# Stock assessment report on winter-spawning stock of Japanese flying squid (2021)

Responsible Institute: National Research Institute of Fisheries Science

## Summary

The stock biomass of the winter-spawning stock of Japanese flying squid was estimated from the standardized CPUE of small-scale squid jigging fishery. Although short term fluctuations were observed in year trend of the stock biomass, it was stable, varying between 0.5 million and one million tons since 1990 due to suitable environmental conditions for reproduction. However, it largely decreased due to unsuitable environmental conditions in spawning grounds in 2015 and 2016 and then, has stayed at lower level. The biomass was estimated as 149 thousand tons in 2021, which was lower than that in the previous year. Although spawning stock biomass (SB) increased to 372 thousand tons in 2007 and then, it had stayed at higher level until 2014 under relatively low fishing mortality, it largely decreased after 2014. The spawning stock biomass in 2021 was estimated as 49 thousand tons.

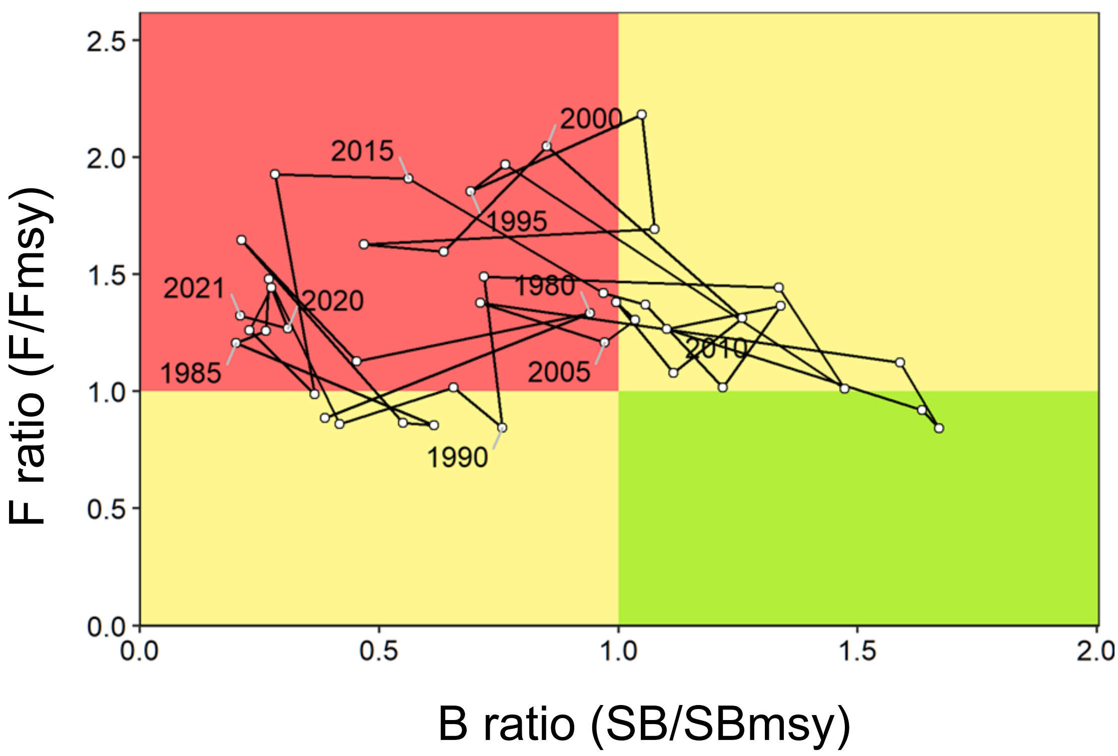
Application of the Beverton-Holt stock-recruitment model to this stock was agreed at the Research Institute Meeting in July 2020. As a result, SB achieving maximum sustainable yield (MSY), that is SBmsy, was estimated as 234 thousand tons. The SB2021 was below SBmsy, whereas fishing mortality for 2021 (F2021) was above Fmsy. There were few changes in SB for recent 5 years (2017 to 2021).

The reference points in this report were tentatively proposed at scientific meeting of research institutes held in July 2020 as a starting point for stakeholder meeting held in December 2020. Those will be finalized after stakeholder meeting.

| Reference | Values |
|---|---|
| Level attain MSY | |
| SBmsy | 234 thousand tons |
| Fmsy | 0.39 |
| %SPR（Fmsy） | 68% |
| MSY | 149 thousand tons |
| SSB and fishing pressure (F) in 2021 | |
| SB2021 | 49 thousand tons |
| F2021 | 0.51 |
| %SPR（F2021） | 60% |
| Ration attain MSY | |
| SB2021/ SBmsy | 0.21 |
| F2021/ Fmsy | 1.32 |

S-R relationship: Beverton and Holt (no autocorrelation)

| Level of SSB | Below SBmsy |
|---|---|
| Level of F | Above Fmsy |
| Status of SSB | stable |



| Fishing year | Biomass (Thousand tons) | SSB (Thousand tons) | Catch (Thousand tons) | F/Fmsy | Exploitation rate (%) |
|---|---|---|---|---|---|
| 2017 | 228 | 85 | 54 | 0.99 | 23.6 |
| 2018 | 158 | 53 | 46 | 1.26 | 29.3 |
| 2019 | 205 | 64 | 62 | 1.44 | 30.1 |
| 2020 | 215 | 72 | 59 | 1.27 | 27.3 |
| 2021* | 149 | 49 | 44 | 1.32 | 29.7 |

*Values in 2021 were tentative which were estimated by biomass expected by recruitment projection and current fishing pressure (F2018-2020).

1. Data set

The data set used for the assessment are as follows.

| Data set | Data source |
|---|---|
| Catch number by month and area (Catch by stock) | National statistics of Ministry of Agriculture, Forestry and Fisheries (MAFF)<br>Squid landing statistics in Japan (All Fisheries Federation)<br>Logbook report of squid fishery (Fishery Agency)<br>Landing and biological survey at major ports (Hokkaido-Kochi [12] prefectures)<br>Fishery statistics (Korea, https://www.fips.go.kr/p/Main/, Oct. 2021)<br>NPFC statistics（North Pacific Fisheries Commission）（URL: https://www.npfc.int/statistics/, Oct. 2021）<br>Research data of FRA (FRA) |
| Abundance index<br>Indices of biomass<br><br>Recruitment index<br><br><br><br><br><br><br><br><br><br>Larval distribution | Monthly CPUE of small squid jigging during July to December (FRA, Hokkaido, Aomori, Iwate and Miyagi prefecture)<br>Second squid fishing ground survey in Pacific Ocean (Aug.-Sep. FRA, Hokkaido, Aomori, Iwate and Miyagi)　jigging<br>Survey for southern migration in eastern Hokkaido of Pacific Ocean (Aug. Hokkaido) jigging<br>First squid fishing ground survey in Pacific Ocean (Jun.-Jul. FRA, Hokkaido, Aomori, Iwate and Miyagi) jigging<br>Survey for young squid in transitional zone（May-Jun. FRA）mid-water trawl<br>Recruitment survey from Sanriku to eastern Hokkaido (July, FRA) mid-water trawl<br>Squid larval survey (Feb. FRA) Bongo tow |
| Natural mortality | Assuming $M = 0.1$ per month (0.6 for 6-month fishing season) |
| Fishing effort | Monthly number of small squid jigging boats operating (FRA, Hokkaido-Kochi [12] prefectures)) |

Catch was summarized by fishing year (April to next March)

## 2. Ecology of the species

### 1) Distribution and migration

Distribution, spawning ground and major fishing ground of the winter-spawning stock of Japanese flying squid were shown in Figure 2-1, and schematic graph of suggested migration routes was shown in Figure 2-2. Japanese flying squid distribute around Japan and reproduces throughout the year. The seasonal recruitment spawned in autumn and winter are dominant and have different distribution and migration, although those hatched in spring and summer are minor (Araya 1967). The winter-spawning stock widely ranges (Figure 2-1) and is mainly caught in the Pacific Ocean. Main spawning grounds are in East China Sea (Matsuda et al. 1972, Mori et al. 2002, Mori 2006), larvae distribute in warm waters south of Honshu and are transported to northern cold waters by the Kuroshio or Tsushima Currents (Figure 2-2). Young squid engaging northward migration in the Pacific Ocean reach coastal waters from Joban to Hokkaido and a part of them enter the Okhotsk Sea. Young ones in the Sea of Japan migrate northward through coastal and offshore waters and a part of them migrate into the Okhotsk Sea through the Soya Strait. As development of gonads progress, they start southward migration, squid distributed in the Pacific Ocean move to the Sea of Japan through the Tsugaru or Soya Straits and swim to spawning grounds in East China Sea. Squid migrating southward in the Pacific Ocean deem to be minor (Mori and Nakamura 2001).

2) Age and growth

Life span of Japanese flying squid is considered one year by daily growth analysis using statolith and growth equation shown below is reported for winter stock (Sugawara et al. 2013).

$$DML = 337exp\{-7.09exp(-0.0136a)\}$$

Here, DML is dorsal mantle length (mm), and *a* is days after hatching. Monthly average mantle length and weight after hatching were shown in Figure 2-3 and Table 2-1.

3) Maturity and spawning

Maturity by monthly age differs between male and female. Male begins maturity after 6 to 7 months of hatching, while it for female is after 7 to 8 months from 2012 to 2020 year class. Spawning ground of winter stock is not known due to the lack of sampling naturally spawned eggs. Nevertheless, spawning grounds are supposed in the East Chine Sea due to the sampling of adults around Kyushu and distribution of larvae (Matsuda et al. 1972, Mori et al. 2002, Mori 2006). Main spawning season is supposed during December to next March by occurrence of larvae and spawning school (Araya 1967).

4) Prey-predator relationship

It is considered that prey of Japanese flying squid is small teleost in coastal area and crustaceans in offshore (Okiyama 1965). It is considered that squid is fed by large fish and marine mammals from young to adults, but depletion rate by predation is not known. The cannibalism between squids is reported in Japan Sea. (Kidokoro and Uji 1999).

5) Remarks

It is reported that biomass of Japanese flying squid is affected by oceanographic environmental change (Murata and Araya 1977, Okutani and Watanabe 1983, Sakurai 1998, Kidokoro and Goto 1999). It is considered that mid-long term oceanographic change, so called “regime shift”, occurred in 1988/1989, then it shifts from cold period to warm period (Yasunaka and Hanawa 2002, Overland et al. 2008). During warm period, increasing biomass synchronized with expansion of available area for spawning, therefore, warm regime is considered suitable for squid reproduction (Sakurai et al. 2000). It was considered that suitable oceanographic condition continued after 1990, SB stayed high level until 2014 and biomass was also stable. However, oceanographic condition of spawning grounds became unsuitable in 2015 and 2016 with high fishing pressure, SB largely decreased and thereafter low SB continued.

Regarding recent environmental change, the possibility of regime shift from warm to cold era was discussed due to the Pacific Interdecadal Oscillation (PDO) change at 2014/15, it became minus to plus, as same phenomena observed for Pacific sardine population change in the past (Watanabe et al. 2017, Kurota and Toya 2017). However, it is understood that the regime shift is not happen. Moreover, higher water temperature partly caused of recent spawning grounds shrink, and average water temperature was higher than past cold period, then it was not considered long-term cold period. Furthermore, environments of spawning ground after 2019 were considered suitable. Affects of oceanographic change on reproduction and the process between spawning to recruitment should be carefully watched.

## 3. Fishery

### 1) Outline of fishery

Main fishing grounds were shown in Figure 3-1. Japanese flying squid is mainly caught by squid jigging but catch by other fisheries increased in Pacific Ocean recently. Squid catch by bottom trawl, set net and purse seine consists around 50% of total catch after 1995. Ratio of other fisheries catch tends to increase after 2016, it obtained 68% in 2020.

Squid are also caught by Korea, China, Russia and north Korea, but catch detail of China and north Korea in Japan sea are unknown. Catch statistics used for stock assessment is the sum of Japan, Korea and catches by China and Russia in Pacific Ocean. Catches by Korea and Russia were large other than Japan, and ratios of Japan, Korea and Russia to the total catch in 2020 were 46%, 29% and 25% respectively.

### 2) History of catch

Historical squid catches are shown in Fig. 3-2 and Table 3-1. Catch stayed at low level in 1980s, it increased after 1989 then reached 400 thousand tons in 1996. Catch stayed from 180 to 290 thousand tons in 2011 to 2015, but it largely decreased after 2016. Catch in 2020 slightly decreased to 59 thousand tons from previous year (Table 3-1). From NPFC statistics (North Pacific Fisheries Commission, https://www.npfc.int/statistics/), Chinese catch was 2698 tons at the peak in 2013 after 2012, then it was 324 tons in 2020. Russian catch was fluctuated between 277 tons to 18 thousand tons after 2012, it was reported 14 thousand tons in 2020. In 2020, Japanese catch was 27 thousand tons (100% of previous year), and Korean catch was 17 thousand tons (100% of previous year).

Moreover, Japanese catch of 2021 during April to August was 1167 tons (at present of Nov. 4th

2021), 37% of same period of previous year, 38% of average between 2016 and 2020. Catch was estimated from summary table of squid landing allover Japan (All fisheries Federation) and Research data of FRA (FRA).

3) Fishing effort

Number of operation vessels of small squid jigging is shown in Figure 3-3. Range of aggregation after 1979 were main landing ports from Miyagi to Pacific side of Hokkaido (main landing ports of Miyagi, Iwate prefecture, Hachinohe, Ohata, Hakodate, Urakawa (after 1993), Kushiro and Tokachi from eastern Hokkaido (after 1980) and Hanasaki (during 2006 to 2008, after 2004 except 2017)), and aggregation period was from July to December. Number of vessels aggregated was divided by targeted stock (fall and winter) following the method described in Appendix 2. Number of operation vessels decreased after 2016, it was 12 thousand vessels in 2020, 142% of previous year and 94% of average between 2015 and 2019.

4. Stock status

1) Stock assessment method

The recruitment was estimated by the abundance index derived from the standardized CPUE obtained through the small-scale squid jigging fisheries (Appendix 1 and Appendix 2-3). The standardized CPUE was estimated using catch and effort data obtained from major landing ports from Miyagi to Hokkaido during July to December (Appendix 3-1). A linear relationship of abundance index with recruitment was assumed with catchability $q$ (18.32). This value of catchability was estimated based on past knowledge regarding exploitation rate $E$ (catch/biomass in number) (Appendix 2-3 (1)). The stock biomass was estimated by multiplying the recruitment by average weight of squid catch (300g before 1988, 312g after 1989) (Appendix 2-2 (3)). The spawners was calculated as number of survivors through fishing and natural mortalities after recruitment. Natural mortality $M$ was assumed to be 0.1 per month. The spawning stock biomass SB was obtained by multiplying the number of spawners by the mean weight of catch.

