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

Responsible Institute: National Research Institute of Fisheries Science

Summary

The stock biomasses from 1981 to 2021 were estimated using standardized CPUE (catch number per jigging-machine-hour) obtained through the recruitment estimation survey on the autumn-spawning stock of Japanese flying squid in the Sea of Japan. Because change in the distribution pattern of this stock during the survey period was highly likely to occur in 2019 and 2021, the recruitments for two years were estimated using the stock-recruitment relationship applied to the spawning stock biomass for the previous years. The stock biomass increased in 1990s from lower level in 1980s to high level of 1990s, reaching the peak of 1.9 million tons in 1997. Although it remained at higher level with fluctuating between 0.9 and 1.8 million tons after 1998, it decreased after 2015, changing between 0.6 and 0.9 million tons. The biomass for 2021 was estimated as 0.931 million tons. Fishing mortality (F), which remained at lower level from 1991 to 2004, has frequently recorded higher values since 2005. The recruitment and subsequent spawning stock biomass (SB) have been increased since 2020 due to enhanced recruitment per spawning, whereas they stayed at lower level between 2015 and 2019.

The Research Institute Meeting held in July 2020 decided to employ the hockey-stick (HS) stock-recruitment model and agreed the MSY-based target reference point of 329 thousand tons estimated with this model. The estimates of SB and F for 2021 were above and below SBmsy and Fmsy, respectively. There were few changes in SB for recent 5 years (2017 to 2021). It is noted that uncertainty included in SB estimates for 2019 onward was likely to be increased, in light of recent changes in distribution of this stock during the survey period, which led uncertainty increase of estimated recruitment, and cryptic catch by the Chinese fleets.

For this stock, reference point, future projection etc. will be determined by management meeting, therefore such values are tentative.

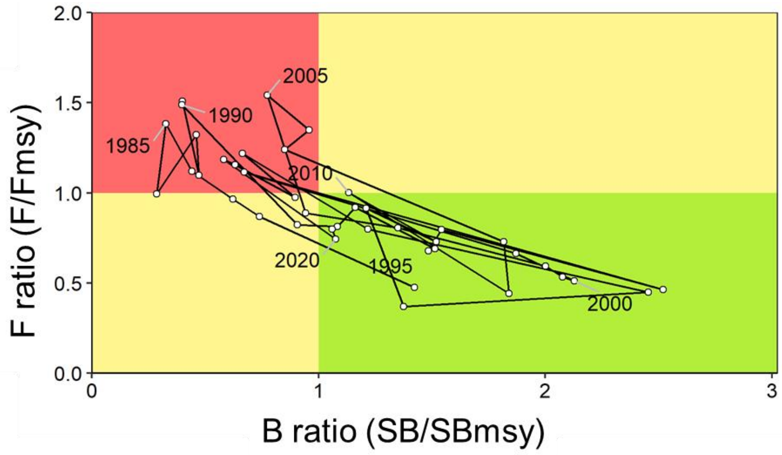
- Summary table of reference relating to MSY

References	**Values**
Regarding MSY	
SBmsy	329,000 tons
Fmsy	0.48
%SPR(Fmsy)	62%
MSY	273,000 tons
SB and Fishing pressure at 2018	
SB2021	349,000 tons
F2021	0.38
%SPR(F2021)	68%
Ratio to MSY	
SB2021/SBmsy	1.06
F2021/Fmsy	0.80

- S-R relationship assumption: Hockey stick (no autocorrelation)

- Summary of stock status

Status of current SB	Above SBmsy
Status of F	Below Fmsy
Status of SB	Stable



Fishing year	Biomass (1000 tons)	SB (1000 tons)	Catch (1000 tons)	F/Fmsy	Exploitation rate
2017	856	295	236	0.97	28
2018	659	208	207	1.16	31
2019	614	191	197	1.19	32
2020	919	354	204	0.74	22
2021	931	349*	219*	0.80*	24*

*Catch of 2021 was sum up with estimated catch (69,000 tons) by average fishing intensity of Japan and Korea from 2018 to 2020 (F=0.11) and extrapolated Chinese catch (150,000 tons). SB, F/Fmsy and Exploitation rate were estimated from such assumption.

1. Data set

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

Data set	Data source and research
Catch number by month and area (catch by stock)	National statistics of Ministry of agriculture, forestry and fisheries (MAFF) Logbook report of squid fishery (Fishery Agency) Squid Landing statistics in Japan (All Fisheries Federation) Landing and biological survey at major ports (Hokkaido-Nagasaki [14] prefectures) Fishery statistics (Korea, https://www.fips.go.kr/p/Main/, Nov. 2021) Research data of FRA (FRA)
Index of abundance	Joint survey of squid fishing ground in Japan Sea (FRA, Hokkaido-Tottori[7] prefectures) in 1995-2021 Research data of Research vessels and training boats (1981-2000) *Research data of squid jigging survey
CPUE of small squid boat	Monthly catch and number of vessels landing at main fishing ports (Hokkaido, Aomori and Ishikawa)
Density distribution of squid larvae	Egg and larvae survey (Aomori-Shimane[11] prefectures, Oct. and Nov.) Research survey of Japanese flying squid larvae in Japan Sea (FRA, Oct.-Dec.) LNP vertical tow and Bongo net
Density distribution of young squid	Recruitment survey of Japanese flying squid in Japan Sea (FRA, Toyama and Ishikawa prefectures, April) Surface trawl
Average 50m depth temperature of Tsushima current	Oceanographic survey (Aomori-Shimane[11] prefectures) CTD
Natural mortality	Assuming $M = 0.1$ per month (0.6 for 6 month fishing season)
Fishing effort index	Logbook report of squid fishery (Fishery Agency)

*used for biomass estimation

The definition of fishing season is from April to next March, but real season is April to November.

2. Ecology of the species

1) Distribution and migration

Distribution of Japanese flying squid extend around the Japanese islands. Spawning of this species occur throughout the year. Two major seasonal recruitments appear in autumn and winter. Because those cohorts have different distribution and migration, they have been regarded as two different stocks. The stock assessment has been conducted to each stock. Two minor cohorts in spring and summer were reported by Araya (1967), yielding small catch. having similar distribution and migration to the autumn-spawning stock, the summer cohort have been included in this stock. Larvae of the this stock are hatched in October to December in the main spawning ground which spreads from the coastal water off Hokuriku Region to the East China Sea and then transported to the Sea of Japan by the Tsushima Warm Current. Subsequently, the squids engage northward and southward migration in spring-summer and autumn, respectively. A small part of this stock moves into the Pacific Ocean and the Okhotsk Sea through the Tsugaru Strait and the Soya Strait, respectively, reaching at the waters off the east south coast of Hokkaido and the northern Sanriku Region (Fig. 2-1).

2) Age and growth

Longevity of this species is one year. The squids die after spawning. The growth of this species differs among spawning seasons, distributions and sexes (Hamabe and Shimizu 1966, Araya 1967, Kidokoro and Hiyama 1996). The average growth of this stock is shown in Fig. 2-2.

3) Reproduction

Male of this species develop gonads 7 to 8 months after hatching (Sakaguchi 2011), attain maturity at approximately 9 months-old. Female attain maturity slower than male. They rapidly develop gonads at 10 months-old right before spawning and die after spawning at the last of their life history like other squids (Rocha et al. 2001). Spawning frequency of this species has been clarified so far (Adachi 1988, Ikeda et al. 1993). The main spawning grounds of the autumn-spawning stock formed in the area from the waters off the Hokuriku Region to the East China Sea (Fig. 2-1).

4) Prey-predator relationships

The diets of Japanese flying squid change according to growth stages. The squids smaller than 5 cm in mantle length mainly feed on plankton. Those of 5 to 7 cm in mantle length grow to the same physical type with adults and consequently obtain enhanced swimming capacity, shifting diets to fishes (Uchikawa and Kidokoro 2014). The diets changes by zone in the Sea of Japan. The squids prey on small fishes such as *Maurolicus japonicus* in coastal areas of the Tsushima Warm Current region, whereas they feed on mainly zoo plankton in offshore subarctic cold waters (Okiyama 1965).

Japanese flying squid was recorded in diet of the sea lion (Goto et al. 2017). It is considered that it is fed by large fish and marine mammals, but depression rate by predation is not known. The cannibalism is common young after 100 days of hatching (Kidokoro and Uji 1999).

5) Special remarks

The biomass of Japanese flying squid is affected by not only fishery but also mid-long term oceanographical change known as “regime shift” and short-term change (Murata and Araya 1977, Okutani and Watanabe 1983, Sakurai et al. 2000, Kidokoro 2009). Especially, it is considered that rise of water temperature of 1989 winter (Hare and Mantua 2000, Yasunaka and Hanawa 2002) might cause of increase of the population in 1990s with change of spawning ground (Sakurai et al. 2000, Goto 2002), migration (Kidokoro et al. 2019) and hatching season (Kidokoro 2009). Therefore, it is important to monitor mid-long term oceanographical change and ecological change of squid for understanding stock fluctuation.

Regarding recent environmental change, the possibility of regime shift from worm to cold era was discussed due to the observed Pacific interdecadal oscillation (PDO) change, it became minus to plus, as same phenomena observed 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.

3. Fisheries on the species

1) Outline of fisheries

The fall stock mainly distributes in Japan Sea and became fishery target at summer and fall (Fig. 2-1). Fishing grounds move following squid migration. Squid are caught by small squid jigging vessel (size less than 30 tons) along coast and by mid-size jigging vessel (size 30-200 tons) at offshore. Squid caught at coast is landed by raw and at offshore by frozen. Squid are also caught by Korea, n. China, Russia and north Korea, but catch detail by Russia and north Korea are unknown. Catch statistics used for stock assessment is sum up it of Japan, Korea and Chine (describe later). There is no information of catch of north Korea, therefore it is not included for assessment. Regarding Russian catch, it reported near 5,000 tons in some year, but it not official statistics and those of many year are less than 500 tons, therefore it is also not included.

2) History of catch

Historical squid catch (Japan + Korea + China assumed) is shown in Fig. 3-1 and Table 3-1. Catch before 1978 are only Japanese catch at Japan Sea. Due to the difficulty of separation by stock before 1978, the catch is shown just as reference. Both fall and winter stock define fishing season from April to next March, but fishing season of fall stock is April to November, therefore catch of fishing year and calendar year are same for fall stock. The catch was 157 thousand tons in average in 1980s, then due to the rapidly increase of Korean catch, it increased more than 300 thousand tons in 1996 and 1999 as same as Japanese catch in early 1970s. Then it became peak in 2000 than decreased, but Chinese catch increased after 2005, it became peak around 380 thousands tons in 2005 and 2006, then decreased again, and those are 197 thousands in 2019 and 204 thousands tons in 2020. Catch after 2005 includes assumed values of Chinese catch.

Regarding Chinese fishery, two vessel purse sine fishery start to operate in North Korean EEZ from 2004, light purse seine joined in recent years then over one thousand vessels operate at the peak

(Chow et al. 2016). Chinese annual catches were assumed as 150 thousands per year after 2004 except the years of 2004, 2009 and 2013 when such catch were considered small (Kubota et al. 220a, Appendix 5) based on Korean report (Chow et al. 2016), satellite survey on fishery activities (Park et al. 2020, Appendix 4).

The activities of fishing nations and Japanese catch status by fisheries were summarized in Appendix 5. Recent Japanese fishing grounds located northern offshore area for both inshore and offshore fisheries and it is considered that it is due to the low catch at inshore Tsushima current area and temperature rising of the Japan Sea. However, although high temperature of Japan Sea continuing, catches around Hokkaido of Japan Sea side down largely for both inshore and offshore area, then main fishing grounds shift to around Yamato rise and inshore area for offshore fishery and to around Noto peninsula for inshore fishery. In addition, catch by bottom trawl rapidly increased north of Ishikawa prefecture, and it is considered that vertical distribution or behavior of squid changed (Appendix Figure 5-6). It is also suggested some relation with decreasing northern migration of squid. Although Japanese catch still continued low, increasing amount of migration to spawning ground at spawning season were observed after 2019 and 2020 (Appendix Figures 3-5 and 5-4). It should be observed continuously.

Squid catches from April to September in 2021 for fall stock by fishery were 6,589 tons for inshore fisheries (squid jigging, set net and bottom trawl), 6,221 tons for offshore fishery (squid jigging), 32,753 tons for south Korea, and 45,563 tons in total. Those were 50%, 196%, 129% and 109% compared with previous year and 52%, 81%, 115% and 93% for past 5 years average in respectively. The statistics of landing in raw squid was raised value which landing statistics of All Fisheries federation were raised to the statistics of MAFF (Ministry of Agriculture, Forestry and Fisheries). The statistics of landing frozen squid (Japan offshore fishery) were raised values which catch by month and area from logbook report were raised by the ration of past logbook report to the statistics of MAFF. The catch of 2021 which logbook report was not summed yet, was estimated raising the catch of 10 hired fishing vessels (FRA) by the ratio between past same research and logbook report, and ratio of reported catch and statistics of MAFF.

3) Annual fishing effort by fisheries

Fishing effort of mid-size squid jigging boats (fishing days from May to October in Japan Sea and May to November in East China Sea) were from 70 to 100 thousand days per year until mid 1980s, then decreased from 1990s and down below 20 thousand days per year in 2000s (Fig. 3-2, Table 3-2). Those were around 10 thousand days after 2007, below 10 thousand after 2013 and decreased about 4400 days in 2020. Long term decrease trend of fishing effort in offshore area caused by decreasing number of vessels (Miki 2003, Yomo 2009) and extending fishing season of Neon flying squid in 2019 and 2020 (Abo et al. 2020).

4. Stock status

1) Stock assessment methods

The stock biomass was estimated through the recruitment estimation survey in the Sea of Japan (Appendices 1 and 3). The method to estimate the stock biomass is described as follows (Appendix 2).

a) CPUE (catch number per jigging-machine-hour), water temperature and mantle length were collected at each survey point through the survey from mid-June to mid-July (after 1995, in addition with those data, research data obtained research vessel and training vessel from June to July in 1981 to 2000 were also used). From those observation, annual distribution of squid was obtained. The CPUE data were standardized to get stock biomass index. The standardized methods used for 2021 was improved from previous year (Appendix 2).
b) Assuming a linear relationship between CPUE and recruitment, the recruitment was estimated through multiplication of the CPUE by catchability of survey gear (q). The stock biomass was calculated by multiplying the recruitment by the mean weight of 280 g, which corresponded to that of squid catch.
c) The catchability was estimated under the following assumption. It was assumed that the mean fishing mortality before 2001 was equal to the average of fishing mortality (F*=0.447) derived from daily decrease rate of CPUE obtained through squid jigging surveys by research/training vessel in May to November of 1979 to 2000. We estimated the catchability meeting this assumption.
d) Number of spawner was estimated through the following procedure. The recruitment was depleted by natural and fishing mortalities. The natural mortality was given as 0.1 per month, and number of fishing mortality corresponded to annual catch in number number, which was obtained by dividing annual catch in weight by the mean weight (280 g).
e) The CPUE from the recruitment estimation survey for 2019 was not employed to estimate recruitment because of change in distribution pattern during the survey period. The stock-recruitment model was served to estimate the recruitment for 2019 with the following procedure (Fig. 4-8). The estimate of SB for 2018 was input to the model with the four residuals for 2015 to 2018. As a result, the average of the four recruitment estimates for 2019 was applied as the recruitment for that year.
f) The CPUE from the survey for 2021 was not used for the same reason to 2019. It was calculated with the same procedure to 2019 (Fig. 4-8).

As mentioned in e) and f), the CPUEs for 2019 and 2021 from the survey were not used to estimate recruitment, which were calculated with the stock-recruitment model. It was presumed that, in 2019, the unusual migration pattern of the squid before the survey period might cause low availability in the whole survey area within the Japanese EEZ of the Sea of Japan (Kubota et al. 2020b, Appendix 5). Although good catch was occurred in offshore waters and coastal waters around the continent of the Sea of Japan in 2021, it was assumed that the availability of squid was low in the whole survey area also in that year (Appendix 5). Therefore, because the low availability of squid within the whole survey area was highly likely to cause underestimation of recruitment, the recruitment for 2019 and 2021 were estimated using the stock-recruitment relationship (Appendix 2).

The standardized survey CPUE time series was updated in the 2021 stock assessment, resulting in updates of the historical recruitment up to 2021. Although there were limited differences in the recruitment estimates in the 2021 stock assessment with those in the 2020 one, year trend in recruitment was consistent between the two-years stock assessments.

2) Trends in recruitment indices

Year trend in recruitment index based on scaled value of the standardized survey CPUE is shown in Fig. 4-1 and Table 4-1 (see Appendix 3 for explanation on surveys). The index decreased early 1980s, recording the lowest of 0.28. It increased since 1990 and attained the peak of 1.92 in 1997. After recording 0.70 in 1998, it varied between 0.88 and 1.86 from 1999 to 2015 and then, decreased below 1 after 2015. It recorded 0.49 in 2019 and then, dropped to the second lowest of 0.29 in 2021 after the spike (0.94) in 2020.

3) Trends in stock biomass and fishing mortality

The stock biomass was increased in 1990s after recording 275 thousand ton in 1986 and then, it reached the historical maximum of 1,890 thousand ton in 1997 (Fig. 4-2, Table 4-1). It varied between 800 thousand and 1.8 million tons after dropping to 690 thousand tons in1998. After the biomass reached 1,820 thousand in 2014, its level shifted downward, varying between 600 thousand and 900 thousand tons after 2015. As described above, the biomasses for 2019 and 2021 were estimated with the stock recruitment models. The biomass recorded the lowest of 614 tons in 2019 since 1991. It was estimated as 919 thousand and 931 thousand tons in 2020 and 2021, respectively.

Exploitation rate were almost over 25% in 1980s with the peak of 38% in 1989 (Fig. 4-2, Table 4-1). It, subsequently, decreased according to increase of the stock biomass, varying between 16 and 26% from 1991 to 2004 except for 1998 when it temporally dropped. The exploitation rate has increased since 2005 when the Chinese fleet started to increase their catch. It estimated as 14 to 39% after 2005 with exception of 2009 and 2013 when the Chinese catch could be regarded as zero.

Fishing mortality F, in general. showed a similar variation with the exploitation rate (Fig. 4-3, Table 4-1). Because the catch statistics for the terminal year (2021) was unavailable, it was calculated with the following procedure. The 2021 catch for Japan and Korea fleets was calculated with the arithmetic mean of Fs relevant to these two fleets from 2018 to 2020. The total catch for 2021 was given by adding 150 thousand tons of the Chinese fleet to that of Japan and Korea and was calculated as 219 thousand tons. This catch amount corresponded to fishing mortality (F2021) of 0.38.

