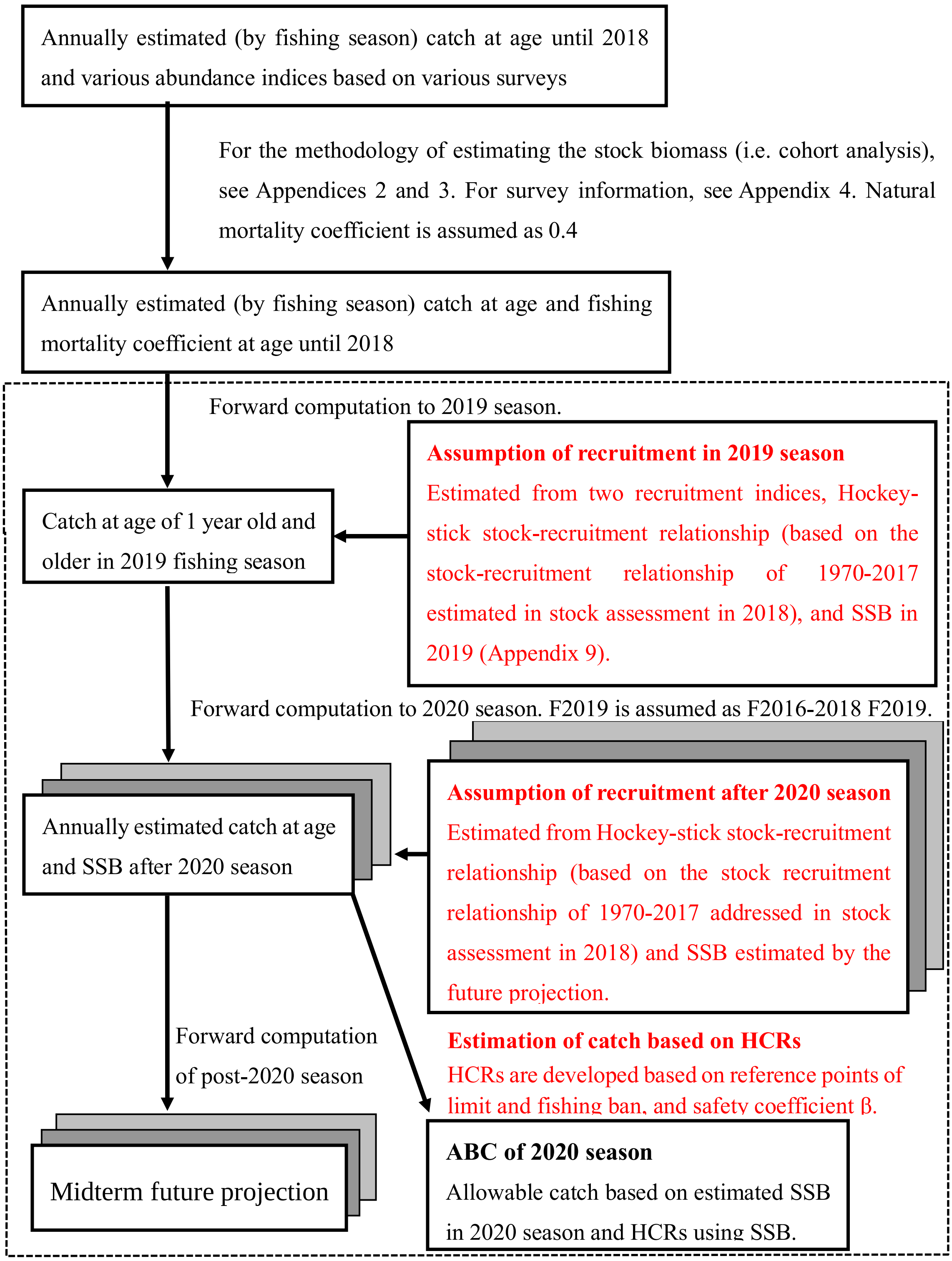
Appendix 1. The workflow of stock assessment




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),

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

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

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

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).

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

Here, $\lambda$ is the size of penalty in ridge regression and between 0 and 1. $\sigma_k^2$ 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 $\sigma_k^2$ are estimated in equations 8 and 9, respectively.