2) Historical change of abundance index

Historical change of the abundance index from the small-scale squid jigging CPUE fishery are shown in Figure 3-2 and Table 3-1. CPUE largely increased after 1988 and reached 1.82 in 1996. It obviously dropped in 1998, remaining at the same in 1999. After increase in 2000, it attained the historical maximum of 1.83 in 2007. Although the index varied around 1.3 after 2011, rapid decrease was observed in 2015 and 2016. It remained at the historically lower level since 2017, showing slight increase in 2020. At the timing of conduction of the 2021 stock assessment, the small-scale squid jigging fishery have not closed, resulting in data unavailability for the CPUE standardization. Therefore, the abundance index for terminal year (2021) was predicted from the standardized CPUE during July to the latest (mid-October) (Appendix 3-3). As a result, the abundance index for 2021 was 69% of that for the previous year.

3) Trends in stock biomass and fishing mortality

Annual changes of the stock biomass and exploitation rate since 1979 are shown in Figure 4-1 and Table 4-1. After the biomass stayed below 0.4 million tons during 1981 to 1988, it increased after 1988 and reached 1.038 million tons in 1996. It remained at higher level up to 2014 despite of fluctuation between 0.5 and 1.0 million tons and then, showed a large decrease from 2015 to 2016. It was below 0.3 million tons at historical lower level. It slightly increased to 0.215 million tons from the previous year (105% of previous year) in 2020. The 2021 stock biomass was estimated as 0.149 million tons (69% of previous year, 70% of average between 2016 and 2020).

The spawning stock biomass (SB), in general, showed the same year trend with the stock biomass (Figure 4-1 and Table 4-1). It has remained at historically lower level after 2015.

Although level of fishing mortality *F* did not shift despite of annual fluctuation during 1980s to early 1990s, it increased to higher level from mid-1990s to 2000 (Figure 4-2). After decrease in 2001, it stayed at a certain level up to 2014. The spike of *F* was showed in 2015 and 2016. Subsequently, it decreased in 2017 and slightly increased after that. The exploitation rate varied at higher level with the average of 36% (34 to 39%) during mid-1990s to 2000 and then, it decreased to average 28% (21 to 32%) until 2014. It increased to 39 and 40% in 2015 and 2016 respectively, and then, slightly decreased to 27% in 2020.

Annual change of spawners is shown in Figure 4-3. The spawners increased from late 1980s and reached 1.11 billion squid in 1993. It decreased after that and then, increased again in 2007 and stayed at higher level until 2014 due to the lower fishing mortality. However, it largely decreased after 2014. SB in 2020 was 0.23 billion squid, corresponding to 112% of previous year. SB in 2021 was estimated to be 0.16 billion squids (49 thousand tons) (Table 4-1, Appendix 2-3) when the current fishing mortality F2018-2020 was given as average fishing pressure during 2018 to 2020. Sensitivity test regarding setting of *M* on SB is shown in Figure 4-4. Under *M* equal to 0.3 and 0.9, SB2021 were estimated to be 0.23 and 0.1 billion squid respectively.

Recruitment per spawning stock biomass (RPS) changed between 0.95 and 7.40, especially showing large fluctuation in 1980s (Figure 4-5). The RPS level in 1990s was higher than that in 1980s. The median of RPS from 1990 to 2001 was 3.48. The yearly change of RPS was relatively stable after 2001 with the median of 2.68, which was lower than 1990s. In recent years, lower RPS were observed in 2015, 2016 and 2018, whereas higher ones were observed in 2017, 2019 and 2020. RPS in 2021 was predicted as 2.06 close to those in 2015, 2016 and 2018 (Table 4-1). In terms of potential spawning area for this stock defined as area with surface temperature of 18.0 to 23.0 ºC over the continental shelf of 100 to 500 m in depth in the East China Sea (Sakurai et al. 2006), conditions to spawning success seemed to be preferable in recent years. Environment factors affecting spawning success should be examined in future, because it is possible that survival of larvae and juveniles might be affected by transport route and destination from spawning area.

| Item | Value | |
|---|---|---|
| SB2021 | 49 thousand tons | SB in 2021 |
| F2021 | 0.51 | F in 2021 |
| U2021 | 29.7% | Exploitation rate |

4) Spawning stock biomass per recruitment (SPR) and latest fishing mortality

Annual %SPR was shown in Figure 4-6. %SPR for 2021 was estimated as 60% under the average *F* in recent three years (from 2018 to 2020). The estimated Fmsy, which agreed at the Research Institute Meeting held on 27 July 2020, corresponded to 68%SPR. F2021 was above Fmsy and below F30%SPR (Figure 4-7).

| Item | Value | Remarks |
|---|---|---|
| %SPR（F2021） | 60% | %SPR in 2021 |

5) Stock-recruitment relationship

Figure 4-8 shows the stock-recruitment (S-R) relationship, where SB was given as number. According to the Research Institute Meeting held in July 2020, it was agreed that the Beverton-Holt stock recruitment model was applied (Kaga et al. 2020). The least-square method was applied to estimate parameters of the S-R relationship using the SB and recruitment, which were identical with those estimated in Kaga et al. 2020, without consideration of auto-correlation of residuals. The estimated parameters are shown in the Table below.

| S-R relationship | Optimization | autocorrelation | $a$ | $b$ | S.D. | $\rho$ |
|---|---|---|---|---|---|---|
| Beverton-Holt | Least square | Non | 4.31 | 0.066 | 0.417 | - |

Here, $a$ and $b$ are parameters of the Beverton-Holt curve, S.D. means standard deviation.

6) Reference points under the current environmental condition.

The table below shows SB (SBmsy) and F (Fmsy) that will achieve MSY under the current environmental condition, which was suggested at the 'Research Institute Meeting held in July 2020 (FRA-SA2020-BRP04-1).

| Item | Value | Remarks |
|---|---|---|
| SBmsy | 234 thousand tons | SB at MSY |
| Fmsy | 0.39 | |
| %SPR（Fmsy） | 68% | %SPR at Fmsy |
| MSY | 149 thousand tons | MSY |

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

The Kobe plot based on SBmsy and Fmsy is shown in Figure 4-9. SB2021 was below SBmsy and 0.21 times of it. F2021 was above Fmsy and 1.32 times of it. The status of SB is considered stable based on recent five years trend (2017 to 2021). *F*s since 2000 exceeded Fmsy except for 2008, 2009 and 2017, although SB remained below SBmsy since 2014.

| Item | Value | Remarks |
|---|---|---|
| SB2021/ SBmsy | 0.21 | Ratio of SB for 2021 to SB achieving MSY |
| F2021/ Fmsy | 1.32 | Ratio of F for 2021 to F achieving MSY |

| | |
|---|---|
| Level of SB | Below SBmsy |
| Level of F | Above Fmsy |
| Trend of SB | Stable |

5. Stock assessment summary

It was reported that stock size fluctuation of Japanese flying squid stock could be related to oceanographic environmental change. The winter-spawning stock biomass stayed at higher level with short-term fluctuation. The biomass largely was decreased by two-year shrinking of the potential spawning area and increase of fishing mortality in 2015 and 2016. The biomass was estimated as 49 thousand tons close to the historical lowest, although it slightly recovered in 2019 and 2020. SB for 2021 was estimated as 49 thousand tons, below SBmsy. *F* for 2021, in addition, was above Fmsy.

6. Others

The current stock biomass was close to the historical lowest level. Consequently, the current level of fishing mortality may accelerate the depletion of stock. Because not only Japanese fleet but also other nations' fleets catch this stock, multi-lateral management would be effective to recover it. Because this species has a single-year longevity, a recruitment corresponds to a stock of the year. It is difficult to predict the next-year recruitment, because recruitment could be varied by environmental factors. Therefore, it is necessary that to establish monitoring framework on recruitment prior to fishing season.

7. Reference

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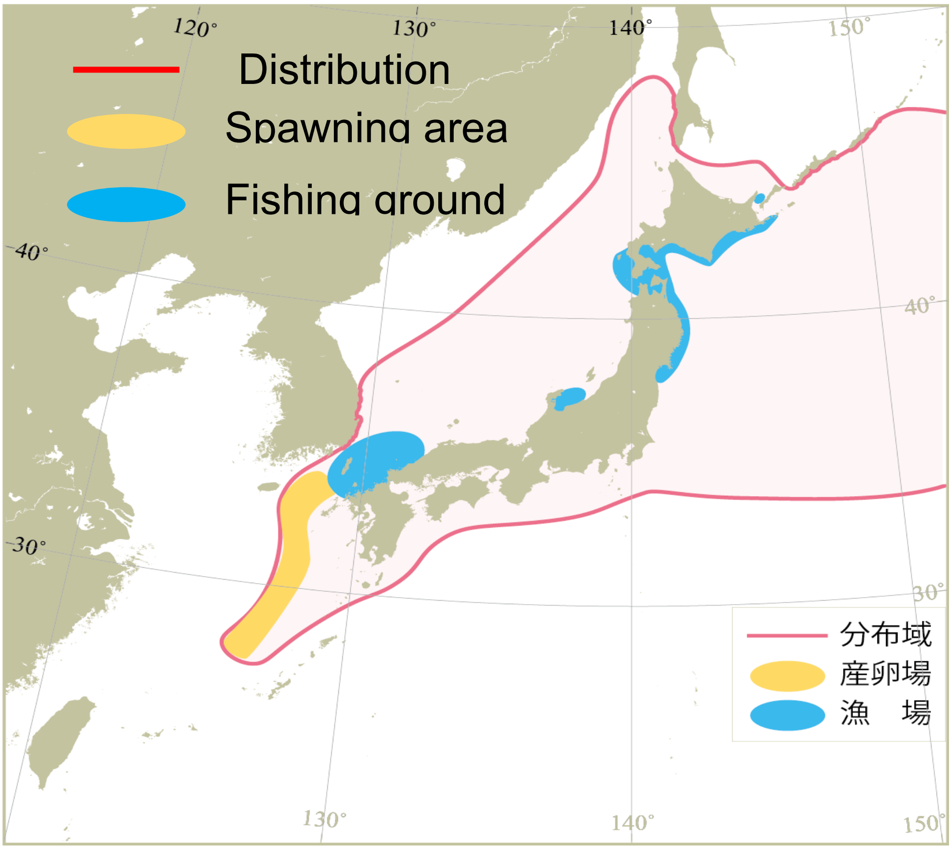



**Figure 2-1**. Distribution and spawning ground of Japanese flying squid winter stock.

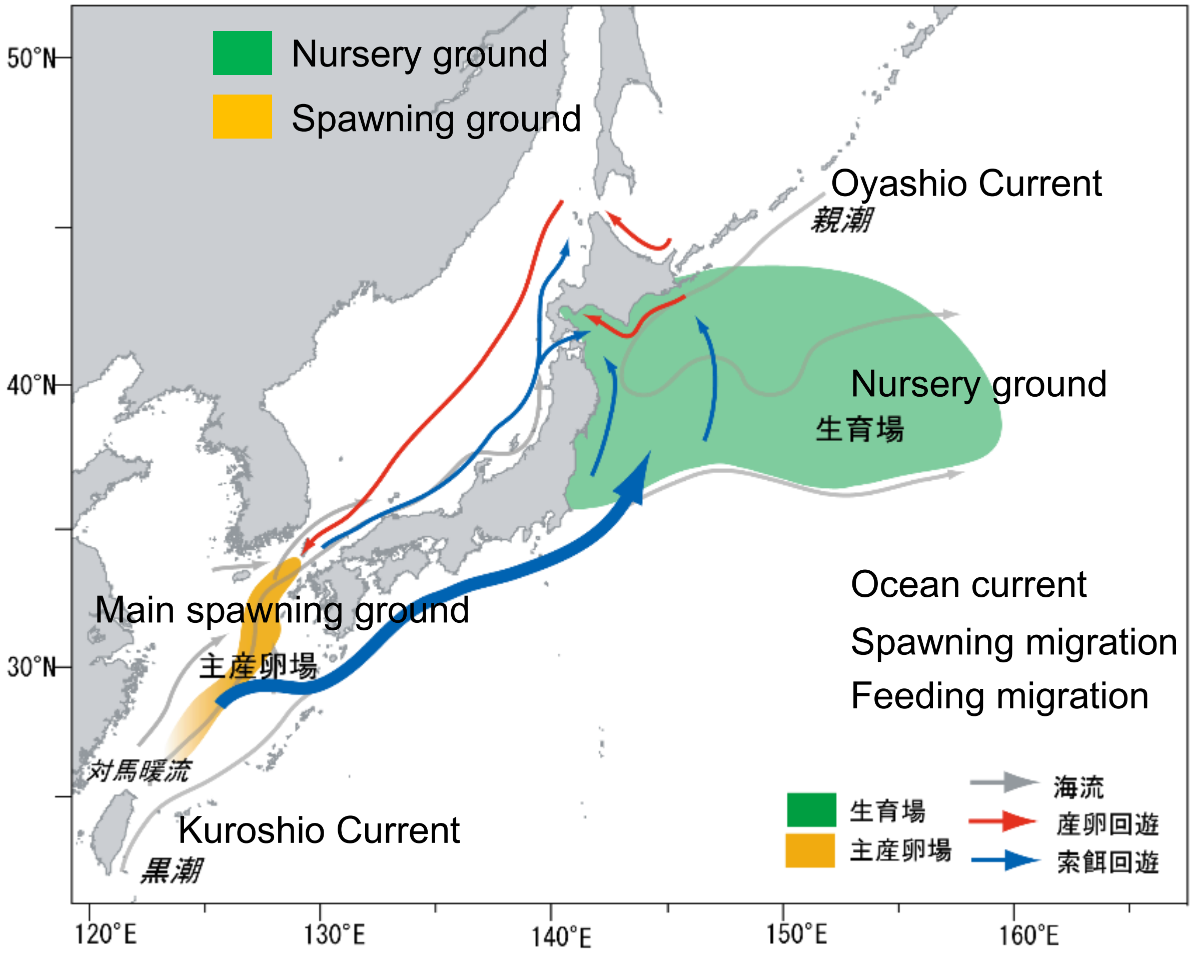



Figure 2-2. Schematic migration map of Japanese flying squid winter stock.

