Stock assessment and evaluation for Sea of Japan Area A stock of snow crab (fiscal year 2021)

Japan Fisheries Research and Education Agency
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Aquaculture Research Department, Fisheries Technology Institute
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Summary

The stock status of Area A stock (west of Toyama) was evaluated using the stock density indices of offshore bottom-trawl fisheries and, cohort analysis based on the results of bottom trawl surveys from 1999 to 2021. Stock density index (kg/net), an indicator of long-term stock levels, declined from over 100 in the early 1970s to a record low of 10 in 1991. Stock density index then started to rise and remained around 50 to 59 in the mid-2000s, followed by a slow decline, reaching 42 in 2020. Stock abundance since 1999, estimated by cohort analysis based on trawl survey results, showed increase from 2003 to 2007, followed by decline until 2015. Stock abundance subsequently showed increase again from 2016 to 2018, then declined from 2019, reaching 14,000 tons in 2021. SSB showed a similar pattern to stock abundance, increased from 2003 to 2007, then started to decline in 2008, followed by increase after 2016. SSB was 3,400 tons in 2020. Recruitment is expected to decrease in 2020 and 2021, followed by increase in 2022 and 2023.

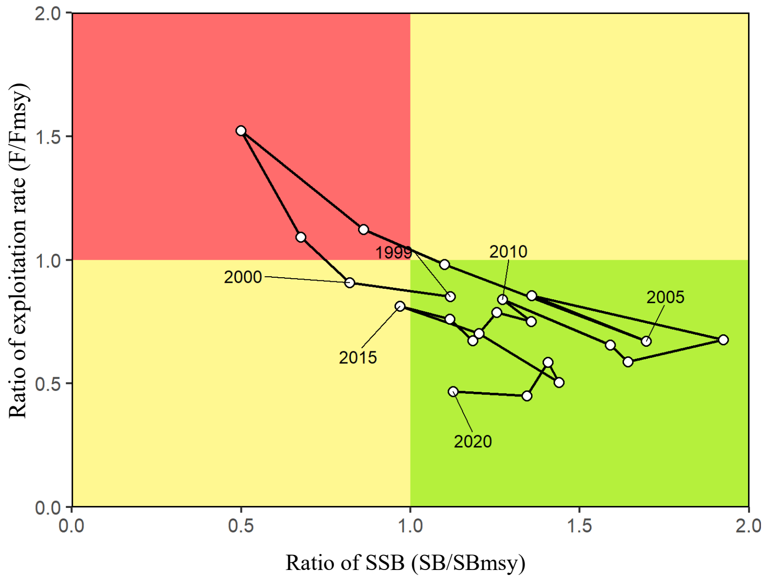
Target reference points, limit reference points, fishing ban levels, and Harvest Control Rules for this stock were decided at the Research Agency Forum on Reference Points held in August and October 2020 and March 2021, and the Fishery Policy Council held in April 2021. The target reference point is the SSB required for MSY (3,000 tons), and the SSB of this stock in 2020 exceeded this. In addition, the fishing pressure for this area in the 2020 fishing season was lower than the fishing pressure level required for MSY (Fmsy). Based on trends seen in the previous 5 years (2016 to 2020 fishing seasons), the SSB is judged to be in a “declining” trend. The ABC for 2022 was calculated to be 2,800 tons based on forecasts for SSB and stock abundance in 2022, and the Harvest Control Rules.

Item	Value	Description
Reference points & MSY values		
SBtarget	3.0 thousand tons	SSB required for MSY (SBmsy)
SBlimit	1.5 thousand tons	Historic minimum SSB (SBmin)
SBban	0.1 thousand tons	SSB required for catch of 10% of MSY (SB0.1msy)
Fmsy	Fishing pressure required for MSY (fishing coefficient F) (Female) = (0.46)	
%SPR (Fmsy)	16%	%SPR corresponding to Fmsy
MSY	3.7 thousand tons	Maximum Sustainable Yield
SSB and fishing pressure in the 2020 fishing season		
SB2020	3.4 thousand tons	SSB in 2020 fishing season
F2020	Fishing pressure in 2020 fishing season (fishing coefficient F) (Soft shell, hard shell, female) = (0.02, 0.34, 0.21)	
%SPR (F2020)	36%	%SPR in 2020 fishing season
%SPR (F2018-2020)	34%	%SPR corresponding to current fishing pressure (2018 to 2020 fishing seasons)
Ratio of levels required for target reference points to levels required for MSY		
SB2020 / SBtarget (SBmsy)	1.13	Ratio of target reference points (SSB required for MSY) to SSB in 2020 fishing season
F2020 / Fmsy	0.47	Ratio of fishing pressure required for MSY to fishing pressure in 2020 fishing season*

*Ratio calculated based on %SPR converted F, which reflects Fmsy fishing pressure at the selection probability of the 2020 fishing season

Stock-recruitment relationship: Ricker model (without autocorrelation)

Level of SSB	Over the level required for MSY
Level of fishing pressure	Under the level required for MSY
Changes in SSB	Decrease



Fishing year	Stock abundance (thousand tons)	SSB (thousand tons)	Catch in weight (thousand tons)	F/Fmsy	Exploitation rate (%)
2017	21.1	4.3	2.8	0.50	13
2018	21.9	4.2	2.8	0.59	14
2019	20.9	4.0	2.5	0.45	12
2020	18.1	3.4	2.2	0.47	12
2021	14.4	2.9	1.7	0.50	12
2022	15.4	2.9	—	—	—

Stock abundance is the values at the start of the season (females: November 1, hard shells: December 1, soft shells: February 1), and catch in weight is the values for the fishing season (from July to June of the following year). SSB in this stock is the stock abundance of females after the fishing season ends, and F is the fishing pressure for females (Appendix 2). In addition, exploitation rate was calculated for the entire stock. The values for 2021 and 2022 are estimates based on future forecasts.

ABC for the 2022 fishing season (thousand tons)	Forecasted average of SSB in 2022 fishing season (thousand tons)	Ratio to current fishing pressure (F/F2018-2020)	Exploitation rate in 2022 fishing season (%)
2.8	2.9	1.60	18

Comments:

- ABC is calculated according to the Harvest Control Rules from catch strategies compiled by the Stock Management Policy Commission in March 2021.
- Recruitment was below average in 2021, but levels for both males and females are expected to increase from 2022.
- The exploitation rate is the value for the entire stock.

1. Data Sets

The data sets used for this stock assessment are as follows:

Data Sets	Basic Information & Related Surveys
Standing stock population by year and by instar	Trawl survey ("Stock survey of demersal species including snow crabs in the Sea of Japan", May to June, Japan Fisheries Research and Education Agency)
Catch in weight	Landing volume by prefecture, fishing method, month, and sex Annual Report of Catch Statistics on Fishery and Aquiculture (Ministry of Agriculture, Forestry and Fisheries) South Korea fishery statistics(URL: http://fs.fips.go.kr/main.jsp) National Federation of Medium Trawlers reports
Catch in number by instar	Carapace width composition survey (Tottori, Hyogo, Kyoto, Fukui), market measurements
Fishing Effort CPUE and Stock Density Index	Catch Performance Report for Bottom-Trawl Fishing in Offshore Waters (Japan Fisheries Research and Education Agency)
Natural mortality coefficient (M) (per year)	M = 0.2 for individuals who completed their terminal molt 1 or more years prior M = 0.35 for individuals who did not complete terminal molt or completed terminal molt less than 1 year prior

2. Ecology

(1) Distribution / Migration

The distribution range of this stock in the Sea of Japan is the margin of the continental shelf slope and the Yamato Bank in the center of the Sea of Japan, most commonly at depths of 200 m to 500 m (Fig. 2-1). The terminal molt and subsequent primiparous brooding of females are observed in a limited area of relatively shallow water (Kon 1980). Mature males and females are distributed at different depths: males mainly distributed in deeper waters and females mainly distributed in shallower waters, with a boundary at depths of 260 m to 300 m. The species have planktonic larvae for 2 to 3 months after hatching (prezoea stage, first zoea stage, second zoea stage, megalop stage) before metamorphosing into juvenile crabs and settling on the seabed (Kon 1980, Yamamoto et al. 2014). Based on the results of tag-recapture experiment, horizontal migration seems to be rare (Ogata 1974).

(2) Age / Growth

Individuals molt multiple times in the first year from hatching until the 6th instar (Ito 1970), then molt once per year afterwards. The period from hatching until recruitment (males: 11th instar, females: 10th instar) is considered to be 7 to 8 years, with a life span of more than 10 years, based on the results of breeding experiments at 1 °C, which is the water temperature in the main distribution area of this stock in the Sea of Japan (Yamamoto et al. 2015).

The molt-age of snow crabs can be estimated based on length-frequency data like carapace width composition (Kon et al. 1968, Yamasaki and Kuwahara 1991, Yamasaki et al. 1992). In juvenile and immature crabs, there is no difference in growth between males and females, and carapace width reaches 60 mm or more in the 10th instar (Fig. 2-2). Mature males that completed their terminal molt usually start to appear in the 11th instar, and the proportion of males that completed their terminal molt is 5%, 20%, and 100% in the 11th, 12th, and 13th instars, respectively. The propodus (claw) grows larger relative to body size at the terminal molt (Fig. 2-3). Females are pre-terminal molt (immature) up to the 10th instar, and all females complete their terminal molts by the 11th instar. At the terminal molt, the abdominal flap becomes wider to carry eggs. Because body growth ceases after the terminal molt, the group of females in the 11th instar and males in the 11th instar or higher contains multiple cohorts.

(3) Maturation / Spawning

Females complete their terminal molt in the summer or fall of their 10th instar, then mate and spawn their primiparous brood (carry eggs) immediately after reaching the 11th instar (Fig. 2-3). After their first spawning, females incubate the eggs for 18 months, and the larvae hatch in February or March of the following year. Shortly after hatching, the second spawning (multiparous spawning) occurs. The multiparous incubation period is 12 months, and they will spawn every year in February or March. The color of the egg clutch is orange after spawning, then transitions to brown or blackish purple as the larvae develop inside before hatching.

Immediately after their first spawning, females with orange egg clutches at the beginning of the fishing season (November) are called “akako” (red-egged females). When the eggs turn to brown or blackish purple by the following fishing season 1 year later, the females are called “kuroko” (black-egged females).

Snow crabs categories are nicknamed by development and by sex: soft shells, hard shells, akako, and kuroko. These nicknames may vary from region to region. In this report, individual males that molted within the past year are called soft shells, and individual males that completed their terminal molt more than 1 year prior are called hard shells. Normally, hard shells are individuals that have completed their terminal molt (large propodus), but there are also individuals that are pre-terminal molt (small propodus), and these are called “momogani” (peach crabs) in Kyoto prefecture. Breeding experiments have shown that almost all momogani molt within 2 years (Yamamoto et al. 2018). In this assessment, the ratio of momogani among hard shells is assumed to be constant regardless of the year. In addition, all landing target female individuals are considered to be kuroko.

(4) Predator-Prey Relationships

This stock feeds year-round except during molting, on crustaceans, fish, squids, polychaetes, shellfish, echinoderms, and other benthic organisms (Ogata 1974).

Smaller individuals are preyed upon by eelpouts (Ito 1968, Konishi et al. 2012) and Pacific cod (Ueda 2018).

3. Fishery Status

(1) Fishery Overview

In this area, snow crabs are primarily caught by offshore bottom-trawlers (Danish seine trawl) (hereinafter referred to as “offshore trawlers”) (Fig. 3-1), and also by small bottom-trawlers and crab pots. Detailed catch regulations have been established for snow crabs in this area through ordinances issued by the Ministry of Agriculture, Forestry and Fisheries, and voluntary regulations (see 6. Recommendations for management measures other than ABC). Ministry ordinances set the fishing season in this area for males from November 6 to March 20 of the following year, and for females from November 6 to January 20 of the following year. Catch targets are hard shell and soft shell males with a carapace width of 90 mm or more (essentially, 12th and 13th instar), and kuroko females (all 11th instar). For more details, see Tables 3-1 and 3-2. Catching this species around the Yamato Bank is prohibited by the ordinances of the Ministry of Agriculture, Forestry and Fisheries.

(2) Trends in Catch in Weight

Catch in weight (by calendar year) peaked in the mid-1960s and around 1970, when it exceeded 14,000 tons. Then, it declined sharply after 1970, falling below 2,000 tons from 1988 to 1993. It shifted to a rising trend from the mid-1990s, reaching nearly 5,000 tons in 2007, followed by decline (Fig. 3-1, Appendix 5).

Catch in weight (by fishing year) since 1999 by fishing year and by sex based on statistical data aggregated for each prefecture is shown Fig. 3-2 (also see Supplementary Table 2-6). The catch of soft shells remained steady around 1,000 tons up to 2007, followed by decline due to stock conservation initiatives by fishermen. The level in 2020 was 158 tons, the same level as 2019. The catch of hard shells rose to 1,935 tons in 2008, followed by decline, then stayed around 1,500 tons from 2009, and remained steady around 1,300 tons since 2015. Catch in weight of hard shells increased again during 2019, but decreased to 1,252 tons in 2021. The catch of females increased from 2001, reaching nearly 2,100 tons in 2007, followed by decline, then ranged from 1,500 to 1,800 tons from 2008, and remained steady around 1,300 tons since 2013. Catch in weight of females fell below 1,000 tons in 2019, and declined further to 802 tons in 2020. The total catch in weight of males and females in 2020 was 2,212 tons.

(3) Fishing Effort

Effective fishing effort of offshore trawlers has decrease since the 1970s for males, and since 1984 for females. In 2020, effective fishing effort was 55,000 casts for males and 31,000 casts for females. These levels are slightly higher than the previous year for both groups, but are still record lows (Fig. 3-3, Table 3-3).

In the following section of this report, mentions of years refer to fishing years (July to June of the following year) unless otherwise noted.

4. Stock Status

(1) Stock Assessment Methods

Stock assessment was conducted based on stock abundance of catch targets at the beginning of the fishing season in each year, which was estimated using cohort analysis of trawl survey results. The values for soft shell and hard shell males in the 12th instar and higher, and kuroko females in the 11th instar, were used for stock abundance of catch targets (Appendix 1, 2, and 3). The standing stock size of juveniles was used to forecast recruitment of 11th instar males and 10th instar females.

Furthermore, stock status was judged based on stock density indices which show the total of males and females in Area A since 1970 taken from the Japanese logbook of the offshore trawlers (Appendix 6).

(2) Trends in Abundance Indices

The total stock density index (kg/net) of males and females in Area A reached a high of 116 in 1970, then declined significantly up to 1974. This declining trend continued, reaching values low as 10 to 13 between 1985 and 1992. It started to rise from 1993, and reached 59 in 2006, followed by a slow decline, reaching 42 in 2020 (Fig. 4-1, Table 4-1, Appendix 6).

(3) Instar Composition in Catches

Catch in number by instar for all of Area A was estimated based on the catch in number of males by instar and by soft shell/hard shell status at major ports in Tottori, Hyogo, and Kyoto prefectures, and catch in weight for each prefecture in Area A (Fig. 4-2, Supplementary Table 2-2). This fiscal year, Hyogo updated CSC (commercial size category) keys for males in 2010 and later, but these updates mostly apply to the hard shell categories, and have little impact on stock assessment (Appendix 7).

Catch in number of 13th instar hard shells has shown a declining trend since 2008, but started to rise again in 2019. Meanwhile, catch in number of 12th instar hard shells peaked in 2013 followed by decline, and levels in 2020 were the lowest since 2004. Catch in number of soft shells has been declining primarily due to stricter voluntary regulations, and has been less than 1/3 of peak levels since 2013. Specifically, the strengthening of voluntary regulations in 2018 and 2019 caused a significant decrease in catch in number of soft shells compared to 2017 and earlier.