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

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

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 $\sigma_k^2$ is estimated as following:

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

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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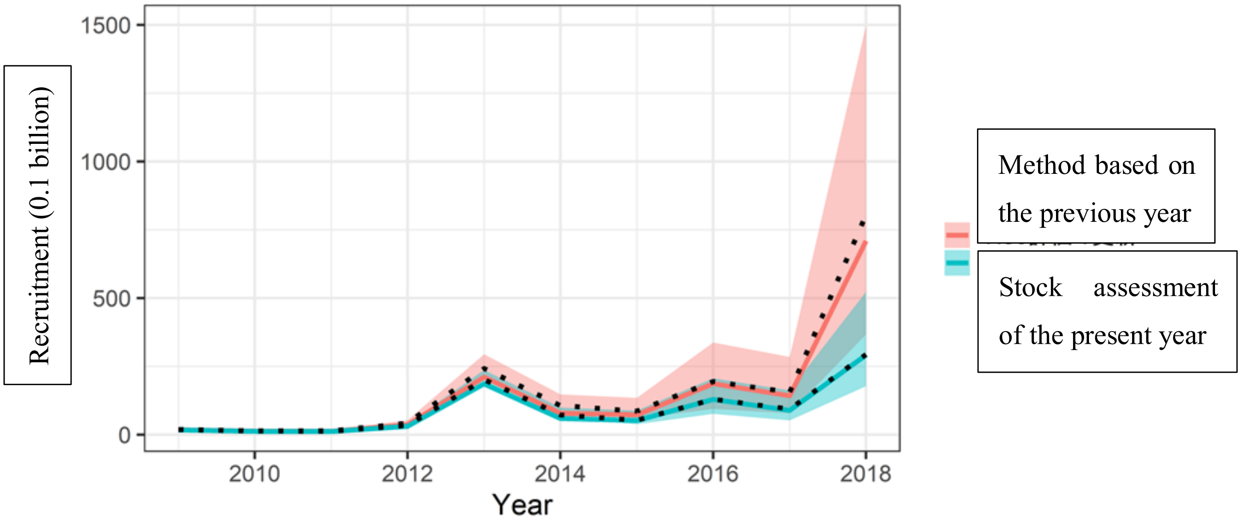


Appendix figure 2-1. The estimated recruitment since 2009. Red line represents the method based on the previous year and blue line represents the stock assessment of the present year. Shaded area represents 80% confidence interval and dots represent the median of bootstrap.

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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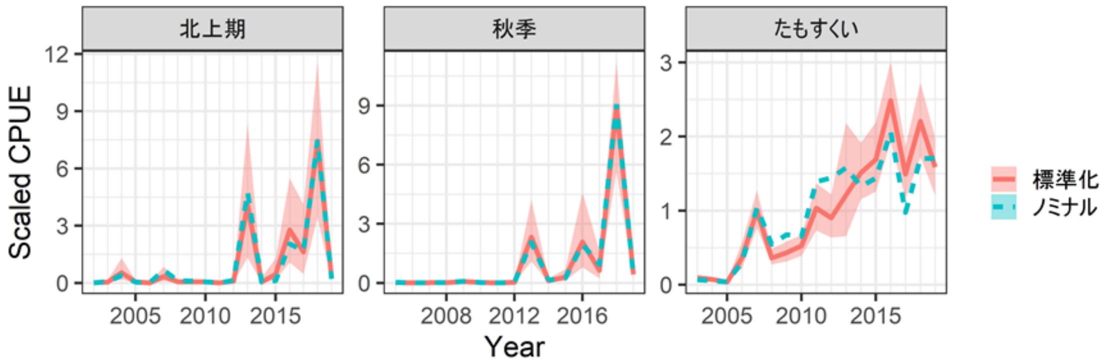


Appendix figure 3-1. Time series of Northern migration CPUE (left), fall CPUE (middle), and dip-net CPUE (right). Blue dotted line represents nominal CPUE and red line represents standardized CPUE. Values are normalized to have mean of 1 and shaded area represents 95% confidence interval.