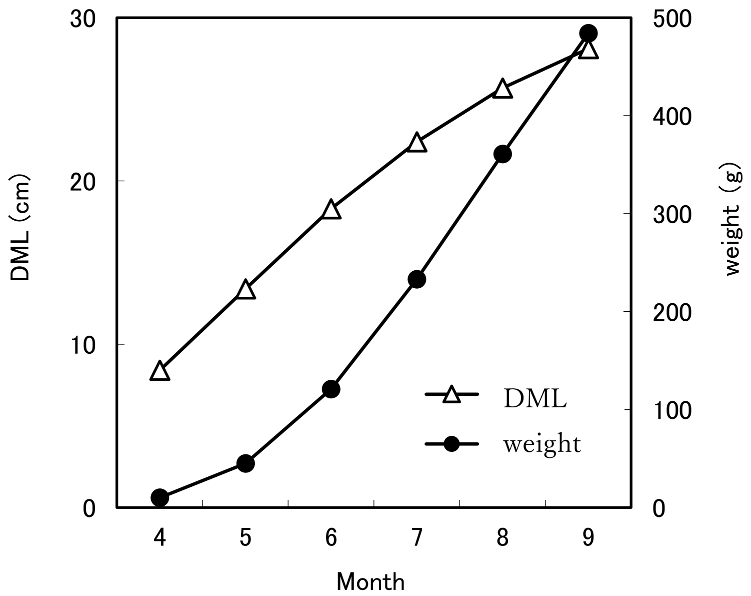



**Figure 2-3**. Growth of Japanese flying squid.

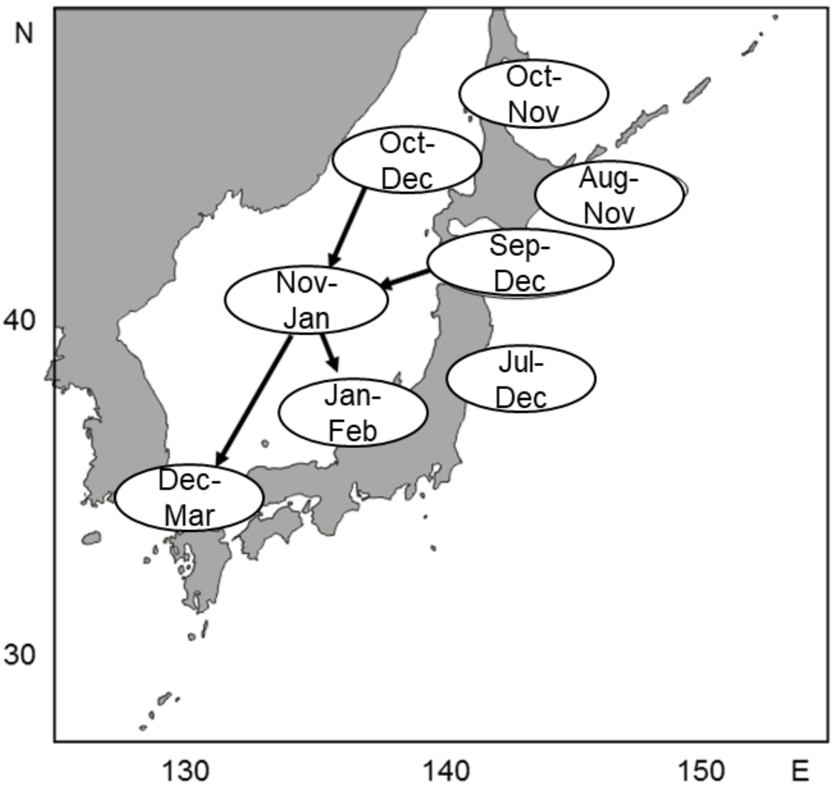



Figure 3-1. Main fishing grounds and month.

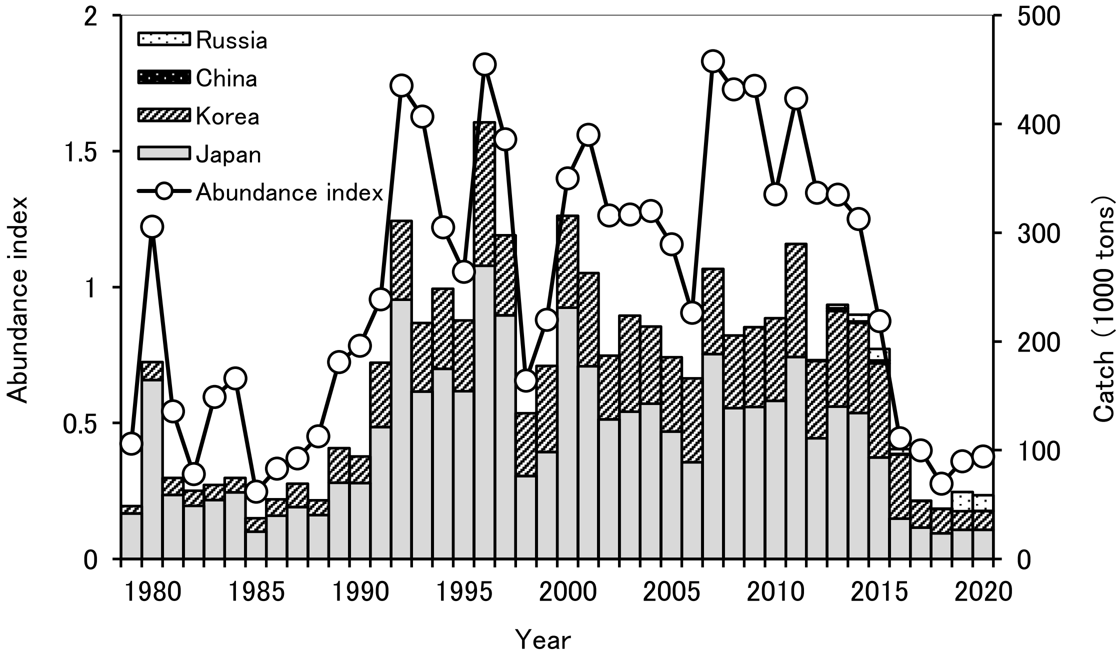



**Figure 3-2**. Abundance index and annual catches of Japanese flying squid by country.

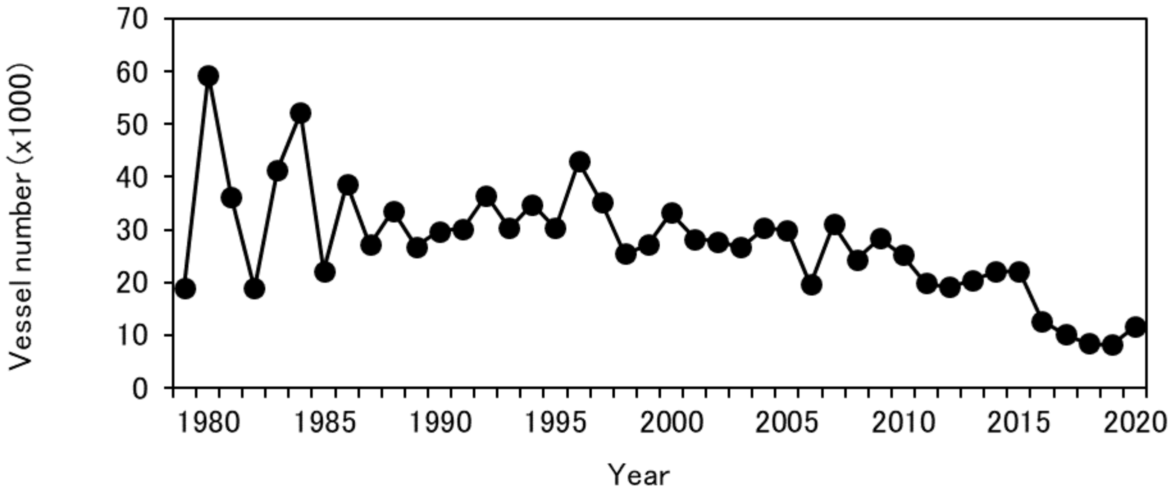



**Figure 3-3**. Annual change of small squid jigging boat number, data obtained main fishing ports from Miyagi to Hokkaido.

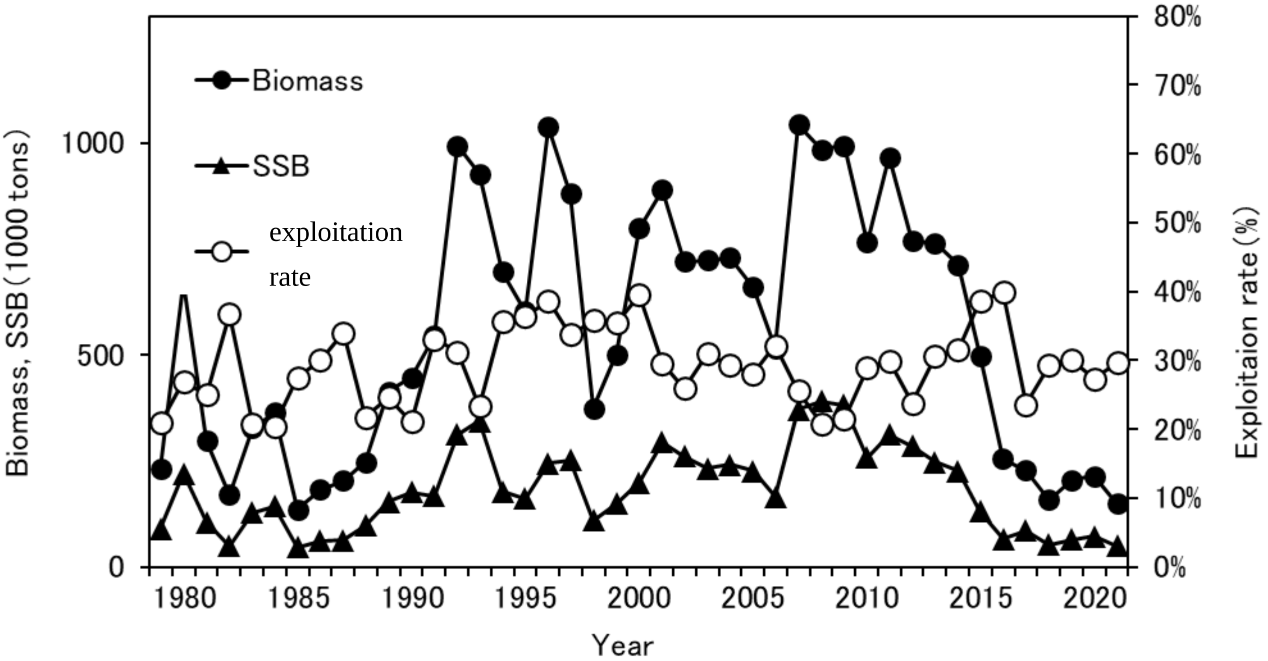



**Figure 4-1**. Annual fluctuation of biomass, spawning stock biomass and exploitation rate. The value of 2021 was estimated by projected biomass and current fishing pressure (F2018-2020).

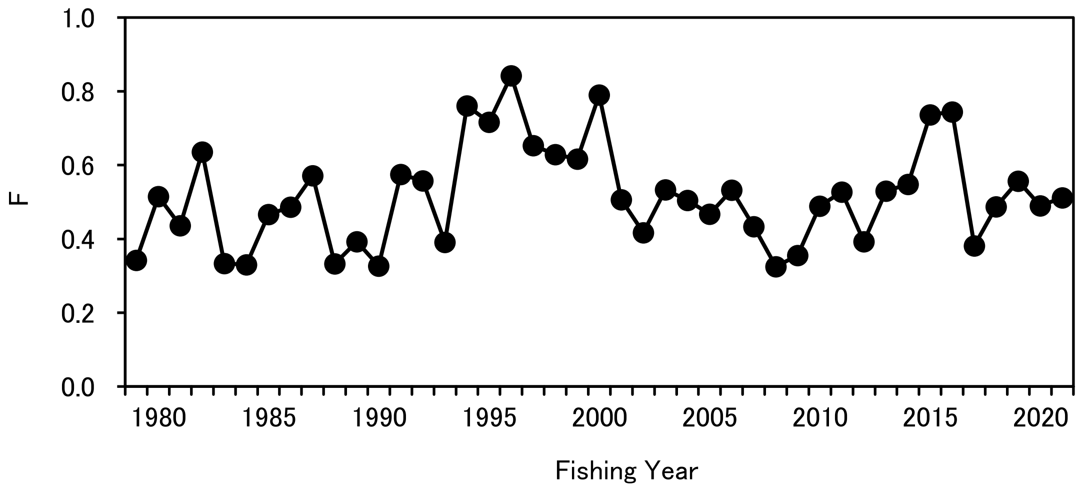



**Figure 4-2**. Fluctuation fishing intensity (F).

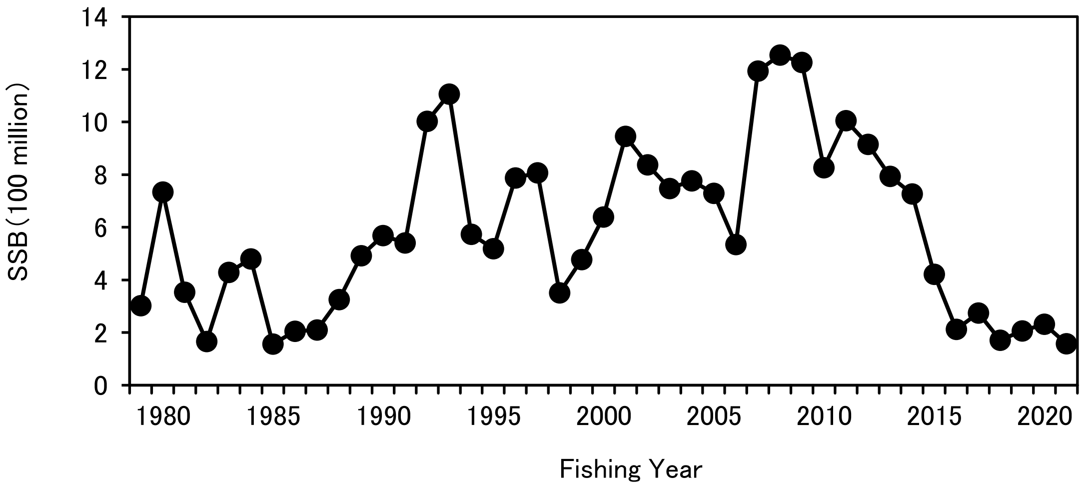



Figure 4-3. Annual fluctuation of SB. The value of 2021 was estimated by projected biomass and current fishing pressure (F2018-2020).