(4) Carapace Width Composition Estimated From Trawl Surveys

Carapace width composition estimated based on trawl survey results using the swept-area method is shown in Fig. 4-3 and 4-4. There are multiple modes for carapace width composition in each year, and each mode is considered to correspond to an instar group. A novel gear has been used since 2015 trawl surveys, so capture efficiency for the 10th instar and younger was corrected from 2017 based on results of comparative surveys on capture efficiency in old and new gears (Appendix 4).

Trawl surveys are conducted in May and June, and the fishing season starts in November (Fig. 2-3). Because crabs molt once per year after they reach the 7th instar, individuals that were pre-terminal molt during the 2021 survey period will have molted a maximum of 1 time before the 2021 fishing season, and a maximum of 2 times before the 2022 fishing season.

Results of surveys in 2021 showed a low standing stock population of hard shells for the 2021 fishing season, specifically fishable 13th instar males (typical carapace width of 120 mm or more) and 12th instar males with large claws (typical carapace width of 94 mm or more). Likewise, the population of 11th instar females that will become fishable in the 2021 fishing season was also low, similar to 2020. Meanwhile, there was a higher number of both males and females in the 9th and 10th instars. Females in the 10th instar during the 2021 survey period will become kuroko (catch targets) by the 2022 fishing season, so catch in weight of females is expected to increase from 2022 (Supplementary

Table 2-1).

(5) Trends in Stock Abundance and Fishing Pressure

Stock abundance at the beginning of the fishing season was calculated from the results of cohort analysis which used standing stock population by year and by instar during the trawl survey period (Appendix 2). Stock abundance at the beginning of the fishing season (Fig. 4-5, Supplementary Table 2-6) was 13,000 tons in 2002, then increased to over 30,000 tons in 2007. Subsequently it declined from 2008, and was slightly more than 17,000 tons in 2015. Stock abundance increased again from 2016 to 2018, but has since declined, and was 14,000 tons in 2021. However, stock abundance is expected to recover slightly to reach 15,000 tons in 2022.

SSB followed a similar pattern to stock abundance, and showed increase from 2002 to 2007, followed by decline until 2015 (Fig. 4-6, Supplementary Table 2-5). It increased in 2016 and 2017, but then fell to 3,385 tons in 2020, and it is expected to be 2,941 tons after the 2021 fishing season. Note that SSB is the stock abundance of females just after the fishing season.

The exploitation rate and fishing coefficient (F) were calculated based on stock abundance at the beginning of the fishing season and catch in weight for each fishing season (Fig. 4-7, Supplementary Table 2-4, 2-5). Hard shells showed the highest exploitation rates and F values, while the levels for soft shells were much lower. In 2020, the exploitation rate (F value) was 2% (0.02) for soft shells, 29% (0.34) for hard shells, 10% (0.11) for all males, 19% (0.21) for females, and 12% (0.13) for all males and females. Both exploitation rate and F value increased for hard shells after stock started to decline in 2008, but recently the levels have started to drop following a peak in 2016. Meanwhile, trends for females were flat since 2008, followed by decline after 2016. Fishing pressure and exploitation rate of soft shells have shown trends of long-term decline, and levels were as low in 2020 as 2019.

Item	Value	Description
SB2020	3.4 thousand tons	SSB in 2020 fishing season
F2020	(Soft shell, hard shell, female) = (0.02, 0.34, 0.21)	
U2020	12.0%	Exploitation rate of all males and females in the 2020 fishing season

(6) Forecasting Future Recruitment

Recruitment in number in 2022 and after was calculated using the results of 2021 trawl surveys and standing stock by instar estimated based on cohort analysis. The forecast value for the standing stock population of 11th instar males, which was calculated using the transition rate of 10th instar male individuals in 2021, and the standing stock population of 10th instar females in 2021, were used for recruitment in number for 2022. Recruitment in number for 2023 was forecasted using the transition rate for the standing stock population of 9th instar individuals in 2021 (Appendix 2). Recruitment in number for 2024 was forecasted based on the standing stock population of 8th instar individuals (not included in cohort analysis) from 2021 trawl surveys (Appendix 2). The method for forecasting recruitment based on the 8th instar standing stock population was changed this year from through-the-origin regression to nonlinear regression.

The standing stock population of immature 11th instar males in 2021 was 14 million, a decrease from 2020. We expect the population to increase to 17 million in 2022, 25 million in 2023, and 28 million in 2024 (Fig. 4-8, Supplementary Table 2-3).

The standing stock population of 10th instar females in 2021 was 16 million, an increase from 2020. We expect the population to increase to 25 million in 2022, and 26 million in 2023 (Fig. 4-8, Supplementary Table 2-5).

Long-term stock fluctuations in this area show that stock decreases to low levels during the cold season, and increases during the warm season (Kinoshita 2009). The results of particle tracking model simulations show that the rate of return to the hatchery by snow crab larvae and yearly changes in recruitment in number are generally consistent, which infers that changes in recruitment are significantly impacted by flow conditions during the drifting larvae stages (Honda et al. 2015).

(7) Yield Per Recruit (YPR), Spawning Per Recruit (SPR), and Current Fishing Pressure

In order to compare the fishing pressures with consideration for selectivity for each category, we compared several models against a scenario without fishing pressure assuming standard spawning per recruit (SPR). Calculations were performed using an instar composition model (Appendix 2) that considers by-catch mortality up to recruitment. We started our stock calculations from individuals in the 8th instar during the trawl survey period in order to consider the influence of by-catch mortality, in addition to using a deterministic natural mortality coefficient (0.2 for hard shells and 11th instar females, 0.35 for other categories, Yamasaki 1996) instead of the transition rate for stock calculations in this area (coefficient which includes the impact of different capture efficiencies of trawl nets for instar a and (a+1) in addition to the survival rate, Appendix 2). In this case, biological lifespan is not considered.

Fig. 4-9 shows changes in the SPR ratio (%SPR), which compares SPR in a scenario without fishing pressure against SPR in a scenario with fishing for each year. Lower fishing pressure means higher %SPR levels. After %SPR reached its maximum level in 2002, it showed a trend of decline, and reached 36% in 2020. Calculations showed that %SPR was 34% using the average F value of the 3 previous years (2018 to 2020) for the current fishing pressure. The relationship between current fishing pressure and YPR and %SPR is shown in Fig. 4-10. Fmsy is equivalent to 16% when converted to %SPR. Current fishing pressure (F2018-2020) is nearly F0.1 for females, and below F30%SPR and Fmax for both sexes.

Item	Value	Description
%SPR (F2020)	36%	%SPR in 2020 fishing season
%SPR (F2018-2020)	34%	%SPR corresponding to current fishing pressure (2018 to 2020 fishing seasons)

(8) Stock-Recruitment Relationship

The relationship (stock-recruitment relationship) between SSB (in weight) and recruitment (individuals) is shown in Figure 4-11. In this figure, SSB is the stock abundance of females after the 1999 to 2014 fishing seasons end, and recruitment is the standing stock population of 10th instar individuals during the survey period 7 years later (2006 to 2021). The Research Agency Forum on Reference Points applied a Ricker model for stock-recruitment relationships to the stock-recruitment relationship model of this stock (Ueda et al. 2020a). The data used to estimate the parameters of the stock-recruitment relationship model was SSB and recruitment based on stock assessments for the 2019 fiscal year (Ueda et al. 2020b), and the optimization method was the minimum absolute value method. In addition, autocorrelation was not considered regarding residuals in recruitment. Each parameter of the stock-recruitment relationship model is shown in the table below:

Stock-recruitment relationship model	Optimization method	Autocorrelation	a	b	S.D.	ρ
Ricker model	Minimum absolute value method	No	22.2	3.68e-4	0.182	-

(9) Levels and Reference Points Required for MSY Under Current Environmental Conditions

The above-mentioned Research Agency Forum on Reference Points estimated MSY to be 3,700 tons under current conditions (2019 fishing season and later). In April 2020, the Stock Management Policy Commission and the Fishery Policy Council set target reference points for the SSB required for this MSY (SBmsy: 3,000 tons) as stock management targets. In addition, the historical low for SSB (1,500 tons) was set as the limit reference point, and the SSB required for 10% of MSY catch in weight was set as the fishing ban level. Fishing pressure required for MSY (Fmsy) and numerical values are shown in the table below:

Item	Value	Description
SBtarget	3.0 thousand tons	A target reference point. SSB required for MSY (SBmsy).
SBlimit	1.5 thousand tons	A limit reference point. Historic minimum SSB (SBmin)
SBban	0.1 thousand tons	Level for fishing ban. SSB required for 10% of MSY catch in weight (SB0.1msy).
Fmsy	Fishing pressure required for MSY (fishing coefficient F) (Female) = (0.46)	
%SPR (Fmsy)	16%	%SPR corresponding to Fmsy
MSY	3.7 thousand tons	Maximum Sustainable Yield

(10) Stock Levels/Trends and Fishing Pressure Levels

SSB and fishing pressure required for MSY are shown in a Kobe plot (Fig. 4-12). SSB of this stock in the 2020 fishing season exceeded the SSB required for MSY (SBmsy), specifically, SSB in the 2020 fishing season was 1.13 times the value of SBmsy. In addition, the fishing pressure in the 2020 fishing season was lower than the fishing pressure required for MSY (Fmsy), specifically, it was 0.44 times the value of Fmsy. The fishing pressure ratio (F/Fmsy) shown in the Kobe plot is the ratio of Fmsy (F of females) to F values of females in each year. Based on trends seen in the previous 5 years (2016 to 2020 fishing seasons), the SSB is judged to be in a “declining” trend. The fishing pressure of this stock has been lower than Fmsy since 2004. SSB was lower than SBmsy from 1999 to 2003, and has generally been higher than SBmsy since 2004 despite fluctuation.

Item	Value	Description
SB2020 / SBmsy (SBtarget)	1.13	Ratio of SSB required for MSY (target reference points) to SSB in 2020 fishing season
F2020 / Fmsy	0.47	Ratio of fishing pressure required for MSY to fishing pressure in 2020 fishing season*

*Ratio calculated based on %SPR converted F, which reflects Fmsy fishing pressure at the selection probability of the 2020 fishing season

Level of SSB	Over the level required for MSY
Level of fishing pressure	Under the level required for MSY
Changes in SSB	Decrease

5. Future Forecast

(1) Setting Future Forecasts

Future forecast calculations were performed for the 2021 to 2030 fishing seasons using a progression method for cohort analysis applied to stock abundance in the 2020 fishing season estimated in stock assessment reports (Appendix 2). The standing stock population of males and females in the 10th instar during the survey period was used for recruitment in future forecasts. Recruitment in 2022 was forecasted using the transition rate of 9th instar individuals based on the results of 2021 trawl surveys (Appendix 2). Recruitment for 2023 was forecasted based on the standing stock population of 8th instar individuals (not included in cohort analysis) from 2021 trawl surveys (Appendix 2). Recruitment in 2024 and later was predicted by applying the stock-recruitment relationship model to the standing stock population of individuals in the 10th instar as predicted from the SSB of 7 years prior (2017 and later). Calculations were repeated 10,000 times assuming errors which follow log-normal distribution to account for uncertainty in recruitment. Catch in weight in the 2021 fishing season was assumed based on forecasted stock abundance and current fishing pressure (F2018-2020). Fishing pressure in 2022 and after was determined using Harvest Control Rules from the catch strategies compiled by the Stock Management Policy Commission and set by the Fishery Policy Council. Catch in weight was calculated using fishing pressure set in Harvest Control Rules based on forecasts for SSB after each fishing season, and forecasts for stock abundance in each fishing year. Note that SSB in this stock is the stock abundance of females after the fishing season ends, and fishing rules for each year are determined according to the SSB of the previous year.

(2) Harvest Control Rules

Harvest Control Rules are rules that reduce fishing pressure in a linear manner down to the fishing ban level, when SSB falls below the limit reference point, in order to conserve and manage SSB at levels higher than target reference points (Fig. 5-1). When SSB is higher than the limit reference point, then fishing pressure is calculated by multiplying Fmsy by the adjustment coefficient β.

(3) Forecasts and ABC Calculation for the 2022 Fishing Season

The catch strategies compiled by the Stock Management Policy Commission and set by the Fishery Policy Council for this stock are based on the premise that there is a 50% or higher probability that SSB in the 2030 fishing season will be higher than target reference points. Catch in weight is 3,000 tons in 2021, and a Harvest Control Rule of β = 0.8 will be used for 2022 and after. The forecasted catch in weight in the 2022 fishing season was calculated to be 2,800 tons based on the Harvest Control Rule, and this will also be the ABC for this stock. Forecasted SSB in the 2022 fishing year is expected to be an average of 2,900 tons, which exceeds the limit reference point in all our repeated calculations.

ABC for the 2022 fishing season (thousand tons)	SSB in 2022 fishing season Forecasted average (thousand tons)	Ratio to current fishing pressure (F/F2018-2020)	Exploitation rate in 2022 fishing season (%)
2.8	2.9	1.60	18

Comments:

・ABC is calculated according to the Harvest Control Rules from catch strategies compiled by the Stock Management Policy Commission and set by the Fishery Policy Council in March 2021.

・Recruitment was below average in the 2021 fishing season, but levels for both males and females are expected to increase from the 2022 fishing season.

・The exploitation rate is the value for the entire stock.

(4) Forecast for the 2023 Fishing Season and After

The results of future forecasts, including those for 2023 and after, are shown in Figure 5-2, Table 5-1, and 5-2. If management based on this Harvest Control Rule is continued for 10 years, then the forecasted value of SSB for the 2030 fishing season will be 3,500 tons (80% confidence interval of 2,800 to 4,400 tons), and there is an 80% probability that the forecast value will exceed the target reference point, and a 100% probability that it will exceed the limit reference point.

We also included the results of future forecasts for a scenario with a different β, and for a scenario that continues current fishing pressure (F2018-2020). The forecasted value of SSB for the 2030 fishing season will be an average of 4,300 tons if β = 0.6 (80% confidence interval of 3,400 to 5,300 tons), and an average of 5,200 tons if β = 0.4 (80% confidence interval of 4,200 to 6,400 tons), and the probability that it will exceed the target reference point is 98% and 100%, respectively. The forecasted value of SSB if the current fishing pressure is continued is 4,700 tons (80% confidence interval of 3,800 to 5,800 tons), and the probability that it will exceed the target reference point is 100%.

Uncertainty under consideration: Recruitment					
Item	SSB in the 2030 fishing season (thousand tons)	80% Confidence interval (thousand tons)	Probability (%) that SSB will exceed the reference points below in the 2030 fishing season		
			SBtarget	SBlimit	SBban
β used in Harvest Control Rule					
β = 0.8	3.5	2.8 – 4.4	80	100	100
Other measures (if β is different from the Harvest Control Rule)					
β = 1.0	2.9	2.3 – 3.6	38	100	100
β = 0.6	4.3	3.4 – 5.3	98	100	100
β = 0.4	5.2	4.2 – 6.4	100	100	100
β = 0.2	6.4	5.1 – 7.7	100	100	100
β = 0	7.7	6.3 – 9.3	100	100	100
F2018-2020	4.7	3.8 – 5.8	100	100	100

6. Summary of Stock Assessment

The stock density index (kg/net) of offshore bottom trawl fisheries, which serves as a long-term abundance index for this area, reached a high of 100 or more in the 1960s to the beginning of the 1970s, followed by decline, a fell to a record low of 10 in 1991. Afterwards, it started to rise, then return to a slow decline since the mid-2000s, and was 42 in 2020.

