exp\left(\frac{M}{2}\right) \qquad (3)$$

where $N_{a,y}$ is the number of fish of age a in year y, $C_{a,y}$ is the catch of fish of age a in year y. The catch at age of the most recent year (2018 fishing season) is calculated based on equation (4) using the most recent fishing mortality coefficient $F_{a,2018}$ (i.e. terminal F).

$$N_{a,2018} = \frac{C_{a,2018}\exp\left(\frac{M}{2}\right)}{1 - \exp\left(-F_{a,2018}\right)} \qquad (4)$$

Fishing mortality coefficient F except for the terminal F are calculated based on the equation (5).

$$F_{a,y} = -\ln\left\{1 - \frac{C_{a,y}}{N_{a,y}}\exp\left(\frac{M}{2}\right)\right\} \qquad (5)$$

In this equation, $F_{a,y}$ is the fishing mortality coefficient of fish of age a in year y. The F of plus group is assumed to equal to the F of the age group which is 1 year younger than the oldest age group observed (equation 6 from Hiramatsu (1999)).

$$F_{6+,y} = F_{5,y} \tag{6}$$

F of 0 to 5 years old for the most recent year ($F_{0,2018} - F_{5,2018}$) are estimated exploratory by tuning. Four indices that is predicted to represent recruitment and SSB are used for tuning (Appendix table 2-1). However, since the number of eggs used as tuning index includes the area IV (Kagoshima pref., Satsunan region), the number is slightly different from that shown in Figure 4-1. Ridge VPA (Okamura et al. 2017) is adopted to cohort analysis to stabilize the estimation of terminal F. In ridge VPA, terminal F is estimated with minimizing the function of negative loglikelihood with penalty term as following equation (7).

$$\text{Minimize}\quad (1-\lambda)\sum_{k=1}^{4}\sum_{y}\left[\frac{\ln(2\pi\sigma_k^2)}{2}+\frac{\left\{\ln\left(I_{k,y}\right)-\ln\left(q_k X_{k,y}^{b_k}\right)\right\}^2}{2\sigma_k^2}\right]+\lambda\sum_{a=0}^{5}F_{a,2018}^2 \tag{7}$$

Here, λ is the size of penalty in ridge regression and between 0 and 1. σ_k^2 is the variance of index k and $I_{k,y}$ is the value of index k in year y. q_k is the proportional constant for index k, $X_{k,y}$ is the objective value (recruitment and SSB) for index k in year y calculated from the cohort analysis, and b_k is a coefficient that represents non-linear relationship between index and estimated VPA values. For standardized CPUE for YOY caught in midwater trawl from Northwestern Pacific spring survey (season of northbound migration) (k = 1) and fall survey (k = 2), which are indices for recruitment, observation error is assumed to be equal ($\sigma_1^2 = \sigma_2^2$) to nonlinear coefficient ($b_k \neq 1$) and therefore, q_k and σ_k^2 are estimated in equations 8 and 9, respectively.

$$q_k = \exp\left\{\frac{1}{n_k}\sum_{y}\ln\left(\frac{I_{k,y}}{X_y^{b_k}}\right)\right\} \tag{8}$$

$$\sigma_1^2 = \sigma_2^2 = \frac{1}{\sum_{k=1}^{2} n_k}\sum_{k=1}^{2}\sum_{y}\left\{\ln\left(I_{k,y}\right)-\ln\left(q_k X_{k,y}^{b_k}\right)\right\}^2 \tag{9}$$

Here, n_k is the length of years used in tuning of index k. For standardized CPUE for dip-net fishery (k = 3) and number of eggs (k = 4), the relationship between SSB was found to be relatively proportional, therefore b_k is fixed as 1 and q_k is estimated in equation 8 and σ_k^2 is estimated as following:

$$\sigma_k^2 = \frac{1}{n_k}\sum_{y}\left\{\ln\left(I_{k,y}\right)-\ln\left(q_k X_{k,y}^{b_k}\right)\right\}^2 \qquad k = 3, 4 \tag{10}$$

When the coefficient that represent nonlinear relationship b_k (k=1,2), which is standardized CPUE for spring and fall season is estimated based on the stock assessment of the previous year (Yukami et al. 2019), the estimated recruitment is 70.92 billion, which is more than three times of the historical maxima, and therefore considered as not appropriate (Appendix figure 2-1). Therefore, for the stock assessment of the present year, the minimum retrospective bias (Mohn's ρ, Mohn 1999) of SSB for the past 8 years is estimated by applying various b_k with interval of 0.1 under assumption of $b_1 = b_2$. As a result, $\lambda = 0.44$, $b_1 = b_2 = 1.8$, and recruitment in 2018 fishing season was found to be 29.21 billion fishes (Appendix figure 2-1). When nonparametric bootstrap is performed with fixed b_k to compare two methods, the coefficient of variation for recruitment of 2018 fishing season is 0.43 and median of bootstrap is 80.59 billion for the method based on the previous year and assumed to be overestimated (Appendix figure 2-1). When the new method is applied, the coefficient of variation is 0.43 and median of bootstrap is 29.41 billion fishes (value of point estimation 29.21 billion, bias of +0.7%). Since uncertainty and bias are decreased compared to the method from the previous year, the method which b_k is selected based on retrospective bias is selected as the method for the present year (Appendix figure 2-1).

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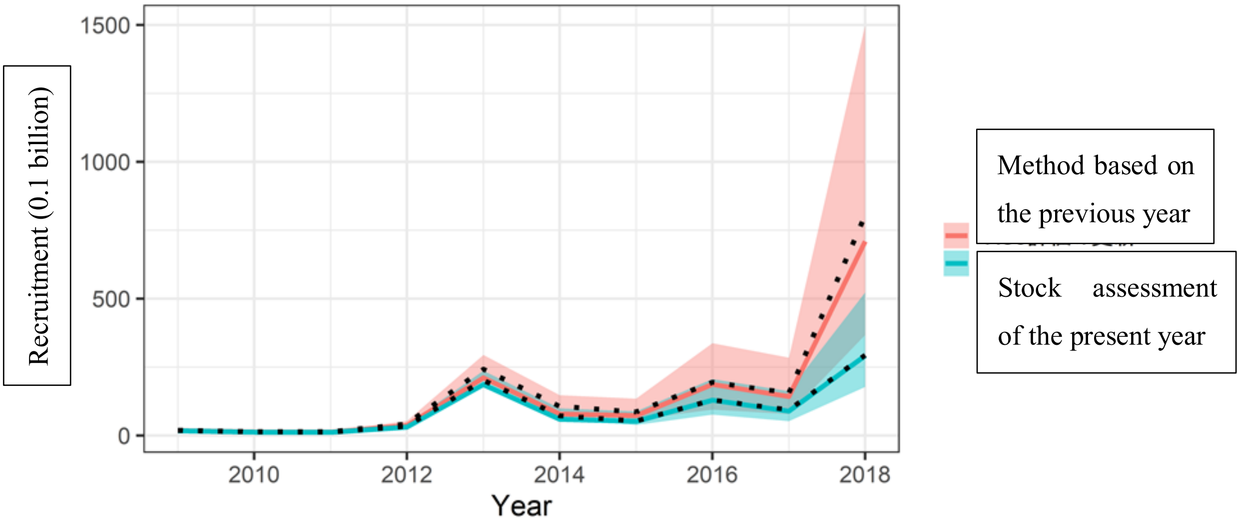

Appendix figure 2-1. The estimated recruitment since 2009. Red line represents the method based on the previous year and blue line represents the stock assessment of the present year. Shaded area represents 80% confidence interval and dots represent the median of bootstrap.

Appendix table 2-1. Tuning indices and estimated values.

Index	①	①’	②	②’	③	③’	④
Target		N_0		N_0		SSB	SSB
2002	3.0	6.2					
2003	31.7	18.7			5.5	8.7	
2004	172.9	210.3			4.5	6.9	
2005	20.8	20.0	23.6	17.7	3.3	3.5	
2006	0.3	0.5	0.8	2.2	25.5	34.6	
2007	296.3	131.7	10.0	6.9	86.6	95.9	334.9
2008	53.3	26.4	9.7	7.9	45.5	34.7	81.7
2009	43.5	22.7	60.7	46.1	56.5	41.5	75.0
2010	26.3	21.0	16.9	17.2	54.5	50.4	164.3
2011	5.4	3.4	4.5	3.2	116.2	99.0	145.5
2012	58.6	37.6	18.2	19.9	120.5	86.6	271.7
2013	2073.9	1614.7	1419.4	1409.4	131.9	116.2	264.3
2014	20.1	16.4	95.1	69.0	110.9	144.9	152.4
2015	49.0	182.0	169.0	183.1	120.3	162.1	145.7
2016	889.4	1097.3	1339.5	1261.4	172.5	238.4	102.8
2017	736.6	639.6	645.0	385.1	81.5	143.2	370.9
2018	3259.9	2931.5	6237.1	5402.3	142.9	211.6	601.6
2019	92.6	115.0	261.0	261.1	142.4	152.2	745.7
q		4.07E-05		4.27E-05		0.19	0.49
b		1.80*		1.80*		1.00**	1.00**
σ		1.05		1.05		0.68	0.71

① CPUE of YOY caught by midwater trawl from the spring survey in Northwestern Pacific (number of fish / net / 60 min)

② CPUE of YOY caught by midwater trawl from the fall survey in Northwestern Pacific (number of fish / net / 60 min)

③ CPUE of dip-net fishery at Izu Islands waters (kg / person / hour)

④ Number of eggs in region I – IV (entire Pacific coast, by 100 billion)

①’, ②’, and ③’are the standardized value of ①, ②, and ③ used as tuning indices (For standardization method, see Appendix 3).