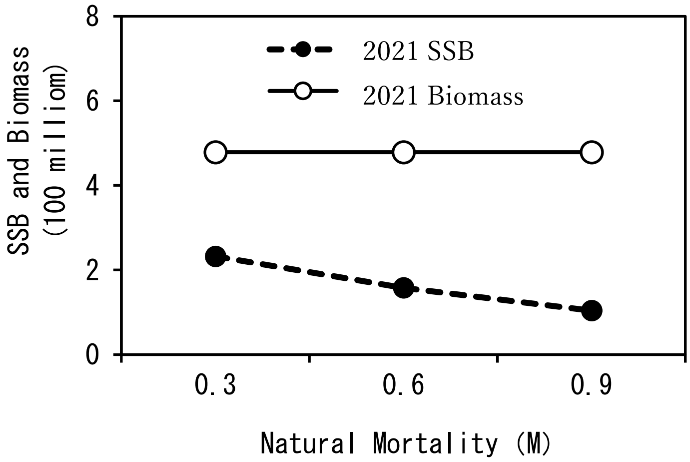



**Figure 4-4**. Results of sensitivity test of natural mortality M on biomass and spawning stock estimation in 2021.

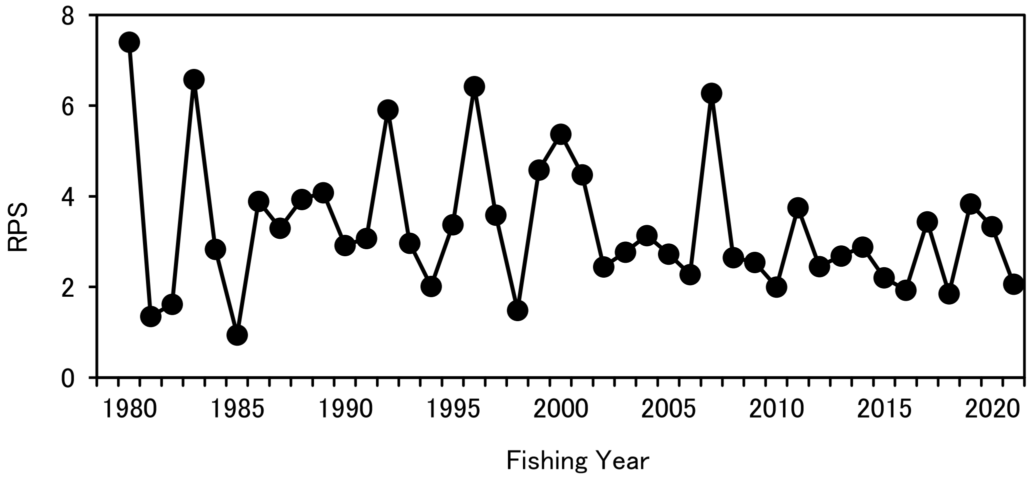



**Figure 4-5**. Annual fluctuations of recruitment and recruitment per spawning (RPS).

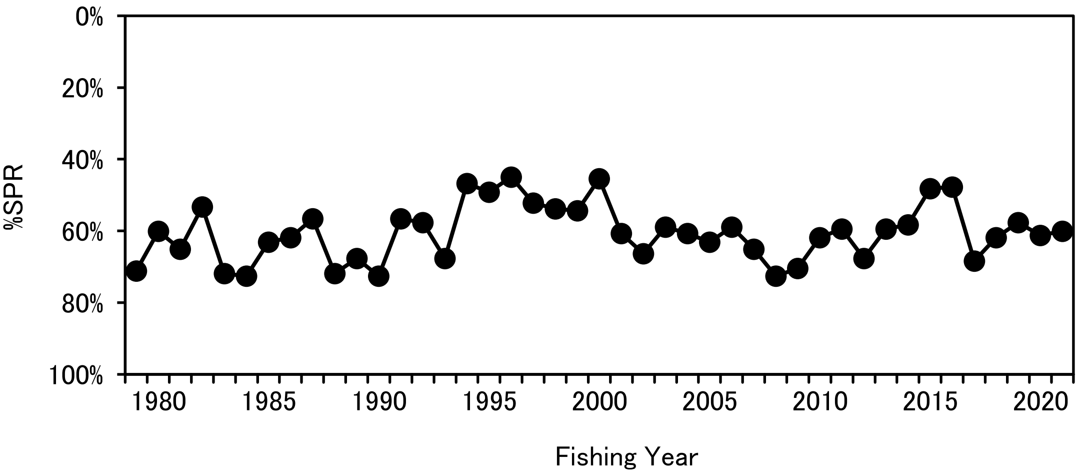



Figure 4-6. Annual fluctuation of %SPR.

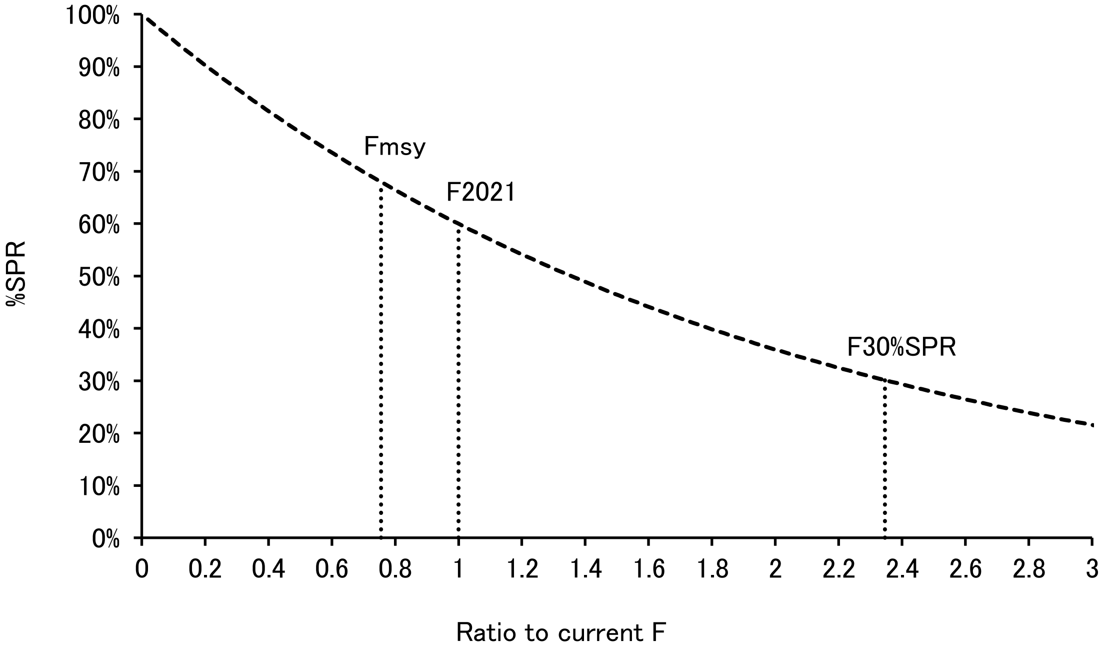



Figure 4-7. Relation between current F (F2021) and %SPR.

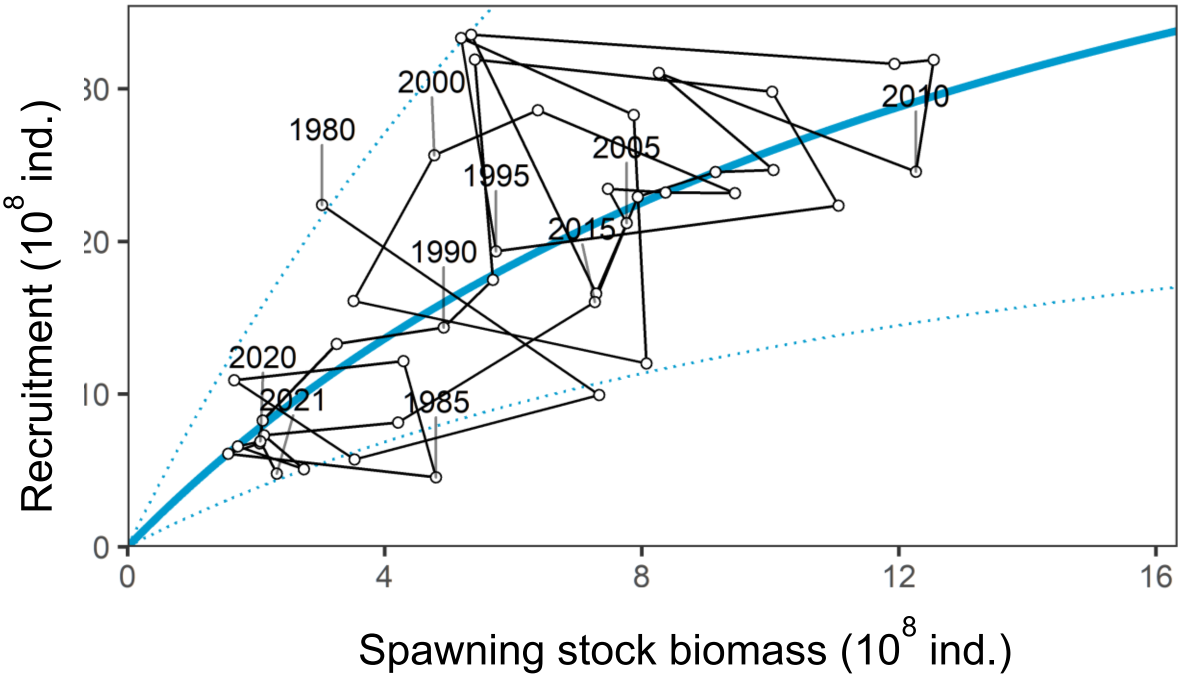



Figure 4-9. Relation between spawning stock biomass and recruitment. Blue solid line indicates reproductive relationship suggested by Scientific meeting of Research Institutes held in July 2020. Break lines above and below indicate 90% of estimations. Values in the figure indicate year.

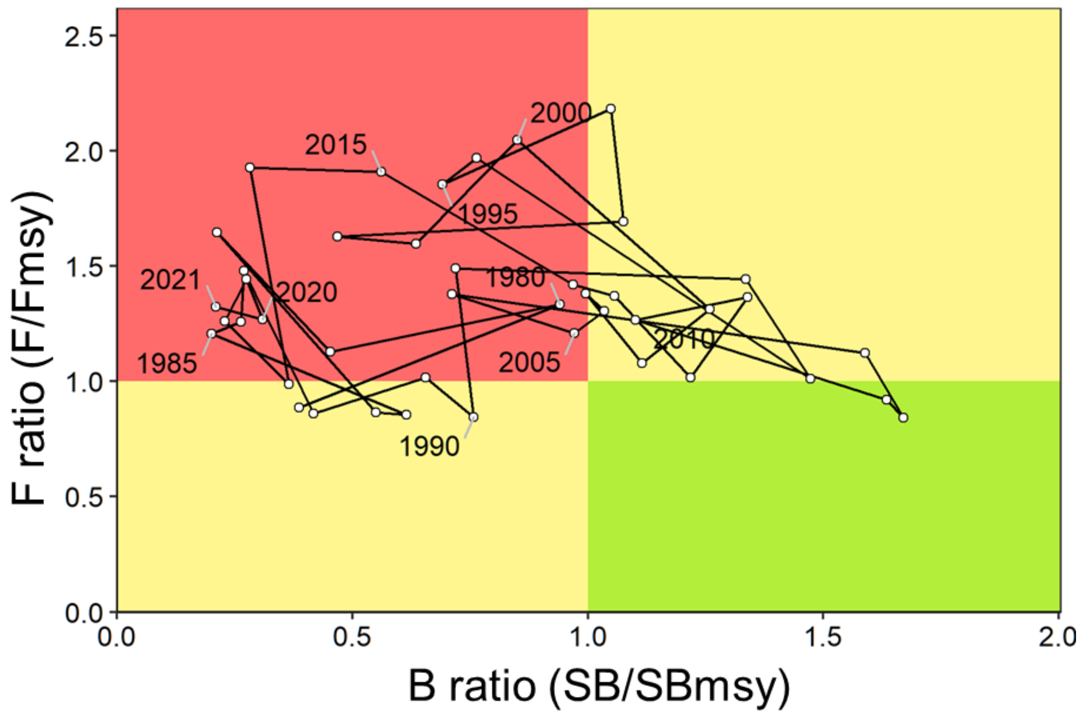



Figure 4-9. Kobe plot of Japanese flying squid. Relation between SB to SBmsy and F to Fmsy.