Stock abundance since 1999, estimated by cohort analysis based on trawl survey results, showed increase from 2003 to 2007, followed by decline from 2008 to 2015. It increased again after 2016, then started to decline from 2019 to 2021. SSB has shown similar trends to stock abundance, and the SSB is judged to be in a “declining” trend. SSB in 2020 was higher than SBmsy, and fishing pressure in 2020 was lower than Fmsy.

7. Additional Comments

(1) Conservation of Stock Through Ministry Ordinances and Voluntary Regulations

The Ministry of Agriculture, Forestry and Fisheries has established rules regarding snow crabs, including fishing season and carapace width restrictions, in addition to fishing bans for immature females and all operations around the Yamato Ridge. Area A also has voluntary initiatives enforced by fishermen for regulating fishing seasons and size which are stricter than the Ministry ordinances (Table 3-1). Furthermore, there are also maximum catch in weight rules per cruise for soft shells which have a low price and generally don’t contribute to reproduction, and for females which are fished intensively immediately after the season starts (Table 3-2).

In order to protect spawning and nursery grounds of snow crabs, artificial nursery reefs composed of concrete blocks have been installed in a wide range across Area A by local prefectures and the

Japanese government (Yamasaki 2002, Moriyama 2011, Miura et al. 2014). In addition, the majority of trawl operations are avoided at depths of 200 m to 350 m in Area A between the start of bottom trawling season (September) and the start of snow crab season (November 6) because it overlaps with the snow crab molting period (Ueda et al. 2014).

Continued compliance with the regulatory measures is essential for sustainable exploitation of this stock in the future.

(2) Reduction of By-catch Mortality

A significant number of non-landing target individuals are assumed to die after catch and release during compliance with the regulations discussed above (Yamasaki et al. 2011, Yamasaki and Miyajima 2013).

Trawlers in Ishikawa, Fukui, and Kyoto which target fish like flathead flounder outside of snow crab season have introduced improved bottom-trawl nets to reduce by-catch mortality of snow crabs. These improved nets have structures that separate flathead flounders which can swim, from snow crabs which can't swim, before the catch reaches the cod end of the bottom-trawl net. Tottori and Hyogo have also already introduced these nets to their bottom-trawl vessels, and research is in progress to design even more efficient fishing nets. Thorough implementation of these improved nets and reduction of by-catch mortality is essential to improve the survival rate of soft shells and small individuals.

In Area A, catch in weight and fishing effort for snow crabs are both highest immediately after the fishing season begins in November, then declines from December. Meanwhile, the survival rate for soft shells after catch and release is low in November, but higher in December and later (Yamasaki et al. 2011), and November also has a high soft shell by-catch mortality rate (Ueda et al. 2016). We advise revising the fishing season and reconsider operational methods in order to reduce by-catch mortality, starting with the conditions in November.

(3) Catch Status by South Korea

South Korea also catches this stock in the Sea of Japan, but only males are catch targets. Catch in weight in South Korea (calendar years) increased rapidly from the late 1990s, reaching 4,800 tons in 2007, but then declined to 1,300 tons in 2019 (Fig. 7-1, Supplementary Table 5-1). These numbers are thought to include catches by illegal operations (website of Sakaiminato Fisheries Coordination Office, Fisheries Agency) within Japan's EEZ (outside of provisional waters), in addition to operations on the East coast of South Korea and in provisional waters between Japan and Korea.

Trawl surveys for this evaluation caught very few male crabs that met South Korean standards for fishable size (carapace width of 90 mm or more) during the surveys in provisional waters between Japan and Korea, which suggests that the stock status of male crabs in this area is seriously poor.

It is therefore necessary to hold constructive talks between the two countries based on the Japan–Korea Fisheries Agreement to develop appropriate stock management measures for areas like the provisional waters between Japan and Korea.

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Fig. 2-1. Distribution of Sea of Japan Area A stock of snow crab

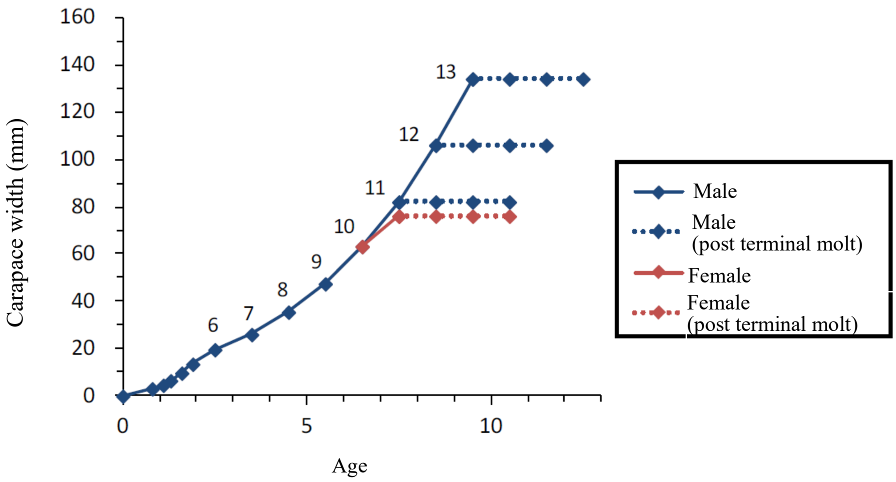


Fig. 2-2. Relationship between age, molt-age, and carapace width of snow crabs

Numbers indicate molt-age. The two sexes are the same until the 10th instar.

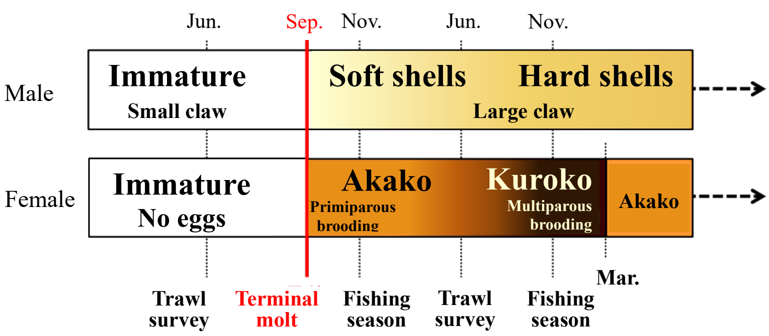


Fig. 2-3. Diagram of snow crab life history and catch categories

・Soft shell: Males that molted within the past year.

・Hard shells: Males that completed their terminal molt more than 1 year prior.

・Akako: Females carrying orange-colored eggs on their abdomen.

・Kuroko: Females carrying brownish to blackish-purple eggs.

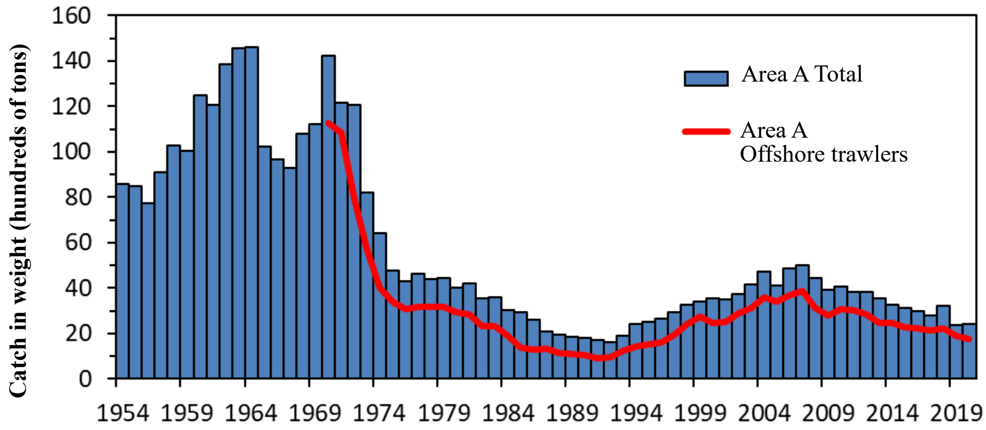


Fig. 3-1. Catch in weight (calendar year) and catch in weight of offshore bottom-trawl fisheries (fishing year)

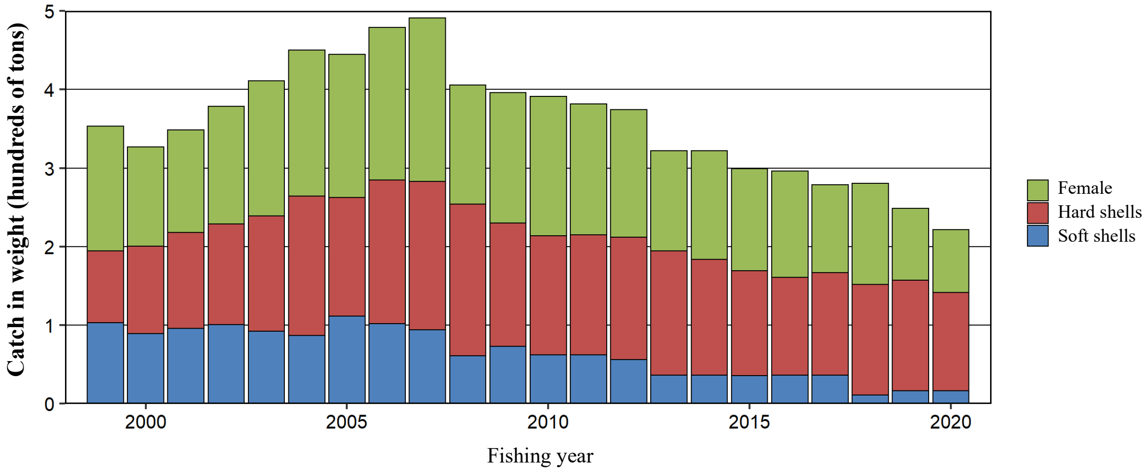


Fig. 3-2. Catch in weight by sex (Males: soft shell/hard shell) (fishing year)

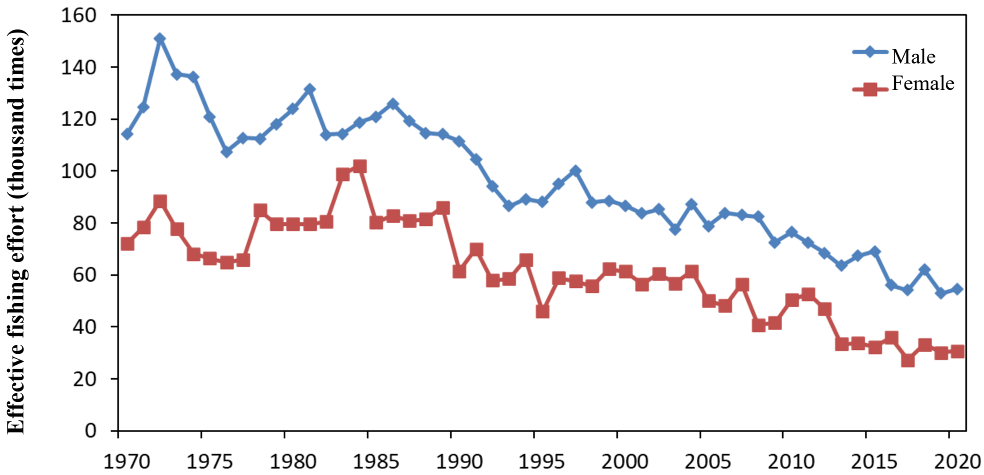


Fig. 3-3. Effective fishing effort of offshore bottom-trawl nets

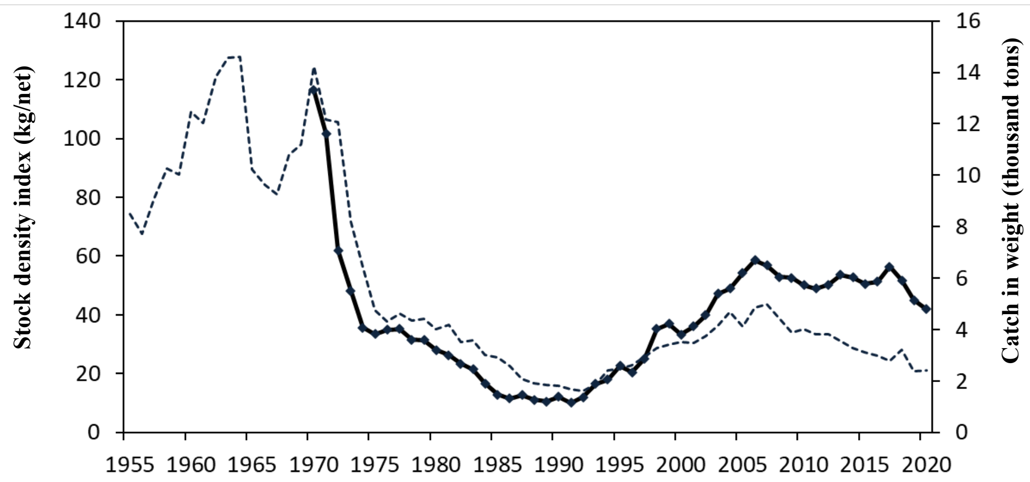


Fig. 4-1. Stock density index based on Offshore Trawl Reports (kg/net, total of males and females in Area A)The dashed line indicates catch in weight, and the solid line indicates the stock density index.