## 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.

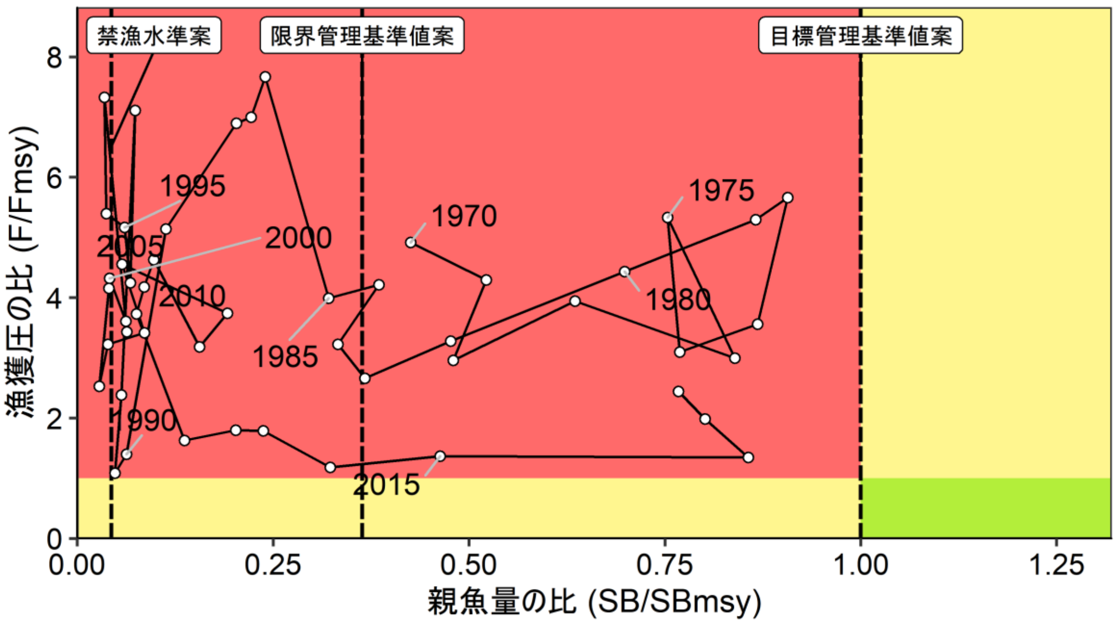
*The Kobe plot using SBtarget and Fmsy is shown in appendix Figure 7-1. Fishing intensity on the species has been over the level of Fmsy after 1970. The SSB has been low from SBtarget after 1970.

*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.

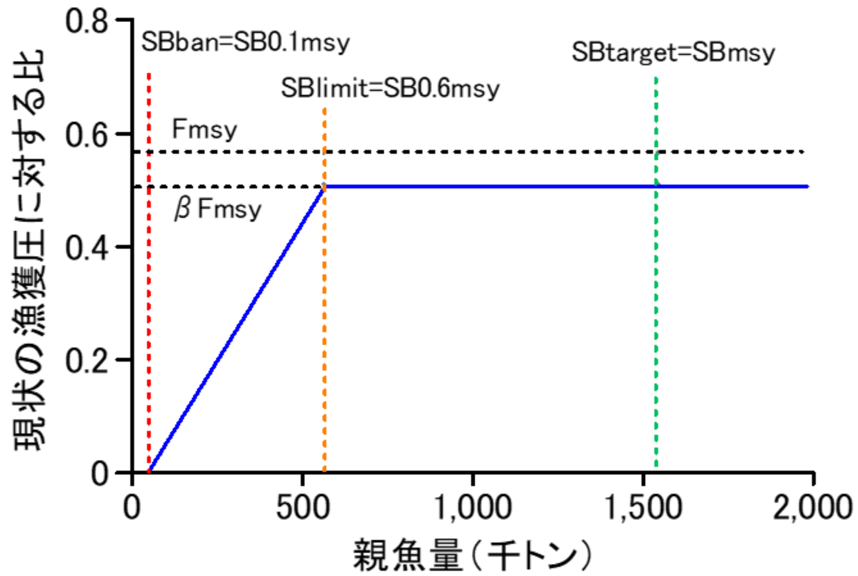
In the results of projection, expected catch in 2020 is 474,000 tons using β=0.9, and 523,000 tons assuming β=1.0. The predicted SSB in 2020 was 1,984,000 tons in average, and all estimation were over SBtarget.