The spawning stock biomass (SB) was at lower level in 1980s and then, increased after 1990, reaching 829 thousand tons (2.96 billion fish) in 1997. It varied between 254 thousand and 808 thousand tons from 1999 to 2015 (0.9 billion to 2.9 billion fish) (Fig. 4-2, Table 4-1). Although it ranged between 191 thousand and 295 thousand tons (0.7 billion to 1.1 billion fish) from 2016 to 2019 at lower level, it increased to 354 thousand ton (1.26 billion fish) in 2020. SB for 2021 was estimated as 349 thousand tons (1.25 billion fish) using the recruitment estimate for 2021, F2021 and natural mortality (0.6). A sensitivity analysis on M against SB for 2020 resulted in 0.85 billion and 1.79 billion fish if 0.3 and 0.9 of M, respectively.

Annual changes in recruitment and recruitment per spawner (RPS) were shown in Fig. 4-5 and Table 4-1. RPS was around 3 in 1990s when the stock increased and then, the level of RPS shifted downward around 2 after 1999. RPS for 2020 revealed high value of 4.81. RPS for 2021 was 2.63, corresponding to a median of past ten years (2.71).

It is noted that the parameters estimated using commercial catch, such as F and SB, include uncertainty related to the assumption regarding the Chinese fleet catch. It is likely to be essential to enhance catch information related to the Chinese and North Korean fleets to decrease the uncertainty.

Item	Value	Remarks
SB2021	349 thousand tons	SB in 2021
F2021*	0. 38	Fishing intensity (F) at 2020 fishing season
U2021	24%	Fishing ratio in 2021

*The catch of 2021 was obtained catches of Japan and Korea (69 thousand tons) calculated by simple average of fishing pressure (F=0.11) during 2018 to 2020 plus assumed Chinese catch of 150 thousand tons. Based on this estimated catch, SB, Fishing intensity and exploitation rate were calculated.

4) Spawner per recruitment (SPR) and latest fishing mortality

Annual %SPR was shown in Figure 4-6. The latest fishing mortality (F2021) was equivalent to 68%SPR and below Fmsy and F30%SPR (Figure 4-7).

Item	Value	Remarks
%SPR（F2021）	68%	%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 hockey-stick-type stock-recruitment model was applied (Kubota *et al.* 2020a). The least-square method was applied to estimate parameters of the S-R relationship using the SB and recruitment provided in the 2020 stock assessment report (Kubota *et al.* 2020a) without consideration of auto-correlation of residuals. The estimated parameters are shown in the Table below.

S-R relationship	Optimization method	Auto-correlation	*a*	*b*	S.D.	ρ
Hockey-Stick (HS) type	Least square	No	3.64	1127	0.34	-

Here, parameter *a* is the steepness of the HS S-R curve from the origin to the break point, and *b* is the SB (million fish) at the break point.

6) Reference points under current environmental condition.

The table below shows the SB (SBmsy) and F (Fmsy) that will achieve MSY under the current environmental condition, which was proposed by the Research Institute Meeting held in July 2020 (Kubota *et al*. 2020a).

Item	Suggested value	Remarks
SBmsy	329 thousand tons	SB that will obtain MSY
Fmsy	0.48	
%SPR（Fmsy）	62%	%SPR corresponding to Fmsy
MSY	273 thousand tons	MSY

7) Status and trend of stock and fishing mortality

The Kobe plot based on SBmsy and Fmsy is shown in Figure 4-9. The SB for 2021 was above SBmsy and 1.06 times of it. F2021 was below Fmsy and 0.80 times of it. The status of SB is considered stable based on recent five years trend (2017 to 2021). Although SB frequently exceeded SBmsy from 1992 to 2015, it was below SBmsy in 2016 to 2019, when F was above Fmsy. After 2019, SB was above SBmsy. Year trend of SB was stable in recent five years (2017 to 2021).

Specification of environmental factors affecting recruitment variation is needed as future task. Meanwhile, it is important to consider changes in distribution and migration which probably has occurred since 2019 (3. Fishery status (2) history of catch, Appendix 5).

Item	Value	Remarks
SB2021/ SBmsy	1.06	Ratio of SB for 2021 to SB achieving MSY
F2021/ Fmsy	0.80	Ratio of F for 2021 to F achieving MSY

Level of SB	Above SBmsy
Level of F	Below Fmsy

Trends in SB	Stable

5. Stock assessment summary

The biomass of stock, which remained at lower levels in 1980s, increased in 1990s and attained the peak of 1.89 million tons in 1997. Although it stayed at higher level from 0.9 to 1.8 million tons after 1998, its level shifted downward from 2016 to 2019. It increased since 2020, recording 931 thousand tons in 2021.

The SB was frequently above SBmsy (0.329 million tons) from 1990s to 2015 and then below SBmsy from 2016 to 2019. it was above SBmsy in both 2020 and 2021. The SB was estimated as 0.349 million tons for 2021.

It is noted that the parameters estimated using commercial catch, such as F and SB, include uncertainty related to the assumption regarding the Chinese fleet catch. It is likely to be essential to enhance catch information related to the Chinese and North Korean fleets to decrease the uncertainty.

6. Other matters

1) Estimation of recruitment

The CPUEs for 2019 and 2021 were not used for estimation of recruitment (Appendix 5). As a reason for this, it was possible that changes in the distribution patten during the period of the recruitment estimation survey in the Sea of Japan occurred in and out of the whole survey area in recent years. Although it is difficult to monitor quantitatively on the distribution of squid outside of Japanese EEZ, it is necessary to strengthen collection information on research and fisheries for stock assessment and to improve assessment method. Therefore, development of information on CPUE from the small-scale squid jigging fisheries (Appendix 5) is promoted and a state space stock assessment model where multiple CPUE time series will be tested (Nishijima et al. 2020, Kubota et al. 2020b). The recent research revealed the density of squid larvae in October to November of 2020 was increased to the same level as that in 2015 (Appendix figure 3-5). Fishing conditions around Oki islands and Tsushima Strait in September and October were improved in 2019 and 2020 (Appendix figure 5-4). This suggested that abundance of spawners was likely to increase, resulting increase of importance of information from researches and fisheries during the spawning season for the stock assessment.

2) Others

The stock-recruiment relationship of Japanese flying squid can be affected by mid-long term and short term oceanographical variations (Okutani and Watanabe 1983, Murata and Araya 1977, Sakurai et al. 2000, Kidokoro 2009). Therefore, it is important to monitor continuously on stock and environment by distribution research of squid larvae and monitoring of oceanographic conditions. Especially considering change of distribution and migration since 2019 comparing with northern and offshore shift of distribution observed until 2018, it is important to clarify the factors affecting on reproduction and change of distribution and migration.

Differing from age-structured stock, Japanese flying squid is annual fish, so that a new cohort could be fished next year. Recruitment prediction error leads to major estimation error in stock abundance estimation. Therefore, the predicted catch for this stock might have larger uncertainty than other age-structured stock. Moreover, because whole annual catch amount is crucial to estimate spawning stock biomass, the cryptic catches, which account for a large portion of total catch, could induce estimation error of it. Therefore, such uncertainty in stock assessment should be considered for fishery management.

Comparing with previous assessment, recruitment increased in 2020, SBs for 2020 and 2021 were estimated to be above SBmsy. However, those mentioned below should be considered which SB in 2020 is close to SBmsy and there are large uncertainties of assessment. It is possible to occur SB below SBmsy due to the nature of annual fish. It should be considered annual fluctuation by the nature of stock for fishery management.

As Japanese flying squid is caught by other nations other than Japan and Korea, it is necessary that establishing international flame work of cooperation for assessment and management with collecting accurate fishery catch and effort.

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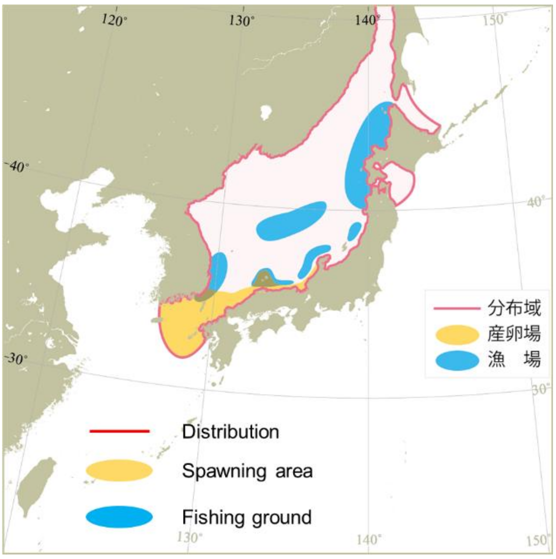


Figure 2-1. Distribution and spawning ground of Japanese flying squid fall stock.

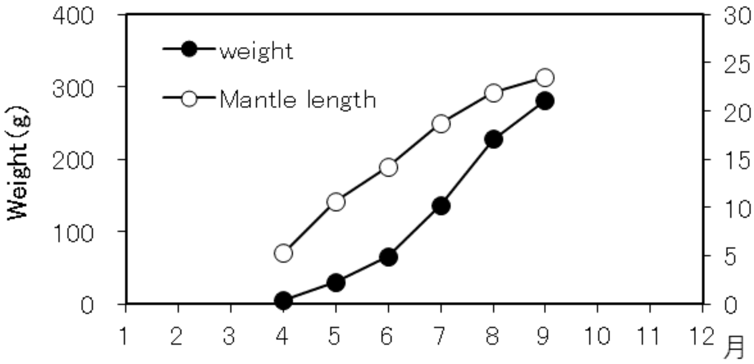


Figure 2-2. Growth of Japanese flying squid.

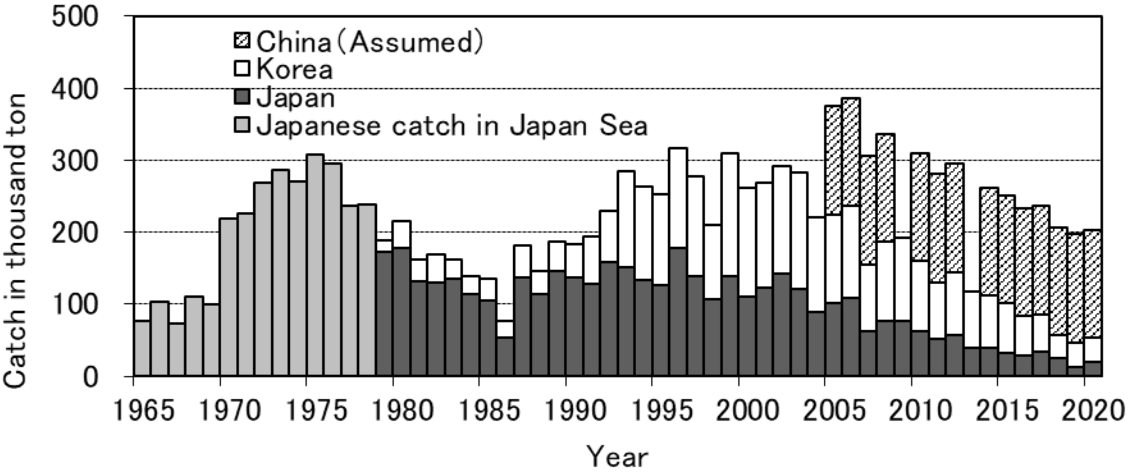


Figure 3-1. Annual catches of Japanese flying squid by country.

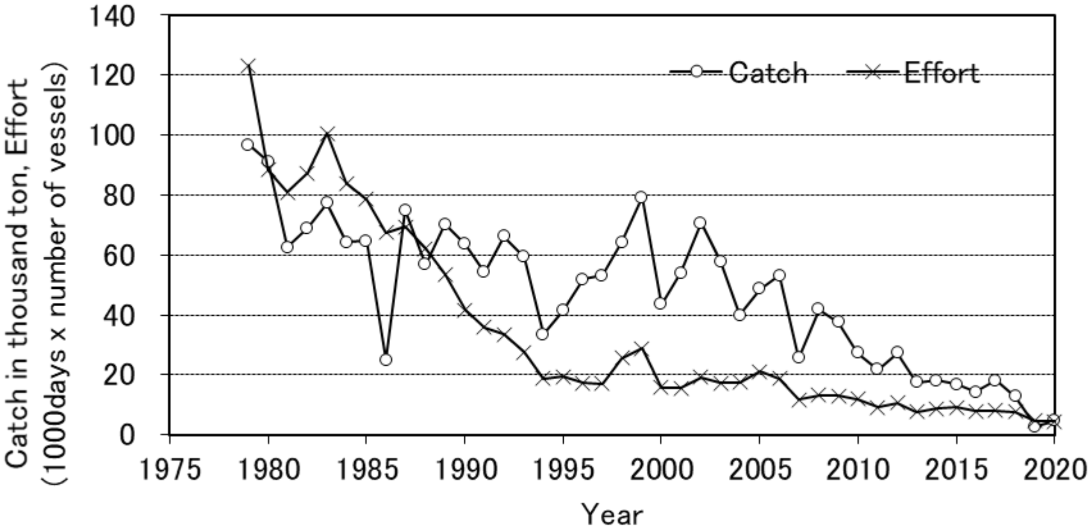


Figure 3-2. Annual change of catch and effort for Japanese mid-size squid jigging boat.

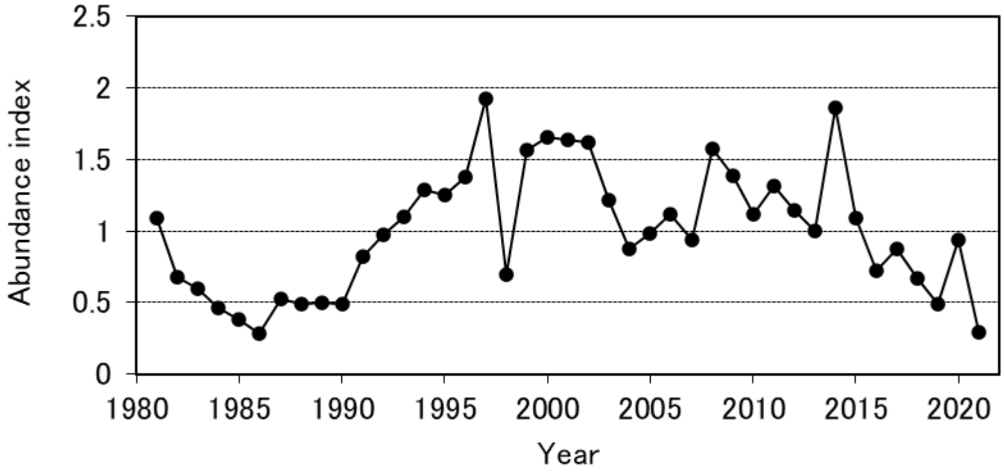


Figure 4-1. Abundance index by year (standardized CPUE of comprehensive squid research in Japan Sea).

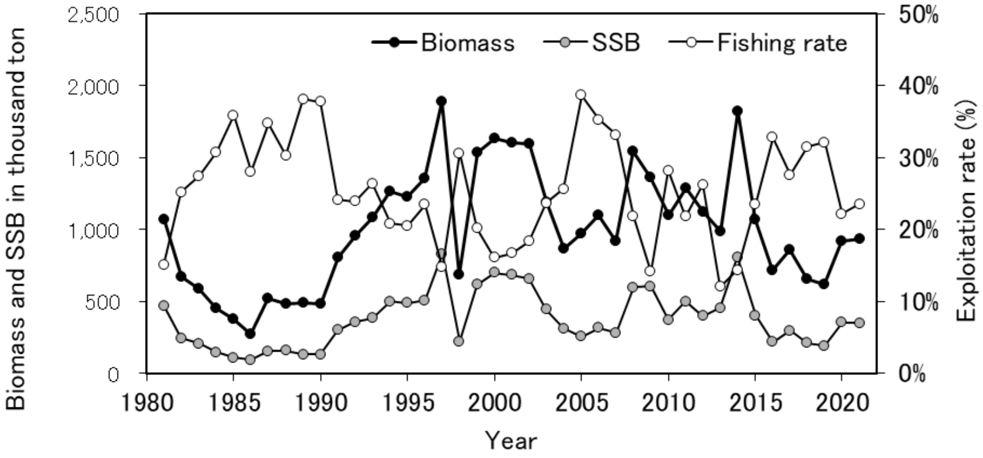
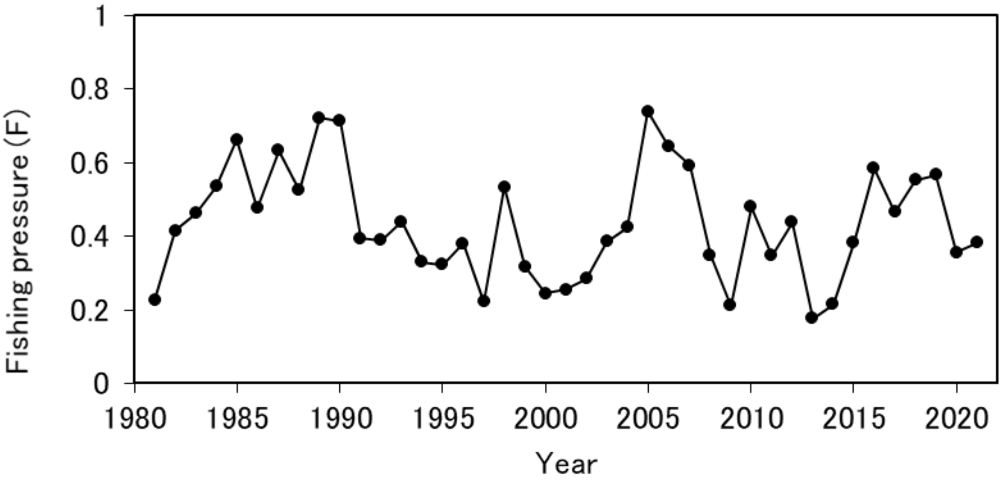


Figure 4-2. Annual fluctuation of biomass, spawning stock biomass and exploitation rate.



1) **Figure 4-3**. Fluctuation fishing intensity (F). Value of 2021 is projected. See 4(1) Stock assessment methods.