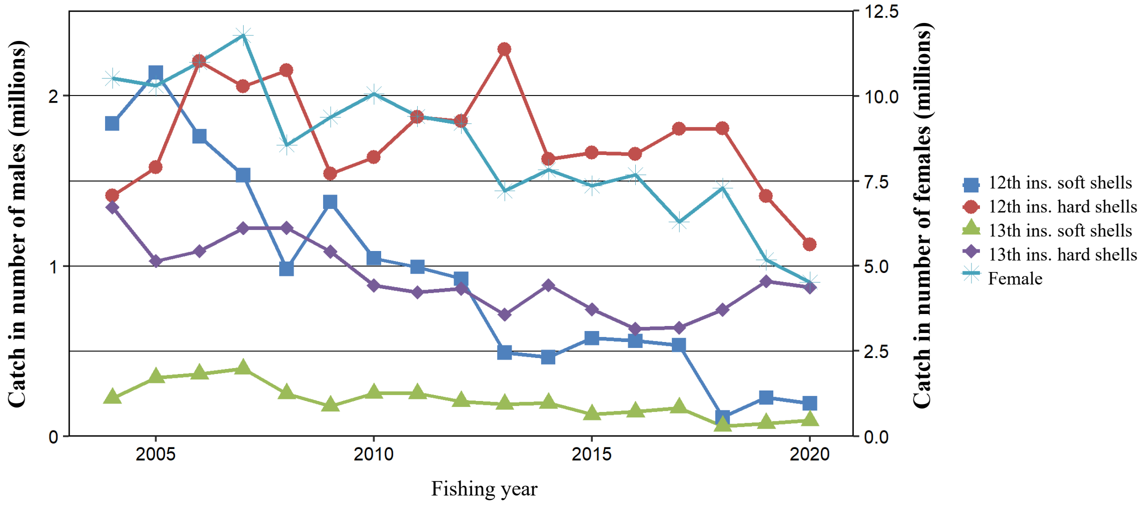


Fig. 4-2. Catch in number by category in this area

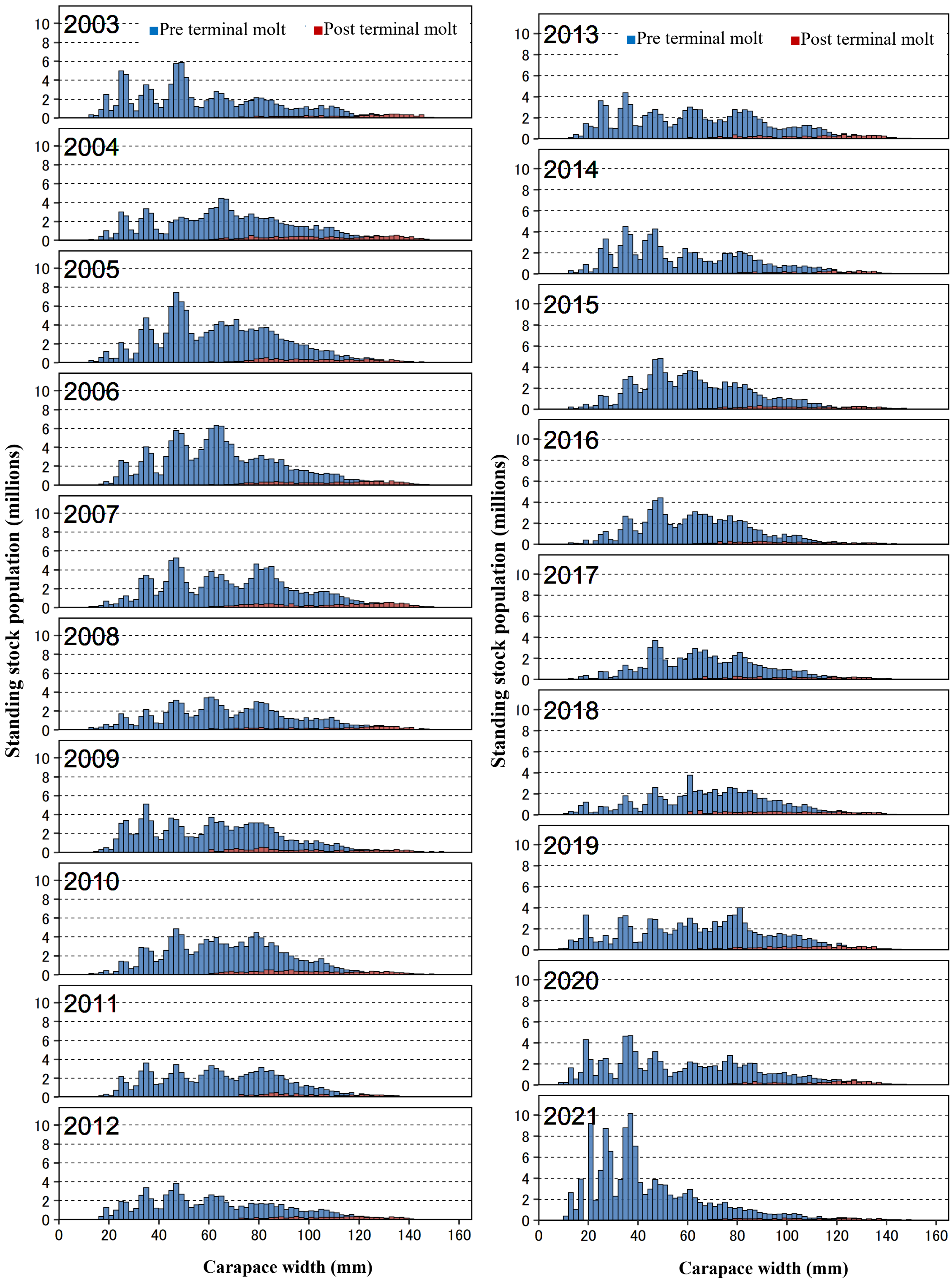


Fig. 4-3. Carapace width composition of males estimated by trawl surveys

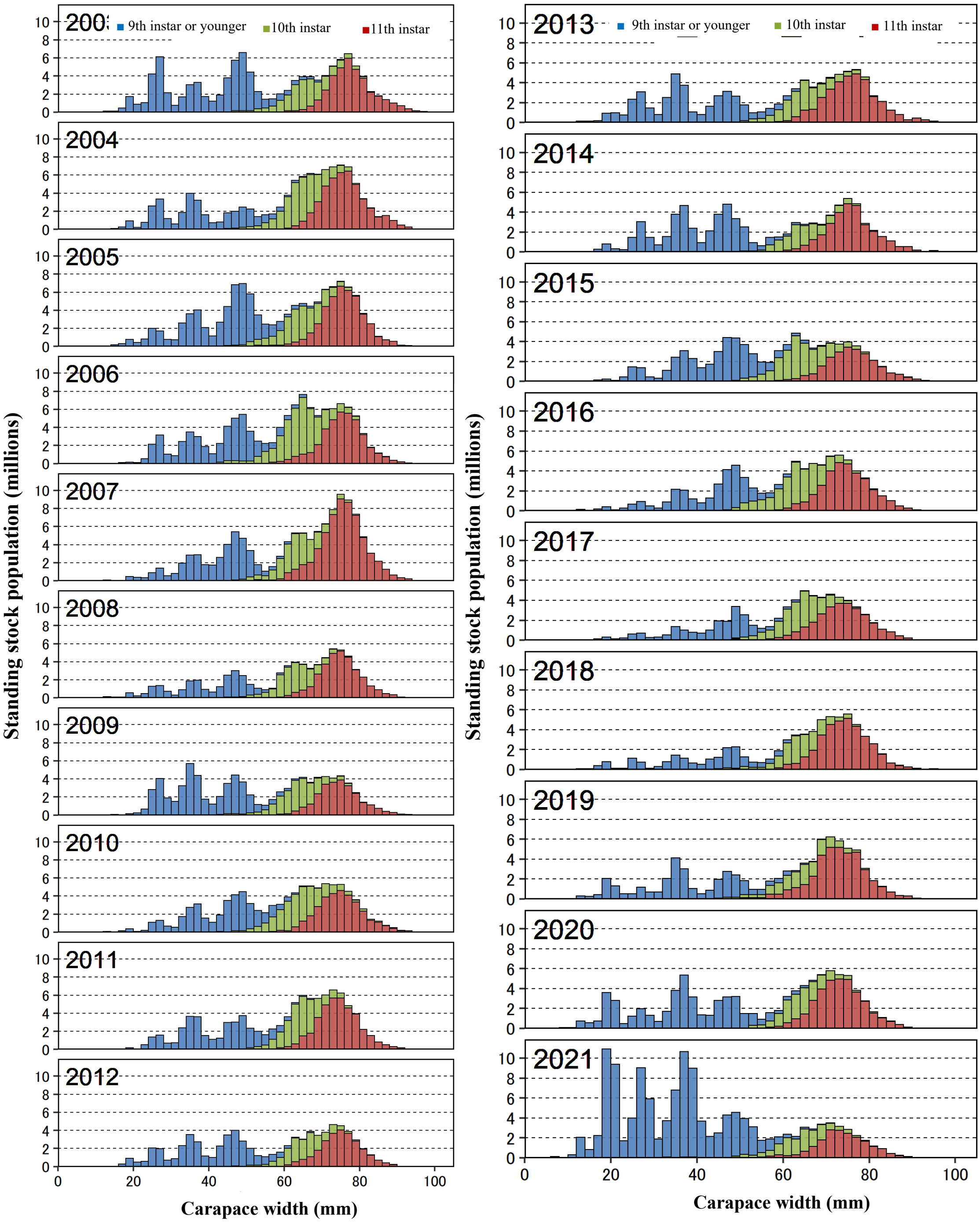


Fig. 4-4. Carapace width composition of males estimated from trawl surveys

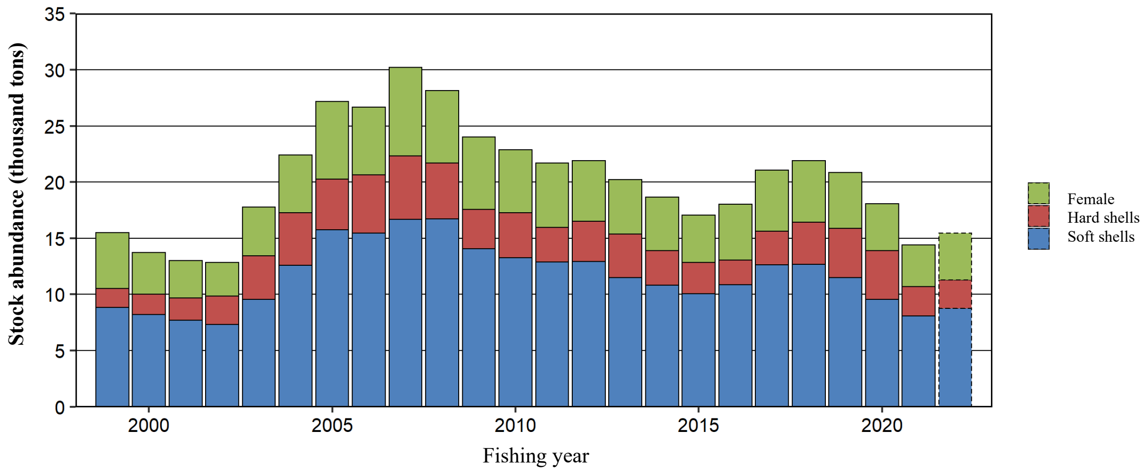


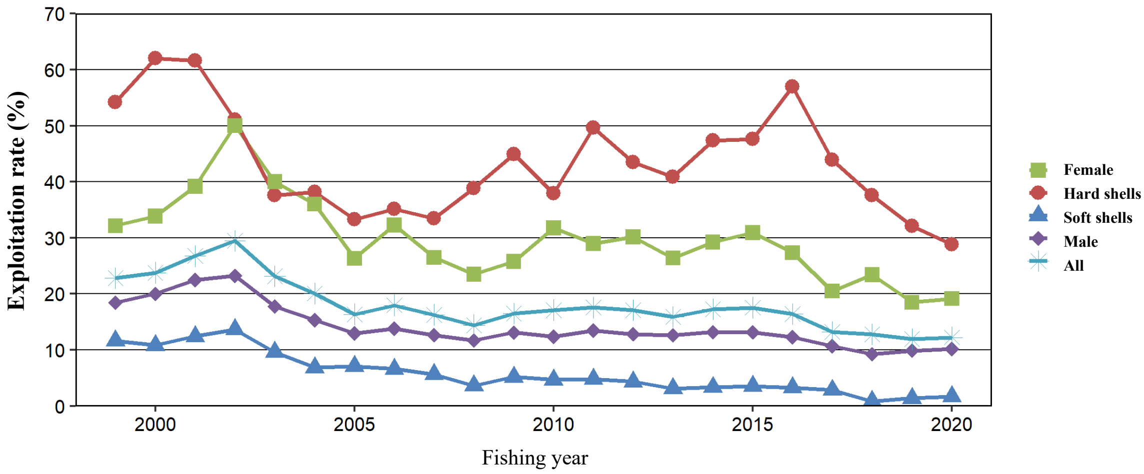
Fig. 4-5. Stock abundance at the beginning of the fishing season estimated by cohort analysis based on trawl survey results

This chart shows the total of 12th and 13th instar individuals for soft shells and hard shells, and 11th instar females.

The values for 2022 are forecast values based on the stock population by instar for individuals in the 10th instar and higher in 2021.

Fig. 4-6. SSB of females

The SSB of this stock is the stock abundance of females after the fishing season ends.



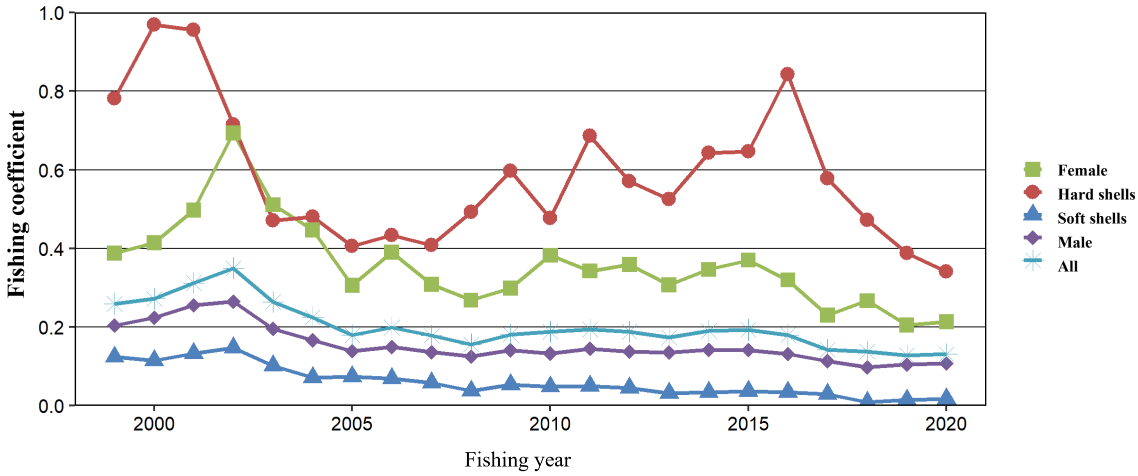


Fig. 4-7. Exploitation rate (top figure) and fishing coefficient (F) (bottom figure)

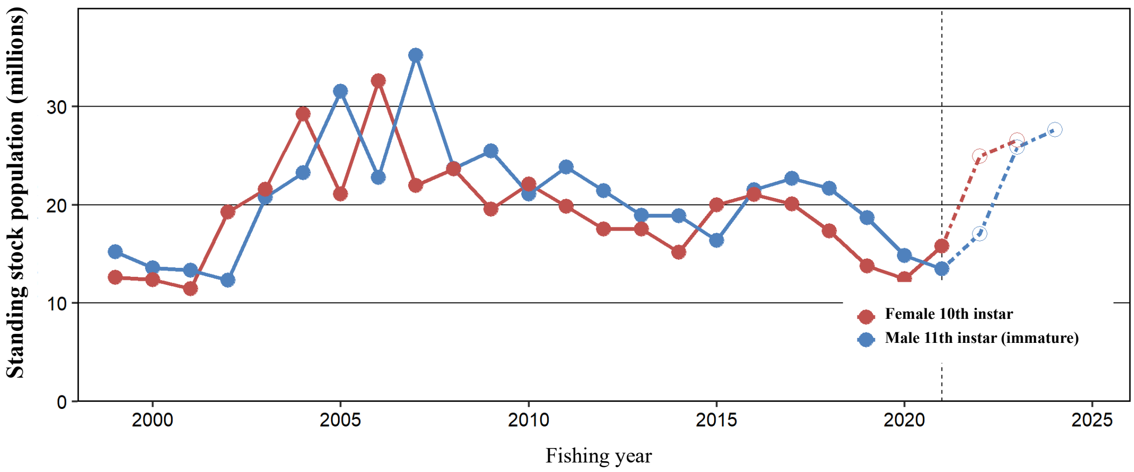


Fig. 4-8. Standing stock populations of 11th instar males for recruitment in the 2021 fishing season, and 10th instar females for recruitment in the 2022 fishing season The dotted lines indicate forecast values used for future forecasts, which are based on the standing stock population of 8th and 9th instar individuals in the 2021 fishing season. However, it is impossible to determine which 11th instar females individuals observed in trawl surveys (May and June) would advance

to stock recruitment in the 2021 fishing season, and which individuals were already recruited in the 2020 fishing season or before, so the stock recruitment in number for females in the 2021 fishing season is unknown.