Table 2-1. Monthly average dorsal mantle length and weight after hatching.

| Month after hatching | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|
| Dorsal mantle length (mm) | 84 | 134 | 183 | 224 | 257 | 281 |
| Weight (g) | 10 | 45 | 121 | 233 | 361 | 484 |

Table 3-1. Japanese flying squid catch by country and abundance index.

| Year | Catch on winter stock | | | | | abundance index |
|---|---|---|---|---|---|---|
| | Japan | Korea | China | Russia | Total | |
| 1979 | 41,712 | 7,019 | | | 48,730 | 0.42 |
| 1980 | 164,659 | 16,383 | | | 181,041 | 1.22 |
| 1981 | 58,903 | 15,673 | | | 74,576 | 0.54 |
| 1982 | 49,025 | 13,799 | | | 62,824 | 0.31 |
| 1983 | 54,350 | 13,813 | | | 68,162 | 0.60 |
| 1984 | 61,406 | 13,140 | | | 74,546 | 0.66 |
| 1985 | 24,976 | 12,498 | | | 37,474 | 0.25 |
| 1986 | 39,858 | 14,945 | | | 54,802 | 0.33 |
| 1987 | 47,689 | 21,520 | | | 69,209 | 0.37 |
| 1988 | 40,368 | 13,436 | | | 53,803 | 0.45 |
| 1989 | 70,006 | 31,894 | | | 101,900 | 0.72 |
| 1990 | 69,910 | 24,319 | | | 94,229 | 0.78 |
| 1991 | 121,272 | 59,101 | | | 180,373 | 0.95 |
| 1992 | 238,517 | 72,200 | | | 310,717 | 1.74 |
| 1993 | 154,048 | 62,902 | | | 216,949 | 1.63 |
| 1994 | 174,743 | 73,630 | | | 248,373 | 1.22 |
| 1995 | 154,358 | 65,056 | | | 219,414 | 1.06 |
| 1996 | 269,605 | 131,711 | | | 401,315 | 1.82 |
| 1997 | 224,088 | 73,573 | | | 297,661 | 1.54 |
| 1998 | 76,264 | 57,611 | | | 133,875 | 0.66 |
| 1999 | 98,263 | 79,338 | | | 177,601 | 0.88 |
| 2000 | 231,030 | 84,366 | | | 315,395 | 1.40 |
| 2001 | 177,165 | 85,779 | | | 262,944 | 1.56 |
| 2002 | 128,252 | 58,669 | | | 186,921 | 1.26 |
| 2003 | 135,534 | 88,320 | | | 223,854 | 1.27 |
| 2004 | 142,837 | 70,773 | | | 213,610 | 1.28 |
| 2005 | 117,196 | 68,174 | | | 185,370 | 1.16 |
| 2006 | 89,025 | 77,021 | | | 166,046 | 0.91 |
| 2007 | 188,312 | 78,287 | | | 266,599 | 1.83 |
| 2008 | 138,713 | 66,756 | | | 205,468 | 1.73 |
| 2009 | 139,825 | 73,301 | | | 213,126 | 1.74 |
| 2010 | 145,301 | 75,922 | | | 221,223 | 1.34 |
| 2011 | 185,854 | 103,703 | | | 289,557 | 1.69 |
| 2012 | 110,926 | 71,145 | 0 | 767 | 182,838 | 1.35 |
| 2013 | 140,071 | 87,761 | 2,698 | 3,277 | 233,806 | 1.34 |
| 2014 | 134,207 | 82,763 | 1,504 | 6,189 | 224,662 | 1.25 |
| 2015 | 93,362 | 86,449 | 2,637 | 10,746 | 193,194 | 0.87 |
| 2016 | 37,148 | 58,773 | 671 | 4,517 | 101,108 | 0.44 |
| 2017 | 29,006 | 24,392 | 0 | 345 | 53,743 | 0.40 |
| 2018 | 23,698 | 22,392 | 0 | 277 | 46,367 | 0.28 |
| 2019 | 26,874 | 17,074 | 0 | 17,619 | 61,567 | 0.36 |
| 2020 | 26,878 | 17,038 | 324 | 14,396 | 58,635 | 0.38 |

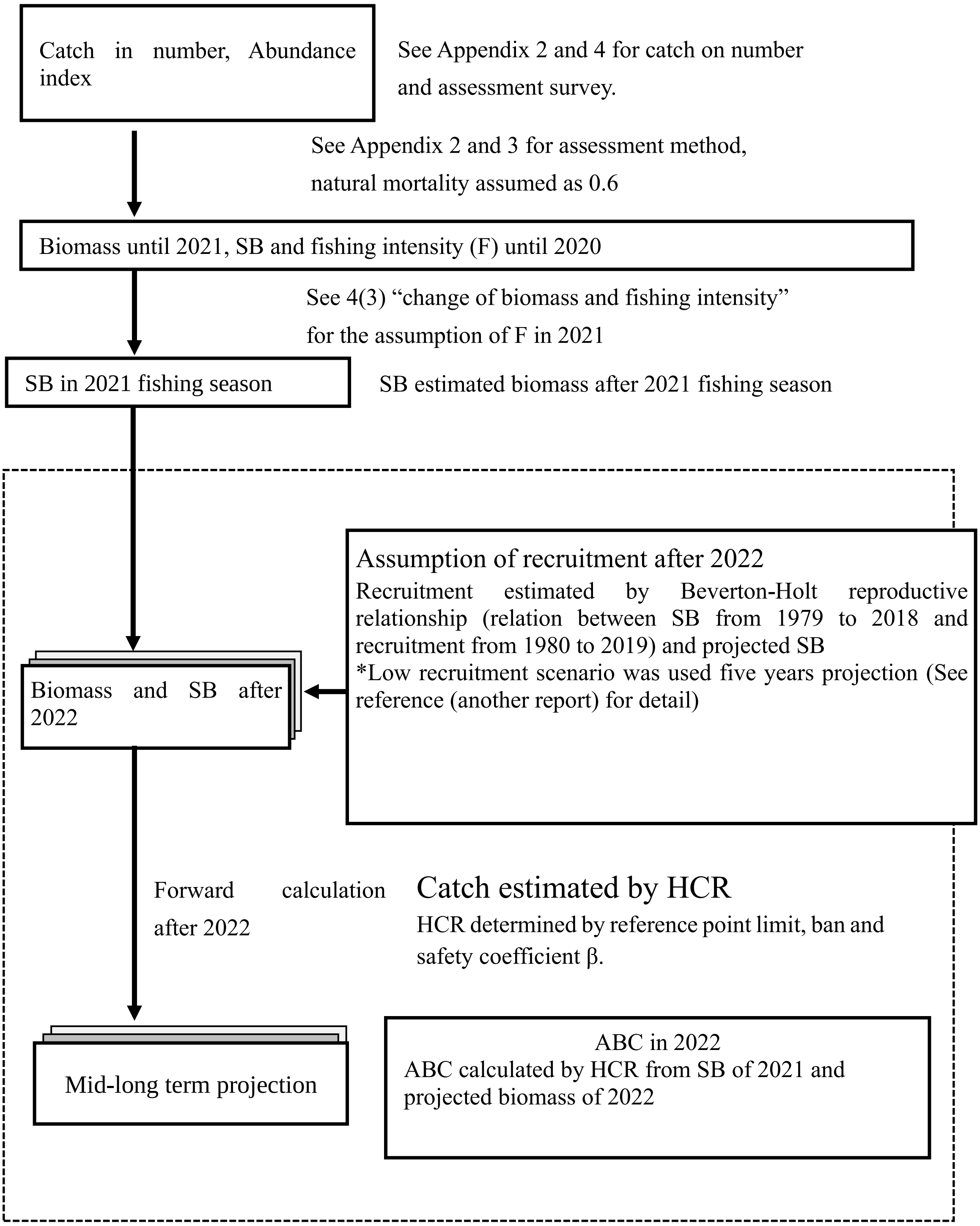
Remarks: Catch in ton. 2020 figures are preliminaly.
Chinese and Russan catch are reported statistics to NPFC.

Table 4-1. Biomass, SB, exploitation rate, fishery coefficient and reproductive success rate of Japanese flying squid.

| Year Apr.-Mar. | Biomass (100 million) | Biomass (1000 tons) | SSB (100 million) | SSB (1000 tons) | Exp rate (%) | F (F) | catch (1000 tons) | Reproductive Success |
|---|---|---|---|---|---|---|---|---|
| 1979 | 7.8 | 233 | 3.0 | 91 | 21 | 0.34 | 49 | |
| 1980 | 22.4 | 671 | 7.3 | 220 | 27 | 0.52 | 181 | 7.40 |
| 1981 | 9.9 | 298 | 3.5 | 106 | 25 | 0.44 | 75 | 1.36 |
| 1982 | 5.7 | 171 | 1.7 | 50 | 37 | 0.64 | 63 | 1.62 |
| 1983 | 10.9 | 327 | 4.3 | 129 | 21 | 0.33 | 68 | 6.58 |
| 1984 | 12.2 | 364 | 4.8 | 144 | 20 | 0.33 | 75 | 2.83 |
| 1985 | 4.5 | 136 | 1.6 | 47 | 28 | 0.47 | 37 | 0.95 |
| 1986 | 6.1 | 183 | 2.1 | 62 | 30 | 0.49 | 55 | 3.89 |
| 1987 | 6.8 | 203 | 2.1 | 63 | 34 | 0.57 | 69 | 3.30 |
| 1988 | 8.3 | 248 | 3.3 | 98 | 22 | 0.33 | 54 | 3.93 |
| 1989 | 13.3 | 414 | 4.9 | 153 | 25 | 0.39 | 102 | 4.08 |
| 1990 | 14.4 | 447 | 5.7 | 177 | 21 | 0.33 | 94 | 2.92 |
| 1991 | 17.5 | 545 | 5.4 | 168 | 33 | 0.58 | 180 | 3.08 |
| 1992 | 31.9 | 994 | 10.0 | 312 | 31 | 0.56 | 311 | 5.91 |
| 1993 | 29.8 | 928 | 11.1 | 345 | 23 | 0.39 | 217 | 2.97 |
| 1994 | 22.3 | 696 | 5.7 | 179 | 36 | 0.76 | 248 | 2.02 |
| 1995 | 19.4 | 603 | 5.2 | 162 | 36 | 0.72 | 219 | 3.38 |
| 1996 | 33.3 | 1038 | 7.9 | 245 | 39 | 0.84 | 401 | 6.42 |
| 1997 | 28.3 | 881 | 8.1 | 252 | 34 | 0.65 | 298 | 3.59 |
| 1998 | 12.0 | 374 | 3.5 | 110 | 36 | 0.63 | 134 | 1.49 |
| 1999 | 16.1 | 502 | 4.8 | 149 | 35 | 0.62 | 178 | 4.58 |
| 2000 | 25.6 | 799 | 6.4 | 199 | 39 | 0.79 | 315 | 5.38 |
| 2001 | 28.6 | 891 | 9.4 | 294 | 30 | 0.51 | 263 | 4.48 |
| 2002 | 23.1 | 721 | 8.4 | 261 | 26 | 0.42 | 187 | 2.45 |
| 2003 | 23.2 | 723 | 7.5 | 233 | 31 | 0.53 | 224 | 2.77 |
| 2004 | 23.4 | 730 | 7.8 | 242 | 29 | 0.50 | 214 | 3.14 |
| 2005 | 21.2 | 661 | 7.3 | 227 | 28 | 0.47 | 185 | 2.73 |
| 2006 | 16.6 | 517 | 5.3 | 166 | 32 | 0.53 | 166 | 2.27 |
| 2007 | 33.5 | 1045 | 11.9 | 372 | 26 | 0.43 | 267 | 6.27 |
| 2008 | 31.6 | 985 | 12.5 | 391 | 21 | 0.33 | 205 | 2.65 |
| 2009 | 31.9 | 993 | 12.3 | 382 | 21 | 0.36 | 213 | 2.54 |
| 2010 | 24.6 | 765 | 8.3 | 257 | 29 | 0.49 | 221 | 2.00 |
| 2011 | 31.0 | 967 | 10.1 | 313 | 30 | 0.53 | 290 | 3.75 |
| 2012 | 24.7 | 769 | 9.1 | 285 | 24 | 0.39 | 183 | 2.46 |
| 2013 | 24.5 | 765 | 7.9 | 247 | 31 | 0.53 | 234 | 2.68 |
| 2014 | 22.9 | 714 | 7.3 | 226 | 31 | 0.55 | 225 | 2.89 |
| 2015 | 16.0 | 499 | 4.2 | 131 | 39 | 0.74 | 193 | 2.20 |
| 2016 | 8.1 | 254 | 2.1 | 66 | 40 | 0.74 | 101 | 1.93 |
| 2017 | 7.3 | 228 | 2.7 | 85 | 24 | 0.38 | 54 | 3.44 |
| 2018 | 5.1 | 158 | 1.7 | 53 | 29 | 0.49 | 46 | 1.85 |
| 2019 | 6.6 | 205 | 2.1 | 64 | 30 | 0.56 | 62 | 3.83 |
| 2020 | 6.9 | 215 | 2.3 | 72 | 27 | 0.49 | 59 | 3.34 |
| 2021 | 4.8 | 149 | 1.6 | 49 | 30 | 0.51 | 44 | 2.06 |

Remarks: F and Reproductive success are calculated by number. SSB is estimated as the value after fishing season.
The values in 2021 were estimated by projection.

Appendix 1 Flowchart of stock assessment.




*The process inside of break line will be decided by the discussion of reference points and HCR at management meeting. (http://www.fra.affrc.go.jp/shigen_hyoka/SCmeeting/2019-1/index.html)

Appendix 2 Methodology of stock assessment

## 1. Fishery statistics of Japanese flying squid caught by Japan and Korea by stock

Squid catch was divided into Japan and Korea based on hatching stock division (fall and winter) shown in Appendix Table 2-1. In the case of mixed stock catch, it was divided by half and half. All Chinese and Russian catch reported to NPFC were occurred in the Pacific Ocean then it was treated as winter stock.

## 2. Input data used for stock assessment

### 1) Abundance index

Standardized CPUE obtained small squid jigging from major port of Miyagi to Hokkaido Pacific coast during July to December was used as abundance index. Method of calculating standardized CPUE was shown Appendix 3-1. Catch and effort (total number of boat) data used for CPUE calculation were compiled by the method of dividing stocks described in Appendix 2-1 (Appendix Table 2-1). CPUE in 2021 could not be obtained at the stock assessment. Therefore, abundance index in 2021 was predicted from CPUE during July to just before assessment (mid-October) (Appendix 3-2). CPUE of small squid jigging is originally weight bases. CPUE in number was obtained by catch weight divided by average monthly weight of squid calculated form data after 1979 by two period of oceanographic regime shift (1979 to 1988 and 1989 to 2007). Average monthly weight of squid used were shown in Appendix Table 2-2.

### 2) Biological parameters

#### a) Target stage for fishing

Assuming recruits of squid occurred after six months of hatching, and was caught until end of lifetime (twelve months after hatching).

b) Natural mortality

Natural mortality (M) was assumed 0.1 per month and 0.6 as 6 month of fishing season.

### 3) Catch in number and average weight calculation

Japanese and Korean catch by month by area were classified into fall and winter stock. Sorting of two stocks from Japanese and Korean catch were set by area considering fishery status (Appendix 2-1). Chinese and Russian catch reported to NPFC were classified into winter stock since both catch came from Pacific Ocean. Monthly catch in number was obtained from monthly catch in weight by stock and monthly average weight (Appendix Table 2-2), then total catch between April to next March was calculated as annual catch. Average weight of squid (300g until 1988 and 312g after 1989) was obtained by annual catch in weight divided by catch in number as using convert from catch in number to weight. For Chinese and Russian catch, catch in number was obtained by catch divided by average weight (253g) of main fishing season during July to November.

## 3. Stock assessment method

1) Estimation of biomass and SB

Biomass in number ($N_t$) was estimated by abundance indices ($U_t$) obtained by equation (1) as shown below.

$$N_t = \mathrm{q}U_t \tag{1}$$

The q is proportional constant. Following the past assessment for fall stock, exploitation rate (E) was supposed between 0.2 and 0.4 (Research institute of Japan Sea fisheries 1997, Research institute of Japan sea fisheries 1998), Kidokoro et al (2006), then its was estimated to 0.3 as an average from 1979 to 2000. Regarding winter stock, E was estimated by various method as similar results of fall stock (Mori 2006). Therefore, average E during 1979 to 2001 was assumed as 0.3, then proportional constant q was obtained.