* Fixed as b = 1.80

** Fixed as b = 1.00

Appendix 3 CPUE standardization

For the present stock assessment, three stock indices are standardized; CPUE of YOY caught in the stock survey of northern migratory pelagic fishes in Northwestern Pacific and the stock survey of fall pelagic fishes in Northwestern Pacific (hereafter, northern migration CPUE and fall CPUE, respectively) and dip-net fishing CPUE at Izu Islands waters (hereafter dip-net CPUE). CPUEs of midwater trawl survey at Northwestern Pacific represent the recruitment indices and dip-net CPUE represents SSB index. Although tuning indices include the number of eggs, the value of egg count is not standardized since the efficiency of egg survey is expected to be constant owing to the survey design. In this document, (1) the standardization of northern migratory CPUE and fall CPUE and (2) the standardization of dip-net CPUE are explained.

(1) Standardization of northern migratory CPUE and fall CPUE

CPUE of YOY (individuals/hour) caught by midwater trawl survey in northern migration survey and fall survey in Northwestern Pacific are standardized. Despite both surveys are conducted since 2001, data from 2002-2019 and 2005-2019 are used for northern migration CPUE and fall CPUE, respectively, due to the coverage of survey regions. Data with no significant catch (east of 175W, south of 32.5N, and north of 45N) are excluded from the northern migration CPUE and likewise similar data are excluded from the fall CPUE data (east of 175E, south of 35N, north of 50N).

To analyze CPUE data, delta-GLM (Lo et al. 1992) is applied since CPUE data consist of continuous numerical value greater than 0. This method analyzes two different models that estimate the probability of catch and estimate the CPUE when fish is caught. For the probability of catch, bimodal distribution is used for the error distribution (logit link) and for CPUE, gamma distribution is used (log link).

For northern migration CPUE, year (categorical), region (categorical), interaction between year and region, SST during the survey (continuous) and its square, water temperature at 50m depth during the survey and its square, and interaction between SST and water temperature at 50m depth are used as explanatory variable to estimate CPUE. Likewise, for fall CPUE, year (categorical), region (categorical), interaction between year and region, SST during the survey (continuous) and its square, water temperature at 30m depth during the survey and its square, and interaction between SST and water temperature at 30m depth are used as explanatory variable to estimate CPUE. To set the regions, delta-GLM-tree (Hashimoto et al. 2019), which is an extended form of GLM-tree (Ichinokawa and Brodziak 2010) is used. The delta-GLM tree model estimates the region to increase statistical predictability based on an assumption that both regions in bimodal model and gamma model are the same. In the present stock assessment, the survey area is divided by 2.5 degrees and region is estimated until the BIC becomes the minimal value. A brute force search is performed for both bimodal and gamma distribution model and the model with the most minimal BIC is selected as the best model.

As a result, year, region, SST and its square, and water temperature at 50m depth are selected as explanatory variables that estimate the probability of catch of northern migration CPUE. Likewise, year, region, water temperature at 30m depth and its square are selected as explanatory variables that estimate the probability of catch of fall CPUE. For both cases, year and region are selected as explanatory variables that estimate CPUE when fish is caught. In addition, region is separated into 4 regions.

Stock index is calculated from the estimated result of the best model estimated above. First, CPUE is estimated for each value of variables; year, region, SST, water temperature at 50m depth (for northern migration), and 30m depth (for fall). Since SST and water temperature at 30 and 50 m depth are continuous variables, CPUE is calculated for various values between the maximal and minimal data. Second, averaged estimated CPUE is calculated for each year and region. Lastly, estimated CPUE for each year is weighted averaged by area of each region and used as a stock index. As a result, standardized CPUE and nominal (arithmetic mean) CPUE show the similar trend (Appendix figure 3-1). For the standardized northern migration CPUE, 2018 was the highest followed by 2013. For standardized fall CPUE, 2018 was the highest followed by two equally high values, 2013 and 2016. Meanwhile 2019 is significantly less than 2018 and considered as second lowest and third lowest since 2013 for northern migration CPUE and fall CPUE, respectively.

(2) Standardization of dip-net CPUE

Following the assessment of the previous year, the dip-net fishery data from Kanagawa prefecture (2003-2019) and Shizuoka prefecture (2014-2019) are used. Since the dip-net CPUE data (kg / hour / person) are continuous numerical value greater than 0, delta-GLM (Lo et al. 1992) is applied. Like that of (1), bimodal distribution (logit link) and gamma distribution (log link) are used for error distribution. Of the available data (2003-2019), data collected during the spawning season, from January till July, are used.

To estimates CPUE, year (categorical), region (categorical), SST during the catch (continuous) and its square, month (categorical), vessel (categorical), and prefecture (categorical) are used as explanatory variables. Region is divided into 7 areas based on the data and longitude-latitude data. The best model is selected as a model with minimal BIC for each bimodal distribution model and gamma distribution model. As a result, year, region, month, and SST are selected as variables that estimate probability of catch and year, region, and month are selected as variables that estimate CPUE when fish is caught.

CPUE is estimated for every combination of variables and its average for each year is used as stock index. Although the standardized CPUE shows increasing trend since 2013 with relatively high level, the trend shows slight decrease in 2019 (Appendix figure 3-1).

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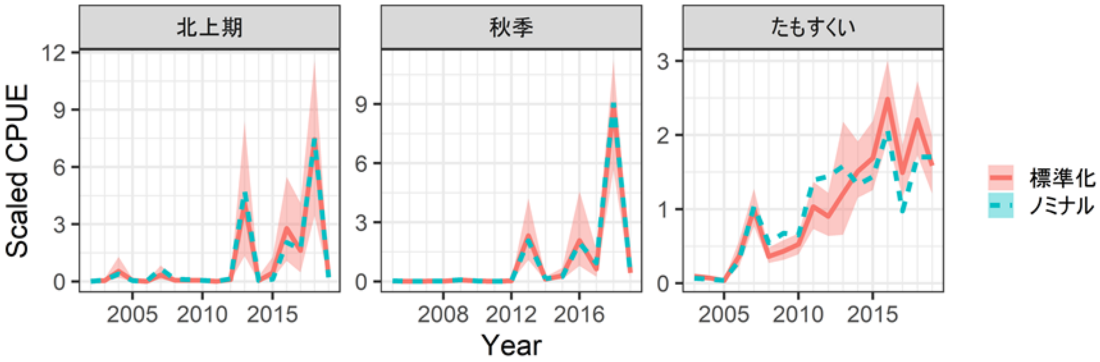

Appendix figure 3-1. Time series of Northern migration CPUE (left), fall CPUE (middle), and dip-net CPUE (right). Blue dotted line represents nominal CPUE and red line represents standardized CPUE. Values are normalized to have mean of 1 and shaded area represents 95% confidence interval.

Appendix 4 Overview of surveys and data sources

1) Larval and Juvenile fish survey at the transitional region

Conducted since 1996 with pre-survey in 1995 by National Research Institute of Fisheries Science (NRIFS) and Hokkaido National Fisheries Research Institute (HNFRI). The midwater trawl is hauled in May and July between Kuroshio extension and Kuroshio-Oyashio transitional area, where is a growing ground for larval and juvenile pelagic fishes. The survey observes the distribution of larval and juvenile fishes.

2) Stock survey of northern migratory pelagic fishes in Northwestern Pacific.

Conducted since 2001 with pre-survey in 2000 by Tohoku National Fisheries Research Institute (TNFRI) and NRIFS. The survey consists of two surveys; survey for direct estimation of pacific saury stock (by TNFRI) and stock survey of northern migratory pelagic fishes in NW Pacific (by NRIFS and TNFRI). Midwater trawl survey is conducted in May to July in waters between Kuroshio-Oyashio transitional area to Oyashio current region (between Pacific coast of Japan to 165W) by multiple research vessels to sample small pelagic fishes including pacific saury in migration to the northern waters. For this survey, CPUE of YOY are used as the recruitment index (Appendix table 2-1). In the present stock assessment, the predicted number of YOY, catchability (the proportion of stations where fish is caught) and length distribution are estimated for the area between Oyashio current and Kuroshio-Oyashio transition area (west of 169W with SST 12~21 degrees C) where is the major distribution of pacific mackerels (Figure 4-2)

3) Drift net survey in Eastern Hokkaido to Sanriku waters

Conducted since 1994 by Kushiro Fisheries Laboratory. The survey consists of four surveys operated in Eastern Hokkaido-Sanriku waters in June-October. The drift net is used to sample small pelagic fishes. The survey data is used to observe the distribution of pacific mackerels from YOY to adults and the CPUE is used for stock index.