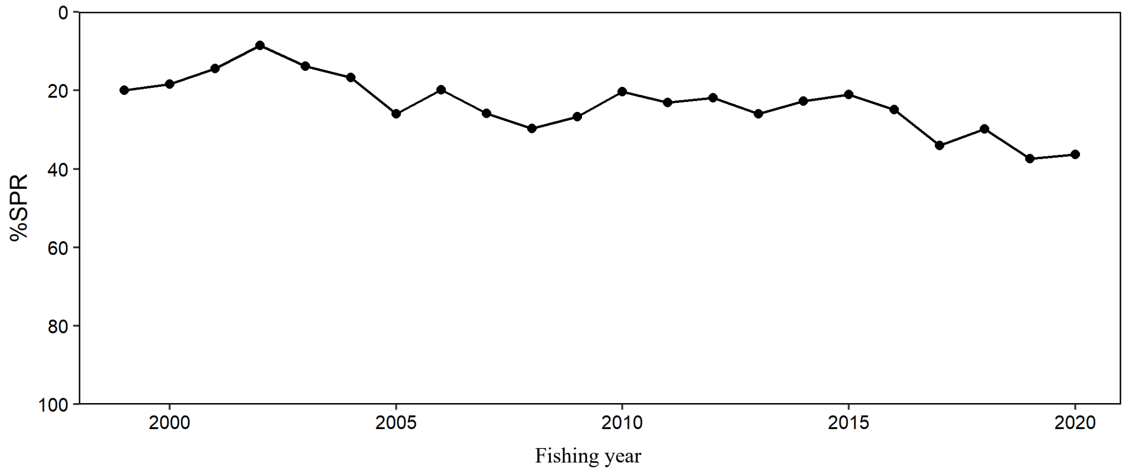


Fig. 4-9. Changes in SPR ratio (%SPR),

which compares SPR in a scenario without fishing pressure against SPR in a scenario with fishing for each year

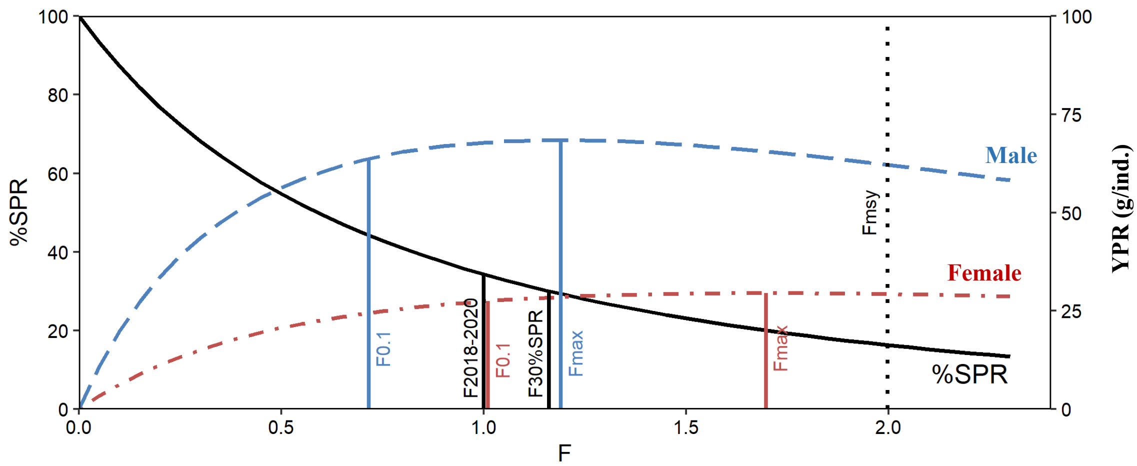


Fig. 4-10. Relationship between current fishing pressure (F2018-2020) and YPR and %SPR

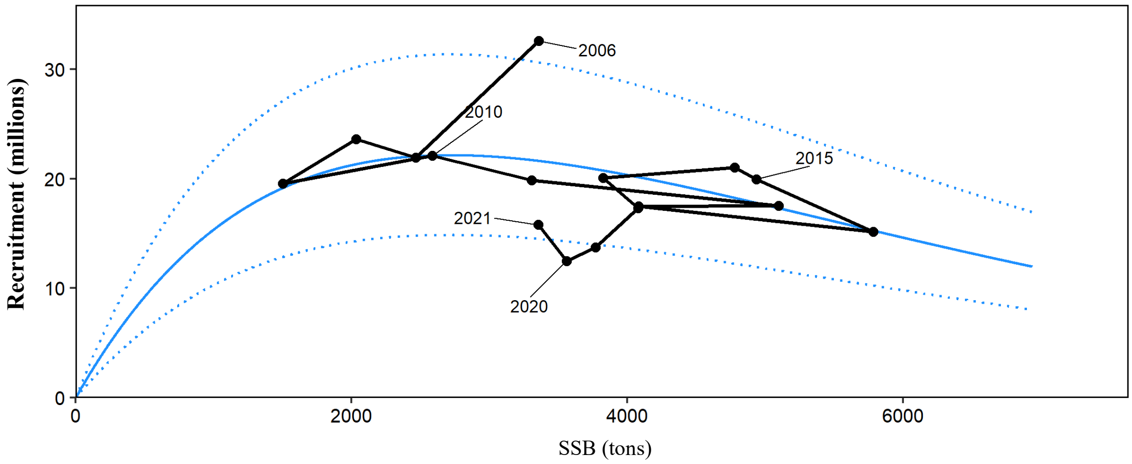
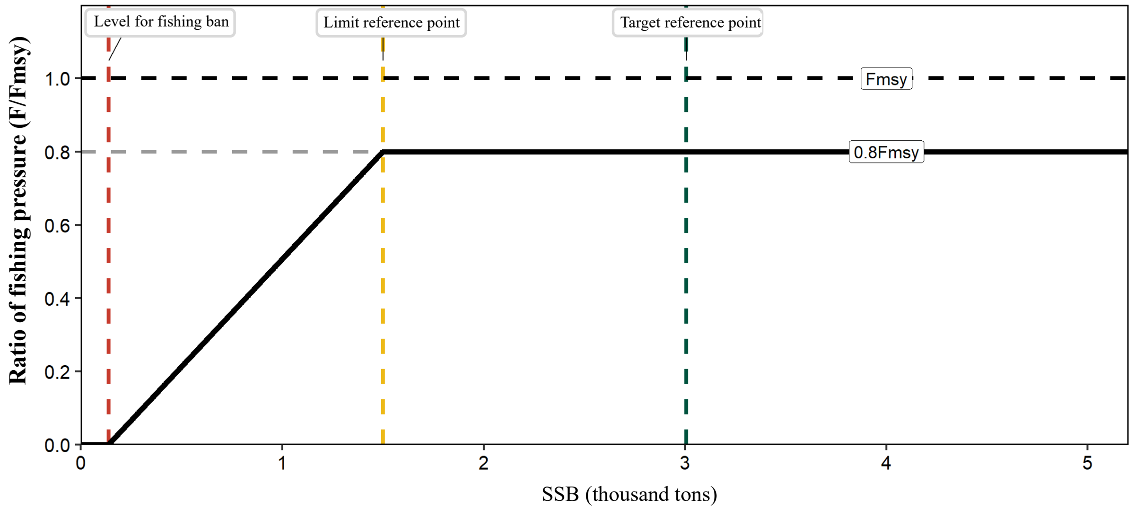


Fig. 4-11. Relationship between SSB and recruitment (stock-recruitment relationship)
This stock-recruitment relationship model was proposed at the Research Agency Forum on Reference Points held in April 2020 (Ueda et al. 2020). The blue solid and dashed lines indicate the median values of the approved Ricker model for stock-recruitment, and the range estimated to contain 90% of observed data. Black dots indicate observed values of SSB and recruitment. The numbers in the figure indicate the year of recruitment. The period until recruitment (10th instar) is assumed to be 7 years in this area, so SSB from 1999 to 2014 corresponds to recruitment in 2006 to 2021.

Fig. 4-12. Relationship of SSB required for MSY (SBmsy) and fishing pressure required for MSY (Fmsy) against previous levels of SSB and fishing pressure (Kobe plot)

(a) When the vertical axis is fishing pressure



(b) When the vertical axis is catch in weight

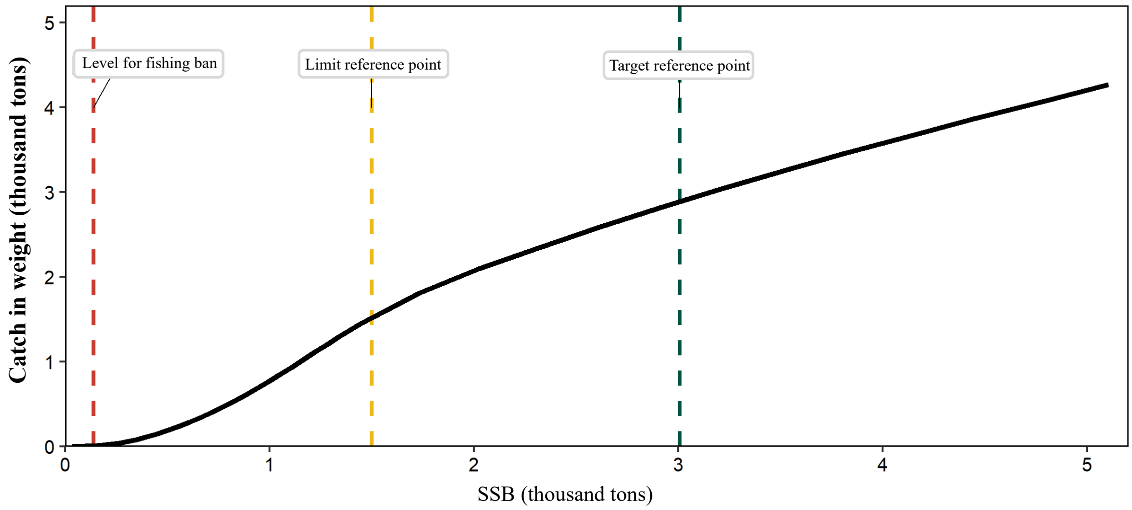


Fig. 5-1. Harvest Control Rule (β = 0.8) The solid black line indicates the Harvest Control Rule, the dashed black line is Fmsy, the dashed grey line is 0.8Fmsy, the red dashed line is the fishing ban level, the yellow dashed line is the limit reference point, and the green dashed line is the target reference point. Graph (a) is the scenario when the vertical axis shows fishing pressure, and graph (b) is the scenario when the vertical axis shows catch in weight.

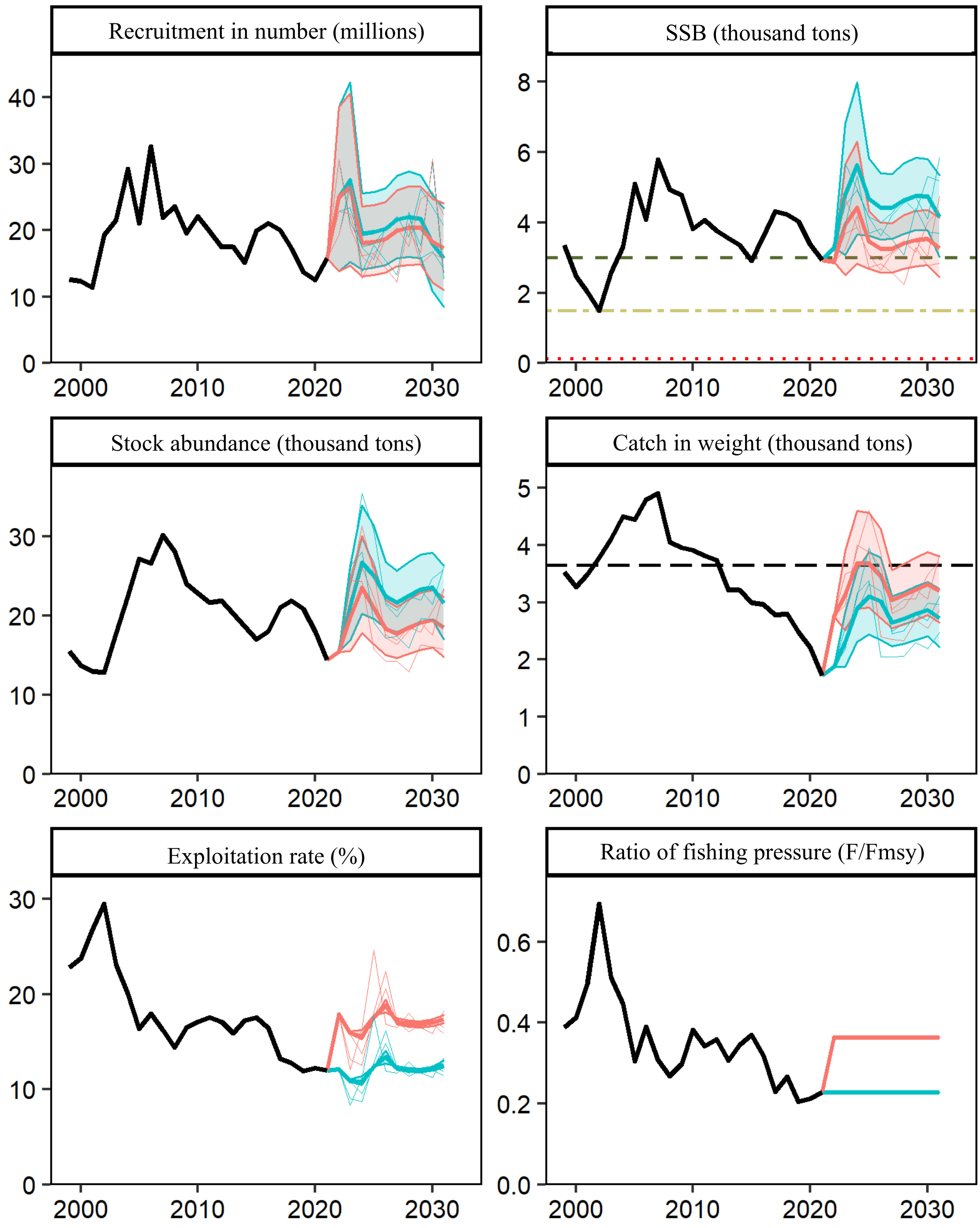


Fig. 5-2. Future forecasts using Harvest Control Rules based on reference points set in the catch strategy (red), and future forecasts in a scenario that continues current fishing pressure (blue) The solid line indicates average values, the shaded area indicates the prediction interval which contains 90% of simulation results, and the thin lines indicate 3 future forecasts. In the SSB graph, the green dashed line is the target reference point, the yellow long dashed dotted line is the limit reference point, and the red dotted line is the fishing ban level. Catch in weight for

2021 was assumed based on estimated stock abundance and F2018-2020. An adjustment coefficient of β = 0.8 was used.