Assuming pulse fishing pressure, fishing coefficient $F_t$ was obtained by equation of Pope (2). Then survivor after fishing season was calculated by equation (3) as SB in numbers $S_t$.

$$F_t = -\ln\left(1 - \frac{C_t \cdot \exp^{\frac{\mathrm{M}}{2}}}{\mathrm{q}U_t}\right) \tag{2}$$

$$S_t = \left(N_t \cdot \exp^{-\frac{\mathrm{M}}{2}} - C_t\right) \cdot \exp^{-\frac{\mathrm{M}}{2}} \tag{3}$$

Here $C_t$ is squid catch of year t, M is natural mortality after recruitment assuming 0.6 (six months of fishing season).

2) Projection of biomass and SB in 2021

(1) Since fishing season was not yet finished at the time of stock assessment, standardized CPUE (0.26) was predicted by the method described in Appendix 3-3 as abundance index in 2021. Biomass in number in 2021 was estimated by equation (1) with abundance index in 2021 and multiplying with proportional constant q (18.32).

Biomass in number in 2021 = 0.48 billion squid (149 thousand tons)

(2) Catch in number in 2021 was estimated by equation (2) with current fishing pressure (F2018-2020).

Catch in number in 2021 = 0.14 billion squid (44 thousand tons)

(3) SB in number in 2021 (SB reproduce recruitment in 2022) was estimated by equation (3) with biomass and catch in number in 2021 and natural mortality.

SB in number in 2021 = 0.16 billion squid (49 thousand tons)

Reference

Kidokoro, H, T. Goto, E. Den and T. Kinoshita (2006) in Japanese. 木所英昭・後藤常夫・田　永軍・木下貴裕 (2006) 平成 17 年スルメイカ秋季発生系群の資源評価. 平成 17 年度我が国周辺漁業資源調査資源評価, 水産庁・水産総合研究センター, 522-546.

Mori, K. (2006) in Japanese. 森　賢 (2006) スルメイカ冬季発生系群の初期生態と資源変動機構に関する研究. 北海道大学博士号論文, 172pp.

Japan Sea Fishery Research Institute (1997) in Japanese.日本海区水産研究所 (1997) 対馬暖流系スルメイカ. 平成 8 年度我が国周辺漁業資源調査資源評価票, 水産庁, 253-261.

Japan Sea Fishery Research Institute (1998) in Japanese.日本海区水産研究所 (1998) 対馬暖流系スルメイカ. 平成 9 年度我が国周辺漁業資源調査資源評価票, 水産庁, 289-299.

Appendix Table 2-1. Catch classification of Japanese flying squid (fall and winter) stock by month by area.

Classification of catch by stock (fall and winter) by manth and area

| Area | | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hokkaido | Ishikari | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Shiribeshi | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Hiyama | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Souya | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Rumoi | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Oshima | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Iburi | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter |
| | Hidaka | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter |
| | Tokachi | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter |
| | Kushiro | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter |
| | Nemuro | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter |
| | Okhotsk | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter | winter |
| Pacific | Ohata | winter | winter | winter | fall | fall | fall | fall | fall | mix | winter | winter | winter |
| | Pacific | winter | winter | winter | fall | fall | fall | mix | winter | winter | winter | winter | winter |
| Japan Sea | Honshu | winter | winter | winter | fall | fall | fall | fall | fall | fall | fall | mix | winter |
| | Kyushu | winter | winter | winter | fall | fall | fall | fall | fall | fall | fall | mix | winter |

Classification of frozon catch by stock (fall and winter) in Japan

| Area | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pacific Okhotsk | winter | winter | Ban | Ban | winter | winter | winter | winter | winter | winter | winter | winter |
| Japan sea | winter | winter | Ban | Ban | fall | fall | fall | fall | fall | fall | winter | winter |
| East China sea | winter | winter | Ban | Ban | fall | fall | fall | fall | fall | fall | fall | winter |

Classification of Korean catch by stock (fall and winter)

| Area | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Korea | winter | winter | winter | fall | fall | fall | fall | fall | fall | fall | mix | winter |

Appendix Table 2-2. Monthly average weight of squid caught.

| Month | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| average weight (g) before 1988 | 84 | 84 | 123 | 156 | 237 | 274 | 301 | 314 | 333 | 333 | 333 | 333 |
| average weight (g) after 1989 | 56 | 56 | 107 | 170 | 213 | 259 | 282 | 341 | 355 | 355 | 355 | 355 |

Appendix 3 Standardized CPUE of small squid jigging fishery.

1. Method to estimate standardized CPUE of small squid jigging (abundance index)

Fishing efficiency of small squid jigging fishery in main ports from Miyagi to Hokkaido coastal area differ by area and month. Therefore, CPUE of small squid jigging fishery was standardized to eliminate those effect (Okamoto et al. 2016). Generalized liner mix model was used for standardization using catch and effort data of small squid jigging by port and month during July to December from 1979 to 2020. Best model was selected by BIC information criteria. As a results of model selection, the model with year, month, and port as main effects, and random intercept by port by year and random intercept of port by month was selected. CPUE was standardized by such model.

2. Method of CPUE standardization at the assessment year

CPUE at the assessment year was standardized using the catch and effort data from July to just before the assessment (mid-October). The method of standardization used is same as mentioned above (Appendix 3-1), but the data during July to October from 1979 to 2021 were used. As a results of model selection, the model with year, month, and port as main effects, and random intercept by port by year was selected. CPUE was standardized by such model and results was used as explanatory variable to estimate abundance index at assessment year in Appendix 3-3.

3. Method to predict standardized CPUE (abundance index) at assessment year

Since assessment was conducted during fishing season, standardized CPUE (abundance index) was estimated using the data from July to just before assessment (mid-October) as used model described below.

$$\log(U_t) = a + b \cdot \log(X_t) + \varepsilon_t\,, \qquad \varepsilon_t \sim \mathrm{N}(0, \sigma^2) \tag{4}$$

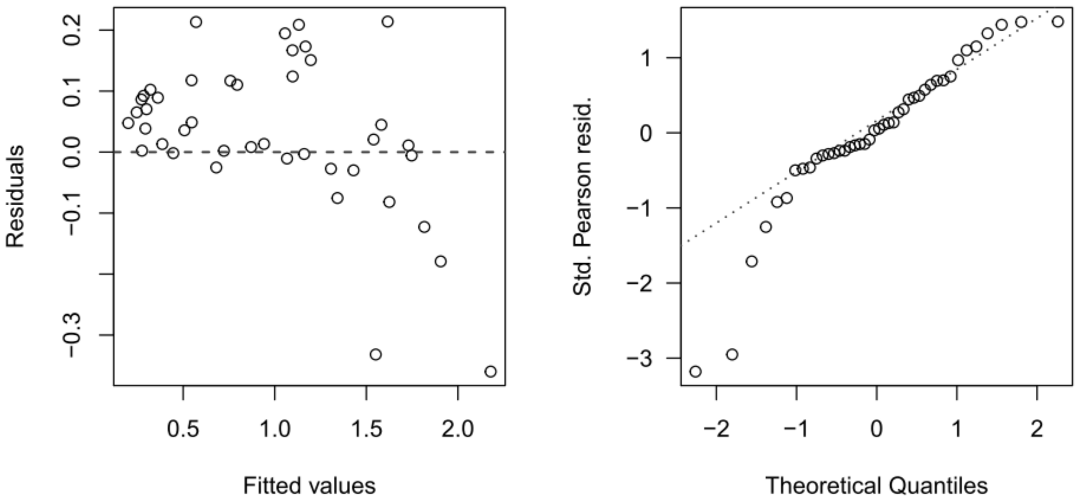
Here, $U_t$ is standardized CPUE of year t using the data during July to December for the main port of Miyagi to Hokkaido coast, $X_t$ is standardized CPUE during July to just before assessment, $\varepsilon_t$ is error of normal distribution. Until last year, abundance index was estimated by multiple regression model including geometric mean of CPUE ($Y_t$) of squid research conducted August and September without log transformation (Kaga et al. 2021). However, a problem was found in residual distribution by diagnosis of multiple regression model (Appendix Figure 3-1), then after resolving an issue (Appendix Figure 3-2), equation (4) was used in this year. Moreover, $Y_t$ was included as an explanatory variable in some models, but such models were not selected by AICc information criteria.

As a results of retrospective analysis, estimation by new model has high accuracy in 2019 and 2020 though slightly low accuracy in 2017 and 2018 (Appendix Figure 3-3). Moreover, as a results of cross validation (Leave one out method), mean absolute error rate during 1979 to 2020 become low as 9.7% comparing with last year as 11.4% (Appendix Figure 3-4).

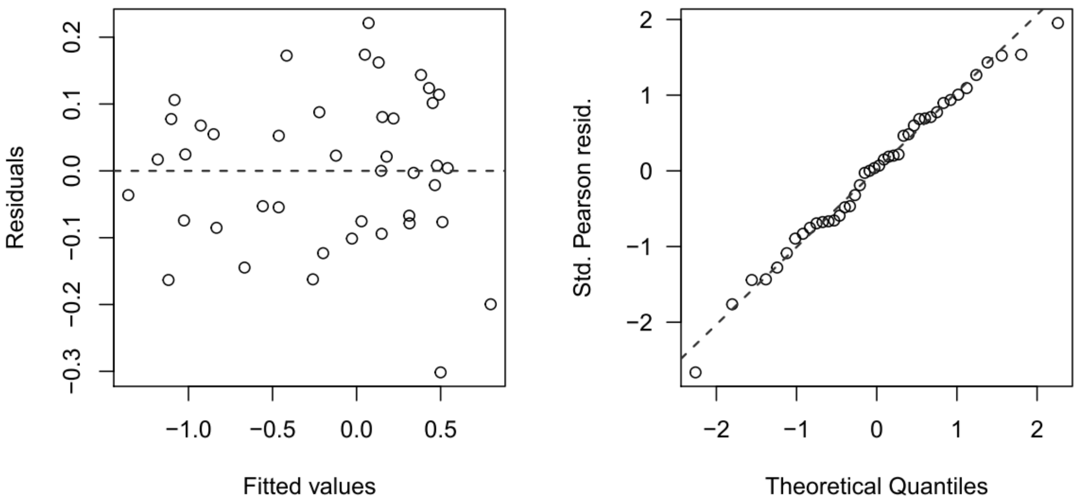
Reference

Okamoto, S., N. Yamashita and T. Kaga (2016) in Japanese. 岡本　俊・山下紀生・加賀敏樹 (2016) 小型いか釣り漁業データを用いたスルメイカ冬季発生系群の CPUE の標準化. 日水誌, **82**, 686-698.

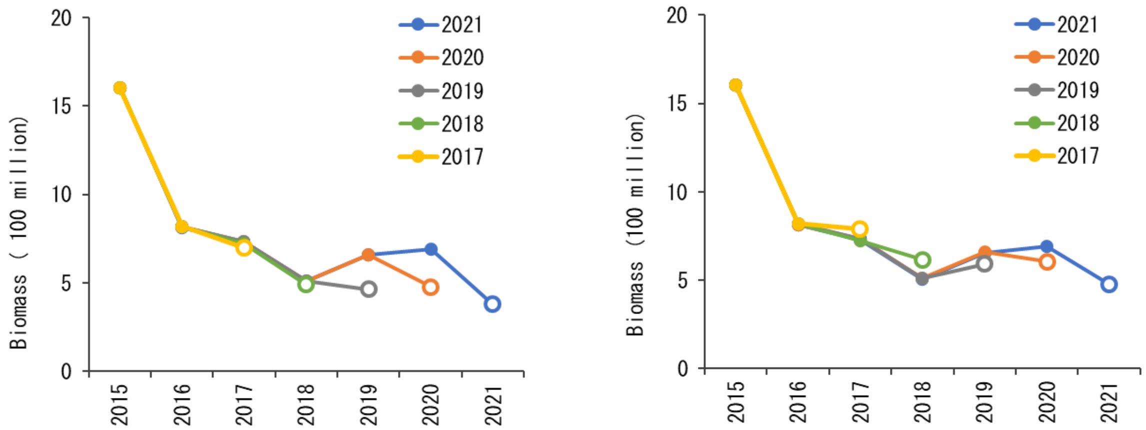
Kaga, T., S. Okamoto, H. Kubota, H. Miyashita and S. Nishijima (2021) in Japanese. 加賀敏樹・岡本　俊・久保田　洋・宮原寿恵・西嶋翔太 (2021) 令和 2（2020）年度スルメイカ冬季発生系群の資源評価. 我が国周辺水域の漁業資源評価, 水産庁・水産研究・教育機構, 東京.



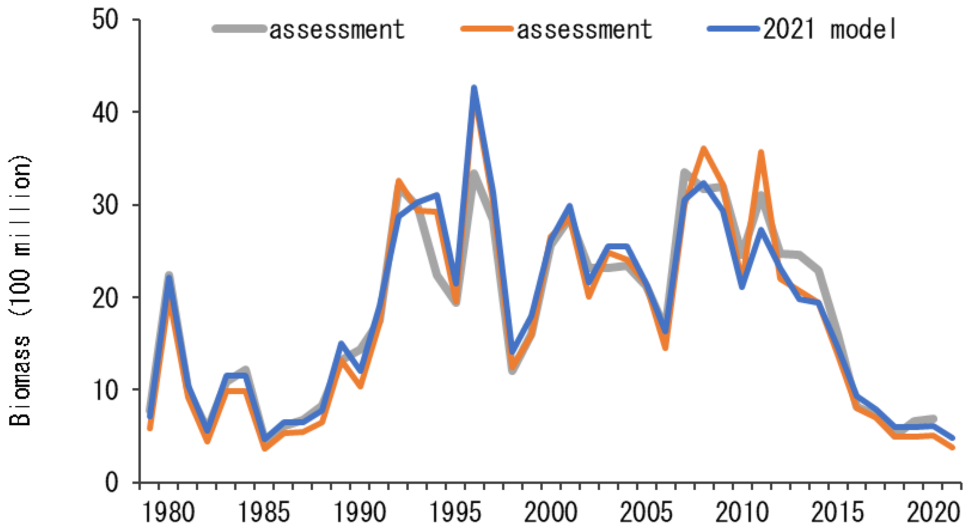

Appendix Figure 3-1. Residual distribution and Q-Q plots of abundance index estimation model in 2020 (Kaga et al 2021).




Appendix Figure 3-2. Residual distribution and Q-Q plots of abundance index estimation model modified in 2021.




Appendix Figure 3-3. Results of retrospective analysis of biomass estimation.
Left figure (a) indicates results of 2020 model (Kaga et al. 2021), and right figure (b) indicates it of 2021 model. White circle indicates projected biomass.