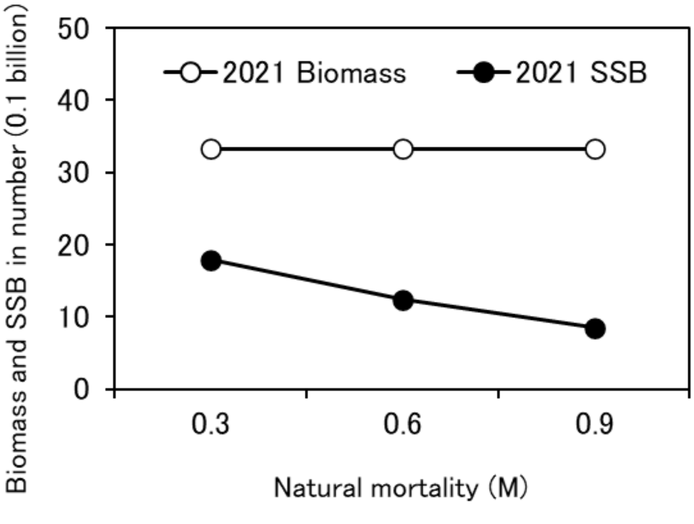


Figure 4-4. Results of sensitivity test of natural mortality M on biomass and spawning stock estimation in 2021.

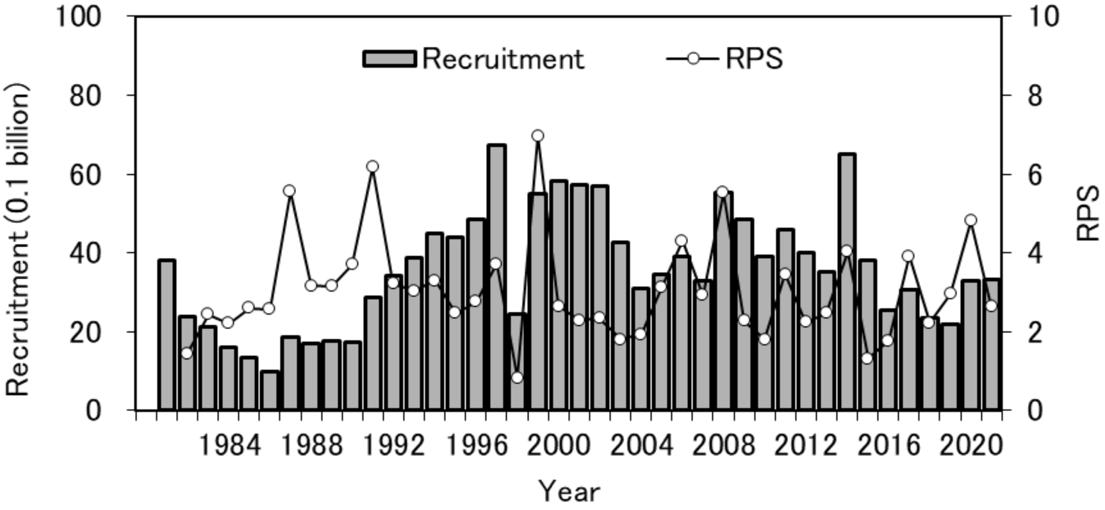


Figure 4-5. Annual fluctuations of recruitment and recruitment per spawning (RPS). Recruitment is almost same as biomass in the case of Japanese flying squid.

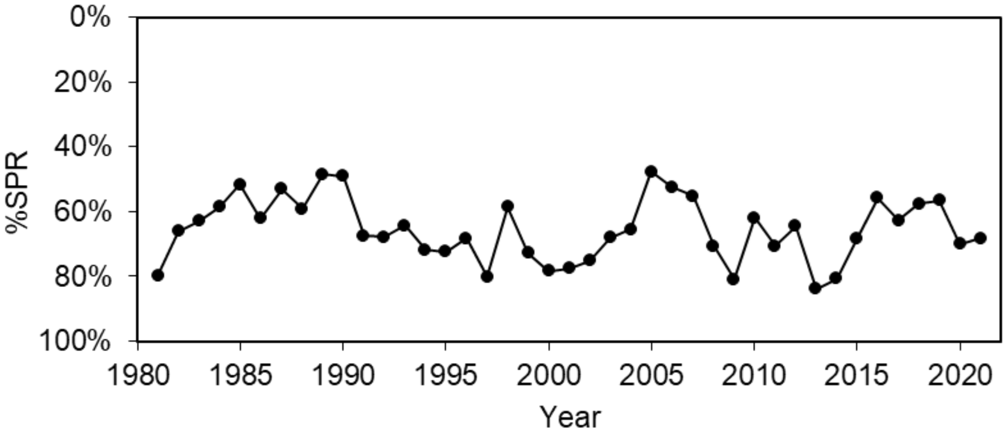


Figure 4-6. Annual fluctuation of %SPR. The %SPR is a ratio of SB under fishery to SB without fishery, then it becomes high (low) when fishing intensity is low (high).

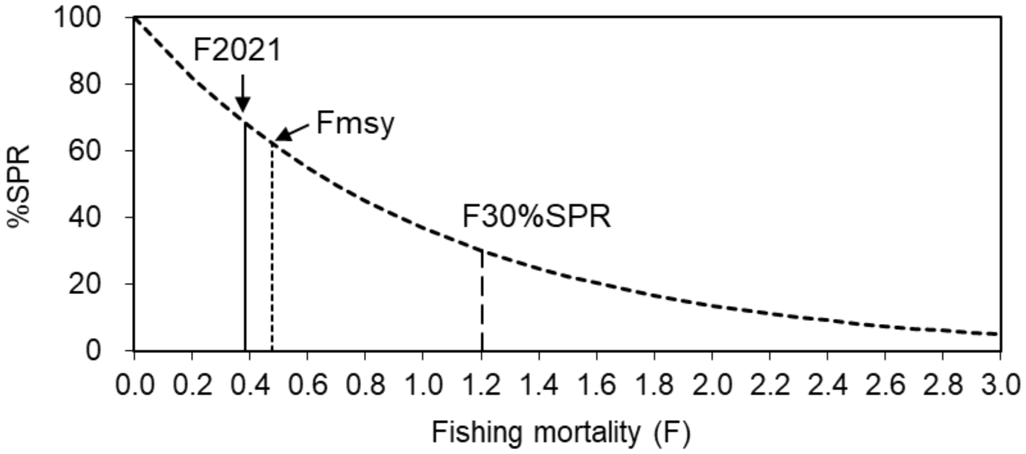


Figure 4-7. Relationship between fishing mortality and %SPR. F2021 means current F.

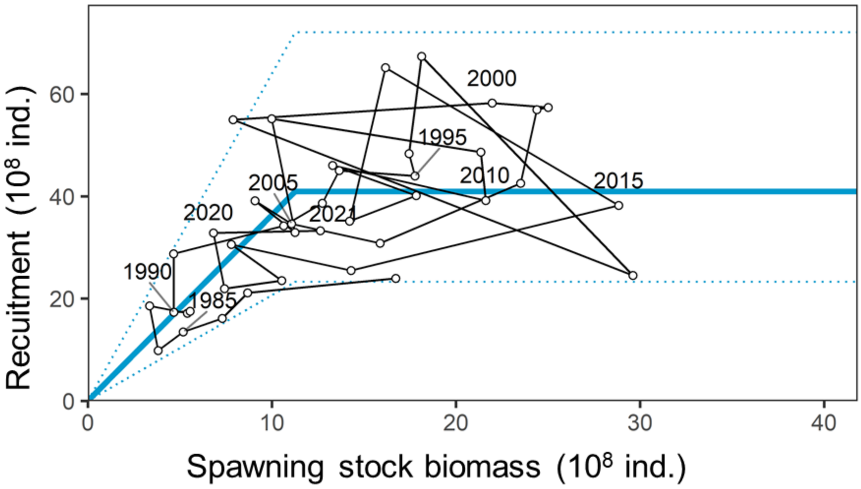


Figure 4-9. Relation between spawning stock biomass and recruitment. Reproductive relationship (HS) was suggested by Scientific meeting of Research Institutes held in July, 2020 (Kubota et al. 2020a). Blue solid line indicates reproductive relationship. Bleak lines above and below indicate 90% of estimations. Values in the figure indicate year. SB in 2021 is projected value after fishery (F2021).

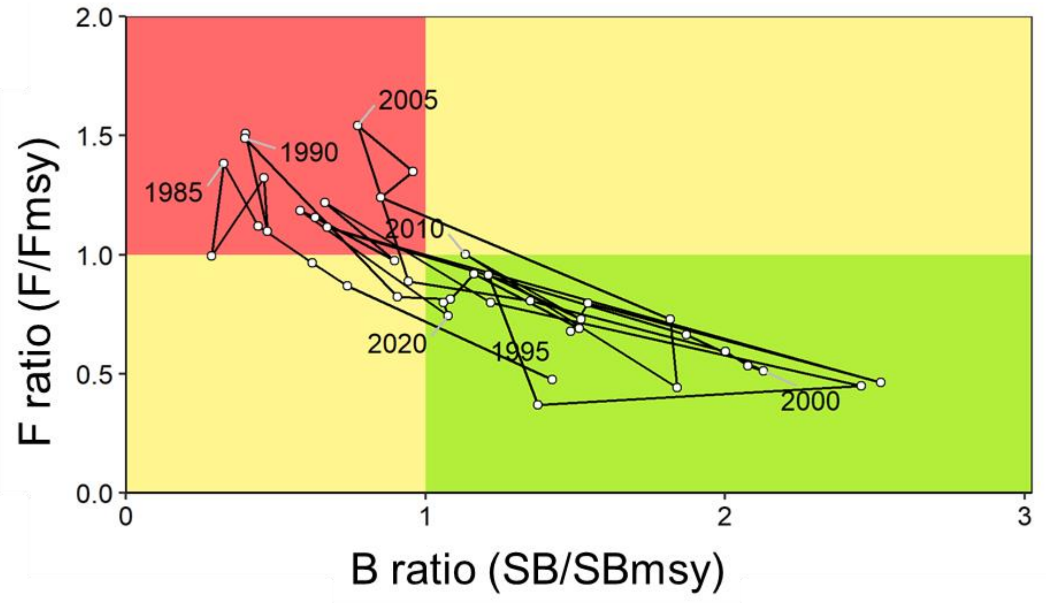


Figure 4-9. Kobe plot of Japanese flying squid. Relation between SB to SBmsy and F to Fmsy.

Table 3-1. Annual Japanese flying squid catch by country.

Fishing year	Japan	Korea	China (assumed)	Total
1979	171,855	17,725		189,581
1980	177,249	37,469		214,718
1981	131,396	29,962		161,358
1982	130,649	38,360		169,009
1983	136,247	25,908		162,155
1984	114,006	25,017		139,023
1985	105,080	30,548		135,628
1986	53,938	23,265		77,203
1987	137,254	43,580		180,834
1988	113,332	31,915		145,247
1989	145,374	41,767		187,140
1990	137,936	44,991		182,926
1991	128,797	65,641		194,438
1992	157,623	71,179		228,802
1993	150,544	134,771		285,314
1994	134,173	128,597		262,770
1995	126,623	125,558		252,181
1996	178,290	139,259		317,548
1997	139,028	138,714		277,741
1998	107,152	102,992		210,144
1999	139,000	170,980		309,980
2000	109,724	152,677		262,401
2001	122,408	146,033		268,441
2002	142,191	150,286		292,477
2003	121,071	161,075		282,146
2004	89,699	131,476		221,175
2005	101,975	123,152	150,000	375,127
2006	108,143	128,124	150,000	386,267
2007	62,518	93,088	150,000	305,606
2008	77,124	109,789	150,000	336,912
2009	76,913	115,095	0	192,008
2010	61,969	97,474	150,000	309,442
2011	51,415	79,393	150,000	280,808
2012	56,266	88,569	150,000	294,835
2013	39,852	77,981	0	117,833
2014	39,632	71,898	150,000	261,530
2015	32,503	69,265	150,000	251,768
2016	27,838	55,756	150,000	233,594
2017	34,462	51,968	150,000	236,430
2018	24,773	32,583	150,000	207,356
2019	13,416	33,566	150,000	196,982
2020	19,903	33,872	150,000	203,774

Chinese catches are assumed values.

Table 3-2. Catch, CPUE (catch in ton per vessel per day) and fishing effort of mid-size Japanese squid jigging vessel for Japanese flying squid fall stock.

Fishing year	Catch (Ton)	CPUE (ton/day*vessel)	Effort (day*Vessel)
1979	96,803	0.786	123,216
1980	91,150	1.032	88,323
1981	62,536	0.774	80,834
1982	69,034	0.790	87,409
1983	77,219	0.767	100,662
1984	64,342	0.767	83,866
1985	64,702	0.824	78,537
1986	24,976	0.370	67,509
1987	74,864	1.077	69,501
1988	56,728	0.914	62,072
1989	70,166	1.307	53,687
1990	63,546	1.525	41,661
1991	54,325	1.517	35,819
1992	66,133	1.973	33,523
1993	59,266	2.149	27,584
1994	33,549	1.789	18,754
1995	41,480	2.134	19,433
1996	51,882	2.999	17,302
1997	53,269	3.117	17,091
1998	64,308	2.514	25,575
1999	79,139	2.754	28,739
2000	43,534	2.749	15,835
2001	53,999	3.465	15,584
2002	70,679	3.692	19,143
2003	57,899	3.343	17,322
2004	39,919	2.276	17,542
2005	48,670	2.293	21,223
2006	53,220	2.825	18,837
2007	25,567	2.192	11,663
2008	41,845	3.146	13,300
2009	37,606	2.895	12,989
2010	27,391	2.290	11,962
2011	21,797	2.374	9,180
2012	27,238	2.555	10,661
2013	17,599	2.279	7,722
2014	18,240	2.076	8,788
2015	16,916	1.839	9,198
2016	14,306	1.797	7,963
2017	18,077	2.240	8,070
2018	12,872	1.654	7,782
2019	2,724	0.580	4,697
2020	4,616	1.050	4,395

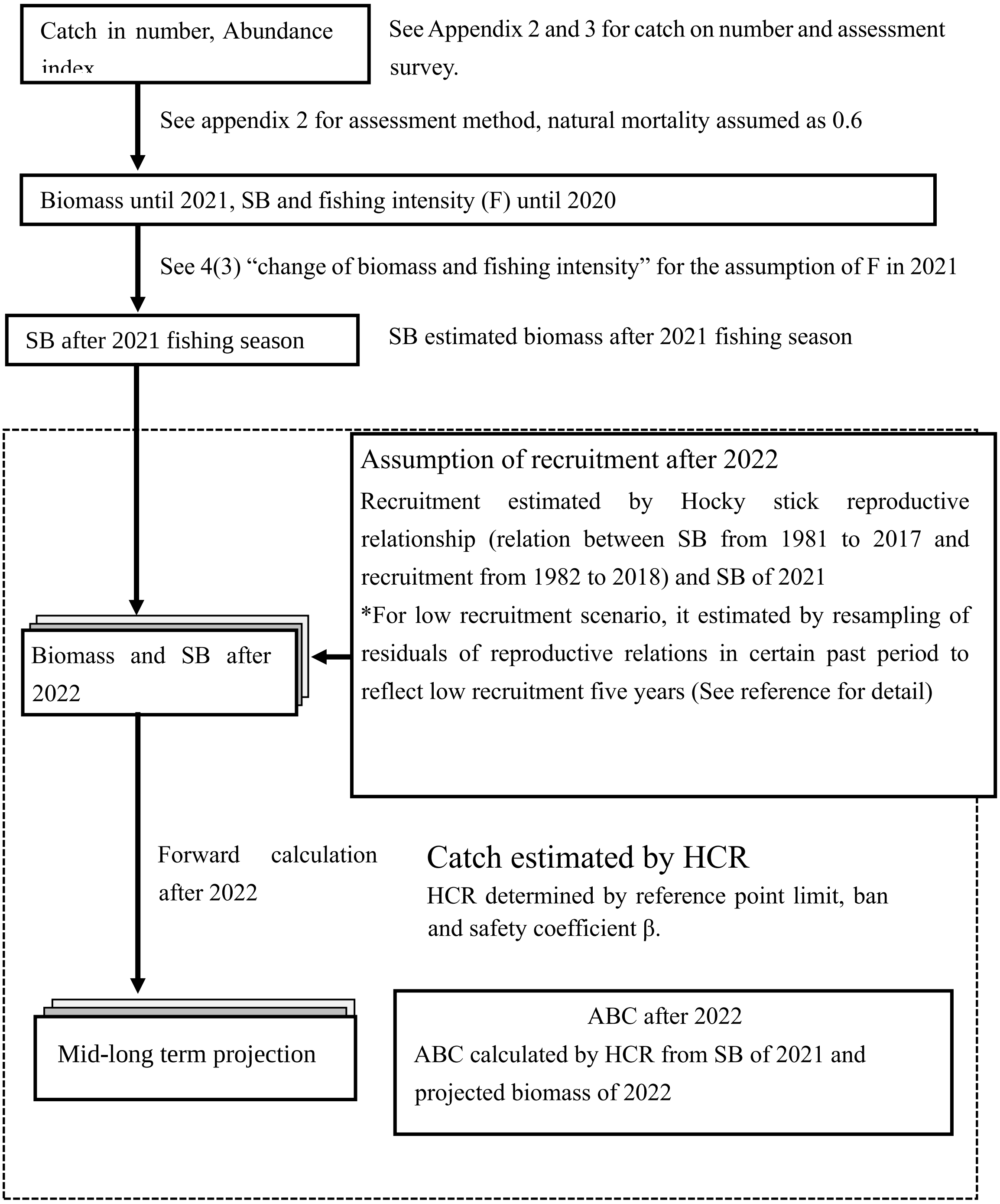
Catch is sum of frozen landing from Japan Sea (May to Oct.) and East China Sea (May to Nov.). CPUE was calculated catch of Japan Sea and East China Sea divided by total operation days. Fishing effort was calculated catch divided by CPUE.

Table 4-1. Results of stock assessment.