4) Stock survey of fall pelagic fishes in Northwestern Pacific.

Conducted since 1984 by TNFRI as survey for improvement of fishery stock assessment systems. Drift net survey for pelagic fishes is conducted in the region in Eastern Hokkaido, Sanriku, and Joban region from August till November. The survey changes its name to distribution survey of pelagic fishes in Tohoku region and conducted in September and October. Since 2001, the survey gear has changed to midwater trawl and quantitative echo sounder as the target sample shifts to small pelagic fishes. Since 2005, the survey region has expanded to the eastern water of Kuril Islands. Starting from 2008, the survey is conducted by NRIFS as the stock survey of fall pelagic fishes in Northwestern Pacific and the survey has been observing the distribution of YOY in waters out of major fishing region with

CPUE of YOY being used as recruitment index (Appendix table 2-1). The recruitment index is calculated from the catchability of YOY by drift-net and midwater trawl surveys (Figure 4-2). Although the gears are different, the catchability of two gears are found to be indifferent based on the comparison of catchabilities in 2001 and 2002, when both gears were used concurrently. To reduce the effect of different station locations per surveys, the survey area is divided into five geographical sections. Each section is divided into Oyashio and warm current section, which comprises total of 10 sections. When the catchability of a section lacks data, a mean catchability of significantly related section is supplemented. The sum of the catchability of each section multiplied by weighting coefficient is used as a recruitment index in which the coefficient is adjusted to have consistency between the recruitment index and the temporal variation of recruitment. In this case, the recruitment consists of the estimated values from stock assessment in 2018 with data years ranging from 1984 to 2013, which uncertainty is expected to be low due to the application of fishing pressure throughout the ages.

5) Winter purse seine survey in Joban waters (Index for wintering juveniles)

Conducted by Ibaraki prefectural fisheries laboratory. The survey calculates index for wintering juveniles by taking a sum of mean catch per haul per day in 10 minutes grid of latitude and longitude in the wintering ground (Boso-southern Joban region: fishing ground of purse seine in 35-37N and west of 142E) (Figure 4-2). The season of the survey is defined as the time when the juvenile fish (< 25cm FL) exceeds 50% of the purse seine catch. Although the catch includes blue mackerels, the index can be considered as that for chub mackerel since 80-100% of juvenile mackerels wintering in the target regions are chub mackerels, according to the survey. However, the index tends to be low owing to lack of catch of YOY in the wintering ground since 2014.

6) Effective fishing effort and stock index of Northern purse seine

Conducted by Japan Fisheries Information Service Center (JAFIC). Fishing effort and stock index are calculated by the operational information of purse seine in the northern waters targeting mackerels (chub and blue). The data need to be treated with precaution since although the primary target is chub mackerel, the proportion of blue mackerels are substantial in certain years although the primary target is chub mackerel, according to JAFIC. CPUE is defined as catch per effort (number of hauls) (Figure 4-3). Stock index is defined as the sum of mean CPUE per region, where region is defined as fishing ground with grid of 30 minutes longitudinally and latitudinally (Figure 4-3). Effective fishing effort is defined as catch per mean density index (Figure 3-3). Mean density index is defined as stock index per number of regions.

7) Egg and larval survey

Conducted by joint venture institutions located on the pacific coast. The distribution of eggs of pelagic fishes are sampled and observed using modified NORPAC plankton net (335 micrometer mesh). Of the mackerel eggs, chub and blue mackerels are segregated since 2005 as species of eggs became identifiable (Figure 4-1, Appendix table 2-1).

8) CPUE of dip-net fishery

Conducted by Kanagawa prefectural fisheries laboratory (since 2003) and Shizuoka prefectural fisheries laboratory (since 2014). The dip net fishery primary catches chub mackerels and operates in Izu Islands waters where is a major spawning ground. The CPUE is calculated from the fishing record of vessels as catch per person per hour. The CPUE is used as an indicator of abundance and distribution of adult fishes in the spawning ground, which is used for SSB index (Appendix table 2-1)

Appendix 5. Fishing activity for chub mackerel by foreign vessels.

Pacific saury catches by foreign vessels, mainly Taiwanese, is increasing since 2000. China started Pacific saury fishing from 2012, it was possible to increase number of foreign vessels since then. It is important to monitor foreign vessels fishing activity for assessing Pacific saury stock accurately. While, Chinese vessels started to catch mackerels in the high sea of Northwest Pacific since 2014, to monitor its activity became important as well as Pacific saury.

Considering such situations, the trial to monitor fishing activity of foreign vessels by satellite remote sensing at night was started from 2014. The aim of project is to measure number of fishing vessels and to detect fishing grounds by extracting vessels from nightlight using remote sensing data of US satellite (Suomi NPP), and to determine fishery kinds by light intensity, EEZ boundary and surface temperature. Although only Pacific saury fishing vessels were target at first stage, the technique was also effective for fishing vessels targeting mackerels.

The method to extract and count fishing vessels targeting mackerels was developed and got good results, and reported the estimate of foreign vessel catch (Oozeki et al. 2018). However, still technical issue remained. Here, the distribution of fishing vessels using fishing light (including Pacific saury and squid fishing vessels) during May to October of 2014 to 2019 are shown in Appendix Fig. 5-1 as an example. It supposed that foreign vessels appeared from May and increased after July around the high sea near EEZ border. Fishing locations tended to shift offshore (Eastward) year by year, and concentrated around 160 degree East in August and September of 2019. Chinese purse seine and firelight dip net fishing vessels which targeted mackerels were recognized by eye watching observation by Japanese research vessels. It is expected that monitoring of foreign fishing vessels activity and catches may be able to be achieved by separating mackerel vessels from Pacific saury and squid vessels and counting number of it.

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Appendix 6: Details of cohort analysis results (Fishing season 1970-1981). From the top, catch at age (million fish), catch at age (thousand tons), F at age, abundance at age (million fish), abundance at age (thousand tons), and average weight at age.

年齢別漁獲尾数（百万尾）

年齢＼漁期年	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0歳	834	334	29	93	351	1,254	632	539	1,039	208	199	266
1歳	1,202	815	1,847	647	182	388	923	2,083	1,256	1,919	472	184
2歳	1,037	888	681	1,211	794	560	548	727	1,468	1,312	286	142
3歳	365	288	242	548	994	618	446	472	641	645	419	149
4歳	127	104	73	183	310	391	251	236	338	158	310	194
5歳	49	56	35	46	26	165	42	82	173	80	126	115
6歳以上	41	19	18	12	4	46	4	16	17	13	11	13
計	3,656	2,504	2,924	2,740	2,662	3,421	2,845	4,154	4,932	4,335	1,824	1,063

年齢別漁獲重量（千トン）

年齢＼漁期年	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0歳	63	21	2	9	25	57	48	48	101	15	12	28
1歳	226	165	417	152	43	71	142	388	328	420	77	39
2歳	299	342	231	346	262	186	159	222	452	416	95	46
3歳	147	159	111	194	387	265	202	213	255	278	188	65
4歳	68	84	43	81	150	189	133	133	174	85	169	122
5歳	32	60	26	28	18	93	28	55	104	52	85	84
6歳以上	30	23	15	11	4	35	3	13	15	9	11	14
計	865	855	845	822	889	897	715	1,071	1,428	1,275	637	398
漁獲割合	29%	23%	19%	20%	23%	26%	19%	23%	30%	39%	33%	22%

年齢別漁獲係数（F）および%SPR

年齢＼漁期年	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0歳	0.11	0.03	0.00	0.02	0.06	0.16	0.06	0.07	0.19	0.08	0.08	0.09
1歳	0.35	0.18	0.28	0.15	0.05	0.11	0.22	0.33	0.27	0.87	0.33	0.12
2歳	0.83	0.61	0.28	0.38	0.36	0.27	0.27	0.34	0.52	0.64	0.37	0.20
3歳	0.85	0.77	0.42	0.50	0.85	0.70	0.45	0.50	0.75	0.60	0.56	0.43
4歳	0.69	0.85	0.57	0.88	0.79	1.57	0.96	0.60	1.20	0.54	0.89	0.74
5歳	1.14	1.08	1.14	1.31	0.36	3.21	0.92	1.51	2.21	1.74	1.87	1.60
6歳以上	1.14	1.08	1.14	1.31	0.36	3.21	0.92	1.51	2.21	1.74	1.87	1.60
平均（Fbar）	0.73	0.66	0.55	0.65	0.40	1.32	0.54	0.69	1.05	0.89	0.85	0.68
%SPR	12.09	16.77	26.59	22.11	23.66	22.42	26.13	22.86	15.46	10.53	19.92	28.67