Appendix Figure 3-4. Cross validation result (Leave one out method) of biomass projection model.

Appendix 4 Outline of research survey

1. Larval survey

It is considered that biomass of Japanese flying squid is highly affected by oceanographic environmental change in spawning grounds (Sakurai et al. 2000). Therefore, larval survey to monitor hatching abundance and distribution was conducted in the East China Sea and the area southwest of Kyusyu mainly February after 2001. Sampling gear is Bongo net (70cm diameter, 0.335mm mesh) , and main target is squid larvae hatching in January.

Recent research area ranged from 29 to 33N and 126°30' to 132°00' E. Research results after 2001 are shown in Appendix Figure 4-1. Larval density in February 2021 was 3.6 squid/1,000 $m^3$ (preliminary), was lower than previous year (82% of previous year) and recent five years average (49% of average).

Squid larval distribution in 2020 and 2021 are shown in Appendix Figure 4-2. Squid distribution in 2021 was mainly found northern area of Kuroshio current as same as past research results. Since squid larval early reduction is strongly affected by oceanographic environmental change, relation between larval density and recruitment is not always clear. However, it is necessary to monitor larval density and oceanographic environment continuously to understand mid-long term reproductive environmental change.

2. Results of second squid fishing grounds survey and research survey on southern migration in the Pacific area of eastern Hokkaido

Research results of second squid fishing grounds survey conducted by Aomori, Iwate, Miyagi and FRA (Hokkaido) in the area from coast to offshore of Tohoku to Hokkaido during August and September and research survey on southern migration in the Pacific area of eastern Hokkaido conducted by Hokkaido fishery experimental station (http://www.hro.or.jp/list/fisheries/research/central/section/shigen/ukiuo/index.html) are shown in Appendix Figure 4-3. Main target is Japanese flying squid hatched during December to March. The area inside Tsugaru strait and area east of 148E were excluded from the results due to the lower or no sampling. Geometric mean of CPUE (squid/machine/hour) in 2021 was 0.02 squid and lower than previous year and recent five years average (40% of previous year, 33% of average, Appendix Table 4-1). Ratio of sampling point without zero was 25% and lower than previous year and five years average.

3. First fishing grounds survey

Fishing grounds survey was conducted using squid jigging machine in June inshore and offshore area of Tohoku and Hokkaido by Hokkaido, Aomori, Iwate, Miyagi prefectures and FRA (Appendix figure 4-4). Main research target was squid above 10cm of dorsal mantle length supposed hatching in December to March. The area inside Tsugaru strait was excluded in the results due to the low sampling number and contamination with fall stock (Sakaguchi et al. 2009). Geometric mean CPUE (squid/machine/hour) in 2021 was 0.01 squid and was lower than previous year and five years average (67% of previous year, 46% of average, Appendix Table 4-2).

4. Larval survey by surface trawl

Surface trawl survey (25m of net mouth, 10mm mesh size at cod end, 30 minutes tow) was conducted at spring in the area tranzitional zone between Kuroshio and Oyashio current to monitor larval distribution before recruitment. Target was squid smaller than 10cm DML supposed hatching February to March. Research area ranged offshore of Joban to Sanriku, and research stations were set as same as in the water temperature of average years. Research was conducted as same method after 1996. Research results until $10^{th}$ of June were used in this report. Since mainly squid smaller than 10 DML were caught by the research, distribution of squid smaller than 10cm were shown in Appendix Figure 4-5. Geometric mean CPUE (squid/tow) in 2021 was 5.6 squid and was below previous year and five years average (13% of previous year, 43% of average, Appendix Table 4-3).

5. Recruitment monitoring by surface trawl

Surface trawl survey (30m net mouth, 17mm mesh size at cod end, 60 minutes tow) was conducted to monitor squid recruitment before fishing season offshore area of Sanriku to eastern Hokkaido. Main target was squid supposed hatching January to April. The research was conducted during early to mid-July from 2019. The mode of squid caught was 3cm DML (7cm and 16cm in previous year). Geometric mean CPUE (squid/net) was 0.3 squid and was below previous year (22% of previous year) and was mainly caught in the area west of 146E (Appendix Figure 4-6).

6. Research of potentially suitable are for spawning

Potential suitable area for spawning in the East China Sea during mid-January to early March (depth range 100-500m, surface temperature range 18.0-23.0$^{\circ}$C (Sakurai 2006)) was shown in Appendix Figure 4-7. Similar map in 2007 when reproductive success was high with suitable water temperature was shown for comparison. Surface temperature was referred from MOVE (Usui et al. 2006) which is weather forecast model of Japan Meteorological Agency. Especially those area widely expanded in early February as same as that in 2007. While it should be carefully monitored in the future since shrink of such area were observed recently like in 2015, 2016 and 2018.

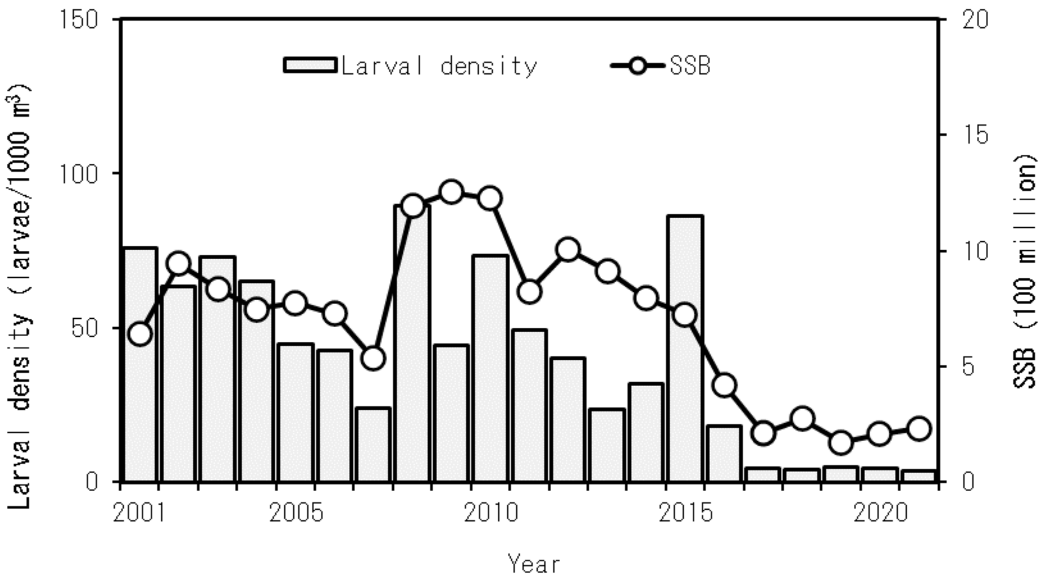
Reference

Sakaguchi, K., M. Sato, M. Mitsuhashi and H. Kidokoro (2009) in Japanese. 坂口健司・佐藤　充・三橋正基・木所英昭 (2009) 北海道周辺海域におけるスルメイカの日齢と発生時期. 日水誌, **75**, 204-212.

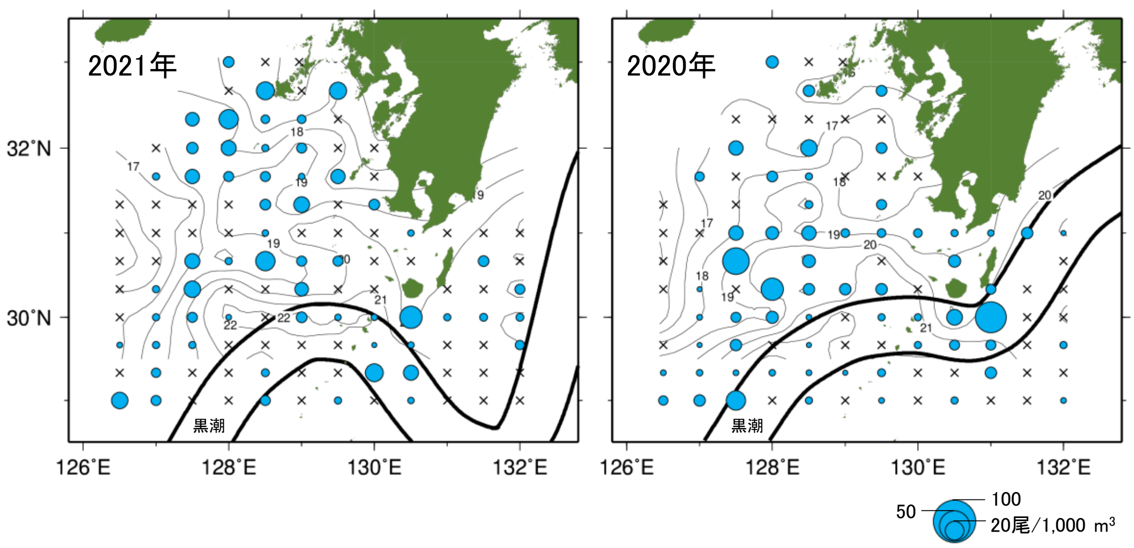
Sakurai, Y., H. Kiyofuji, S. Saitoh, T. Goto and Y. Hiyama (2000) Changes in inferred spawning areas of *Todarodes pacificus* (Cephalopoda: Ommastrephidae) due to changing environmental conditions. ICES J. Mar. Sci., **57**, 24-30.

Sakurai, Y. (2006) How climate change might impact squid populations and ecosystems: a case study of the Japanese common squid, *Todarodes pacificus*. Globec Report, **24**, 33-34.

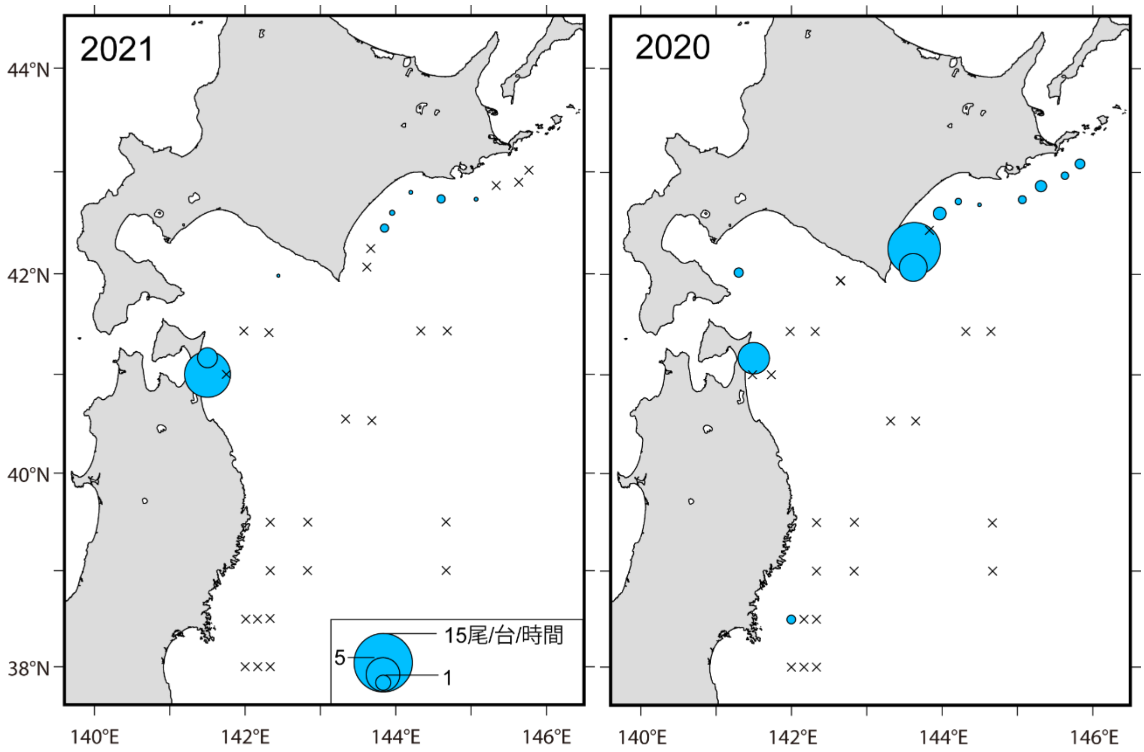
Usui, N., H. Tsujino, Y. Fujii and M. Kamachi (2006) Short-range prediction experiments of the Kuroshio path variabilities south of Japan. Ocean Dynamics, **56**, 607-623.



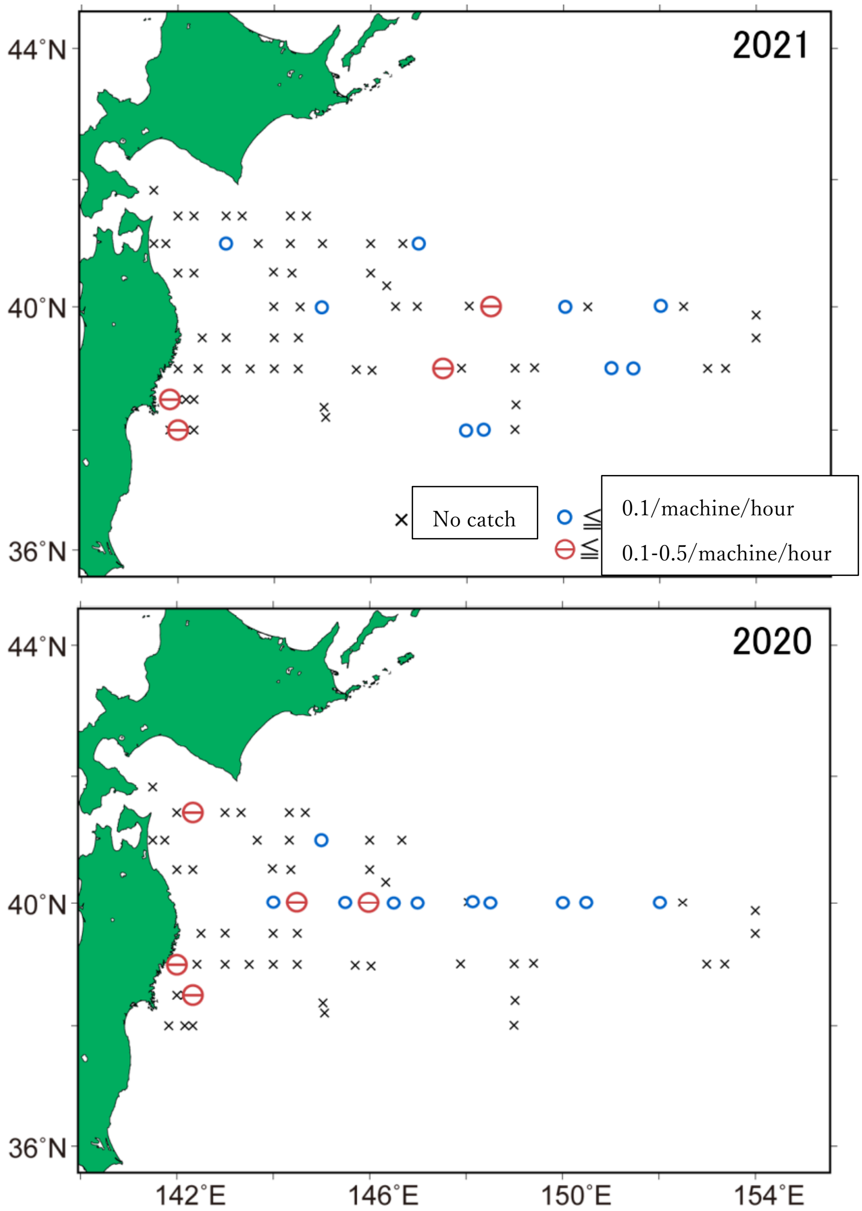

Appendix Figure 4-1. Annual larval distribution density and SB in number.