Fishing year	fishing ground surveyCPUE	Abundance index	Biomass in number (0.1 billion squid)	catch (thousand tons)	biomass (thousand tons)	SSB (0.1 billion squid)	SSB (thousand)	exploitaion rate (%)	Fishing pressure (F)	RPS
1979	13.32			190						
1980	16.20			215						
1981	9.59	1.09	38.25	161	1,071	16.72	468	15.1	0.23	
1982	6.54	0.68	23.96	169	671	8.68	243	25.2	0.42	1.43
1983	7.28	0.60	21.12	162	591	7.30	204	27.4	0.46	2.43
1984	8.82	0.46	16.15	139	452	5.19	145	30.7	0.54	2.21
1985	4.36	0.38	13.51	136	378	3.82	107	35.9	0.66	2.60
1986	2.76	0.28	9.83	77	275	3.35	94	28.1	0.48	2.57
1987	6.18	0.53	18.58	181	520	5.41	152	34.8	0.63	5.55
1988	5.09	0.49	17.12	145	479	5.56	156	30.3	0.53	3.16
1989	6.04	0.50	17.55	187	491	4.68	131	38.1	0.72	3.16
1990	7.58	0.49	17.31	183	485	4.66	130	37.7	0.71	3.70
1991	8.29	0.82	28.77	194	806	10.65	298	24.1	0.39	6.18
1992	11.46	0.98	34.23	229	958	12.73	356	23.9	0.39	3.22
1993	12.00	1.10	38.64	285	1,082	13.66	382	26.4	0.44	3.03
1994	15.08	1.28	45.05	263	1,261	17.77	498	20.8	0.33	3.30
1995	15.80	1.25	43.95	252	1,231	17.45	489	20.5	0.32	2.47
1996	14.64	1.38	48.34	318	1,354	18.13	508	23.5	0.38	2.77
1997	21.70	1.92	67.34	278	1,886	29.61	829	14.7	0.22	3.71
1998	8.46	0.70	24.51	210	686	7.89	221	30.6	0.53	0.83
1999	18.46	1.57	54.97	310	1,539	21.97	615	20.1	0.32	6.97
2000	23.01	1.66	58.21	262	1,630	25.01	700	16.1	0.25	2.65
2001	21.68	1.63	57.38	268	1,607	24.39	683	16.7	0.26	2.29
2002	25.04	1.62	56.95	292	1,594	23.51	658	18.3	0.28	2.33
2003	16.88	1.21	42.52	282	1,190	15.87	444	23.7	0.39	1.81
2004	12.07	0.88	30.83	221	863	11.07	310	25.6	0.42	1.94
2005	16.24	0.99	34.63	375	970	9.08	254	38.7	0.74	3.13
2006	15.80	1.11	39.13	386	1,096	11.26	315	35.3	0.65	4.31
2007	11.18	0.94	32.92	306	922	9.98	279	33.2	0.59	2.92
2008	21.06	1.57	55.14	337	1,544	21.35	598	21.8	0.35	5.52
2009	18.24	1.39	48.64	192	1,362	21.61	605	14.1	0.21	2.28
2010	14.59	1.12	39.16	309	1,096	13.30	372	28.2	0.48	1.81
2011	16.59	1.31	46.05	281	1,289	17.84	500	21.8	0.35	3.46
2012	17.32	1.14	40.13	295	1,124	14.22	398	26.2	0.44	2.25
2013	14.12	1.00	35.13	118	984	16.16	453	12.0	0.18	2.47
2014	28.80	1.86	65.16	262	1,824	28.84	808	14.3	0.22	4.03
2015	14.56	1.09	38.20	252	1,070	14.30	400	23.5	0.38	1.32
2016	11.12	0.73	25.47	234	713	7.80	218	32.8	0.58	1.78
2017	11.89	0.87	30.59	236	856	10.53	295	27.6	0.47	3.92
2018	10.16	0.67	23.53	207	659	7.43	208	31.5	0.55	2.23
2019	7.40	0.49	21.93	197	614	6.82	191	32.1	0.57	2.95
2020	14.32	0.94	32.83	204	919	12.63	354	22.2	0.36	4.81
2021	5.43	0.29	33.26	219 *	931	12.46 *	349 *	23.5 *	0.38 *	2.63

*Catch of 2021 was obtained from Japanese and Korean catch (69 thousand tons) estimated by simple average of fishing pressure of Japan and Korea during 2018 to 2020 (F=0.11) plus Chinese catch 150 thousand tons (assumed). Then SB in number and weight, exploitation rate and fishing intensity F were estimated from the catch.

Appendix 1 Flowchart of stock assessment.



Catch in number, Abundance index

See Appendix 2 and 3 for catch on number and assessment survey.

See appendix 2 for assessment method, natural mortality assumed as 0.6

Biomass until 2021, SB and fishing intensity (F) until 2020

See 4(3) “change of biomass and fishing intensity” for the assumption of F in 2021

SB after 2021 fishing season

SB estimated biomass after 2021 fishing season

Assumption of recruitment after 2022

Recruitment estimated by Hocky stick reproductive relationship (relation between SB from 1981 to 2017 and recruitment from 1982 to 2018) and SB of 2021

*For low recruitment scenario, it estimated by resampling of residuals of reproductive relations in certain past period to reflect low recruitment five years (See reference for detail)

Biomass and SB after 2022

Forward calculation after 2022

Catch estimated by HCR

HCR determined by reference point limit, ban and safety coefficient β.

Mid-long term projection

ABC after 2022

ABC calculated by HCR from SB of 2021 and projected biomass of 2022

*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) Abundance index

Abundance index (Ut) was estimated from CPUE (catch in number per jigging machine per hour) obtained by squid fishing grounds survey (Japan Sea) during June to July (Appendix 3). Abundance index estimated are used to annual stock assessment. Arithmetic mean of research CPUE was used for assessment until 2017, and standardized CPUE was replaced as abundance index for stock assessment from 2018. Research data which extracted from provisional area between Japan and Korea, and southern area from central line of Japan and Russian EEZ, and east of 132E were used for analysis based on squid fishing grounds survey during June and July and oceanographic condition. Research data from 1981 to 2021 were only used for analysis since data before 1980 sometime lacking surface temperature etc.

Two step delta model including General Liner Model (GLM) for zero catch model and General liner mixed model (GLMM) for CPUE with gamma distribution was used for CPUE standardization in 2021. The GLM with gamma distribution was used for standardization until 2020, but it replaced to GLMM which can extract year effect in the case of lack of interaction (year and area in this case) since lack of data found at one area in 1993. Moreover, calculation of weighting average by area for CPUE standardization revised from 2020. The details of revision were described in the report of CPUE standardization and model diagnosis (FRA-SA2021-SC04-202).

The normalized results (each CPUE normalized at average 1) of arithmetic means of research CPUE of squid fishing grounds survey (abundance indices used for assessment until 2017), and standardized CPUE in 2020 and 2021 assessment were shown in Appendix figure 2-1. Biomass in number estimated from above results were shown in Appendix figure 2-2. There is no large difference among CPUEs in long term trends, but it tends to increase biomass estimation from previous year in 2019 and 2020 especially after 2014 and 2016. By the way, forward calculation was used for biomass estimation in 2019 and 2021 instead of the estimation results indicated in Appendix figure 2-2.

Results of biomass estimation obtained by standardized CPUE in 2019 and 2021 were shown in Appendix figure 2-3. Reproductive relationship of the stock obtained by biomass and spawning stock biomass in number until 2018 estimated at stock assessment in 2019. There is no large difference in long term trends of biomass estimation until 2018 between the assessment in 2019 and 2021.

By the revision of standardized CPUE mentioned above, proportional constant q was replaced from 2.96×10^{8} to 3.51×10^{9}. Furthermore, biomass, spawning stock biomass, and fishery coefficient from 1981 were also revised in 2021.

2) Method of stock estimation (except for 2019 and 2021)

Stock biomass in number was estimated by the method described below assuming biomass (N_t) to be proportional of abundance index (U_t). Furthermore, fishing process, and biological parameters (growth and natural mortality) were described below.

Fishing process: Japanese flying squid is targeted during six months (180 days) from recruitment of six month after hatching to one-year life span (twelve months after hatching). However, young squid just after recruitment and before spawning was not easy to catch. Then, all catches were assumed to occurre nine month after hatching for the assessment.

Biological parameters: Squid weight at caught was assumed of 280g after nine months of hatching based on growth curve (Figure 2-2) following fishing process. Moreover, considering exploitation ratio (catch/biomass), squid weight at recruitment and spawning were also assumed of 280g. Natural mortality of Japanese flying squid obtained by biomass analysis (M=0.431, Adachi 1988), and tag recapture analysis (Machinaka et al. 1980). However, it is supposed to be overestimated. Then monthly M=0.1 (M=0.6, at 6 month after recruitment) was assumed for the analysis.

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

$$N_t = q \cdot U_t \qquad (1)$$

Here, N_t is biomass in number (0.1 billion squid) of year t, q is proportional constant, and U_t is abundance index of year t. Biomass in number (N_t) was estimated from abundance index multiplied by proportional constant (q). Furthermore, biomass in weight (B_t) is obtained from biomass in number multiplied by body weight per squid (280g).

3) Estimation method for proportional constant (q) used for biomass assessment

Proportional constant (q) was estimated to reproduce average fishing coefficient F*=0.447 during 1979 to 2000 by "(4) estimation method for average fishing coefficient before 2000" mentioned below. Fishery coefficient in year t (F_t) is expressed as below by catch (C_t) and abundance index (U_t) in year t.

$$F_t = -\ln\left[1 - \frac{C_t \cdot e^{-\frac{1}{2}M}}{q \cdot U_t}\right] \qquad (2)$$

Fs of each year were obtained using the equation shown above, and q obtained same value of average F* was estimated as $q = 2.96\times10^{8}$.

4) Estimation method of average fishing coefficient before 2000

Average fishing coefficient (F*) before 2000 was obtained by taking assumed natural mortality (M=0.6) from total mortality coefficient (Z*) estimated by research survey data conducted during May to November between 1979 to 2000. Here, Fishery coefficient (F*), total mortality coefficient (Z*) and natural mortality (M=0.6) are the values during fishing season (6 months).

First, relative CPUE (ud) was obtained by average CPUE (ud,y) of research survey daily CPUE in each year divided by average CPUE of research survey (uavg, y). Then, relative CPUE (ud) was expressed with daily total mortality coefficient (z*) in the equation shown below.

$$u_d = a \cdot e^{-z^* \cdot d} \qquad (3)$$

Here, (z*) is average daily total mortality coefficient during 1979 to 2000, d is number of days from 1st of June.

However, relative CPUE (ud) increased until July and did not show decreasing of biomass in number though it decreased from late July (after d = 50 days) (Appendix figure 2-5). Then, considering catchability relating average mantle length of squid (xd) on relative CPUE (ud) (assumed exponential relationship) with effects of total mortality coefficient, change total mortality coefficient was estimated by the equation shown below (z*).

$$u_d = a \cdot e^{-(bx_d - z^* \cdot d)} \qquad (4)$$

Each parameters of equation (4) were estimated as a = 0.0153, b = 0.212 and z* = 0.00582/day by least square methods in respectively. Then, decrease process during fishing season corrected by catchability relating with average mantle length of squid was shown in Appendix figure 2-5. Assuming fishing season for 180 days, total mortality coefficient (fishing season) was estimated Z* = 1.047 by daily total mortality coefficient (z* = 0.00582), then taking natural mortality (M = 0.6) from estimated total mortality coefficient Z*, average fishing mortality during fishing seasons between 1979 and 2000 was estimated as F*=0.447 .

5) Estimation of spawning stock biomass

Spawning stock biomass (S_t) was estimated using biomass (N_t) and total catch (C_t) estimations by the equation below.

$$S_t = \left[N_t - C_t \cdot e^{\frac{M}{2}}\right] \cdot e^{-M} \qquad (5)$$

Here, M is natural mortality (=0.6).

Spawning stock biomass in weight (SB_t) was calculated by spawning stock in number multiplied by average weight of adult squid as 280g as same as biomass estimation.

6) Reproductive success rate (RPS) and residuals of recruitment

Reproductive success rate (RPS) was calculated using biomass in number (N_t) and spawning biomass in number of previous year (S_{t-1}) by the equation below.

$$RPS = \frac{N_t}{S_{t-1}} \qquad (6)$$

Then estimation of recruitment and residuals of observation error ε_t ($T_1 \leq t \leq T_2$) obtained by Hockey stick reproductive relationship was estimated by the equation below (Appendix figure 2-1) based on “Technical note for estimation of reproductive relationship, reference points and future projection (Scientific meeting of research Institutes in 2020) FRA200-ABCWG01-02”.

$$\varepsilon_t = \log\left(N_{S_{min},t}^{obs}\right) - \log \mathrm{R}\left(SB_{t-S_{min}}^{-mathrmobs} | a, b\right) \qquad (7)$$

Here, biomass in number obtained by equation (1) was used as observations (biomass in 2019 and 2021 were obtained by other method described below in section 7).

7) Estimation of stock biomass in 2019 and 2021, and verification

It was considered that to use standardized CPUE for biomass estimation in 2019 and 2021 was not appropriate as mentioned in Kubota et al. (2020a) and Appendix 5. Therefore, biomass in 2019 and 2021 were estimated by forward calculation from spawning biomass of previous year and residuals between recruitment and projected recruitment by reproductive relationship as mentioned in 4. Stock status. In the results of that, biomass were estimated as 2.19 billion squid, 0.614 million tons in 2019 and 3.33 billion squid, 0.931 million tons in 2021 in respectively.

Regarding 2019 fishing season, it was considered that biomass estimation from abundance index was not appropriate, because migration pattern by area were unusual in 2019 (Kubota et al. 2020a, Appendix 5) from the fishing status in coastal area of Japan and Korean fishery, although standardized CPUE of squid fishing grounds survey (abundance index) was low of 0.49 (Figure 4-1, Table 4-1) and fit to lower CPUE of Japanese mid-size squid vessels (Table 3-2).

Regarding 2021 fishing season, biomass estimation from abundance index of 0.29 is 0.286 million tons. Based on the assumption of biomass in 2021 were 0.286 million tons, estimated catch of Japan and Korea in 2021 by average F (0.11) obtained Japanese and Korean catch during 2018 to 2020 was 21 thousand tons and much lower than reported catch of 46 thousand tons during April to September in 2021. When Japanese and Korean catch in 2021 were assumed 54 thousand tons as same as 2020 fishing season, F of Japanese and Korean fisheries was 0.29, and was extremely high comparing with F which was lower than 0.2 after 2011. Therefore, it was considered that using abundance index for estimation of biomass in 2021 was also not appropriate.

While Japanese and Korean Fifing pressure (F) obtained from biomass estimation by forward calculation in 2019 and 2021 (614 and 931 thousand tons in respectively) and catch in 2019 was 0.11, and 0.57 including assuming Chinese catch of 150 thousand tons, and those were in the range of recent fluctuations. Moreover, the estimation of Japanese and Korean catch obtained by average F (0.11) of Japan and Korea during 2018 to 2020 and reported catch in 2021 was 69 thousand tons. It was considered reasonable range of fluctuation, especially Korea still continued fishing in October.

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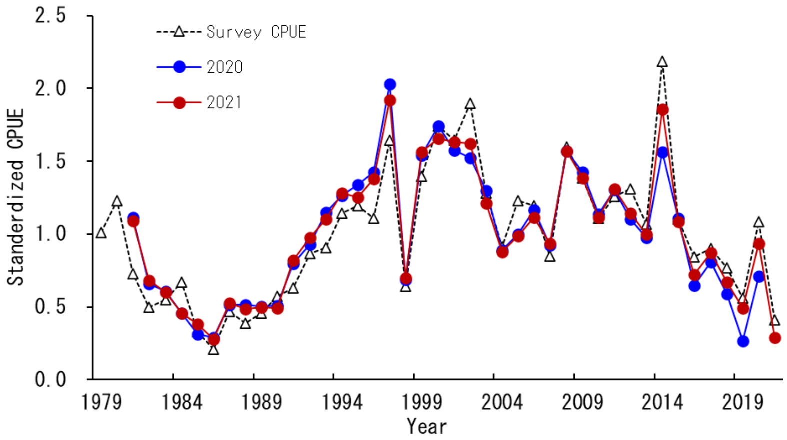
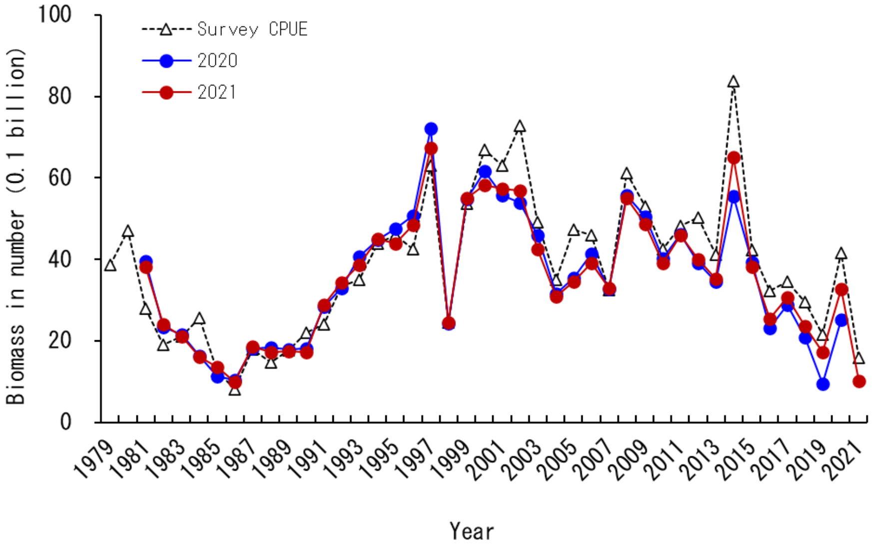
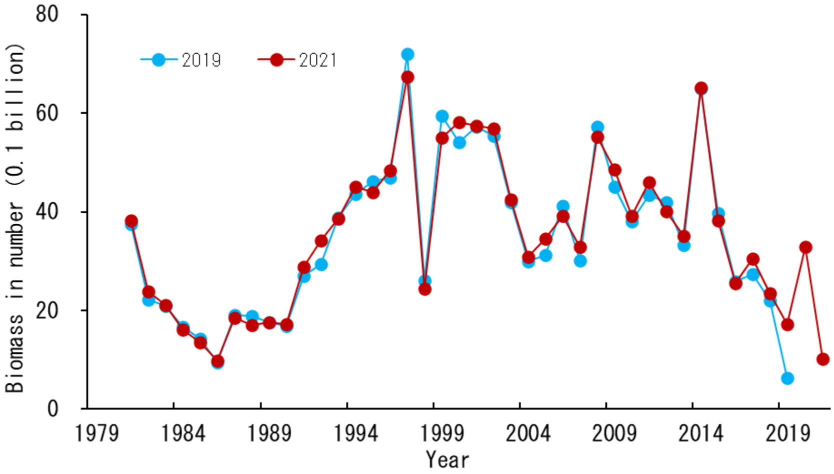


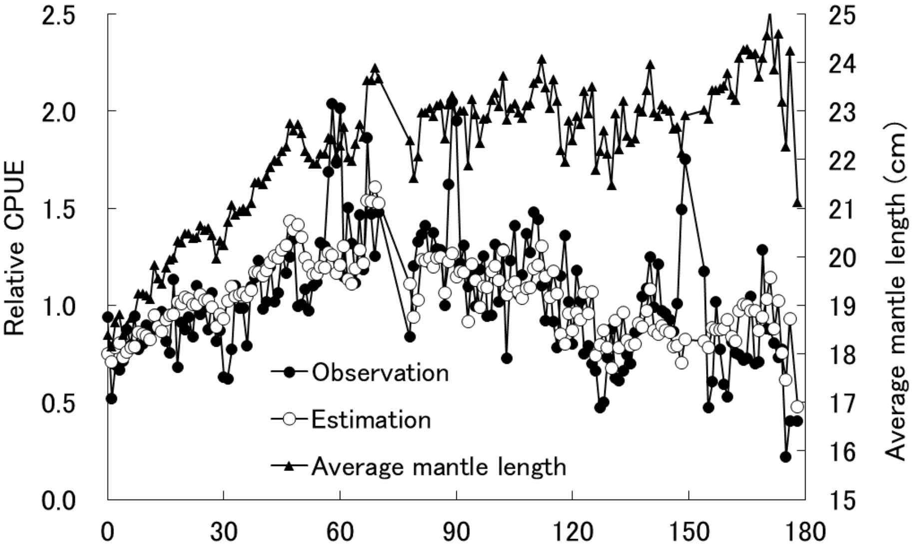
Appendix Figure 2-1. Average CPUE of comprehensive squid fishing ground research (CPUE of chartered vessels), standardized CPUE estimated in 2020 and 2021. Those CPUEs are equalized by average into 1.