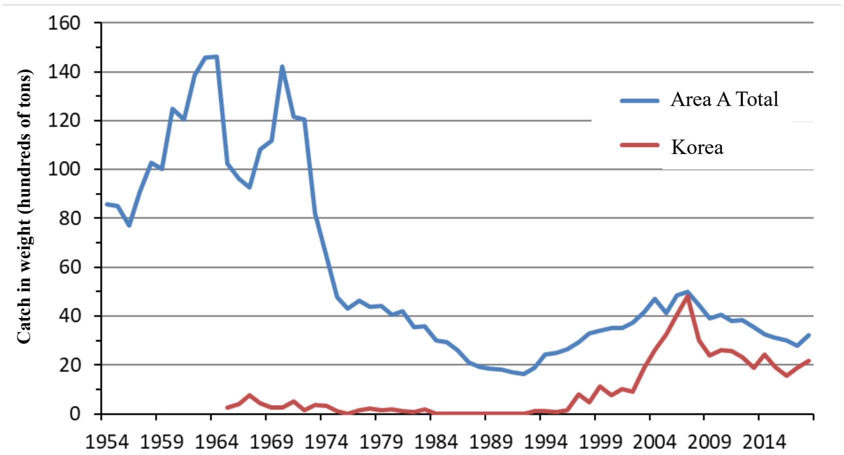


Fig. 7-1. Catch in weight (calendar year total) of Japan (Area A) and South Korea

Table 3-1. Fishing season and size regulations (2020)

			Fishing season		Catch regulations (size refers to carapace width)	
Male	Ministry ordinances		Nov. 6 - Mar. 20		90 mm or more	
			(Soft shells)	(Hard shells)	(Soft shells)	(Hard shells)
	Voluntary regulations	Tottori, Hyogo, Shimane	Feb. 1 - Feb. 28/29	Same as Ministry ordinances	105 mm or more	105 mm or more
		Kyoto	Fishing ban	Same as Ministry ordinances	Fishing ban	Same as Ministry ordinances
		Fukui	Feb. 19 - Mar. 20	Same as Ministry ordinances	100 mm or more	Same as Ministry ordinances
		Ishikawa	Fishing ban	Same as Ministry ordinances	Fishing ban	Same as Ministry ordinances
Female	Ministry ordinances		Nov. 6 - Jan. 20		Mature Crabs	
	Voluntary regulations	Tottori, Hyogo, Shimane Fukui, Kyoto, Ishikawa	Nov. 6 - Dec. 31		Kuroko, 70 mm or more	
Male and female	Voluntary regulations	Tottori, Hyogo, Shimane	Setting official holidays in November ・3 port stays of more than 32 hours, or ・4 port stays of more than 24 hours			

Table 3-2. Voluntary regulations for catch in weight per voyage for soft shells and kuroko in this area (2020)

Voyage time	Maximum catch in weight	
	Soft shells	Kuroko
Less than 24 hours	800 ind.	5,000 ind.
Less than 48 hours	1,600 ind.	8,000 ind.
More than 48 hours	2,300 ind.	16,000 ind.

Table 3-3. Effective fishing effort of offshore bottom-trawl net fishery (nets)

Fishing year	Male	Female
1970	114,223	72,019
1971	124,530	78,378
1972	151,020	88,650
1973	137,288	77,692
1974	136,372	68,184
1975	120,915	66,411
1976	107,409	64,848
1977	112,818	65,947
1978	112,376	84,993
1979	118,133	79,600
1980	123,839	79,598
1981	131,444	79,549
1982	114,006	80,548
1983	114,285	98,747
1984	118,754	102,112
1985	120,892	80,298
1986	126,009	82,864
1987	119,322	80,956
1988	114,592	81,444
1989	114,162	86,059
1990	111,532	61,609
1991	104,668	69,972
1992	94,306	57,888
1993	86,501	58,535
1994	89,255	65,978
1995	88,167	46,073
1996	95,009	58,844
1997	100,166	57,707
1998	87,936	55,779
1999	88,589	62,347
2000	86,732	61,424
2001	83,742	56,547
2002	85,305	60,481
2003	77,661	56,806
2004	87,392	61,586
2005	78,785	50,048
2006	83,846	48,201
2007	83,078	56,501
2008	82,508	40,827
2009	72,592	41,601
2010	76,453	50,431
2011	72,339	52,797
2012	68,488	46,983
2013	63,539	33,463
2014	67,386	33,808
2015	69,060	32,402
2016	56,136	35,913
2017	54,122	27,340
2018	61,979	33,382
2019	52,931	30,153
2020	54,617	30,795

Table 4-1. Stock density index of offshore bottom-trawl nets (kg/net)

	Male			Female			Male and female
Fishing year	All of Area A	Central	West	All of Area A	Central	West	Area A Total
1970	68	32	85	48	23	61	116
1971	62	26	78	40	17	49	102
1972	40	20	52	22	11	29	62
1973	33	14	42	16	8	20	48
1974	23	13	29	12	8	15	36
1975	21	16	23	12	11	13	34
1976	19	22	19	15	13	16	35
1977	18	15	20	17	12	20	35
1978	17	13	19	14	9	17	32
1979	18	12	21	14	8	16	31
1980	15	11	17	13	13	13	28
1981	14	14	14	13	11	13	26
1982	13	16	12	10	10	10	23
1983	11	12	11	10	10	10	22
1984	11	13	10	6	5	6	17
1985	8	12	6	5	6	5	13
1986	8	10	7	4	5	4	12
1987	8	12	6	5	7	4	13
1988	7	12	5	4	6	4	11
1989	6	10	5	4	4	5	11
1990	6	10	5	6	9	6	12
1991	6	10	4	4	5	4	10
1992	7	12	5	5	7	5	12
1993	9	17	5	8	11	6	17
1994	10	19	6	8	11	7	18
1995	12	21	8	11	16	9	23
1996	11	18	8	10	13	9	21
1997	12	15	11	13	10	15	25
1998	14	17	13	21	10	26	35
1999	16	15	17	21	11	25	37
2000	17	16	17	17	8	22	33
2001	17	19	17	19	13	22	36
2002	19	19	19	21	10	26	40
2003	22	17	24	26	12	32	47
2004	23	16	26	26	11	33	49
2005	24	20	26	30	15	36	54
2006	25	18	27	34	20	40	59
2007	26	20	28	31	19	36	57
2008	23	21	24	30	22	32	53
2009	20	20	20	32	14	40	53
2010	20	22	20	30	15	36	50
2011	22	21	23	27	12	33	49
2012	21	21	22	29	23	31	50
2013	22	19	23	32	26	33	54
2014	20	16	21	33	20	38	53
2015	18	16	18	33	36	32	51
2016	20	15	21	32	18	35	51
2017	22	17	24	35	17	40	56
2018	17	15	18	34	12	42	52
2019	20	15	22	25	8	30	45
2020	20	13	23	22	14	24	42

Table 5-1. Probability (%) that future SSB will exceed target reference point (a) or limit reference point (b)Future forecast results are shown for scenarios when β changes from 0 to 1.0. Catch in weight for 2021 is 1,700 tons, based on forecasts using current fishing pressure (F2018-2020), and catches in 2022 and after are based on the Harvest Control Rule.

Probability of exceeding the target reference point

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.0	100	0	0	60	70	35	22	22	31	36	38
0.9	100	0	0	68	79	56	41	41	52	58	61
0.8	100	0	0	75	86	75	64	64	74	78	80
0.7	100	0	100	81	91	89	84	84	89	92	93
0.6	100	0	100	87	95	96	95	95	97	98	98
0.5	100	0	100	92	98	99	99	99	100	100	100
0.4	100	0	100	95	99	100	100	100	100	100	100
0.3	100	0	100	97	99	100	100	100	100	100	100
0.2	100	0	100	99	100	100	100	100	100	100	100
0.1	100	0	100	100	100	100	100	100	100	100	100
0.0	100	0	100	100	100	100	100	100	100	100	100
Fcurrernt	100	0	100	92	98	99	99	99	100	100	100

Probability of exceeding the limit reference point

β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.0	100	100	100	100	100	100	100	100	100	100	100
0.9	100	100	100	100	100	100	100	100	100	100	100
0.8	100	100	100	100	100	100	100	100	100	100	100
0.7	100	100	100	100	100	100	100	100	100	100	100
0.6	100	100	100	100	100	100	100	100	100	100	100
0.5	100	100	100	100	100	100	100	100	100	100	100
0.4	100	100	100	100	100	100	100	100	100	100	100
0.3	100	100	100	100	100	100	100	100	100	100	100
0.2	100	100	100	100	100	100	100	100	100	100	100
0.1	100	100	100	100	100	100	100	100	100	100	100
0.0	100	100	100	100	100	100	100	100	100	100	100
Fcurrernt	100	100	100	100	100	100	100	100	100	100	100

Table 5-2. Trends in future SSB (a) and average catch in weight (b) (thousand tons)

Future forecast results are shown for scenarios when β changes from 0 to 1.0. Catch in weight for 2021 is 1,700 tons, based on forecasts using current fishing pressure (F2018-2020), and catches in 2022 and after are based on the Harvest Control Rule.

Average SSB

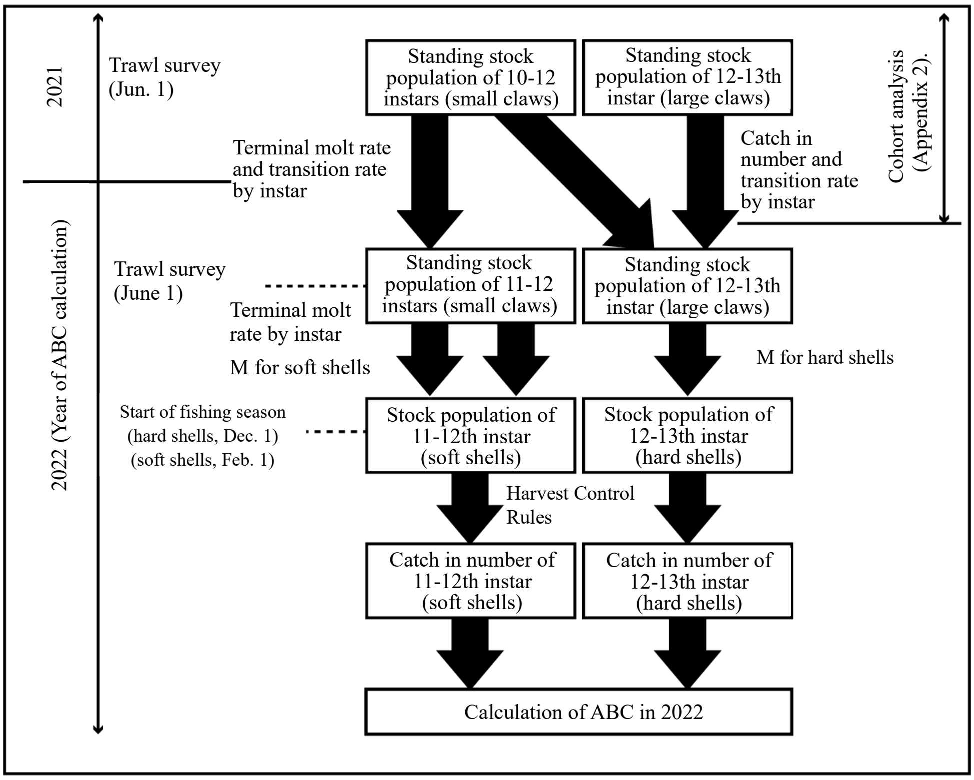
β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.0	3.4	2.9	2.6	3.5	3.8	2.9	2.7	2.7	2.8	2.9	2.9
0.9	3.4	2.9	2.7	3.7	4.1	3.1	2.9	2.9	3.1	3.2	3.2
0.8	3.4	2.9	2.9	3.9	4.4	3.5	3.3	3.3	3.4	3.5	3.5
0.7	3.4	2.9	3.0	4.2	4.8	3.8	3.6	3.6	3.8	3.9	3.9
0.6	3.4	2.9	3.2	4.5	5.2	4.2	4.0	4.0	4.2	4.3	4.3
0.5	3.4	2.9	3.3	4.8	5.6	4.7	4.4	4.4	4.6	4.8	4.7
0.4	3.4	2.9	3.5	5.1	6.1	5.2	4.9	4.9	5.1	5.3	5.2
0.3	3.4	2.9	3.6	5.5	6.6	5.7	5.5	5.5	5.7	5.9	5.8
0.2	3.4	2.9	3.8	5.8	7.2	6.3	6.1	6.1	6.4	6.5	6.4
0.1	3.4	2.9	4.0	6.2	7.8	7.0	6.8	6.8	7.1	7.3	7.0
0.0	3.4	2.9	4.1	6.7	8.5	7.8	7.5	7.6	7.9	8.1	7.7
Fcurrernt	3.4	2.9	3.3	4.8	5.6	4.7	4.4	4.4	4.6	4.8	4.7

Average catch in weight

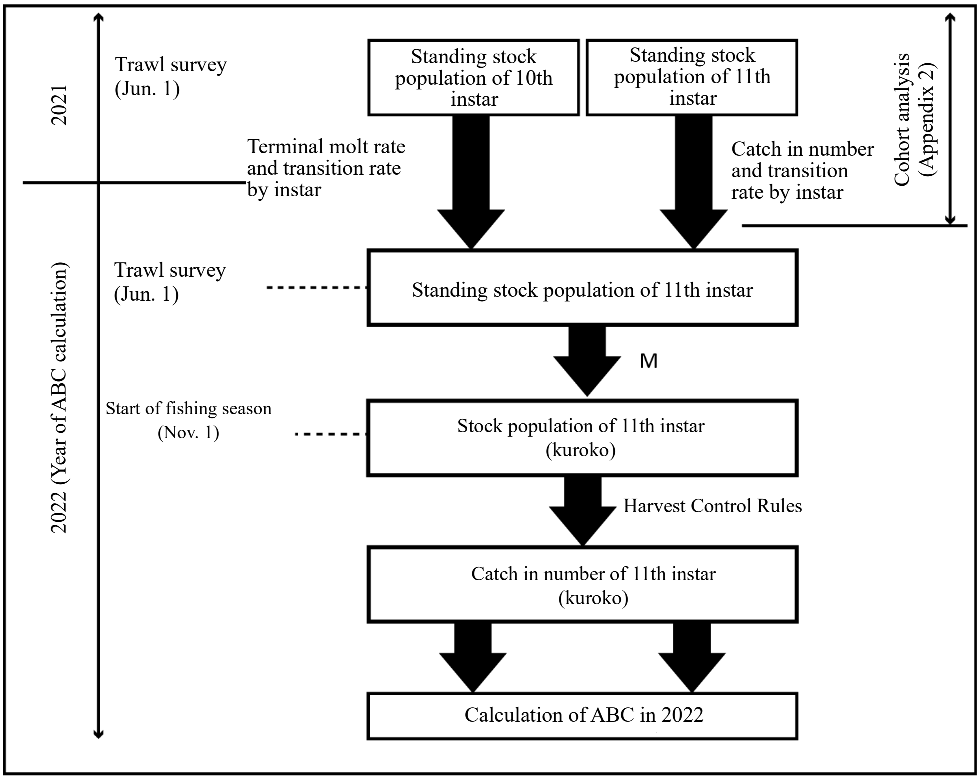
β	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1.0	2.2	1.7	3.3	3.5	4.0	3.8	3.5	3.1	3.2	3.3	3.4
0.9	2.2	1.7	3.0	3.4	3.8	3.8	3.5	3.1	3.2	3.3	3.4
0.8	2.2	1.7	2.8	3.1	3.7	3.7	3.5	3.0	3.1	3.2	3.3
0.7	2.2	1.7	2.5	2.9	3.5	3.6	3.4	3.0	3.0	3.1	3.2
0.6	2.2	1.7	2.2	2.6	3.2	3.4	3.2	2.8	2.9	3.0	3.1
0.5	2.2	1.7	1.9	2.3	2.9	3.1	3.0	2.6	2.7	2.8	2.9
0.4	2.2	1.7	1.5	2.0	2.5	2.8	2.7	2.4	2.4	2.5	2.6
0.3	2.2	1.7	1.2	1.5	2.0	2.3	2.3	2.0	2.1	2.1	2.2
0.2	2.2	1.7	0.8	1.1	1.5	1.7	1.7	1.5	1.5	1.6	1.6
0.1	2.2	1.7	0.4	0.6	0.8	0.9	1.0	0.9	0.9	0.9	0.9
0.0	2.2	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fcurrernt	2.2	1.7	1.9	2.3	2.9	3.1	3.0	2.7	2.7	2.8	2.9

Appendix 1 Flow of Stock Assessment

(1) Male



(2) Females



Appendix 2 Stock Calculation Methods

2-1. Cohort analysis based on standing stock population by year and by instar from trawl surveys

Stock abundance of snow crabs is estimated using direct estimates from trawl-surveys. Direct estimates allow for estimation of stock abundance without assistance from fisheries, but values estimated with this method are vulnerable to observation errors during trawl surveys, which lends uncertainty to ABC levels calculated based on these less accurate stock abundance estimates. Therefore, in order to reduce the influence of observation errors, cohort analysis was conducted using the standing stock population by year and by instar from trawl surveys (Supplementary Table 2-1).