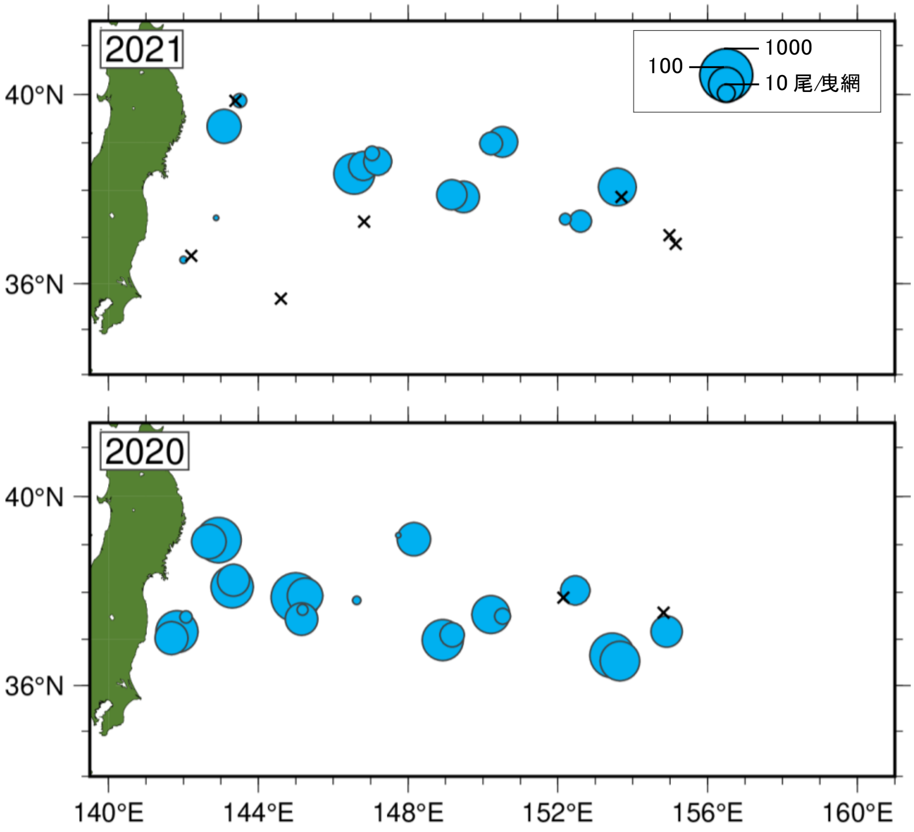

Appendix Figure 4-2. Larval distribution (squid/1,000 m$^3$), surface temperature (thin solid line) and Kuroshio current route (bold line) collected during early to late February in 2020 and 2021 southwest Kyushu. Kuroshio current route was referred Oceanographic report (http://www.kaiho.mlit.go.jp/). The cross mark x indicates zero catch.



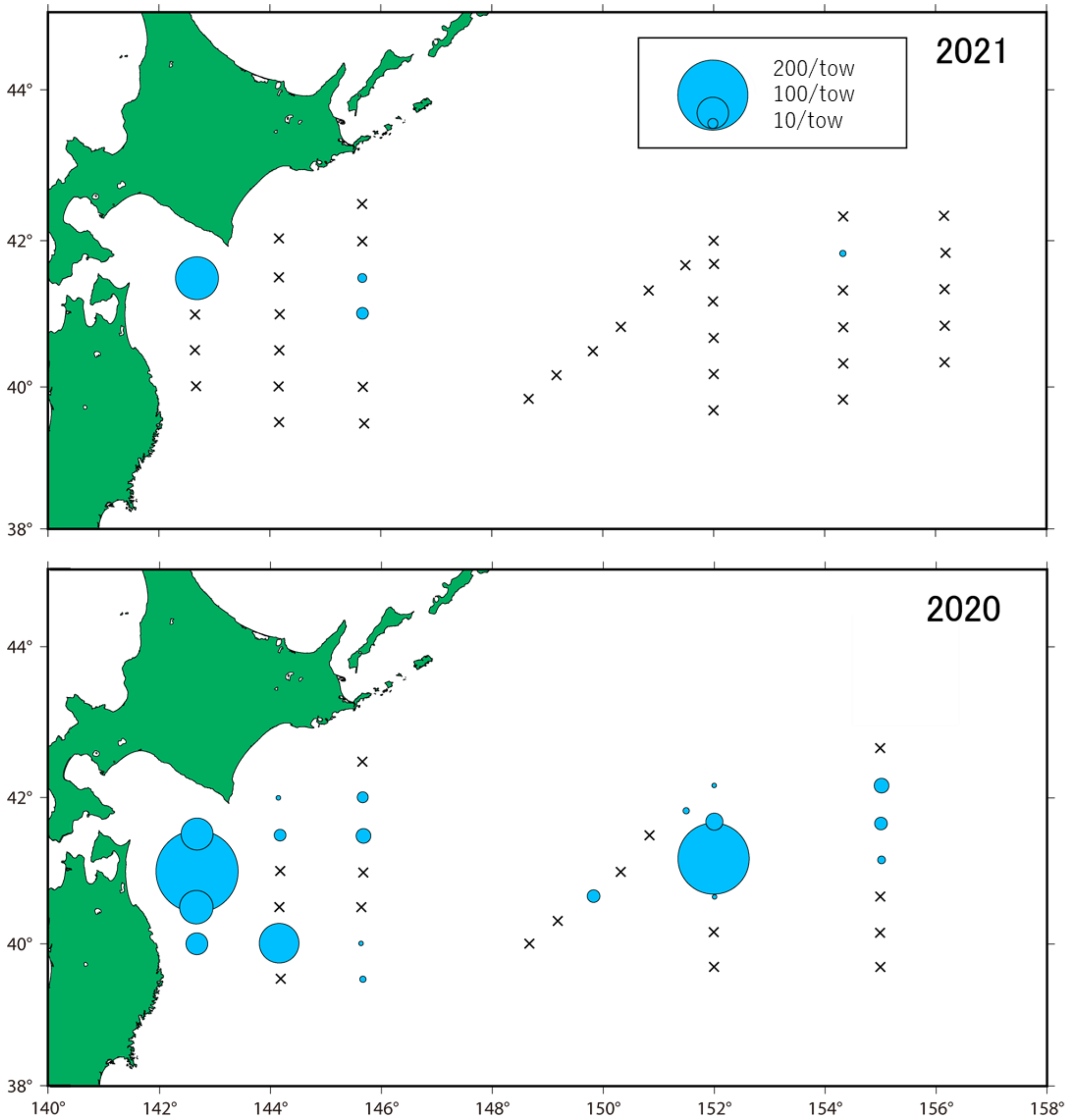

Appendix Figure 4-3. CPUE (squid/machine/hour) distribution collected by the second squid fishing grounds survey during late August to mid-September in 2020 and 2021. The cross mark x indicates zero catch.



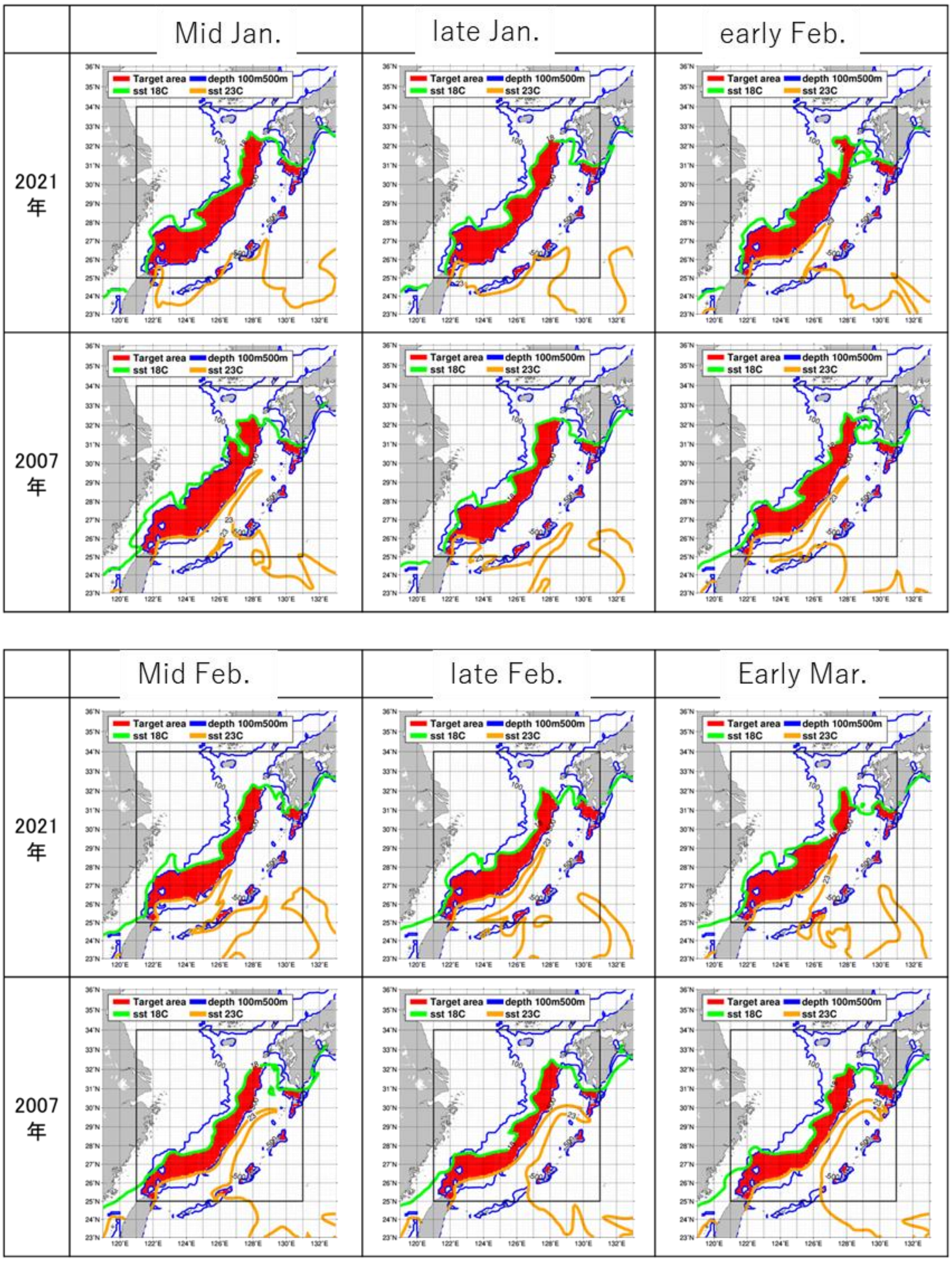

Appendix Figure 4-4. CPUE (squid/machine/hour) distribution collected by the first squid fishing grounds survey during June in 2020 and 2021. The cross-mark x indicates zero catch.




Appendix Figure 4-5. CPUE (squid/tow) distribution collected by larval survey during May to June in 2020 and 2021. The cross-mark x indicates zero catch.




Appendix Figure 4-6. Distribution of CPUE (squid/tow) collected by squid recruitment survey during July in 2020 and 2021. The cross-mark x indicates zero catch.




Appendix Figure 4-7. Potential suitable area for spawning (red area) during mid-January to early March in 2007 and 2021. The definition of suitable area was ranging 100 to 500m depth and surface temperature ranging 18.0 to 23.0°C.

Appendix Table 4-1. Annual geometry mean CPUE (squid/machine/hour) collected by the second squid fishing grounds survey and squid south migration survey.

| 年 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CPUE | 0.002 | 0.06 | 0.09 | 0.02 | 0.05 | 0.04 | 0.000 | 0.02 | 0.04 | 0.05 | 0.03 | 0.03 |

| 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.08 | 1.15 | 0.28 | 0.04 | 0.07 | 0.15 | 0.24 | 0.05 | 0.03 | 0.50 | 0.20 | 0.16 |

| 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.31 | 0.19 | 0.42 | 0.06 | 0.33 | 1.06 | 0.97 | 0.51 | 1.66 | 0.23 | 0.61 | 0.42 |

| 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| 0.22 | 0.07 | 0.11 | 0.06 | 0.03 | 0.05 | 0.02 |

Appendix Table 4-2. Annual geometric mean CPUE (squid/machine/hour) collected by the first squid fishing grounds survey.

| 年 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CPUE | 0.36 | 0.09 | 0.02 | 0.05 | 0.07 | 0.08 | 0.12 | 0.08 | 0.12 | 0.04 | 0.05 | 0.18 |

| 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.02 | 0.07 | 0.03 | 0.10 | 0.04 | 0.03 | 0.06 | 0.10 | 0.04 | 0.01 | 0.01 | 0.01 |

| 2020 | 2021 |
|---|---|
| 0.01 | 0.01 |

Appendix Table 4-3. Annual geometric mean CPUE (squid/tow) collected by larval survey in the transitional zone.

| 年 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CPUE | 9.8 | 4.5 | 4.8 | 10.6 | 13.9 | 27.6 | 61.5 | 59.6 | 53.1 | 142.0 | 49.2 | 43.9 |

| 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 110.9 | 199.3 | 51.9 | 33.5 | 39.9 | 18.1 | 14.1 | 6.0 | 7.4 | 4.2 | 1.6 | 10.5 |

| 2020 | 2021 |
|---|---|
| 41.7 | 5.6 |