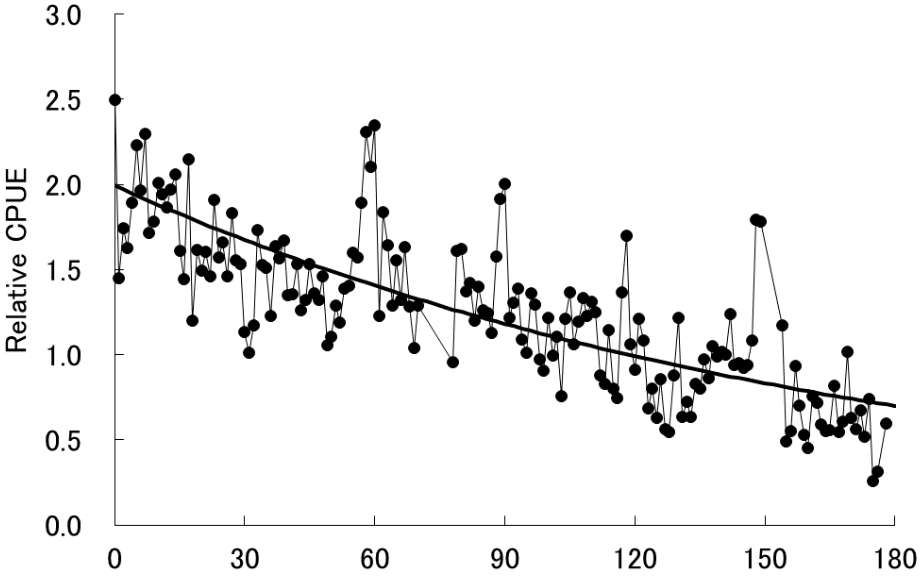
Appendix figure 2-2. Biomass in number estimated by CPUEs shown in Appendix figure 2-1.



Appendix figure 2-3. Biomass in number estimated by standardized CPUE by stock assessment in 2019 and 2021.



Appendix figure 2-4. Daily observation and estimates of relative CPUE and average mantle length.



Appendix figure 2-5. Daily change of relative CPUE corrected by average mantle length. It indicates as a change of relative CPUE (ud) when recruitment rate is assumed 1 at 23cm mantle length (intercept of Y axis).

Appendix table 2-1. Residuals of recruitment projection to observation values.

year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
residuals	-0.54	-0.40	-0.50	-0.33	-0.35	0.42	-0.14	-0.14	0.02	0.53

year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
residuals	-0.12	-0.06	0.10	0.07	0.17	0.50	-0.51	0.65	0.35	0.34

year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
residuals	0.33	0.04	-0.28	-0.15	0.17	-0.22	0.42	0.17	-0.04	0.12

year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
residuals	-0.02	-0.15	0.46	-0.07	-0.47	0.08	-0.49	-0.21	0.28	-0.21

Appendix 3 Research vessel survey and results

1) Squid fishing grounds survey in Japan Sea (squid jigging research)

Distribution survey by squid jigging (50 to 70 research points) has been conducted during June to July by research institutes located along the coast of Japan Sea to monitor distribution and size of squid (Appendix figure 3-1). Abundance index of the stock has been obtained to standardize CPUE (catch in number per jigging machine per hour) of research vessels (Appendix 2). The biomass estimated by abundance indices has some relation with fishery status of offshore fishery (average CPUE of mid-size squid jigging boats) (Appendix figure 3-2).

Research result in 2021 was shown in Appendix figure 3-1. Squid at mantle length 14 to 17cm were mainly caught in the waters of northern and central Hokkaido, distribution density was extremely low of 5 squid in the maximum compere with normal years. Squid at mantle length 14 to 16cm were mainly caught in the waters of southern Hokkaido and Tsugaru strait, distribution density was low of 2 squid in the maximum caught at offshore of Hiyama. Squid at mantle length 15 to 18cm were mainly caught in the waters of northern Honshu in Japan Sea and CPUE were lower than 0.2 squids with some no catch except of 24 squid caught at the research point of Northwest Noto peninsula. Squid at wide range of mantle length 12 to 22cm were caught in the waters of western Japan Sea, CPUE were lower than 4 squids with some no catch except of 15 squid at the research point of Northwest Oki Islands and 8 squids at the point of Fukui prefecture offshore. In the offshore area, squid at mantle length 18 to 20cm were mainly caught and CPUE was the maximum of 143 squid at the point located 40°20'N, 136°20'E and 65 squid at the point located 41°20'N, 137°40'E for the next. Pattern of distribution was similar of previous year, CPUEs around Yamato rise were low, where usually high in normal year, CPUE were high in northeast outside of Yamato rise.

The mantle length distribution weighted by density distribution of each point (CPUE of each research point by vessel) caught by squid fishing grounds survey is shown Appendix figure 3-3. The mode of mantle length ranging 17 to 18cm in 2020 research was little smaller than normal year, but large portion of small squid less than 16cm was specific same as 2019. The mode of mantle length in 2021 research ranging 18 to 19cm was larger than previous year and almost same as average of recent years.

By the way, squid fishing grounds survey were conducted three times a year of June, July and September before 1994, but it became one in June and July after 1995.

2) Squid larval survey

Squid larval survey by plankton net has been conducted to monitor distribution of squid larvae in October and November in the main spawning ground of coastal waters from Sanin to northwest Kyusyu (appendix figure 3-4). Number of larvae caught per vertical taw by 45cm diameter net in the Squid larval survey in Japan Sea were low in 1980s (around 0.1) but raised after 1990s (more than 1) and up to around 2.5 near 2000 (Appendix figure 3-5). However, it decreased after that. Especially during 2016 to 2019, average number of sampled down 0.1 to 0.3 which were same as observed before 1988, although larvae were collected at around Tsushima strait as same as stock increasing period after 1989. While it of 2020 raised to 0.62, larger than 2019 (0.27), as same as 2015 (0.64).

It is known that distribution density of squid larvae relates to spawning stock biomass than recruitment next year (Kasahara and Nagasawa 1988), It was effective to predict spawning stock biomass during the periods of high stock level (Goto 1999). However, such relation became unclear, because of unfitting with spawning season and survey period due to the shift of main spawning season late after 2000 (Sakurai et al. 2007, Sakurai 2014), and lower accuracy of SB estimation by large uncertainty of Chinese catch after 2005.

While it is known by the research that distribution area of squid larvae (mostly spawning grounds) changed by biomass level (Goto 2002). The main distribution area of squid larvae was coastal area of Hokuriku in 1980s when stock decreased, but it expanded from Tsushima strait to East China Sea in

1990s when stock increased (Appendix figure 3-6). The change of squid larvae distribution (spawning grounds) relates to oceanographic environmental change, and is important information to understand stock status.

3) Recruitment survey

Japanese flying squid is annual fish (one year life span), then survival from larvae to recruitment is easily affected by environmental change, therefore biomass may decrease largely nevertheless maintaining enough amount of SB. Therefore, recruitment survey by surface trawl net (12m diameter at net mouth) has been conducted to forecast stock biomass just before fishing season from 2001. From the observation of the research from 2001 to 2010, it is known that average number of squid less than 5cm in mantle length caught by survey has significant relation with biomass estimated by fishing grounds survey (Kidokoro et al. 2014).

Young squid were mainly caught in the area west of 134°30'E by the survey conducted April 2021 (Appendix figure 3-7). Average number of caught was 18.5 squid per point, it was above of previous year (5.3 squid), but below recent average (23.5 squid). The average number of caught in mantle length larger than 5cm was 3.4 squid, it was above previous year (0.7 squid) and below recent average (6.9 squid) (Appendix figure 3-8). As mentioned above, distribution density of young squid in 2021 was relatively low level though it was above of previous year when was lowest.

4) Average water temperature at 50m depth of western Tsushima warm current in fall

Appendix figure 3-9 shows annual fluctuation of water temperature at 50m depth of western Tsushima warm current. Water temperature of the area, where main distribution area of squid, increased in winter after late 1980s, and it increased between spring and fall after 1998, then it became warm all-around year (Kato et al. 2006). Raising temperature was observed in 1998, squid biomass decreased at same year, but it increased in 1999, then stayed at relatively high level. Therefore, it was considered that water temperature change in 1998 did not affected on squid biomass at that time (Kidokoro et al. 2004).

However, after that, affect on fishing grounds formation by raising water temperature of Tsushima warm current in fall after 1998 (Rosa et al. 2011), and on the change of fishing ground in the coastal area of Japan Sea (Kidokoro 2011) were reported. Then it is considered that main spawning season shift to later season (Sakurai et al. 2007). As mentioned above, it is considered that rising temperature after 1998 may affect to the ecology of squid and decreasing of reproductive success. While, as mentioned in 2. Ecology (5) Remarks, it is considered that minus change of SPR residuals after 2016 is different from the situation of stock decreasing by cold era in 1980s. Furthermore, raising temperature at 50m depth of Tsushima warm current in fall does not continue to the recent, therefore it should be carefully monitored on oceanographic environment and research survey results.

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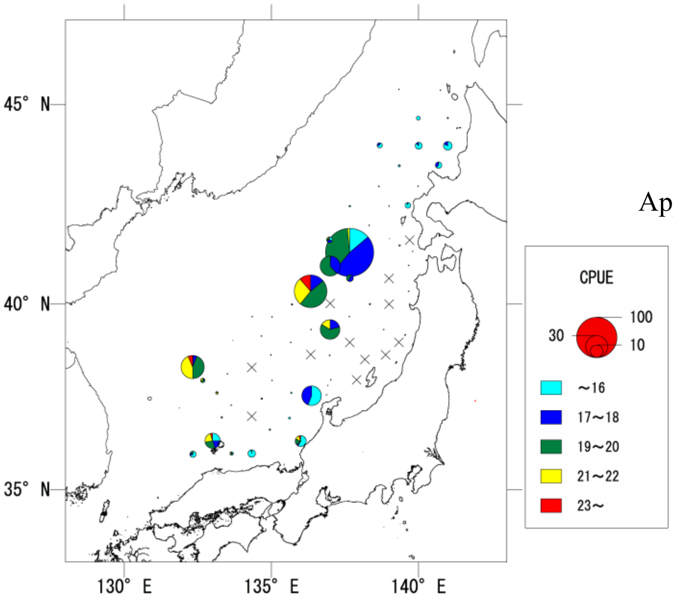
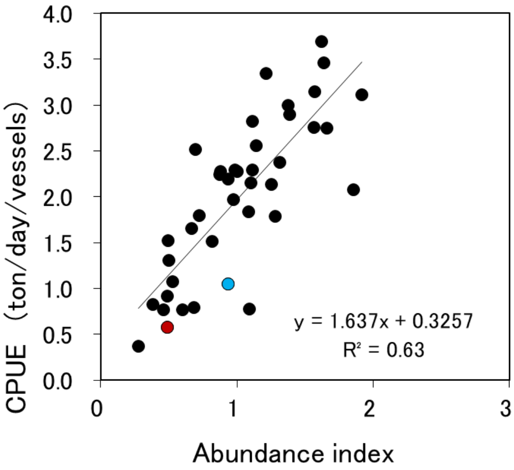
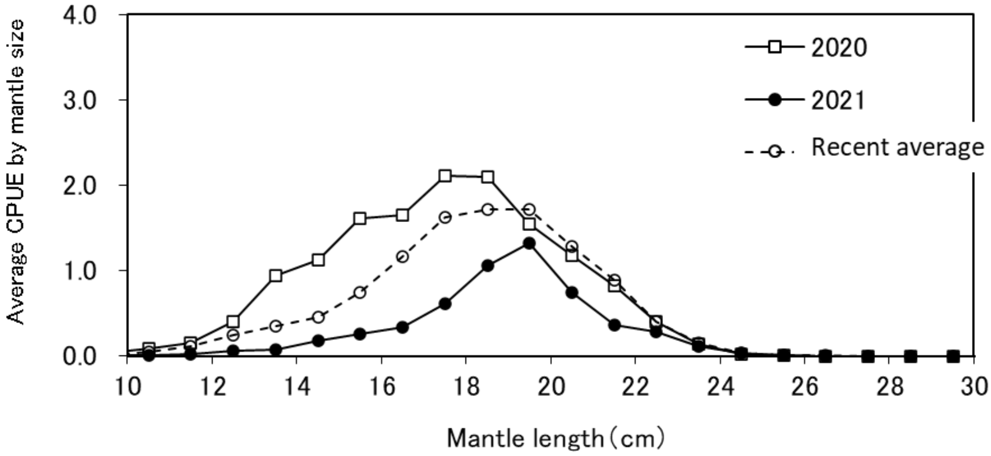


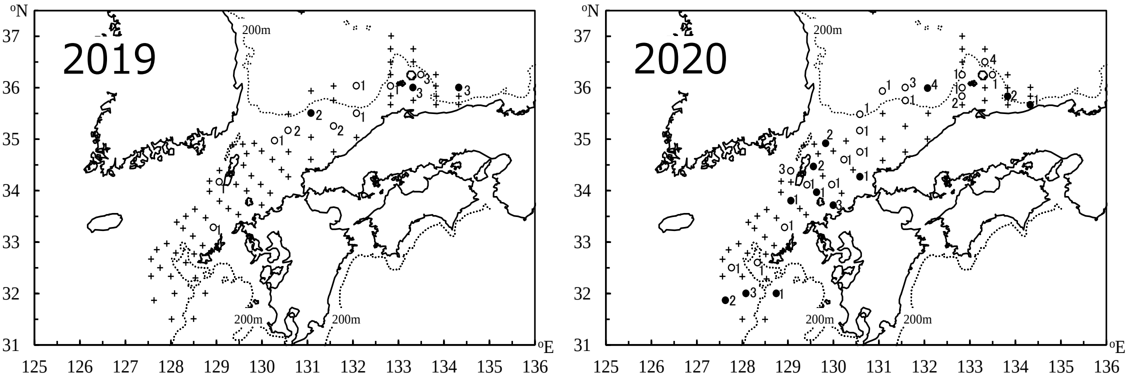
Appendix Fig. 3-1. Results of comprehensive squid research in Japan Sea. In the figure, x indicates zero catch, circles indicate CPUE (catch in number per machine per hour). Colors indicate mantle length class (cm).



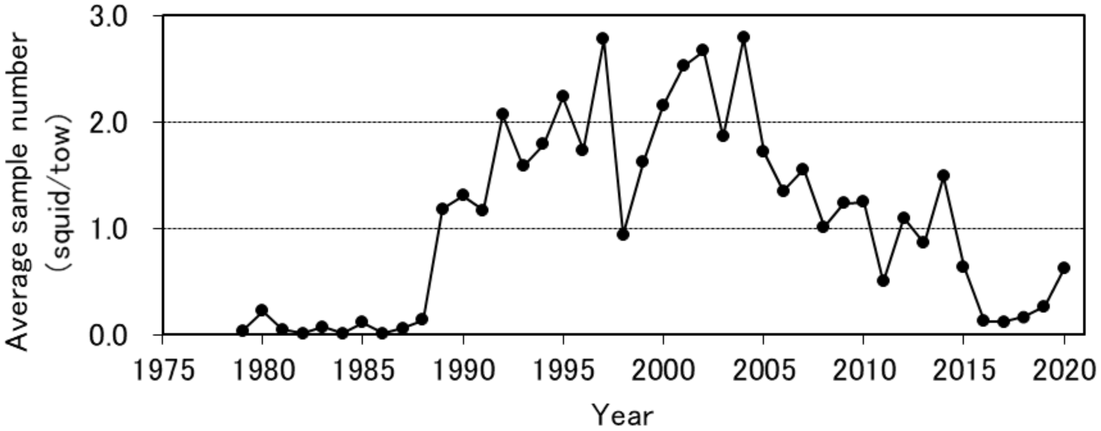
Appendix Fig. 3-2. Relation between biomass and CPUE of mid-size squid jigging boats. Regression line was calculated from the data in 1981 to 2018. Each Red and blue circles indicate 2018 and 2019 in respectively.