年齢別資源尾数（百万尾）

年齢＼漁期年	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0歳	9,998	14,084	8,345	6,958	7,462	10,095	14,344	10,460	7,283	3,291	3,302	3,725
1歳	5,015	6,019	9,167	5,570	4,588	4,714	5,740	9,098	6,570	4,032	2,036	2,051
2歳	2,248	2,378	3,368	4,633	3,204	2,926	2,843	3,092	4,393	3,376	1,132	978
3歳	776	657	867	1,700	2,115	1,498	1,503	1,457	1,478	1,742	1,189	524
4歳	311	221	204	383	691	604	498	642	590	466	640	454
5歳	88	104	63	77	107	209	84	128	237	119	183	175
6歳以上	74	35	32	20	18	58	7	25	23	19	16	20
計	18,509	23,499	22,047	19,342	18,184	20,105	25,019	24,902	20,574	13,045	8,497	7,927

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率（RPS、尾／kg）

年齢＼漁期年	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0歳	755	903	649	700	527	459	1,089	939	705	231	204	397
1歳	944	1,222	2,071	1,311	1,083	862	882	1,693	1,714	883	333	433
2歳	648	915	1,141	1,323	1,057	972	824	943	1,353	1,071	376	315
3歳	313	362	398	601	824	642	680	656	587	750	532	230
4歳	166	180	121	170	334	292	264	361	304	250	348	285
5歳	57	111	47	47	75	119	58	86	142	77	123	128
6歳以上	54	43	27	19	17	45	7	21	20	14	16	22
計	2,938	3,737	4,454	4,171	3,917	3,391	3,803	4,699	4,826	3,276	1,932	1,810
親魚量	657	807	741	981	1,296	1,164	1,188	1,341	1,401	1,337	1,079	737
RPS(尾/kg)	15.2	17.5	11.3	7.1	5.8	8.7	12.1	7.8	5.2	2.5	3.1	5.1

年齢別体重（g）

年齢＼漁期年	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
0歳	76	64	78	101	71	45	76	90	97	70	62	107
1歳	188	203	226	235	236	183	154	186	261	219	164	211
2歳	288	385	339	286	330	332	290	305	308	317	332	322
3歳	404	551	459	354	390	429	453	450	397	431	448	439
4歳	532	811	592	443	484	484	530	563	515	536	544	628
5歳	655	1,066	737	611	699	567	683	668	601	648	675	732
6歳以上	731	1,242	843	908	946	768	917	847	893	738	954	1,067

Appendix 6: Details of cohort analysis results (Fishing season 1982-1994). From the top, catch at age (million fish), catch at age (thousand tons), F at age, abundance at age (million fish), abundance at age (thousand tons), and average weight at age.

年齢別漁獲尾数（百万尾）

年齢＼漁期年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0歳	123	250	549	378	183	72	67	34	29	53	297	96	128
1歳	324	284	544	398	1,336	316	106	24	6	8	11	957	98
2歳	301	440	358	253	555	352	253	53	6	11	13	240	98
3歳	160	225	208	190	276	170	253	71	11	8	12	39	28
4歳	81	76	90	75	79	41	26	77	6	5	7	5	5
5歳	70	44	46	38	28	19	4	4	4	2	10	2	2
6歳以上	13	23	18	21	9	6	2	1	1	0	8	2	2
計	1,072	1,343	1,812	1,352	2,465	976	711	263	63	87	357	1,341	361

年齢別漁獲重量（千トン）

年齢＼漁期年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0歳	14	19	66	31	18	6	11	7	5	9	43	14	19
1歳	75	57	122	96	266	77	27	8	2	2	3	272	29
2歳	83	135	130	95	156	118	86	23	3	5	6	88	47
3歳	70	91	114	93	112	76	111	38	7	5	6	17	16
4歳	47	36	59	55	45	27	17	46	5	3	5	4	3
5歳	48	25	35	33	21	16	4	3	4	2	10	2	1
6歳以上	10	15	18	20	9	7	2	1	1	0	9	2	2
計	347	378	543	422	627	327	259	125	28	26	81	398	117
漁獲割合	20%	26%	30%	25%	43%	36%	46%	42%	13%	8%	12%	56%	35%

年齢別漁獲係数（F）および%SPR

年齢＼漁期年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0歳	0.05	0.09	0.19	0.09	0.12	0.15	0.37	0.23	0.11	0.07	0.15	0.23	0.34
1歳	0.19	0.19	0.39	0.26	0.68	0.40	0.44	0.27	0.07	0.05	0.02	1.54	0.51
2歳	0.36	0.55	0.52	0.40	0.98	0.48	0.89	0.53	0.13	0.22	0.13	1.34	0.82
3歳	0.45	0.65	0.74	0.76	1.57	1.45	1.07	0.92	0.24	0.32	0.53	0.96	0.69
4歳	0.56	0.52	0.80	0.88	1.24	1.86	1.39	2.10	0.22	0.20	0.59	0.61	0.36
5歳	0.90	0.93	0.93	1.49	1.53	2.19	1.66	1.16	0.88	0.14	1.23	0.38	0.51
6歳以上	0.90	0.93	0.93	1.49	1.53	2.19	1.66	1.16	0.88	0.14	1.23	0.38	0.51
平均（Fbar）	0.49	0.55	0.64	0.77	1.09	1.25	1.07	0.91	0.36	0.16	0.55	0.78	0.54
%SPR	28.22	22.71	15.41	20.35	6.54	12.79	8.32	16.27	46.24	51.66	34.84	2.80	11.66

年齢別資源尾数（百万尾）

年齢＼漁期年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0歳	3,084	3,397	3,805	5,410	1,962	630	263	199	342	965	2,581	565	536
1歳	2,279	1,967	2,072	2,102	3,317	1,165	363	122	106	206	604	1,487	299
2歳	1,224	1,263	1,086	944	1,083	1,130	523	156	62	66	131	396	213
3歳	539	573	486	434	426	272	469	143	61	37	35	77	69
4歳	230	231	200	155	136	60	43	107	38	32	18	14	20
5歳	145	88	92	60	43	26	6	7	9	21	18	7	5
6歳以上	26	47	36	34	14	8	3	1	2	3	14	6	6
計	7,527	7,566	7,777	9,140	6,981	3,291	1,670	736	620	1,329	3,401	2,552	1,148

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率（RPS、尾／kg）

年齢＼漁期年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0歳	348	262	457	441	192	54	44	41	58	163	370	81	78
1歳	531	393	463	507	661	284	92	40	39	63	174	423	88
2歳	338	388	393	355	304	379	178	66	36	32	56	146	101
3歳	237	230	266	212	173	121	206	77	41	21	19	33	40
4歳	134	110	131	115	78	38	28	64	32	21	13	10	13
5歳	99	51	71	52	33	22	6	6	8	16	18	6	5
6歳以上	20	30	35	32	13	9	3	1	2	3	15	7	7
計	1,706	1,464	1,816	1,713	1,455	909	558	295	215	320	665	705	332
親魚量	567	514	595	496	371	343	314	175	97	74	87	114	105
RPS（尾/kg）	5.4	6.6	6.4	10.9	5.3	1.8	0.8	1.1	3.5	13.0	29.5	4.9	5.1

年齢別体重（g）

年齢＼漁期年	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
0歳	113	77	120	82	98	86	168	207	170	169	143	143	146
1歳	233	200	223	241	199	244	255	325	365	305	288	284	294
2歳	276	307	362	376	281	336	341	426	582	488	424	368	476
3歳	439	402	547	489	407	446	440	537	661	585	529	430	578
4歳	583	475	656	741	572	644	654	599	828	654	749	705	661
5歳	681	576	768	855	755	838	886	814	954	790	990	943	896
6歳以上	758	645	993	943	947	1,112	1,066	1,034	1,101	957	1,114	1,115	1,116

Appendix 6: Details of cohort analysis results (Fishing season 1995-2007). From the top, catch at age (million fish), catch at age (thousand tons), F at age, abundance at age (million fish), abundance at age (thousand tons), and average weight at age.