Using the standing stock population by instar during the 1st year of the analysis period and the recruitment in number for each year as starting points, forward calculations were performed with consideration of terminal molt status. The calculation process is shown schematically in Supplementary Figure 2-1.

$N_{i,a,j,t}$ labels standing stock population by sex (i), year (t), instar (a), and molting stage (j). Molting stage (j) defines groups as immature, mature, soft shell, or hard shell as follows:

Molting stage 1: immature, soft shell

Molting stage 2: mature, soft shell

Molting stage 3: mature, hard shell

Using the standing stock population in the 9th to 12th instar ($R_{i,a,j,t}$) in 1999 (t) and the standing stock population in the 9th instar ($R_{i,a,1,t}$) in 2000 to 2020 (t), we forward calculated the standing stock population in the 10th to 13th instar (9th to 11th instar for females) in 2000 (t+1) and the standing stock population in the 10th instar in 2001 to 2021 (t+1) with the following equations:

Immature: $$\widehat{N}_{i,a+1,1,t+1} = (1 - \gamma_{i,a+1})(R_{i,a,1,t} - C_{i,a,1,t})S_{i,a,1} \quad (1)$$

Mature: $$\widehat{N}_{i,a+1,2-3,t+1} = \gamma_{i,a+1}(R_{i,a,1,t} - C_{i,a,1,t})S_{i,a,1} + (R_{i,a+1,2-3,t} - C_{i,a,2-3,t})S_{i,a+1,2-3} \quad (2)$$

In these equations, $\gamma_{i,a}$ is the terminal molt rate for instar a, and $C_{i,a,j,t}$ is catch in number for year (t), instar (a), and molting stage (j).

$S_{i,a}$ is the transition rate from the stock population of year (t), in instar (a) into (1) the stock population of year (t+1), in instar (a+1), or (2) the stock population of year (t+1), in instar (a). In scenario (1), the transition rate is a coefficient that includes the impact of different trawl net capture efficiencies between instar (a) and (a+1) in addition to the survival rate. In scenario (2), it is a coefficient that only shows the survival rate. When performing stock calculations, it is normal to determine the stock population for the following year based on factors like catch in number by instar and M. However, in Area A, it is also necessary to consider by-catch mortality and South Korean catch in weight in the provisional waters between Japan and Korea as factors which affect the survival rate, in addition to fishing. Since it is currently impossible to fully account for these factors, calculations are performed using the transition rate.

In addition, $\gamma_{i,a}$ and $S_{i,a}$ were assumed to be constant for all years. Catch in number ($C_{i,a,j,t}$) was used for mature males in the 12th and 13th instars (hard shells) and females in the 11th instar, while 0 was used for other instars. In reality, immature 12th instar males are caught as soft shells, and other instars are also affected by by-catch mortality, so these factors were estimated as parameters included in the transition rate.

Next, the standing stock population in the 11th to 13th instars (11th instar for females) for 2001 to 2021 was forward calculated with the following equations:

Immature: $\hat{N}_{i,a+1,1,t+1} = (1 - \gamma_{i,a+1})(\hat{N}_{i,a,1,t} - C_{i,a,1,t})S_{i,a,1,t}$ (3)

Mature: $\hat{N}_{i,a+1,2-3,t+1} = \gamma_{i,a+1}(\hat{N}_{i,a,1,t} - C_{i,a,1,t})S_{i,a,1,t} + (\hat{N}_{i,a+1,2-3,t} - C_{i,a,2-3,t})S_{i,a+1,2-3,t}$ (4)

The likelihood function (L) for the calculated standing stock population ($\hat{N}_{i,a,j,t}$) and the standing stock population observed in trawl surveys ($N_{i,a,j,t}$) is shown in equation (5). The R v4.0.2 optim function was used to determine parameter values that will maximize the likelihood function (L), specifically, the estimate parameters were standing stock population in the 9th to 13th instars ($R_{i,a,1,t}$) in 1999 (t), the standing stock population in the 9th instar ($R_{i,a,1,t}$) in 2000 to 2021 (t), the terminal molt rate ($\gamma_{i,a}$), and the transition rate ($S_{i,a,j}$).

$$L = \prod_i \prod_a \prod_j \prod_t \frac{1}{N_{i,a,j,t}\sqrt{2\pi\sigma_i^2}} exp\left[-\frac{\left(ln(\hat{N}_{i,a,j,t}) - ln(N_{i,a,j,t})\right)^2}{2\sigma_i^2}\right] \quad (5)$$

$$\sigma_i^2 = \frac{1}{AJT}\sum_a \sum_j \sum_t \left(ln(\hat{N}_{i,a,j,t}) - ln(N_{i,a,j,t})\right)^2 \quad (6)$$

Both males and females in the 9th and 10th instars are immature individuals, and no differences have been observed in the distribution of males and females for immature individuals. Therefore, the standing stock population in the 9th and 10th instars was assumed to be equal for males and females for parameter estimation.

Males in the 13th instar were excluded from this analysis, and observed values were used for ABC calculation instead, because the influence of observation error in trawl surveys was considered to be small, and because the transition rate was considered to have annual variation. Even if males in 13th instar are excluded from this analysis, the transition rate of immature males in the 12th instar ($S_{12,1}$) is necessary for estimation of the standing stock population in 2022, and for future forecasts. Therefore, we estimated $S_{12,1}$ by calculating the likelihood of transitioning to the 13th instar using equation (5), only for the past 5 years (2017 to 2021), when the annual variation in transition rate is considered to be small.

The 90% confidence interval ($\hat{N}^{lower}_{i,a,j,t}$, $\hat{N}^{upper}_{i,a,j,t}$) of the estimated standing stock population ($\hat{N}_{i,a,j,t}$) was found using the following parametric bootstrapping method:

$$\mu^b_{i,a,j,t} = ln(\hat{N}_{i,a,j,t}) + \varepsilon^b_{i,a,j,t} \quad (7)$$

$$\varepsilon^b_{i,a,j,t} \sim N(0, \sigma_i^2) \quad (8)$$

$$N^b_{i,a,j,t} = exp(\mu^b_{i,a,j,t}) \quad (9)$$

In these equations, b is a variable that indicates the bootstrap sample (b=1, ..., B). Using $N^b_{i,a,j,t}$, parameters were re-estimated using equations (3) to (6) to obtain $\hat{N}^b_{i,a,j,t}$. Calculations were repeated 1,000 times (B = 1,000), and the 50th lowest and 50th highest values of $\hat{N}^b_{i,a,j,t}$ were set as $\hat{N}^{\mathrm{lower}}_{\mathrm{i,a,j,t}}$ and $\hat{N}^{\mathrm{upper}}_{\mathrm{i,a,j,t}}$, respectively.

The catch in number (C), estimated transition rate (S), and male terminal molt rate (γ) values used for analysis are shown in Supplementary Table 2-2, and the estimated recruitment in number (R) from the 9th instar in each year, and the 10th instar in 1999, are shown in Supplementary Tables 2-3 and 2-5, respectively. In addition, the observed and estimated values for standing stock population by instar used for analysis are shown in Supplementary Figure 2-2, and their residuals are shown in Supplementary Figure 2-3.

2-2. Assumptions for recruitment (10th instar) in future forecasts

Stock calculations for this area can improve the accuracy of recent recruitment for future forecasts by utilizing information on juvenile individuals from trawl surveys. Recruitment in 2021 is the standing stock population in the 10th instar obtained from cohort analysis results, and recruitment in number for 2022 is the standing stock population in the 10th instar based on the standing stock population in the 9th instar and the transition rate in 2021.

Recruitment in number for 2023 was forecast based on the standing stock population in the 8th instar obtained from trawl survey results for each year, and the relationships of the standing stock population in the 10th instar obtained from cohort analysis results. It is known that juvenile snow crabs are impacted by cannibalism, and that juvenile individuals are often captured in high density clusters during surveys. Therefore, we considered the non-linearity of standing stock population in the 8th instar and recruitment, and forecasted recruitment assuming a lognormal error distribution. Parameters were optimized using the minimum absolute value method to ensure robustness against missing data and outliers. Recruitment in number for individuals into the 10th instar in 2023 is expected to be 28 million for both sexes based on our model. Because recruitment is impacted by by-catch mortality in the 8th instar and after, as discussed later in this evaluation, the actual recruitment used for future forecasts is slightly different than this forecast value.

2-3. Future Forecast Methods

Future forecasts assumed that surveys (June 1) and fishing (soft shells: February 1, hard shells: December 1, females: November 1) would be conducted within a short period of time. The natural mortality coefficient M was assumed to be 0.35 for soft shells (Yamasaki 1996), and 0.35 for 10th instar females because they molted less than 1 year prior, and 0.2 for both hard shells and 11th instar females, which have completed their terminal molts. Molting was assumed to occur immediately after the survey.

Sea of Japan Area A snow crabs are considered to be landing targets in the 11th instar for females, and in the 12th or 13th instar for males, but by-catch mortality occurs among non-landing target individuals, such as females in the 10th instar or younger (Yamasaki et al. 2011, Yamasaki and Miyajima 2013). Therefore, the impact of by-catch mortality was considered when calculating future forecasts.

1) By-catch mortality prior to recruitment

In this area, by-catch mortality in the 8th and 9th instars prior to recruitment was assumed to occur in a similar manner as in the 10th instar. Please note that all males and females are immature prior to recruitment. In this case, recruitment in number into the 10th instar in year (t) is depleted by by-catch mortality in the 8th instar in year (t-2) and in the 9th instar in year (t-1) as follows:

$$N_{10,t} = N_{8,t-2}\, exp\left(-G_{8,t-2}\right) S_{8,t-2}\, exp\left(-G_{9,t-1}\right) S_{9,t-1} \quad (1)$$

In this equation, $G_{8,t-2}$ and $G_{9,t-1}$ indicate the by-catch coefficients for the 8th instar in year (t-2) and the 9th instar in year (t-1), and $S_{8,t-2}$ and $S_{9,t-1}$ indicate the transition rates excluding by-catch mortality. Transition rates are coefficients that include the impact of different trawl net capture efficiencies for instar (a) and (a+1) in addition to the survival rate in the 8th to 10th instars. Next, G was assumed to be constant regardless of year when calculating stock forecasts, and it was assumed to be the same in the 8th and 9th instars, so recruitment in number into the 10th instar was calculated as follows:

$$N_{10} = N'_{10}\, exp(-2G_{8-9})\, S_{8-9} \quad (2)$$

In this equation, N'_{10} is the recruitment in number based on the stock-recruitment relationship for stock forecasts, $G_{8\text{-}9}$ is the by-catch coefficient in the 8th and 9th instars, and $S_{8\text{-}9}$ is the transition rate excluding by-catch mortality in the 8th and 9th instars.

When calculating stock forecasts for the period from the start of management in 2022 to 1 year later in 2023, the impact of by-catch mortality on recruitment in number into the 10th instar was only considered for a 1 year period in the 9th instar, so the recruitment in number from the 10th instar is as follows:

$$N_{10} = N'_{10}\, exp(-G_{8-9})\, S_9 \quad (3)$$

The following relationship was assumed for the by-catch coefficient and the fishing coefficient:

$$G_t = \alpha F_t \quad (4)$$

In this equation, α is a proportional constant. When α = 1, by-catch mortality changes equally to fishing mortality, when α = 0, by-catch mortality is unchanged by fishing mortality, specifically, it indicates that by-catch mortality is in the transition rate.

The transition rates S_9 and $S_{8\text{-}9}$, which excluding by-catch mortality, are values at the total current fishing pressure for males and females (Fcurrent = 0.130 : average of 2018 to 2020), and were calculated as follows:

$$S_9 = \frac{1}{\exp\left(-\alpha F_{2018-2020}\right)} \quad (5)$$

$$S_{8-9} = \frac{1}{\exp\left(-2\alpha F_{2018-2020}\right)} \quad (6)$$

In this appendix, α = 0.5 was used for calculating future forecasts and reference points. This value is also set in the assumptions for YPR/SPR analysis in the stock assessment for this area in the 2019 fiscal year, and S_9 and $S_{8\text{-}9}$ are 1.15 and 1.18, respectively.

2) Parameters after recruitment

$N_{i,a,j,t}$ labels standing stock population by sex (i), year (t), instar (a), and molting stage (j). For sex (i), 1 indicates females and 2 indicates males, and molting stage (j) defines groups as immature, mature, soft shell (molted in the past year), or hard shell (molted more than 1 year prior) as follows:

Molting stage 1: immature, soft shell

Molting stage 2: mature, soft shell

Molting stage 3: mature, hard shell

In the 11th instar and after, the standing stock population in year (t) was forward calculated from the standing stock population in year (t-1) using the following equations:

Immature: $$N_{i,a,1,t} = (1 - \gamma_{i,a}) N_{i,a-1,1,t-1}\, exp(-G_{i,a-1,1,t-1})\, S_{i,a-1,1} \quad (7)$$

Mature:

$$N_{i,a,2-3,t} = \gamma_{i,a} N_{i,a-1,1,t-1}\, exp(-G_{i,a-1,1,t-1})\, S_{i,a-1,1} + N_{i,a,2-3,t-1}\, exp(-F_{i,a,2-3,t-1})\, S_{i,a,2-3} \quad (8)$$

In these equations, $\gamma_{i,a}$ is the terminal molt rate for molting in instar (a).

The transition rate $S_{i,10,1}$ for immature individuals into the 10th instar, excluding by-catch mortality, is a value at the total current fishing pressure for males and females (Fcurrent = 0.130 : average of 2018 to 2020), in the same manner as transition rates in the 8th and 9th instars, and was calculated as follows:

$$S_{i,10,1} = S'_{i,10,1} \frac{1}{\exp(-2\alpha F_{2018-2020})} \quad (9)$$

In this equation, $S'_{i,10,1}$ indicates the transition rate which includes by-catch mortality at Fcurrent.

The transition rates $S_{2,11,1}$ and $S_{2,12,1}$ for immature individuals in the 11th and 12th instars, excluding by-catch mortality, are values at the total current fishing pressure for hard shell males (Fcurrent = 0.400 : average of 2018 to 2020), and were calculated as follows:

$$S_{2,a,1} = S'_{2,a,1} \frac{1}{\exp(-\alpha F_{2018-2020})} \quad (10)$$

In this equation, $S_{2,a,1}$ indicates the transition rates which include by-catch mortality at Fcurrent, which are 0.607 and 0.345, respectively.

3) Calculation of catch in weight and SSB

The stock population (N') of females (a = 11), soft shells, and hard shells (a = 12 or 13) at the beginning of the fishing season were calculated from the standing stock population obtained in section 2) using the following equations:

Females: $$N'_{1,11,3,t} = N_{1,11,2-3,t}\, exp\left(-\frac{5}{12} M_{2-3}\right) \quad (11)$$

Soft shells: $N'_{2,a,1-2,t} = N_{2,a-1,1,t}\, exp\left(-\frac{8}{12}M_1\right)$ (12)

Hard shells: $N'_{2,a,3,t} = N_{2,a,2-3,t}\, exp\left(-\frac{6}{12}M_{2-3}\right)$ (13)

For the equations above, the stock abundance (B) and catch in weight (Y) were calculated from the stock population (N') using the following equations:

$B_{i,a,j,t} = N'_{i,a,j,t} w_{i,a,j}$ (14)

$Y_{i,a,j,t} = N'_{i,a,j,t}\left[1 - exp\left(-F_{i,a,j,t}\right)\right] w_{i,a,j}$ (15)

In the equations above, $w_{a,j}$ indicates body weight. which was calculated based on carapace width composition by instar estimated by carapace width composition analysis, and a carapace width-body weight relationship for soft shells and hard shells, to obtain the following values:

12th instar, soft shells ($w_{12,1\text{-}2}$): 373 g, hard shells ($w_{12,3}$): 403 g

13th instar, soft shells ($w_{13,1\text{-}2}$): 728 g, hard shells ($w_{13,3}$): 799 g

The value for 11th instar females, 177 g, was obtained using the same methods.