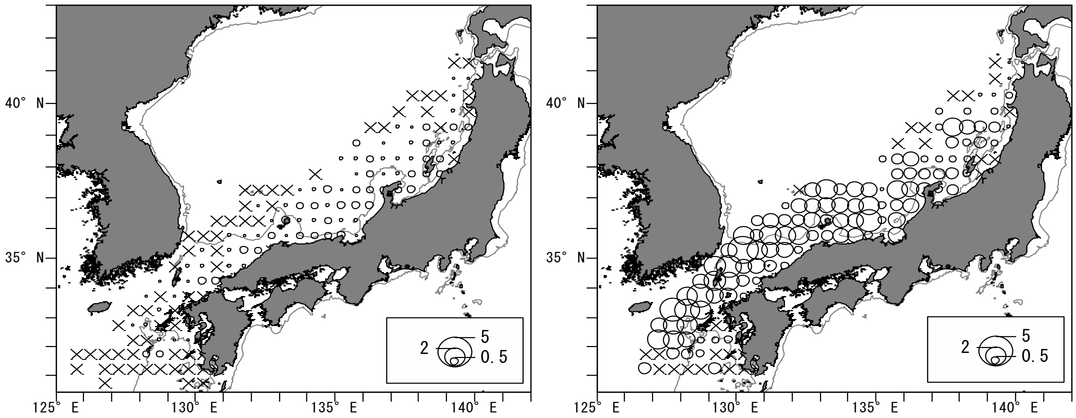
Appendix figure 3-3. Average mantle length distribution weight by CPUE of Japan Sea squid research for 2020, 2021 and recent five years average (2016 to 2020).



Appendix figure 3-4. Number of squid larvae sampled by vertical tow of 45cm diameter net by squid larval survey (FRA). The plus mark indicates zero catch. Black and white circles indicate sample including and not including larvae just after hatching in respectively.



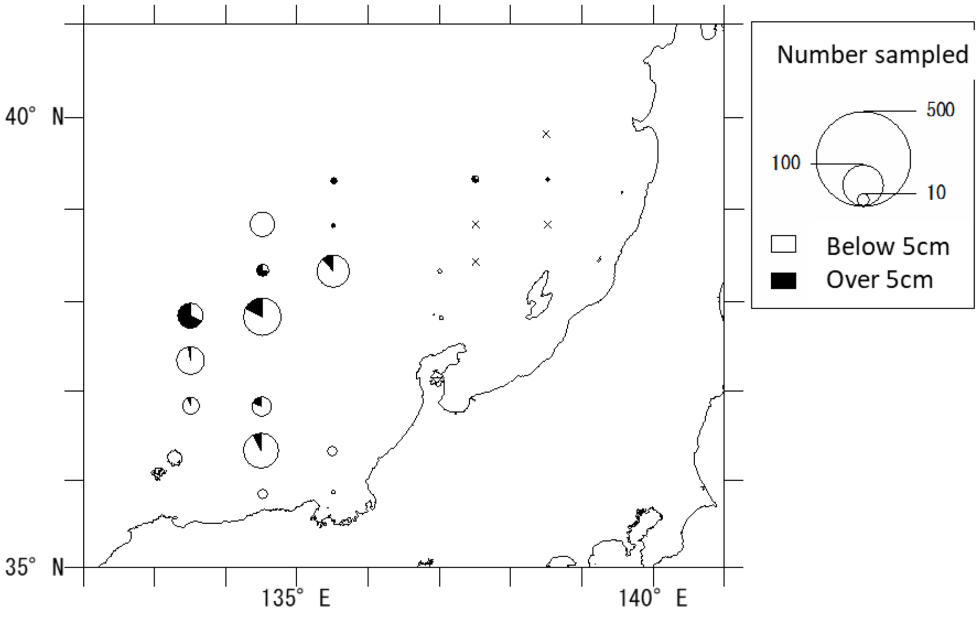
Appendix figure 3-5. Annual change of average sampling number of squid larvae per net collected by vertical tow of 45cm diameter net during Japan Sea squid larval survey (FRA) conducted from Oct. to Nov.



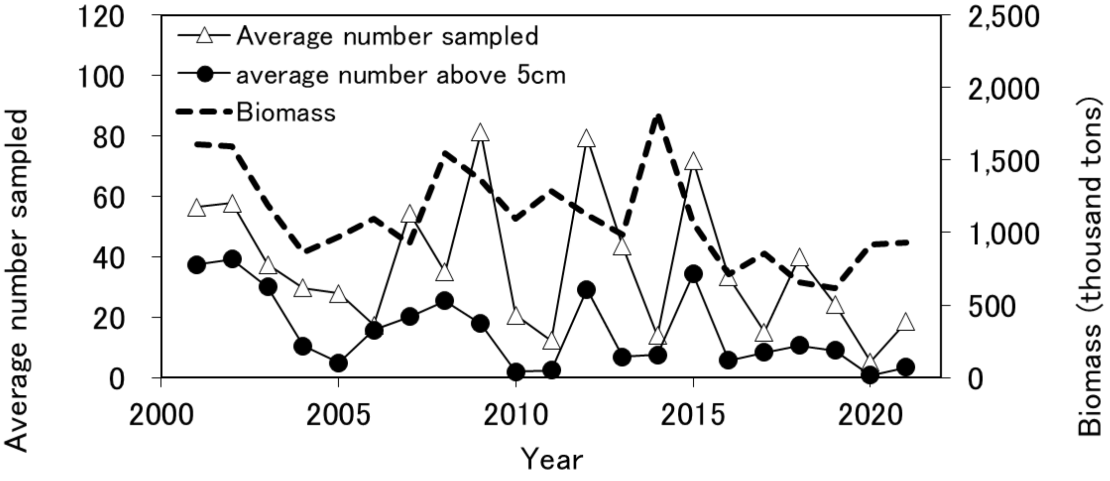
Distribution at decreasing period (1980 to 1990), (number of caught per vertical tow)

Distribution at increasing period (1989 to 2000), (number of caught per vertical tow)

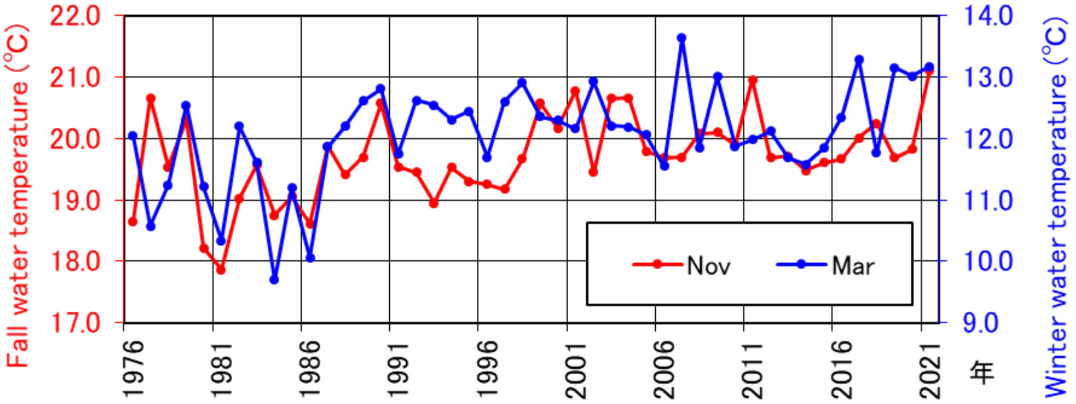
Appendix figure 3-6. Change of distribution of Japanese flying squid larvae (Kidokoro at al. 2010).



Appendix figure 3-7. Sampling number of squid by surface trawl survey in April of 2021. Circles indicate number of caught and x indicates zero catch.



Appendix figure 3-8. Annual change of average number of catch during recruitment survey and biomass estimated.



Appendix figure 3-9. Annual fluctuation of average water temperature at 50m depth in western area of Tsushima warm current (130E to 134E).

Appendix 4 Monitoring Chinese and north Korean fishing operation by satellite

It is important to monitor catches and fishing operations in Japan Sea by Chine and north Korea on the stock assessment of Japanese flying squid fall stock. Therefore, the monitoring of light fishing operation by establishing analysis of satellite night vision data were conducted from 2014. In this analysis, light fishing vessels is detected as light points, blight level, number of light points and positions are measured using night vision data of US satellite (Suomi NPP) (Miller et al. 2011). The monitoring for operations of twin trawler which does not use light was also stared using Synthetic aperture Rader (PALSAR-2) of Japanese satellite ALOS-2 (JAXA) from 2017 (Takahashi et al. 2020).

Typical light points distribution obtained in October during 2019 to 2021 is shown in Appendix figure 4-1 as an example. Bright points (red to orange) observed in the provisional water between Japan and Korea and northeast side of Japanese EEZ were mainly squid jigging boats of Japan and Korea, bright points observed in Russian EEZ were mostly Korean vessels in 2019 and 2020 but including Japanese vessels in 2021. While bright points observed in the area from western Yamato and Kita-Yamato rise to north Korean EEZ located northern edge of the provisional water between Japan and Korea were considered mostly Chinese light net fishing vessels, and it disappeared in 2021. Furthermore, many dark light points (light blue to blue) observed north of the area mentioned above, those were considered mostly wooden fishing boats of north Korea, but Chinese twin trawler and other vessels might be included. Small number of dark light points observed in North Korean EEZ in 2021 were considered as Chinese twin trawler by the analysis of Synthetic aperture Rader. Although light points distribution shown here are only partial but monitoring on number of light points (fishing boats) and locations has been continued.

Monthly change of bright points number (above 400×10^{-10} W cm^{-2} sr^{-1}), distributed in the area west of Yamato rise to North Korean EEZ (west of provisional water between Japan and Korea) and which only good condition without moon light and cloud and the days maximum number observed were selected, was shown in Appendix figure 4-2. The number of bright points increased until 2017, decreased in 2018, decreased again in 2019, then increased in 2020. Its of 2021 was as same as those in 2015,2016 and 2020. Although number was as normal year, bright points assumed Chinese vessels were not observed in 2021 in the area from Yamato rise to North Korean EEZ, certain number of dark bright points (yellow) supposed Chinese light net boats were observed in coastal area of North Korean EEZ.

Monthly change of dark points (below 300×10^{-10} W cm^{-2} sr^{-1}) located wider area then bright one which were extracted the day of maximum number, was shown in Appendix figure 4-3. The number of dark points supposed wooden boats of North Korea increased until 2018, and it indicates almost same level in 2019 as 2018. The distribution area of dark points widely expanded to Russian and Japanese EEZ during 2017 to 2019. While the number of dark points decreased in 2020 and 2021, it was suggested fishing operation of wooden boats of North Korea decreased.

Chinese twin trawler mainly consisted of fishing operation by China in the North Korean EEZ from the biggening and still twin trawler was main comportment (Park et al. 2020), it was difficult to separate from North Korean wooden boats by night vision due to the darkness of light. While Synthetic aperture Rader can identify location of fishing vessels which is as same as resolution size instead of with and without light, day and night, and with cloud. Furthermore, the method to detect and measure twin trawler using unique location of twin trawling operation was developed (Takahashi et al. 2020).

Although daily and short-term periodic observation is difficult by ALOS-2 due to the several reasons, number of twin trawlers operating in the North Korean EEZ after 2018 was measured using observation pictures as much as possible (Appendix figure 4-4). Moreover, monthly number of twin trawl pair extracting the maximum number in each month as index was shown in Appendix figure 4-5. However, if many twin trawlers were detected in high density of light, separation method from light net vessels was not developed yet, then those observations were excluded from the measurement. In the observation results, number of points in 2021was the lowest after 2017, and 1/3 of average during 2017 to 2020. Nevertheless, it was considered that 150 pair of twin trawler (300 vessels) operated in the peak of fishing season in 2021 in the area of North Korean EEZ and adjacent waters.

As mentioned above, quantitative estimate of catch is difficult by the analysis using satellite data, due to the limit of fishery identification and difficulty to estimate daily catch per vessel. However, monitoring of fishing operations are important, then monitoring and development of analysis should be continued.

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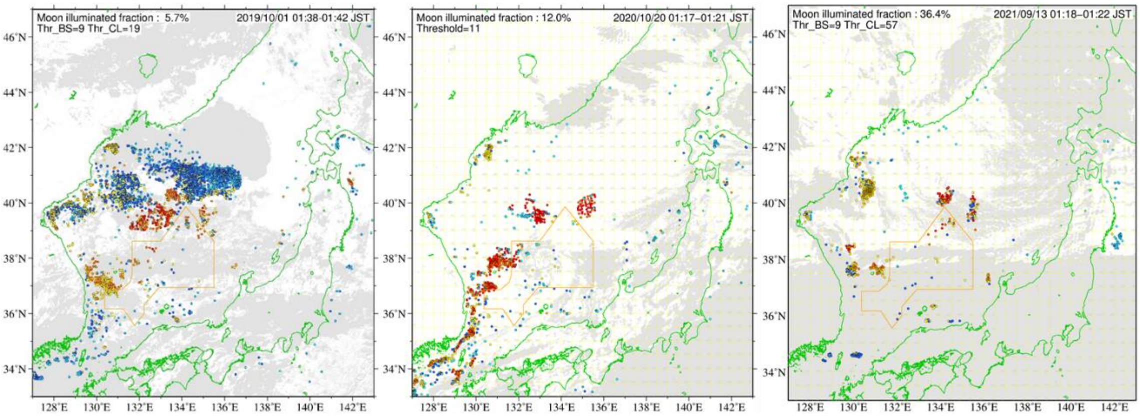
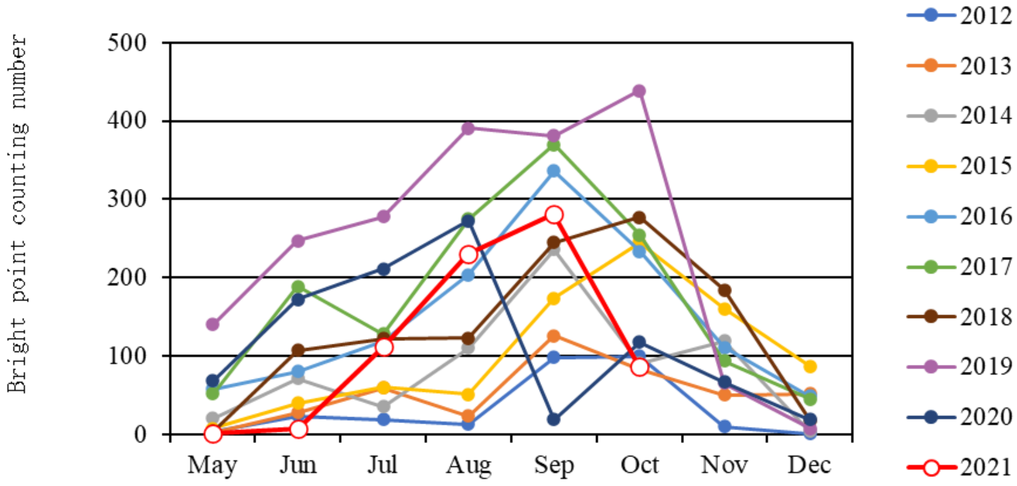
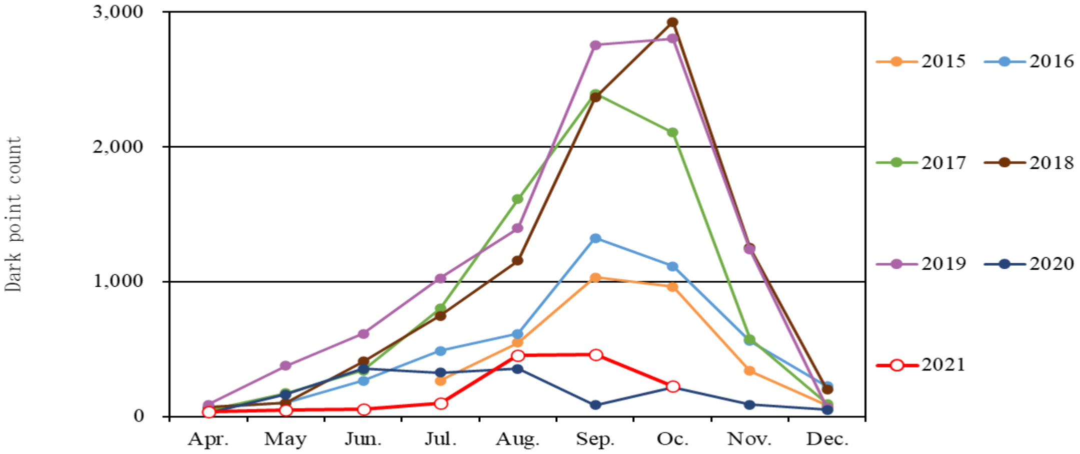


01/Oct/2019　　20/Oct/2020　　13/Sep/2021

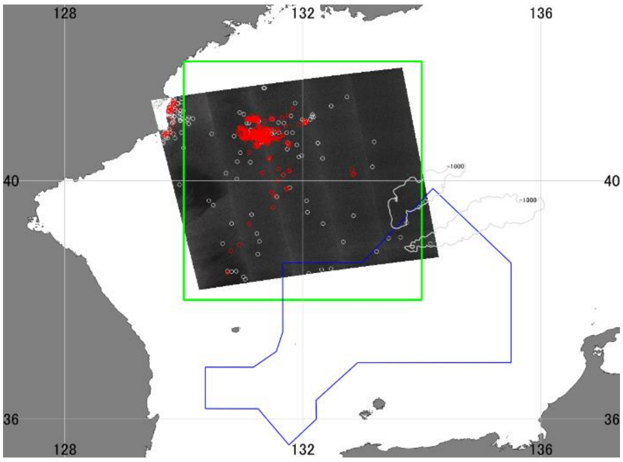
Appendix figure 4-1. Distribution of light points in Japan Sea obtained NPP satellite night visible data during 2019 to 2021. Warm and cold colors indicate brighter and darker points in respectively. Gray color indicates cloud.