年齢別漁獲尾数（百万尾）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0歳	362	1,578	147	32	145	252	7	244	66	767	42	6	425
1歳	123	193	885	69	17	86	69	17	206	87	523	62	53
2歳	49	23	61	177	24	13	40	6	32	72	53	376	70
3歳	28	20	13	13	41	11	5	6	7	11	32	25	157
4歳	9	10	6	1	10	14	4	4	2	4	13	8	4
5歳	3	4	4	0	1	1	3	3	1	1	1	2	1
6歳以上	2	3	2	0	0	0	2	2	1	1	1	0	0
計	576	1,830	1,118	292	238	376	131	281	314	944	664	479	709

年齢別漁獲重量（千トン）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0歳	38	186	22	5	24	40	1	27	8	101	5	1	51
1歳	50	50	254	22	5	31	24	6	48	24	165	22	17
2歳	23	10	26	79	12	6	18	3	12	41	25	199	33
3歳	17	11	7	7	25	6	3	4	3	8	18	16	84
4歳	7	6	4	1	8	8	2	2	2	4	10	5	3
5歳	3	3	3	0	1	1	2	3	1	1	1	2	1
6歳以上	2	2	2	0	0	0	3	2	1	1	1	1	0
計	141	269	318	115	77	91	53	47	76	181	226	245	188
漁獲割合	40%	38%	51%	40%	33%	41%	35%	20%	30%	24%	27%	33%	33%

年齢別漁獲係数（F）および%SPR

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0歳	0.50	0.59	0.46	0.25	0.43	0.91	0.03	0.33	0.16	0.27	0.08	0.02	0.38
1歳	0.90	0.72	1.12	0.52	0.26	0.65	0.93	0.12	0.66	0.41	0.37	0.20	0.27
2歳	0.68	0.51	0.69	0.96	0.44	0.42	1.01	0.22	0.46	0.67	0.63	0.66	0.47
3歳	0.77	0.89	0.87	0.39	0.80	0.46	0.37	0.55	0.52	0.37	1.01	0.96	0.88
4歳	0.63	0.95	1.15	0.18	0.77	0.95	0.37	0.60	0.41	1.11	1.48	0.96	0.44
5歳	0.61	1.08	2.54	0.19	0.44	0.14	0.72	0.82	0.44	0.74	1.06	1.15	0.30
6歳以上	0.61	1.08	2.54	0.19	0.44	0.14	0.72	0.82	0.44	0.74	1.06	1.15	0.30
平均（Fbar）	0.67	0.83	1.34	0.38	0.51	0.52	0.59	0.49	0.44	0.62	0.81	0.73	0.44
%SPR	7.28	8.62	5.71	14.44	16.74	9.44	13.79	30.07	18.53	20.17	17.36	23.08	19.18

年齢別資源尾数（百万尾）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0歳	1,126	4,321	489	176	504	514	276	1,071	545	4,001	666	418	1,636
1歳	254	459	1,604	207	92	219	138	179	518	312	2,054	412	275
2歳	120	69	149	351	83	48	77	36	107	179	138	949	226
3歳	63	41	28	50	90	36	21	19	20	45	61	49	328
4歳	23	19	11	8	23	27	15	10	7	8	21	15	13
5歳	9	8	5	2	4	7	7	7	4	3	2	3	4
6歳以上	4	5	3	0	2	3	6	4	3	3	2	1	1
計	1,601	4,922	2,290	796	798	854	541	1,327	1,204	4,551	2,943	1,847	2,482

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率（RPS、尾／kg）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0歳	119	510	74	29	85	81	38	121	68	527	78	57	198
1歳	103	119	461	67	28	80	48	63	122	87	649	149	86
2歳	57	31	64	157	43	20	34	17	40	102	66	501	106
3歳	39	22	15	26	55	18	13	11	10	33	35	31	176
4歳	19	12	7	6	18	16	9	6	6	7	16	11	9
5歳	8	6	3	2	4	6	5	5	3	3	2	3	3
6歳以上	4	4	3	0	2	3	6	5	4	3	2	1	1
計	350	705	628	288	235	225	153	228	252	763	849	752	579
親魚量	94	57	54	98	96	64	63	44	60	132	89	296	241
RPS(尾/kg)	12.0	75.4	9.1	1.8	5.3	8.1	4.4	24.5	9.0	30.2	7.5	1.4	6.8

年齢別体重（g）

年齢＼漁期年	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0歳	106	118	152	165	169	158	137	113	124	132	118	136	121
1歳	406	260	287	325	308	366	350	354	236	280	316	362	314
2歳	474	451	428	446	515	421	440	455	374	569	477	528	469
3歳	626	545	535	523	606	517	599	576	530	742	578	631	537
4歳	809	633	642	787	803	593	626	643	756	835	787	726	683
5歳	908	743	699	879	950	895	689	780	788	1,011	1,002	1,013	745
6歳以上	973	819	840	970	1,099	1,031	1,078	1,126	1,078	1,087	1,089	1,122	921

Appendix 6: Details of cohort analysis results (Fishing season 2008-2018). From the top, catch at age (million fish), catch at age (thousand tons), F at age, abundance at age (million fish), abundance at age (thousand tons), and average weight at age.

年齢別漁獲尾数（百万尾）

年齢＼漁期年	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	60	174	80	28	63	297	140	33	100	92	294
1歳	275	35	163	88	52	248	812	177	141	140	82
2歳	47	127	54	87	90	75	165	1,401	236	265	245
3歳	44	24	37	21	66	77	65	128	1,147	423	365
4歳	51	13	9	7	21	25	17	16	32	695	359
5歳	3	15	6	2	4	5	18	11	15	60	300
6歳以上	1	1	1	0	1	2	1	10	10	16	53
計	481	388	349	234	297	729	1,219	1,777	1,681	1,690	1,697

年齢別漁獲重量（千トン）

年齢＼漁期年	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	8	21	10	5	10	37	15	3	8	6	20
1歳	86	13	57	35	19	78	157	35	28	30	17
2歳	18	64	26	43	43	37	68	334	60	78	62
3歳	26	13	23	13	37	47	37	56	349	138	126
4歳	34	8	7	5	13	17	12	10	17	243	142
5歳	2	10	5	2	3	4	12	7	10	32	124
6歳以上	1	1	1	0	1	2	1	7	7	11	36
計	176	130	128	102	126	221	302	453	480	539	527
漁獲割合	36%	24%	19%	12%	11%	6%	8%	13%	13%	12%	9%

年齢別漁獲係数（F）および%SPR

年齢＼漁期年	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	0.14	0.13	0.08	0.03	0.03	0.02	0.03	0.01	0.01	0.01	0.01
1歳	0.60	0.14	0.21	0.15	0.09	0.16	0.08	0.06	0.05	0.02	0.02
2歳	0.52	0.82	0.42	0.21	0.28	0.22	0.19	0.26	0.12	0.16	0.05
3歳	0.85	0.72	0.82	0.36	0.31	0.52	0.38	0.28	0.44	0.44	0.44
4歳	1.16	0.90	0.95	0.41	1.03	0.23	0.26	0.19	0.13	0.70	1.17
5歳	1.14	2.98	2.89	0.77	0.61	1.03	0.32	0.34	0.35	0.49	1.07
6歳以上	1.14	2.98	2.89	0.77	0.61	1.03	0.32	0.34	0.35	0.49	1.07
平均（Fbar）	0.79	1.24	1.18	0.39	0.42	0.46	0.23	0.21	0.21	0.33	0.55
%SPR	14.62	23.36	26.49	42.12	40.66	40.33	49.60	45.05	45.73	37.09	37.88

年齢別資源尾数（百万尾）

年齢＼漁期年	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	566	1,769	1,266	1,161	3,097	18,632	5,992	5,211	12,958	8,927	29,212
1歳	749	330	1,043	783	755	2,025	12,247	3,902	3,466	8,604	5,909
2歳	141	277	193	566	453	464	1,154	7,544	2,470	2,208	5,653
3歳	95	56	81	85	308	230	249	639	3,910	1,463	1,263
4歳	91	27	18	24	40	152	91	114	323	1,682	635
5歳	6	19	7	5	11	9	81	47	63	190	558
6歳以上	2	2	1	0	2	4	3	41	42	50	99
計	1,649	2,480	2,610	2,625	4,665	21,516	19,818	17,498	23,233	23,124	43,329

年齢別資源量（千トン）、親魚量（千トン）、再生産成功率（RPS、尾／kg）

年齢＼漁期年	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	78	212	159	210	482	2,295	628	490	1,049	613	1,958
1歳	234	125	366	308	282	635	2,373	778	690	1,858	1,212
2歳	54	139	95	276	217	227	474	1,796	633	654	1,441
3歳	56	31	49	52	169	141	143	279	1,191	479	436
4歳	61	16	13	17	25	102	63	72	175	587	251
5歳	4	13	6	4	8	7	53	29	40	101	231
6歳以上	2	1	1	0	1	4	3	31	29	36	66
計	490	538	689	868	1,185	3,411	3,738	3,476	3,807	4,327	5,595
親魚量	151	132	117	212	312	367	499	715	1,323	1,238	1,185
RPS(尾/kg)	3.8	13.4	10.9	5.5	9.9	50.8	12.0	7.3	9.8	7.2	24.6

年齢別体重（g）

年齢＼漁期年	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
0歳	138	120	126	181	156	123	105	94	81	69	67
1歳	312	377	351	393	373	314	194	199	199	216	205
2歳	385	503	490	488	480	489	410	238	256	296	255
3歳	589	557	606	614	550	612	574	436	305	328	345
4歳	672	599	729	701	627	672	693	637	540	349	396
5歳	806	694	796	842	751	747	656	624	629	529	414
6歳以上	995	838	940	909	868	886	793	761	697	724	671

Appendix 7. The values of References, Stock status and Fishing intensity.