| 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 |

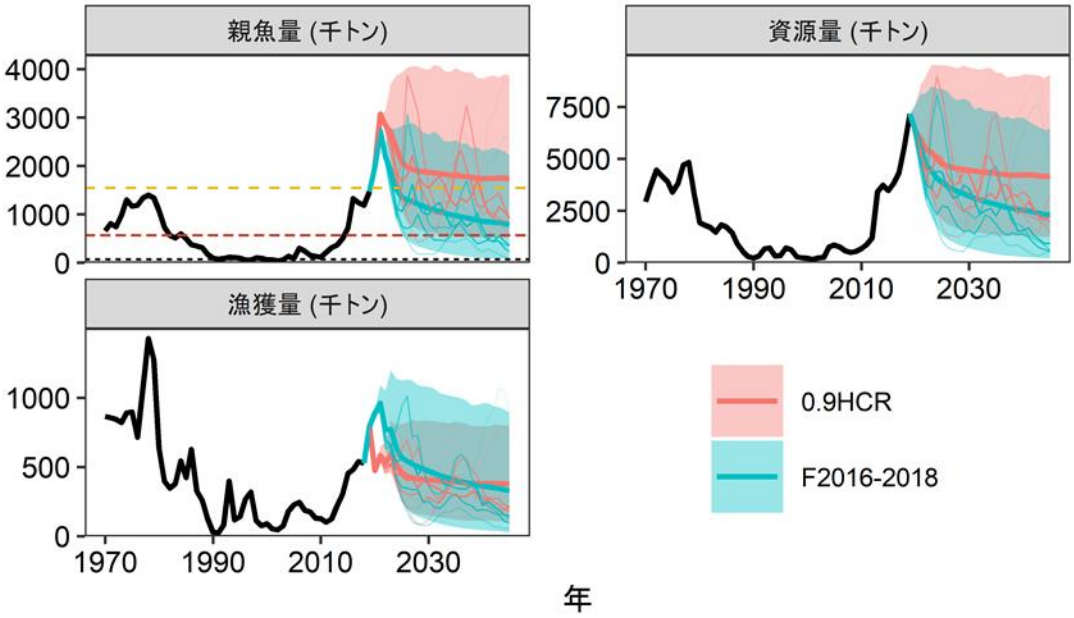
The mid and long term projection results were shown in Appendix table 8-1, 8-2 and Fig.8-2. Assuming HCR is going to be continued 10 years, expected catch in 2030 is 1,768,000 tons usingβ=1.0 (80% confidence limit ranged 717,000-3,091,000 tons), and 1,870,000 tons usingβ=0.9 (80% confidence limit ranged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

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

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

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

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:

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

This results in an estimated recruitment of 13.02 billion in numbers. Where, $\rho$ 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:

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

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:

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

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):

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

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 $\hat{R}_k = (I_{k,2019}/\hat{q})^{\frac{1}{\hat{b}_k}}$ (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).

$$N_{a+1,y+1} = N_{a,y} \exp(-F_{a,y} - M) \quad ※ \text{ when } a \leq 4 \quad (17a)$$

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

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.

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

## 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)

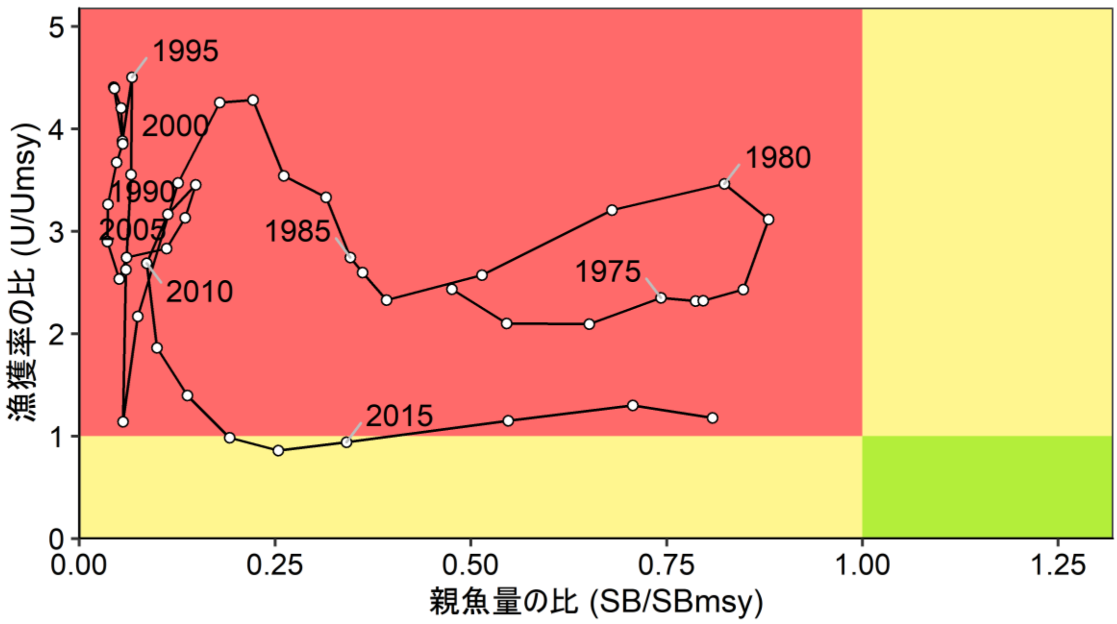

Appendix Table 9-1. Parameters used for the future projection

| 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.