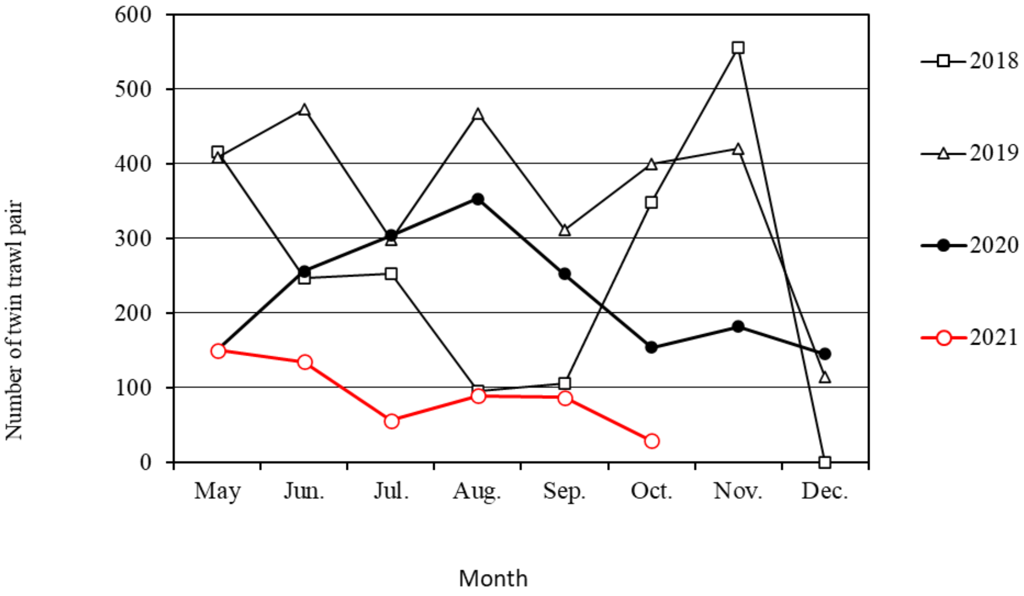
Appendix figure 4-2. Monthly change of maximum number daily bright points (above 400 x 10^{-10} W $cm^{-2}sr^{1}$, Yellow and red colors in Appendix figure 4-1) observed at areas of north Korea and western water of Yamato rise. Most bright points are supposed Chinese light net fishing vessels.



Appendix figure 4-3. Monthly change of maximum number daily dark light points (below 300 x 10^{-10} W $cm^{-2}sr^{1}$, light blue and blue colors in Appendix figure 4-1) observed at areas between 130E and 137E, 38°37'N and 45°N(130E and 138°30'E, 38°37'N and 45°N after August of 2018, it includes areas of north Korea, Russian EEZ and Japanese EEZ). Those are supposed north Korean fishing vessels including some Chinese twin trawlers.



Appendix figure 4-4. The example of area measured and analysis by satellite survey of ALOS-2/PALSAR-2. Red points and white points are supposed twin trawler and other fishing vessels in respectively. Green line indicates the area analyzed. Blue line indicates temporally waters between Japan and Korea. Grey line indicates 1000m depth contour around Yamato rise. The picture was obtained at August 1st of 2020.



Appendix figure 4-5. Monthly change of number of pair supposed twin trawler by the analysis of the data form satellite ALOS-2/PALSAR-2 in the area between 130E and 134E, 38N and 42N （including EEZs of north Korea, Russia and Japan）. Number of vessels is two times due to the pair trawler.

Appendix 5 Fishry status by country and fishery kind

1) Japan

Japanese catch of the stock increased from development of fishing ground in the central water of Japan Sea in late 1960, it reached 308 thousand tons at the peak of 1975. The catch decreased after mid-1970s, down to 54 thousand tons in 1986, then increased again between 107 and 178 thousand tons in 1990s. The catch peak was in 1996, then it decreased, and those were below 40 thousand tons after 2013. Catch in 2020 was 20 thousand and larger than 2019 catch (), but second lowest in history (figure 3-1, Table 3-1). Status in each fishery are described below.

1-1) Offshore squid jigging fishery

Licensed (by minister of MAFF) squid jigging fishery (mid-sized squid jigging) has been operating offshore area of Japanese EEZ in Japan Sea during May to next February, it is considered that fall hatched stock is targeted in Japan Sea during May to October and in East China Sea during May to November (See Appendix 2 of Stock assessment report of Japanese flying squid winter stock). CPUE of mid-sized squid jigging vessels (catch per vessel per day for vessel more than 90 tons) mainly targeting fall stock was below one ton in early 1980s, those increased in 1990s as same as abundance indices, then it was around 3 tons in first half of 2000 fishing season. Then it gradually decreased, stayed low level after 2015, down to 0.58 ton in 2019 as same as 1980s level, then recovered to 1.05 in 2020 (Table 3-2, Appendix figure 5-1, 5-2). It is considered that bad fishery status operating offshore in Japan Sea in 2019 may relates to decreasing of abundance index observed in offshore of Japan Sea in 2019. While CPUE of offshore fishery was the lowest in June of 2021, fishing grounds were located north edge around water of Yamato rise after July where almost no distribution found at the fishing ground survey, but it stayed same level of CPUE observed during 2015 to 2018 (Appendix 5-3). Fishing status after July in 2021 was conflicted with observed abundance index which was the second lowest after 1981. The reason of conflicting results, it is considered that fishing grounds survey does not include outside of Japanese EEZ, distribution shift to continental side of Japan Sea suggested form catch proportion between Japan and Korea during June to July (mentioned later, Appendix figure 5-8), then large migration into Japanese EEZ from outside caused after good catch.

1-2) Inshore squid jigging fishery

Inshore squid jigging fishery (small squid jigging) is operated alongside of Japan Sea from Hokkaido to Kyusyu. Fishing season targeting fall stock during May to August for northern migration and during September to October for spawning season, but main catch was consisted during northern migration. Major fishing season and fishing grounds during northern migration are May to July in Ishikawa prefecture, June to July in Japan Sea side of Aomori prefecture (Aomori), July to August in Tsugaru strait of Aomori prefecture (Ohata), June to August in Hakodate, and July to September in Japan Sea side of Hokkaido (western Hokkaido). Although fishery during northern migration operates other areas (from Akita to Niigata, west of Fukui prefecture), major five fishing grounds mentioned above have relatively long-term data of monthly catches and number of vessels operating. Then CPUEs (catch per vessel per day) of major five fishing grounds were shown (Appendix figure 5-3). Catch of Hokkaido largely decreased in 2019, CPUEs decreased in Wakkanai and Rumoi, those also decreased in Yoichi and Matsumae, and such low CPUE (or no londing) continued in 2021. CPUEs at Hakodate, Ohata and Aomori have decreasing trend after peak in 1995 and stays the lowest level of history since 2017. Similar long-term decreasing trend is observed in Ishikawa prefecture, but less significant than Hokkaido and Aomori. CPUE of Ishikawa prefecture in 2019 was lower than 2018, but higher than between 2014 and 2016, average level after 2002. CPUE in 2020 was above previous year and higher level comparing with long term trend. While it decreased at low level in 2021 which was not the lowest. As mentioned above, after 2019, schools migrating to western Hokkaido largely decreased, but migration to south of Tsugaru strait did not largely change during 2017 to 2020. Fishing status of Ishikawa was better in 2019 and 2020, but CPUEs were low in every area in 2021 and the lowest except

Ishikawa prefecture.

While fishing grounds for southern migration are around Oki islands and Tsushima strait during September to October. Change of squid jigging total catch (raw fish) of Sakai port and Nagasaki prefecture (Iki-Katsumoto and Tsushima) during September to October after 1994 are shown in Appendix figure 5-4 as fishing status of those grounds. Squid catch of Tottori prefecture raised 42 tons in 2019, zero ton in 2020, 142 tons in 202 from near zero after 2007. Those of Nagasaki prefecture increased to 37 tons in 2020, 77 tons in 2021 from less than 10 tons during 2016 to 2019. It is considered that biomass migrating to spawning grounds may be increasing though its verification needs CPUE instead of catches which is affected by long term reduction of fishing vessels.

Then, standardized CPUE for small squid jigging for northern migrating was estimated as an attempt to monitor stock status instead of abundance index used for assessment (standardized CPUE of squid fishing grounds survey). For standardization of CPUE of small squid jigging, generalized liner model was adapted for revised CPUE as CPUE (catch in ton/vessel/day) divided by average weight of squid by month by fishing ground, with explanation variable of year (Year), month (Month), landing port (Port), and response variable of log CPUE (fcpue). The CPUEs of four major landing ports (Hakodate: June to August, Ohata: July to August, Aomori: June to July, Ishikawa: May to July) during May to August between 1979 and 2020 were used for analysis. Normal distribution was assumed for distribution of residuals. All exploration variables were categorical, and interaction term among variables were also examined. The model below was selected based on Bayesian information criteria (BIC).

$$\log\left(fcpue_{ijk}\right) = \alpha + Year_i + Month_j + Port_{jk} + \varepsilon_{ijk} \qquad (1)$$

Here, α is intercept, $Year_i$ is effect of year, $Month_j$ is effect of month, $Port_{jk}$ is effect of landing port, ε_{ijk} is residual of year$i$, month$i$, and port$k$. Term $fcpue_{ijk}$ is CPUE of year$i$, month$j$, and port$k$. No interaction was selected.

CPUE of small squid jigging rapidly increased until the maximum in 1997 from the bottom in 1986. It rapidly decreased in 1998, thereafter it stayed high level lower than of 1997, then it decreased in 2014 and stayed at low level during 2017 to 2020, and it decreased at the lowest in 2021. Comparing with standardized CPUE of small squid jigging and CPUE of squid fishing grounds survey (abundance index) by normalization, CPUE of small squid jigging tends relatively high until 1998 and low after 1999 (Appendix figure 5-5). It is planned to be considered to use this new index for improvement of stock assessment for this stock.

1-3)Bottom trawl fishery

Japanese flying squid was not targeted by bottom trawl fishery before 2018 in Japan sea, and annual squid catch was around 1,000 tons in statistics of MAFF. Therefore, trawl fishery was not focused on assessment, but trawl catch were reported from many place of coastal area of Japan Sea from 2019, then fishery statistics were collected from research institutes of prefectures (Appendix figure 5-6). Considering annual total catch of major ports and fisheries (offshore bottom trawl or offshore and inshore both bottom trawl fishery) during April to September, catch larger than before after 2019 was reported from Ishikawa to Aomori prefecture, it stayed almost same level in the western region of Fukui prefecture where some places have larger catch in 2019 and 2020. Moreover, bottom trawl survey (sampling operated at 200 to 250m depth) of Tottori prefecture caught 10, 13 and 7 times of catch during August comparing with normal year in 2019, 2020 and 2021 in respectively (Tottori Fishery Experimental Stations). As mentioned above, bottom trawl catches during April to September increased continuously from 2019 to 2021 in the water from Ishikawa to Aomori prefecture, and squid tended to concentrate near bottom at the coast of Sanin region.

2) Korea

Japanese flying squid are caught by large trawl and jigging fisheries in Korea. The catch increased from May to October with peaks of October and December. Therefore, it is supposed that the catch is consisted with fall stock during April to October and winter stock during December to next March and November is divided into two (Assessment report of Japanese flying squid winter stock 2021, Appendix 2). Korean catch was the maximum of 45 thousand tons until 1990. However, it rapidly increased in 1991, and raised over 100 thousand tons in 1993. Although Korean catches were larger than Japanese catch after 1999, it tended to decrease in long term, it down to 33 thousand tons in 2018, the lowest from 1989, and those were 33 and 34 thousand tons in 2019 and 2020 in respectively (Figure 3-1, Table 3-1).

The squid catches by Korean vessels were poor after October in 2019 but catches were good until August then annual catch was almost same as normal year (Appendix figure 5-7). In 2020, it was around 8,000 tons in September, but no significant peak of monthly catch and total was almost same as normal year. In 2021, catch increased from April to September, and it was 32,753 tons until September as 129% of previous year and 115% of recent five years average. The catch in October was above 10 thousand tons (Fishery resources management office of Korea: https://www.fira.or.kr/fira/fira_030605.jsp checked at 1st of Nov. 2021). It was reported that some fishery closed fishery due to the catch reaching TAC (Daily Mainichi http://m.imaeil.com/page/view/2021101416564011092 checked 1st of Nov. 2021). Catch may not exceed following large migration.

Proportion of catch between Japan and Korea from June to July are examined as an index of migration to Japan Sea during the period of squid fishery grounds survey. Proportion of Japanese fishery stayed above 70% until 2014, it gradually decreased to around 60% during 2015 to 2018. Then Japanese proportion rapidly decreased to 33% in 2019, increased (54%) in 2020, then decreased again to 39% in 2021 (Appendix figure 5-8). From those observations, it is suggested that migration of squid shift to continental side during June to July in 2019 and 2021.

3) China

As mentioned in 3(2) Change of catch in this report, Chinese vessels, mainly consists with twin trawler, operated fishing into North Korean EEZ from 2004, including light net vessels in recent years, and it was reported more than 1,000 vessels in some years (Chow et al. 2016). Fishing season of Chinese vessels analyzed by satellite night vision were during August to October as a peak and until November, it largely decreased in December (Appendix 4). Furthermore, from satellite image analysis, twin trawler started fishery in May and increased until fall, and it was suggested that 500 pairs of trawlers operated at October in 2018 (Takahashi et al. 2020, Park et al. 2020, Appendix 4). Although fishery target shift from fall to winter stock after November, main target of Chinese fishery supposed to fall stock since Chinese fishery operations having peak until October and almost end in December.

Chinese catches until 2019 were assumed 150 thousand tons except in 2004, 2009, and 2013, from catch per one pair of twin trawlers at developing stage of fishing grounds in North Korean EEZ (Song et al. 2008), research report of Korea (Chow et al. 2016), and fishery activity analysis by satellite image data (Park et al. 2020, Appendix 4) and recent media reports (mentioned later) as same as Kubota et al. (2020a).

Topics of recent major media report on Chinese catch or fishing operation on Japanese flying squid are summarized below. 1) Chinese catch in 2019 was 130 thousand tons until June, 140 to 150 thousand tons in previous year, 20 thousand tons in July and August, then it was supposed as same as previous year of 150 thousand tons (Minato Shinbun, 18th of September 2019). 2) North Korea stopped to sell fishing right to Chinese vessels (2000) due to the awareness of COVID-19 pandemic (Suisan Keizai Shinbun, 19th of August 2020). 3) Chinese catch in 2020 June to July was 60 to 70 thousand tons as almost half of previous year (Minato Shinbun, 3rd of September 2020). 4) Total number of Chinese vessels for exclusion warning in Japanese EEZ around Yamato rise were 1,115 vessels in 2019, and 4,393 in 2020 (in total of January to December) (Fishery Agency of Japan 29th of January 2021, https://www.jfa.maff.go.jp/j/kanri/torishimari/attach/pdf/20210129.pdf). Chinese good catch was not expected for this fishing season (2021) due to the practical fishery ban in fishing grounds (Minato Shinbun, 16th of August 2021). 6) The number of exclusion warning to Chinese vessels at 30th of September 2021 were 582 vessels (2,586 in same speriod of 2020) (Fishery Agency of Japan 5th of October 2021 https://www.jfa.maff.go.jp/ j/kanri/torishimari/attach/pdf/20211005.pdf).

As mentioned in appendix 4, it was supposed that number of operating vessels of twin trawlers and light net fishery decreased in 2021 as same as information by media reports. Although number of Chinese vessels decreased in 2021, but still large number of boats were operating in Japan Sea. It is considered that Chinese catch assumption of 150 thousand tons in 2021 still should be used for assessment as same as before due to the lack of qualitative information of catch.

4) North Korea

Regarding North Korean catch, it was reported that increase number of wooden and steel vessels in the water of Yamato rise, illegal catch in Japanese and Russian EEZ, interruption of fishing operation on Japanese vessels, and wooden boat wreckage washed ashore of the Japanese coast. Although expansion of fishing activity is obvious from satellite image analysis (Park et al. 2020, appendix 4), but there is no report of catch estimates.

The number of North Korean vessels rapidly increased during 2017 to 2019, it was estimated 3,000 vessels per day at the maximum. Those boats came into not only North Korean EEZ but illegally into Japanese and Russian EEZ at the peak. While dark light points supposed of North Korean wooden boats largely decreased during 2020 to 2021. As the reason of reduction following story was reported (Suisan Keizai Shinbun, 19th of August 2020), North Korean vessels came to offshore of Japan Sea seeking new fishing grounds since government giving North Korean EEZ (fishing right) to China, but Chinese vessels reduced in North Korean EEZ and North Korean government prohibited offshore fishery, then they came back to their EEZ. Moreover, it was reported that they stopped fishing by preventing COVID-19 infection (Daily NK 30th of September 2021 https://www.dailynk.com/북한-어민-불만-보다-코로나-방역-연말까지-조업-불/).

The fishing season of North Korea obtained by satellite night vision analysis were August to October as peak, to November and it largely decreased in December (Appendix 4). Therefore, it is considered that North Korea targets Japanese flying squid fall stock as same as China.

5) Russia

The catches of Russia were low as few tons to 500 tons until 2015, then increased 1,300 tons in 2016, around 5,000 tons in 2017 and 2018, 300 to 400 tons in 2019 and 2020. The catch in 2021 was 2,200 tons until 2021 reported by Russian scientist. Main fishing grounds in 2021 was southern waters of Primorsky Krai.

Considering fishery status of each country, it is considered that Chinese catch supposed as the largest should be included in the assessment and management which projects future biomass, fishing pressure, reproductive status by setting reference points based on reproductive relationship (Kubota et al. 2020a). Therefore, estimated catch including Japan and Korea plus assumed Chinese catch was used for the analysis as total catch on the stock.

The catch and fishery status in 2021 were summarized as follows. 1) Abundance of migration increased in offshore area from 2020 and poor catch in 2019, fishing status was as same as that of 2015 to 2018. 2) Inshore squid jigging in 2021 were poor catch in everywhere and mostly the lowest during the period except Ishikawa prefecture. 3) Bottom trawls have good catch since 2019 and catch in 2021 was larger than previous year. 4) Korean catch exceeded previous year until September, as same as past five years, and migration in October was high. 5) Number of Chinese vessels more decreased from previous year. 6) Number of North Korean vessels largely decreased in 2020 and 2021 from past years.

7) Migration into Russian EEZ was supposed larger than 2019 and 2020. Moreover, Korean proportion of catch in 2021was larger than Japanese during June and July as same as 2019. As mentioned above, catch in 2021 decreased at inshore jigging fisheries, but increased at offshore jigging fisheries comparing with 2020. It was supposed migration shift to continental side including Korea and Russia, and abundance may be same or above of previous year.

Considering migration status of each area in 2021, it is supposed that migration of stock to offshore area in Japan Sea increased. However, abundance index (CPUE of squid fishing ground survey) could not monitor major migration of squid because squid migration timing into Japanese EEZ does not fit to survey period (mismatch between survey period and migration timing).

Comparing catch trends between Japan and Korea, Japanese catch significantly decreased to biomass trends (Figure 3-1). It is considered that increasing of water temperature in Japan Sea during spring to fall effect on decreasing of catch (Kato et al. 2006). Catches coastline of Honsyu significantly reduced in summer and fall (Kidikoro 2011), decreasing trend of CPUE is clearer at inshore than offshore (Kidokoro 2016, Appendix figure 5-1, 5-3, 5-5). It is considered that coastal area, where Tsushima warm current flows and relatively higher temperature than offshore and continental side, becomes unsuitable habitant to squid during summer and fall (August to November) due to the high temperature of whole Japan Sea. Therefore, it is supposed that distribution shift of squid to north and offshore in summer and fall caused decreasing trends of Japanese catch, increasing catch in Russian EEZ and fishing grounds shift to north and offshore observed in Japanese EEZ. Furthermore, long-term decreasing trends of Japanese squid jigging vessels until recent years (Miki 2003, Sato 2009, Yomo 2009) may affect to the decreasing of catch.