The estimated value of Biological reference points and results of cohort model.

Items	Values	Remarks
SBtarget	1,545,000 tons	SBmsy
SBlimit	562,000 tons	SB 0.6msy
SBban	67,000 tons	SB 0.1msy
Umsy	10%	Catch ratio at MSY
MSY	372,000 tons	
β	0.9	The constant multiplied to Fishing intensity to maintain stock certain level. In the case of β=0.9, the stock will increase more than management target at 2030.
SB2018	1,185,000 tons	SSB at 2018
U2018	9%	Fishing ratio at 2018
F2018/Fmsy	2.48	

*It is recommended that SBmsy=1,545,000 tons as SBtarget, SB0.6msy as SBlimit, and SB0.1msy as SBban, respectively at the stock assessment meeting in 2019.

*SBcurrent=1,185,000 tons estimated by cohort model is below SBtarget, but is above SBlimit and SBban. F2018 is above Fmsy (F2018/Fmsy=2.48), but U2018 is similar to Umsy.

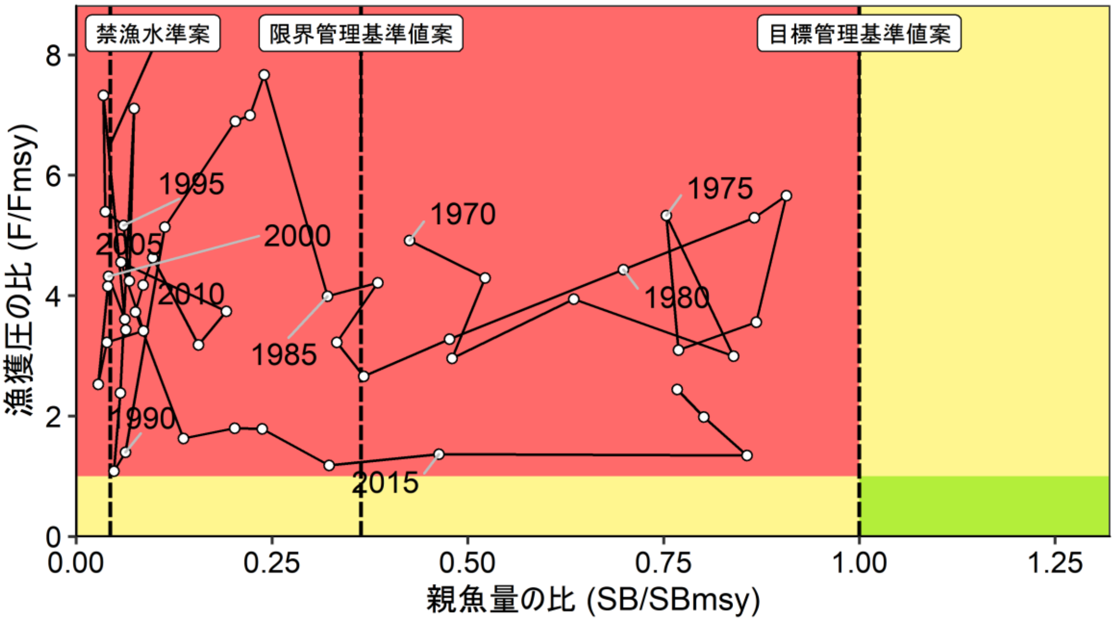
*The Kobe plot using SBtarget and Fmsy is shown in appendix Figure 7-1. Fishing intensity on the species has been over the level of Fmsy after 1970. The SSB has been low from SBtarget after 1970.

*The status of SSB and Fishing pressure are considered using Kobe plots. It is defined if SSB above SBtarget as “appropriate”, SSB below SBtarget and above SBlimit as “warning”, and SSB below SBlimit and above SBban as “rebuilt required”, and SSB below SBban as “fishery ban”.

For Fishing pressure, it is defined if it below Fmsy as “appropriate”, it over Fmsy as “over fishing”.

*SB2018 is below SBtarget and above SBlimit, then considered as “warning”. F2018 is over Fmsy, then considered as “over fishing”. The status of SSB is considered “increasing” from the transition of past five years (2014-2018).

Status of SSB	warning
Status of fishing pressure	Over fishing
Status of SSB transition	increasing



Appendix Fig. 7-2. Kobe plots of chub mackerel pacific stock.

Appendix 8. Estimations of catch under HCR.

The HCR is a rule which determine Fishing mortality and ABC level to maintain SSB above SBtarget. If the SSB decreased below SBlimit, fishing mortality was decreased until SBban along straight line. Fmsy should be multifield with β. The recommended HCR was shown in Appendix Fig. 8-1. For instance, it is shown in the case of β=0.9.

The desirable catch of 2020 was estimated by the projection following the HCR. The projection was made using forward cohort model and recruitment predicted by reproductive relation with SSB. Ten thousands of iteration was made for the estimation considering uncertainty of recruitments.

The catch of 2019 was assumed 794,000 tons predicted by the fishing pressure (F2016-F2018). The expected fishing pressure in 2020 by projection using SSB2020 was assumed fishing pressure to estimate expected catch in 2020.

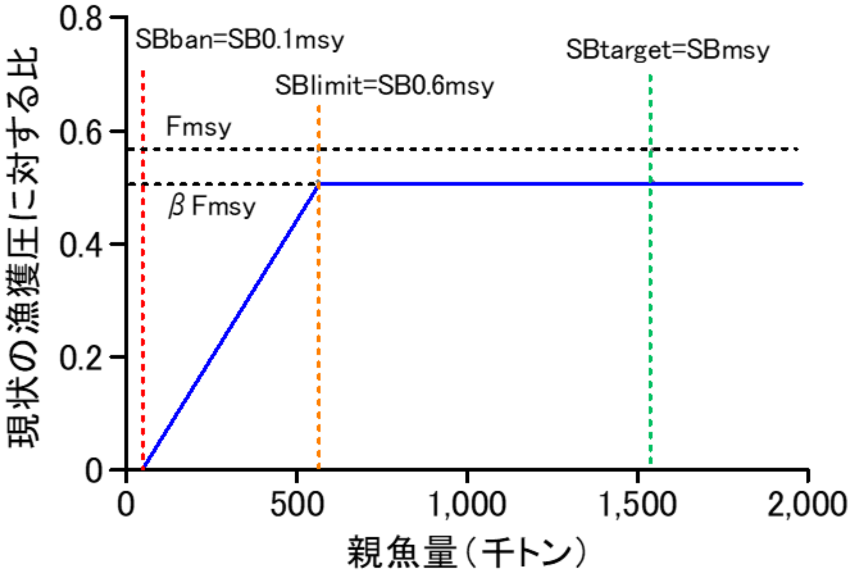
In the results of projection, expected catch in 2020 is 474,000 tons using β=0.9, and 523,000 tons assuming β=1.0. The predicted SSB in 2020 was 1,984,000 tons in average, and all estimation were over SBtarget.

SSB in 2020（average of prediction）: 1,984,000 tons			
Items	predicted catch in 2020 (thousands tons)	（F/F2016-2018）	Fishing rate in 2020 (%)
Fishing pressure scientifically suggested			
β=0.9	474	0.50	7
Other suggested catch (using differentβin HCR)			
β=1.0	523	0.55	8
β=0.8	424	0.44	7
β=0.6	323	0.33	5
β=0.4	218	0.22	3
β=0.2	111	0.11	2
β=0	0	0	0
F2016-2018	891	1.00	14

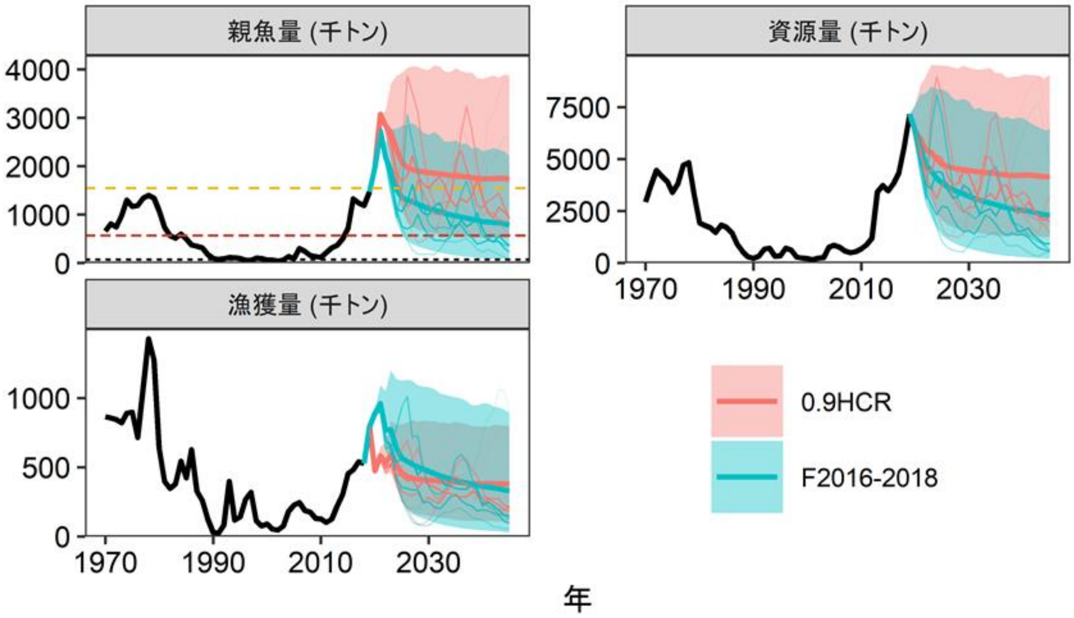
The mid and long term projection results were shown in Appendix table 8-1, 8-2 and Fig.8-2. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 1,768,000 tons usingβ=1.0 (80% confidence limit ranged 717,000-3,091,000 tons), and 1,870,000 tons usingβ=0.9 (80% confidence limit ranged 780,000-3,239,000 tons).

The probability of SB above SBtarget is 47% usingβ=1.0, and 52% usingβ=0.9. The probability of SB above SBlimit is 96% usingβ=1.0, and 97% usingβ=0.9. The probabilities above SBban are 100% in all cases.

Uncertainty considered: Recruitment					
Items	predicted SSB in 2030 (thousands tons)	80% confidence limits （thousands tons ）	Probability of SSB above References below (%)		
			SBtarget	SBlimit	SBban
Fishing pressure scientifically suggested					
β=0.9	1,870	780-3,239	52	97	100
Other suggested catch (using differentβin HCR)					
β=1.0	1,768	717-3,091	47	96	100
β=0.8	1,981	845-3,408	56	98	100
β=0.6	2,229	1,000-3,772	65	99	100
β=0.4	2,531	1,176-4,237	76	100	100
β=0.2	2,913	1,406-4,807	86	100	100
β=0	3,418	1,718-5,550	94	100	100
F2016-2018	1,128	353-2,144	22	75	100



Appendix Figure 8-1. HCR for chub mackerel Pacific stock. Current fishing pressure is F2016-2018. The value of βis 0.9.



Appendix Figure 8-2. Comparison of the projection results between HCR adapted case and to keep Fishing pressure F2016-2018 case. The bold line indicates average values, shadow zone shown 80% confidence limits, solid lines are some example of projection. The yellow dotted line indicates SBtarget, red dotted is SBlimit, and Black dotted is SBban, respectively. The catch in 2019 was predicted 794,000 tons by Fcurrent (F2016-2018) and β=0.9 of HCR. The Fcurrent (F2016-2018) was detarmined by assuming %SPR at average F during 2016-2018 is equal to the %SPR at Fmsy.

Explanation of figure: Top left is projection of SSB (thousands tons), top right is stock biomass, and bottom left is catch projection.

Appendix table 8-1. The probability of SSB above SBtarget (table a) and above SBlimit (table b) are estimated by future projection under β values from 0 to 1.0. The catch in 2019 was assumed as 794,000 tons projected by Fcurrent (F2016-2018), and the catch from 2020 was calculated by HCR.

(a) The probabilities SSB above SBtarget.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	0	100	100	100	100	88	61	53	50	49	48	47	42	42
0.9	0	100	100	100	100	95	67	58	54	53	52	52	47	46
0.8	0	100	100	100	100	99	74	63	59	58	56	56	52	51
0.7	0	100	100	100	100	100	81	68	64	62	61	61	57	57
0.6	0	100	100	100	100	100	88	74	69	67	66	65	62	62
0.5	0	100	100	100	100	100	94	81	75	72	71	70	68	68
0.4	0	100	100	100	100	100	98	87	81	78	76	76	74	73
0.3	0	100	100	100	100	100	100	92	87	83	81	81	79	79
0.2	0	100	100	100	100	100	100	97	91	88	86	86	84	84
0.1	0	100	100	100	100	100	100	99	95	93	91	90	89	88
0.0	0	100	100	100	100	100	100	100	99	96	95	94	93	92

(b) The probabilities SSB above SBlimit.

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	100	100	100	100	100	100	100	100	98	97	97	96	91	90
0.9	100	100	100	100	100	100	100	100	99	98	98	97	94	92
0.8	100	100	100	100	100	100	100	100	100	99	98	98	96	95
0.7	100	100	100	100	100	100	100	100	100	100	99	99	97	96
0.6	100	100	100	100	100	100	100	100	100	100	99	99	98	98
0.5	100	100	100	100	100	100	100	100	100	100	100	100	99	99
0.4	100	100	100	100	100	100	100	100	100	100	100	100	99	99
0.3	100	100	100	100	100	100	100	100	100	100	100	100	99	100
0.2	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Appendix table 8-2. The projection results for SSB (a) and future catch (b) were estimated by future projection under β values from 0 to 1.0.　The catch in 2019 was assumed as 794,000 tons projected by Fcurrent (F2016-2018), and the catch from 2020 was calculated by HCR.

(a)　Predicted SSB in thousands tons (average of 10,000 iterations)

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	1,472	1,984	3,032	2,761	2,581	2,231	1,977	1,870	1,829	1,807	1,784	1,768	1,623	1,614
0.9	1,472	1,984	3,073	2,844	2,691	2,351	2,087	1,973	1,927	1,904	1,884	1,871	1,737	1,733
0.8	1,472	1,984	3,114	2,929	2,807	2,479	2,208	2,086	2,034	2,010	1,991	1,981	1,860	1,860
0.7	1,472	1,984	3,156	3,017	2,929	2,617	2,341	2,210	2,153	2,126	2,108	2,100	1,991	1,995
0.6	1,472	1,984	3,199	3,109	3,058	2,767	2,486	2,348	2,285	2,255	2,236	2,229	2,132	2,139
0.5	1,472	1,984	3,243	3,204	3,195	2,928	2,645	2,501	2,433	2,398	2,378	2,372	2,284	2,294
0.4	1,472	1,984	3,287	3,302	3,338	3,102	2,820	2,672	2,598	2,559	2,537	2,531	2,450	2,461
0.3	1,472	1,984	3,332	3,404	3,491	3,290	3,013	2,862	2,784	2,742	2,717	2,710	2,633	2,645
0.2	1,472	1,984	3,378	3,510	3,651	3,493	3,226	3,076	2,995	2,949	2,921	2,913	2,838	2,849
0.1	1,472	1,984	3,424	3,619	3,821	3,713	3,461	3,315	3,234	3,186	3,157	3,147	3,071	3,082
0.0	1,472	1,984	3,471	3,733	4,001	3,952	3,721	3,585	3,507	3,460	3,429	3,418	3,340	3,350

(b)　Predicted future catch in thousands tons (average of 10,000 iterations)

（千トン）

β	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2040	2050
1.0	794	523	633	566	625	540	478	453	440	433	428	425	391	386
0.9	794	474	582	529	592	516	457	433	421	414	410	408	380	376
0.8	794	424	529	488	554	488	434	410	398	392	389	387	365	362
0.7	794	374	473	444	512	456	406	383	372	366	363	362	345	343
0.6	794	323	415	395	463	417	373	352	342	336	334	333	319	318
0.5	794	271	354	343	407	372	334	316	306	301	299	298	288	287
0.4	794	218	290	285	345	319	288	273	264	260	258	257	250	249
0.3	794	165	222	223	274	257	234	222	215	211	210	209	204	203
0.2	794	111	152	155	193	184	169	161	156	153	152	152	148	148
0.1	794	56	78	81	102	99	92	88	85	84	83	83	81	81
0.0	794	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 9 Stock projection method

Based on the abundance estimate obtained, we conducted future projection of the stock by applying the HCR. For the projection of the recruitment of the assessment year (2019 fishing season), we applied a value which the projected recruitment was updated by the recruitment indices of that year using Bayes theorem, which the detail is as follows. At first, we set a prior distribution for the recruitment in 2019 (R_{2019}) based on the Hockey-stick S-R relationship. For the estimation of the parameters of the S-R relationship, we used the SSB and recruitment based on the stock assessment conducted in 2018, which uses least-squares method as optimization method, and considers autocorrelation of the recruitment residuals (for details see Nishijima *et al.* 2019). The residuals between the projected value from the S-R relationship and recruitment and SSB in 2018 (29.2 billion in numbers, and 1.185 million tons respectively) is estimated from equation (11), resulting in a value of 1.29.