In 2019 fishing season, it was considered that migration into offshore of Japanese EEZ (Yamato rise to Musashi rise) was extremely small with low level of stock biomass (Kubota et al. 2020b). While relative high catch was observed inshore area of central Honshu in 2019, similar high catch observed in same area in 2020. As other topics in 2019, catch in western Hokkaido disappeared both inshore and offshore areas, and bottom trawl catch in North of Ishikawa prefecture rapidly increased. As mentioned above, some changes other than fishing grounds shift to north and offshore were observed, then it is important to understand the relation between squid distribution and environment.

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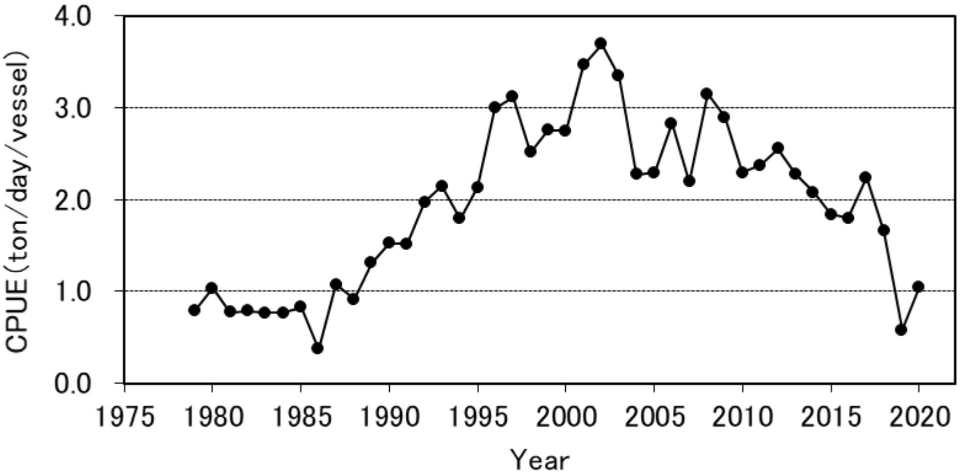
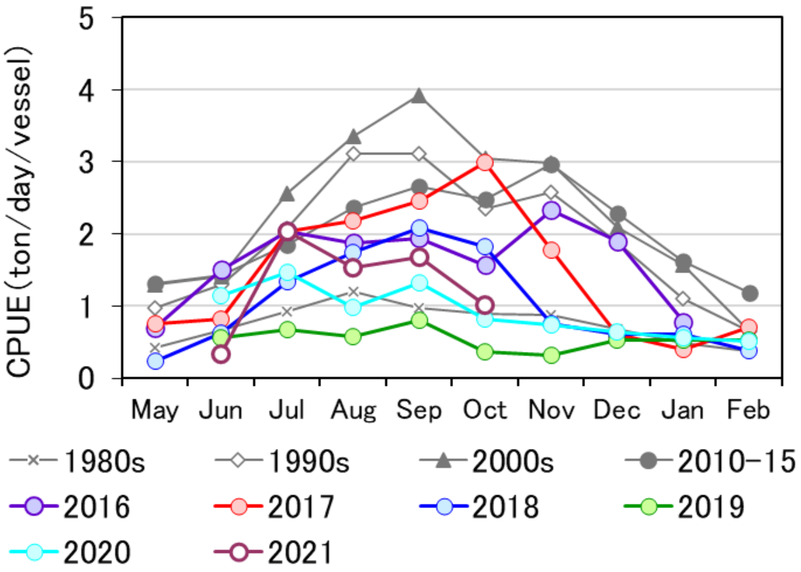
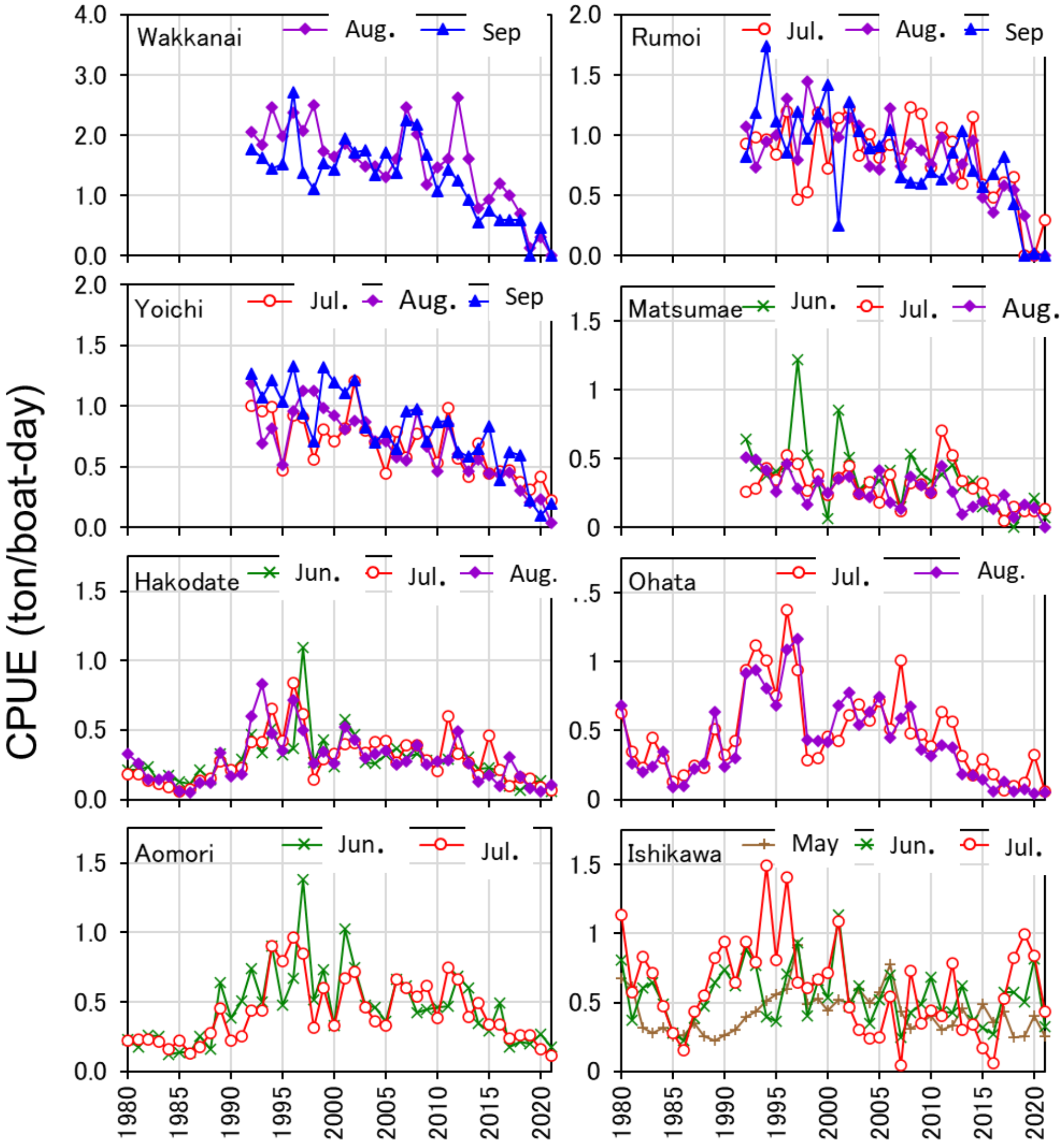


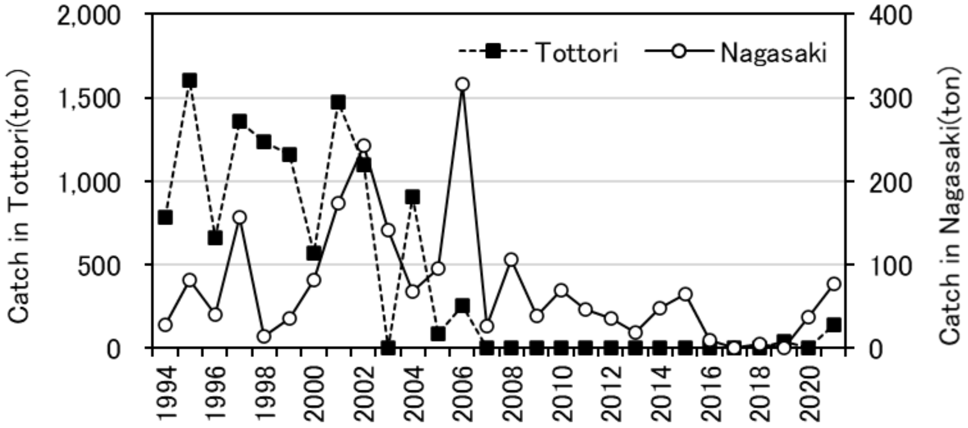
Appendix figure 5-1. Annual change of CPUE (catch per vessel per day) of Japanese mid-size squid jigging vessels.



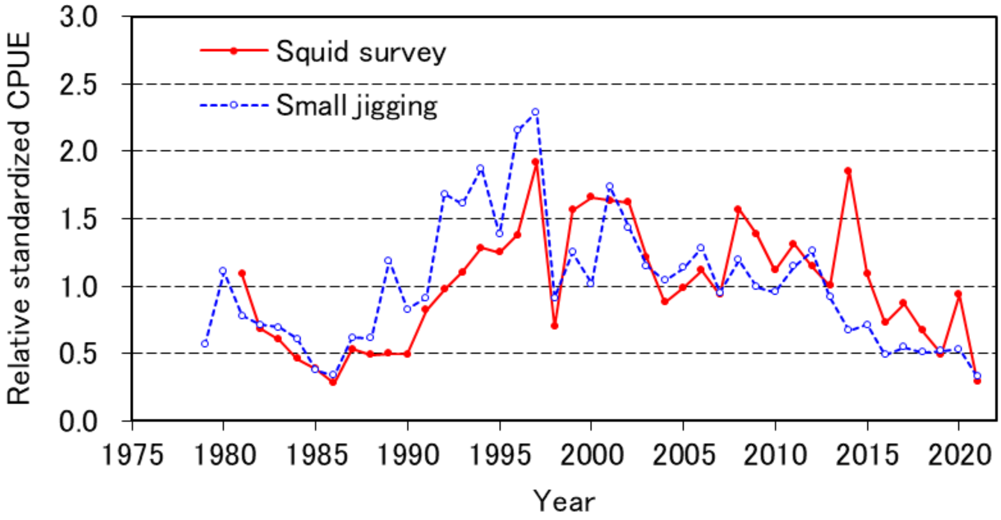
Appendix figure 5-2. Monthly change of average CPUE of Japanese mid-size squid jigging vessels in Japan Sea. The average CPUE calculated using the logbook report until 2020, then it was obtained the research data of chartered vessels (10 vessels) after 2021.



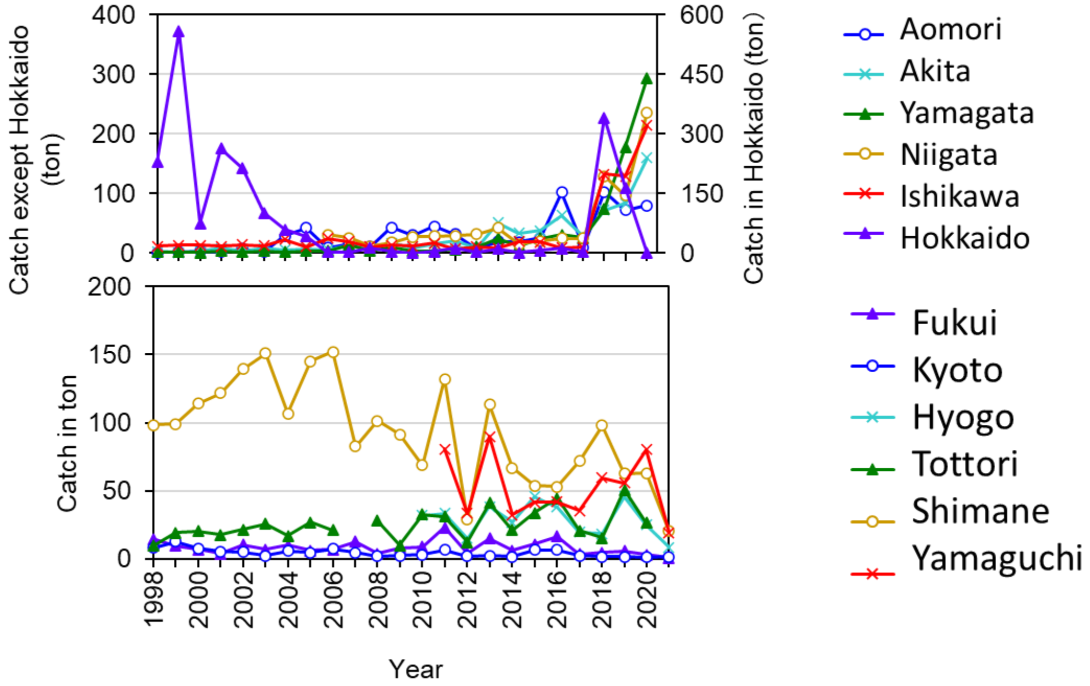
Appendix figure 5-3. Monthly change of CPUE of small squid jigging vessels in major area and seasons. The CPUE is catch (ton) per vessel per day. Aomori obtained total of four major ports and Ishikawa includes six major ports.



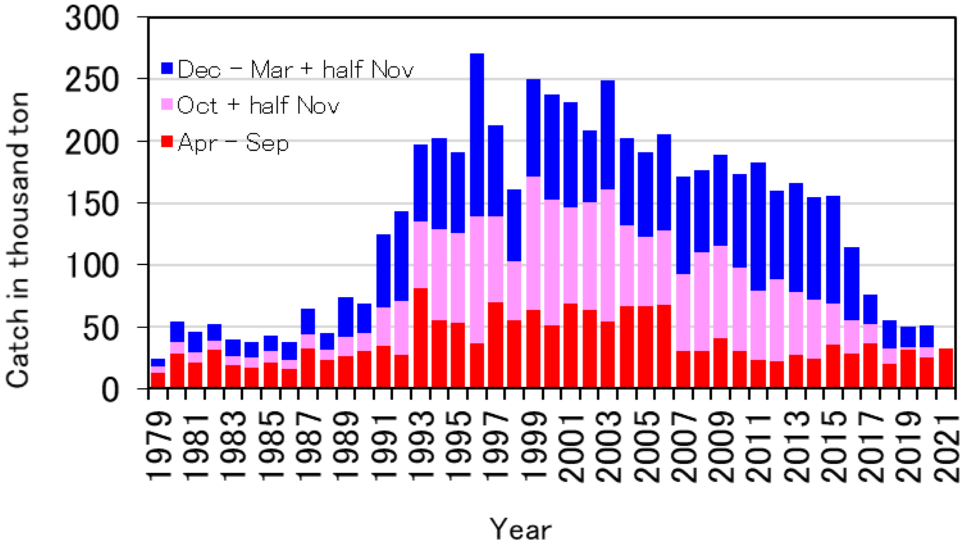
Appendix figure 5-4. Annual change of squid catch by inshore squid jigging fishery (September and October) at Tottori (Sakai port, small + mid-size raw landing boat) and Nagasaki (Iki-katsumoto, Tsushima, small boats).



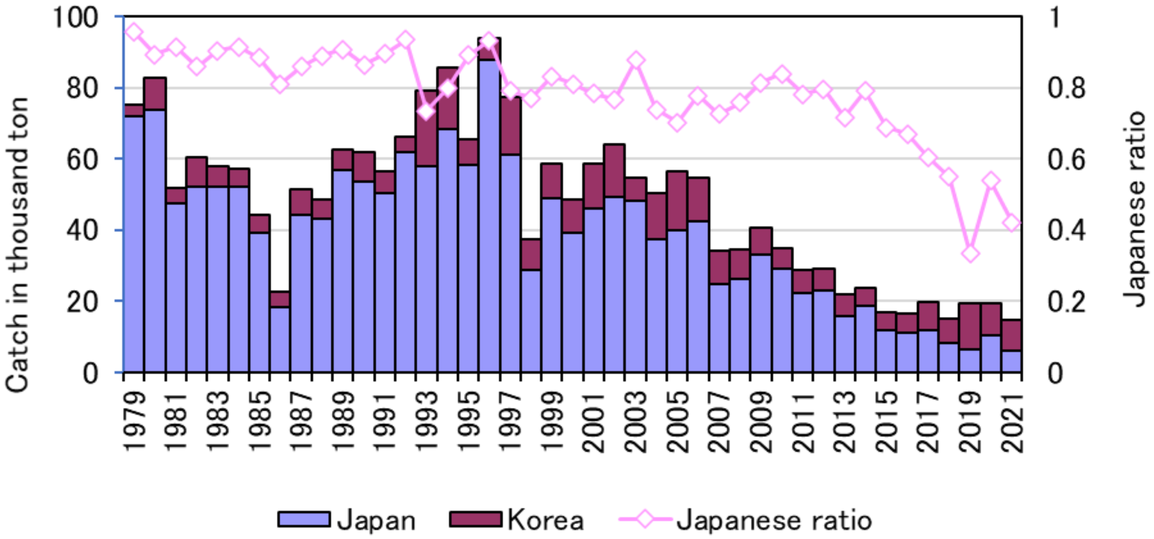
Appendix figure 5-5. Annual change of standardized relative CPUE (relative value at average 1) of squid fishing grounds survey and small squid jigging fishery.



Appendix figure 5-6. Annual change of catch (April to September) of bottom trawl fisheries at major fishing ports of the prefectures along the coast of Japan Sea (mostly offshore bottom trawl including small portion of small bottom trawler). Tottori catch of 2007 was not included as data error. Fishing season of Hokkaido is from April to august.



Appendix figure 5-7. Annual change of Korean catch. The catch from April to October are supposed catch of fall stock and from December to next March supposed from winter stock. November catch was divided into two.



Appendix figure 5-8. Annual change of Japanese and Korean catch from June to July, and Japanese ratio in total catch.