$$\varepsilon_{2018} = \ln R_{2018} - \ln[f(a, b, SSB_{2018})] = 1.29 \tag{11}$$

$f(a, b, SSB)$ is defined as follows:

$$f(a, b, SSB) = \begin{cases} a \times SSB & if\ SSB < b \\ a \times b & otherwise \end{cases} \tag{12}$$

where, *a*=7.578 (thousand in numbers/ton) and *b*=1.056 (thousand tons) (Nishijima *et al.* 2019). Based on these values and the estimated SSB in 2019 (1.471 million tons), the recruitment in 2019 based on the S-R relationship is estimated by the following equation:

$$\hat{R}_{2019,0} = f(a, b, SSB_{2019}) \times \exp(\rho \times \varepsilon_{2018}) \tag{13}$$

This results in an estimated recruitment of 13.02 billion in numbers. Where, ρ is the autocorrelation parameter, which is set to be 0.376. Together with this estimate and recruitment variation of $\hat{\sigma}_0^2 = 0.837^2$, the prior distribution of the recruitment in 2019 is as follows:

$$\ln(R_{2019}) \sim \mathrm{Normal}\left(\ln\left(\hat{R}_{2019,0}\right), \hat{\sigma}_0^2\right) \tag{14}$$

Next, the likelihoods of the two recruitment indices (normalized CPUE while heading to the north, and normalized CPUE during autumn fishing season) used as the tuning indices is given by the following equation:

$$\ln\left(I_{k,2019}\right) \sim \mathrm{Normal}\left(\ln\left(\hat{q}_k R_{2019}^{b_k}\right), \hat{\sigma}_k^2\right) \qquad k = 1, 2 \tag{15}$$

This equation is as that of Appendix Table 2-1. The projected recruitment in 2019 which maximizes the posterior probability is given by the weighted average shown below (Gelman *et al.* 1995):

$$\ln\left(\hat{R}_{2019}\right) = \frac{\hat{w}_0 \ln\left(\hat{R}_{2019,0}\right) + \hat{w}_1 \ln\left(\hat{R}_{2019,1}\right) + \hat{w}_2 \ln\left(\hat{R}_{2019,2}\right)}{\hat{w}_0 + \hat{w}_1 + \hat{w}_2} \qquad (16)$$

where, $\hat{w}_k$is the weight of the prior distribution (k=0) and that of the recruitment indices (k=1,2) defined as $\hat{w}_k = 1/\hat{\sigma}_k^2$, （$\hat{w}_0 = 1.43$, $\hat{w}_1 = \hat{w}_2 = 0.91$）. $\hat{R}_{2019,k}$（k=1,2）is the recruitment for 2019 estimated by each recruitment indices, and is defined as $\hat{R}_k = \left(I_{k,2019}/\hat{q}\right)^{\frac{1}{\hat{b}_k}}$ (3.84 billion in numbers for the CPUE while heading to the north, and 6.83 billion in numbers for the CPUE during autumn fishing season). From equation (16), the weighted average of the estimated recruitment in 2019 is calculated to be $\hat{R}_{2019} = 7.72$ billion in numbers. The recruitment onwards from 2020 is projected based on the Hockey-stick S-R relationship (a=0.00758, b=1056000) suggested at the Research Institute meeting on biological reference points for the Pacific stock of Chub Mackerel in 2019. The data used for the estimation of the parameters of the S-R relationship is based on the SSB and recruitment estimated by the stock assessment in 2018, which uses least-squares method as the optimization method. For more details, please refer to 'Technical details on the estimation of S-R relationship, calculation of the biological reference point, and the simulation of the projections' (Meeting report of the research institutes in 2019, https://github.com/ichimomo/future-text/blob/master/technical_document.pdf).

The F used for the projection is estimated based on the HCR set for the first group of stocks (group of data rich species) which is detailed in 'Basic guidelines for the harvest control rules and the estimation of the Allowable Biological Catch (ABC)'. The parameters used for the future projections are shown in Appendix Table 9-1. As for the selectivity and average weight of the catch, we used the values that was suggested at the research institute meeting on reference point held in 2019. As for the S-R relationship parameters, these values of selectivity and average weight of catch are based on the stock assessment of this species in 2018, and was used in the projection there. The %SPR estimated by the current fishing pressure (F2016-2018) under this selectivity was set to be same as the %SPR estimated by the average F of 2016-2018. The catch in 2019 was estimated to be 794 thousand tons based on the current fishing pressure (F2016-2018).

As for the projection of the numbers at age, we used forward calculation method for the cohort-analysis (equation 17).

$$N_{a+1,y+1} = N_{a,y} \exp\left(-F_{a,y} - M\right) \qquad \text{※ when } a \le 4 \qquad (17a)$$

$$N_{6+,y+1} = \left(N_5 + N_{6+}\right) \exp\left(-F_{5,y} - M\right) \qquad (17b)$$

The catch at age in numbers are calculated by equation (18) which uses the numbers at age estimated by the above equation and the F value assumed for each fishing scenarios.

$$C_{a,y} = N_{a,y}\left(1 - exp\left(-F_{a,y}\right)\right) exp\left(-\frac{M}{2}\right) \qquad (18)$$

References

Gelman, A., J. B. Carlin, H. S. Stern and D. B. Rubin (1995) Bayesian Data Analysis, Chapman & Hall/CRC.

西嶋翔太・由上龍嗣・井須小羊子・上村泰洋・古市　生 (2019) 平成31（2019）年度マサバ太平洋系群の管理基準値等に関する研究機関会議報告書. http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/detail_masaba_p.pdf (last accessed 30 October 2019)

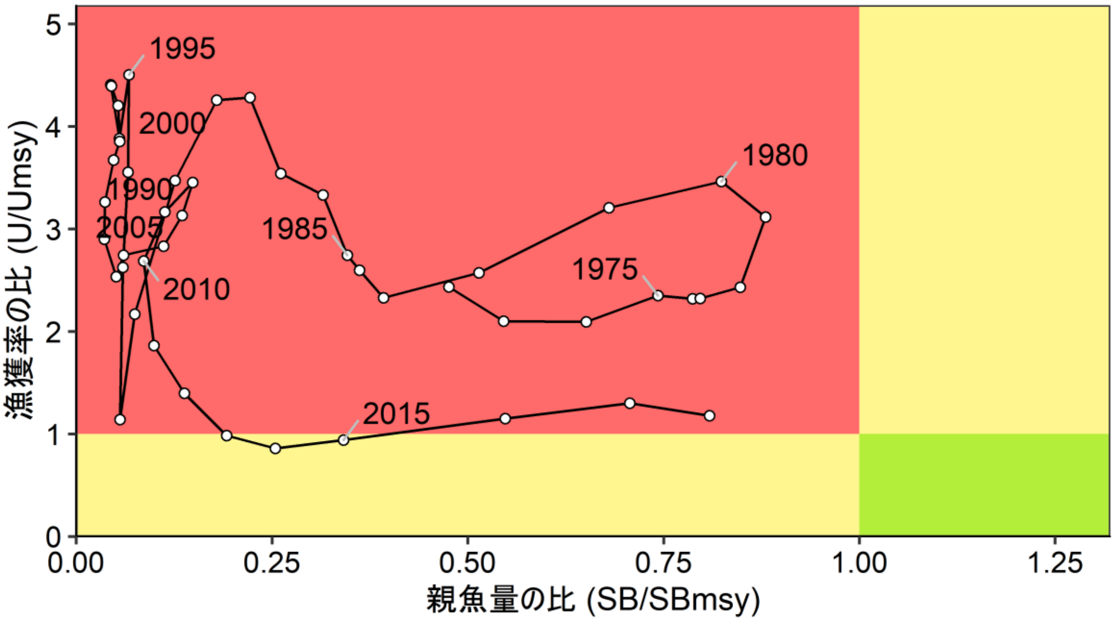
Appendix Table 9-1. Parameters used for the future projection

Age	Selectivity	Fmsy	F2016-2018	Average weight（g）	*M*	Proportion matured
0	0.04	0.02	0.03	94	0.40	0.00
1	0.14	0.05	0.09	202	0.40	0.00
2	0.29	0.10	0.18	264	0.40	0.20
3	0.53	0.18	0.33	316	0.40	0.80
4	0.55	0.19	0.34	349	0.40	1.00
5	1.00	0.35	0.62	529	0.40	1.00
6+	1.00	0.35	0.62	645	0.40	1.00

Appendix 10 Kobe plot based on fishing proportion

Below shows a Kobe plot based on the SSB and its corresponding fishing rate (U). The SSB for the entire period considered is below the level which attains MSY. The ratio of the fishing rate (U/Umsy) during the 1970s to the 2000s were higher than that which attains MSY except for year 1991; however, since 2013, the ratio is around the level which attains MSY.

Item	Suggested value	Remarks
SBmsy	1.545 million tons	SSB that attains MSY
Umsy	10%	Fishing rate that attains MSY
U2018	9%	Fishing rate in 2018
U2018/ Umsy	0.965	Ratio of the fishing rate in 2018 to that which attains MSY



Appendix Figure 10-1. The relationship between past SSB and fishing rate to that which gives MSY (SBmsy and Umsy) (Kobe plot). The fishing rate and SSB is the three year moving average. For year 2015, it is the average of 2013-2015.