SSB of females (SB) was calculated by subtracting the catch in weight of females (Y) from the stock abundance of females at the beginning of the fishing season:

$SB_{1,t} = B_{1,11,3,t} - Y_{1,t}$ (16)

In future forecasts, the female F value to Fcurrent ratio was multiplied by the male Fcurrent value, and the result was used as the male F value. Because catch in weight converted from instar composition of catches is not perfectly identical to the actual catch in weight, a coefficient to correct the differences between these values was obtained (1.08, average value of 2016 to 2020), and was used for catch in weight forecasts.

References

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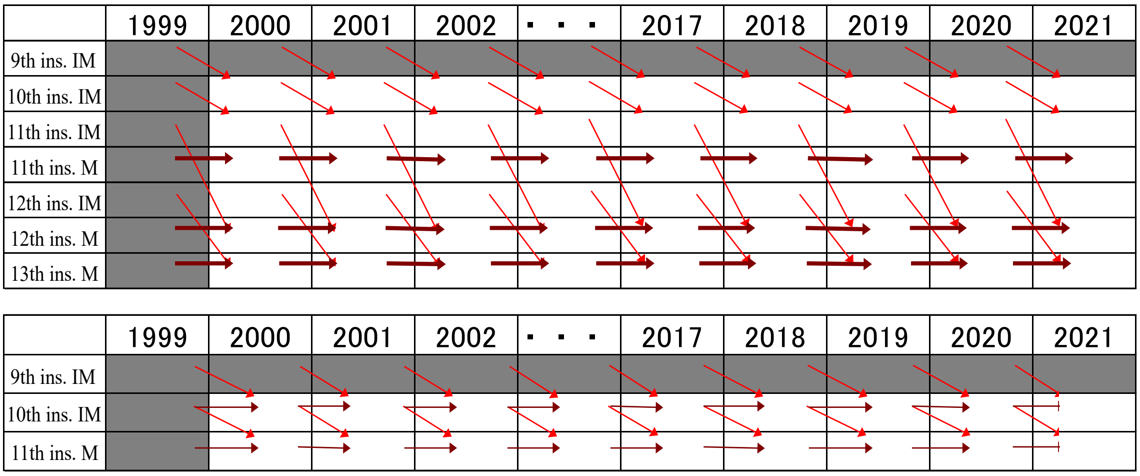
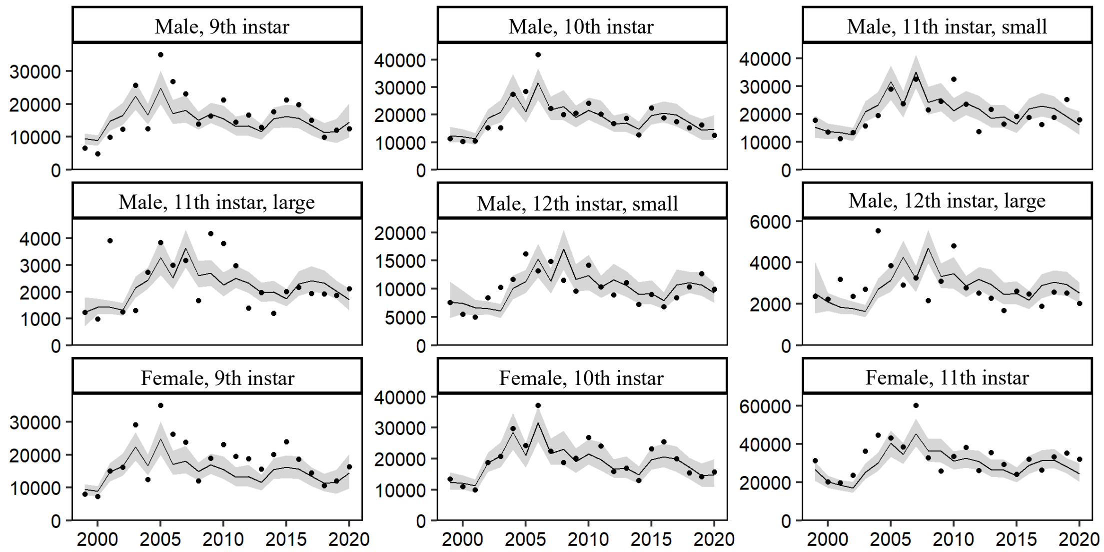


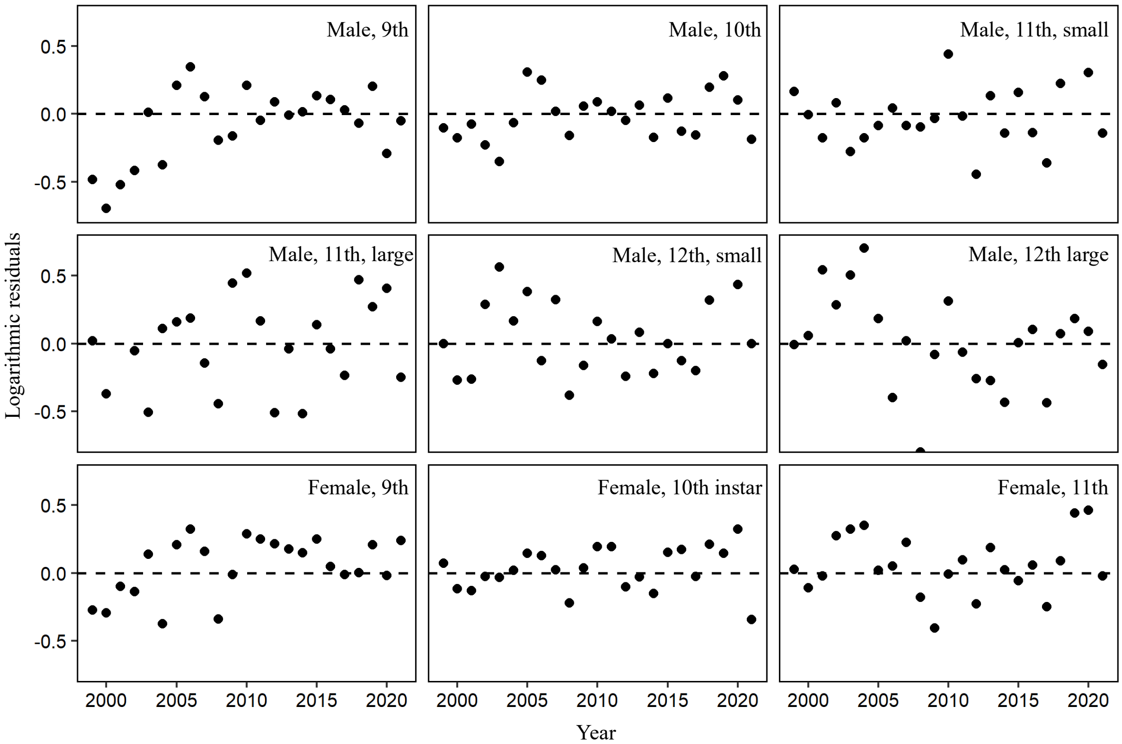
Supplementary Figure 2-1. Schematic diagram of stock calculation

The upper diagram shows males and the lower diagram shows females. Thin lines indicate transition to the next instar by molting, and the thick lines indicate staying in the same instar after completion of terminal molt. “IM” means immature (small claws/pre terminal molt) and “M” means mature (large claws/post terminal molt).



Supplementary Figure 2-2. Observed (black dots) and estimated (black line) values for standing stock population by year and by instar from trawl surveys

Shading indicates the 90% confidence interval of estimates, the vertical axis represents standing stock population (thousands), “small” means small claws (immature/pre terminal molt), and “large” means large claws (mature/post terminal molt).



Supplementary Figure 2-3. Residuals of observed and estimated values (logarithms) for standing stock population by year and by instar from trawl surveys

The dotted line indicates 0, the vertical axis represents residuals, "small" means small claws (immature/pre terminal molt), and "large" means large claws (mature/post terminal molt).

Supplementary Table 2-1. Direct estimates of standing stock population at the time of trawl surveys (swept-area method)

Male standing stock population (thousands)

Instar	Maturity	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
6th	IM	0	22	150	898	3,960	1,485	1,776	553	1,069	1,023	890	717	491
7th	IM	702	699	1,393	6,322	12,432	7,193	3,985	6,254	2,835	3,825	9,022	3,437	4,973
8th	IM	3,714	2,082	4,835	18,942	11,401	11,239	14,348	12,433	11,615	6,285	15,900	10,095	11,800
9th	IM	6,566	4,930	9,937	12,309	25,621	12,541	35,047	26,863	23,101	13,883	16,333	21,291	14,531
10th	IM	11,297	10,271	10,548	15,322	15,189	27,359	28,492	41,899	22,348	20,013	20,576	24,133	20,279
	M	103	98	943	276	263	977	529	357	703	471	1,247	1,209	508
11th	IM	17,696	13,456	11,090	13,313	15,779	19,466	28,992	23,697	32,490	21,517	24,493	32,526	23,502
	M	1,231	985	3,919	1,251	1,294	2,732	3,858	3,004	3,174	1,682	4,191	3,818	2,976
12th	IM	7,559	5,464	4,958	8,413	10,271	11,696	16,199	13,234	14,899	11,516	9,592	14,186	10,312
	M	2,372	2,223	3,188	2,364	2,707	5,545	3,854	2,913	3,253	2,166	3,106	4,809	2,769
13th	M	1,117	1,454	1,841	2,605	4,615	5,114	4,728	5,110	6,250	4,577	3,212	3,822	2,838

Instar	Maturity	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
6th	IM	1,978	2,715	1,403	799	498	645	2,081	5,520	7,698	27,823
7th	IM	5,137	8,527	7,708	3,247	2,611	1,686	1,768	3,034	6,634	23,064
8th	IM	10,541	13,174	13,575	10,748	8,220	3,919	5,026	10,727	16,574	35,592
9th	IM	16,581	12,955	17,590	21,296	19,786	15,117	9,922	12,106	12,503	17,721
10th	IM	16,774	18,649	12,681	22,456	18,889	17,550	15,278	16,216	12,406	15,915
	M	200	361	122	238	399	636	1,016	257	197	85
11th	IM	13,792	21,696	16,396	19,115	18,837	16,186	18,777	25,279	17,919	10,659
	M	1,390	1,969	1,203	2,018	2,168	1,942	1,929	1,866	2,120	1,029
12th	IM	8,937	11,134	7,253	8,986	6,843	8,426	10,386	12,659	9,963	6,298
	M	2,522	2,269	1,678	2,610	2,490	1,891	2,573	2,517	2,032	1,525
13th	M	3,383	3,934	3,054	2,625	1,934	2,723	3,677	4,625	4,741	2,627

Female standing stock population (thousands)

Instar	Maturity	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
6th	IM	121	143	35	621	2,987	1,344	1,441	323	972	983	407	566	247
7th	IM	723	735	610	5,326	13,787	7,686	5,216	6,967	3,231	3,773	9,419	3,132	3,820
8th	IM	3,832	1,712	3,704	17,069	10,502	11,981	13,640	11,562	10,432	6,223	16,780	9,959	12,475
9th	IM	8,111	7,362	15,137	16,261	29,117	12,539	35,017	26,209	23,848	12,001	18,947	23,035	19,526
10th	IM	13,466	10,928	10,000	18,777	20,784	29,805	24,245	37,239	22,388	18,786	20,125	26,791	24,097
11th	M	31,423	20,398	19,806	23,877	36,351	44,839	43,212	38,532	60,364	32,854	25,999	33,543	38,432

Instar	Maturity	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
6th	IM	1,481	2,145	1,240	361	672	530	1,186	3,896	7,396	23,306
7th	IM	5,153	7,296	6,338	3,606	2,261	1,847	2,144	2,545	4,785	21,304
8th	IM	10,794	13,713	13,303	10,026	6,913	4,207	4,281	11,322	15,627	34,957
9th	IM	18,776	15,631	20,100	23,914	18,671	14,518	10,674	12,126	16,412	23,695
10th	IM	15,855	16,978	12,984	23,214	25,501	19,977	15,492	14,155	15,695	13,658
11th	M	26,210	35,501	29,539	24,200	32,198	26,368	33,441	35,325	32,165	17,765

Age stratification by cohort slicing method up to 2002. Values for standing stock population by instar are estimated assuming that capture efficiency by trawl net size is constant, and that the stock populations of juvenile instars are underestimated compared to the actual populations.

Supplementary Table 2-2. Catch in number (C), estimated transition rates by instar (S), and terminal molt rate of males (γ) used in cohort analysis

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Catch in number	Male, 12th, hard shell	1,253	1,442	1,626	1,756	1,836	1,413	1,579	2,203	2,054	2,150	1,541	1,638	1,876
	Male, 13th, hard shell	626	721	813	878	918	1,345	1,029	1,088	1,223	1,224	1,084	886	845
	Female, 11th	8,990	7,141	7,393	8,485	9,754	10,520	10,297	10,988	11,777	8,561	9,380	10,056	9,395

		2012	2013	2014	2015	2016	2017	2018	2019	2020
Catch in number	Male, 12th, hard shell	1,850	2,274	1,628	1,665	1,658	1,805	1,808	1,409	1,125
	Male, 13th, hard shell	868	715	887	745	631	638	744	911	874
	Female, 11th	9,192	7,215	7,832	7,360	7,681	6,304	7,292	5,180	4,529

	Instar	Maturity	
Transition rate	Male and female, 9th	IM	1.151
	Male and female, 10th	IM	1.183
	Male, 11th	IM	0.607
	Male, 12th	IM	0.345
	Male 11-13th	M	0.083
	Female, 11th	M	0.374

	Instar	
Terminal molt rate	11th	0.088
	12th	0.210

See Supplementary Tables 2-3 and 2-5 for recruitment in number (R) in the 9th instar for each year, and the 10th instar in 1999.

Supplementary Table 2-3. Standing stock population at the time of trawl surveys, stock population and stock abundance at the beginning of the fishing season, for males based on cohort analysis

Standing stock population at the time of survey (thousands)

Instar	Maturity	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
9th	IM	10,737	9,935	16,719	18,716	25,380	18,333	28,326	19,052	20,514	16,984	19,194	17,242	15,227
10th	IM	12,601	12,362	11,439	19,251	21,550	29,223	21,109	32,615	21,936	23,620	19,555	22,100	19,853
11th	IM	15,219	13,596	13,338	12,342	20,770	23,251	31,530	22,775	35,189	23,668	25,484	21,099	23,845
	M	1,208	1,409	1,401	1,304	2,108	2,413	3,235	2,461	3,592	2,577	2,667	2,253	2,482
12th	IM	7,558	7,294	6,516	6,393	5,915	9,955	11,144	15,112	10,916	16,866	11,344	12,214	10,113
	M	2,404	2,039	1,786	1,717	1,573	2,630	3,071	4,151	3,071	4,578	3,225	3,395	2,841
13th	M	1,117	1,454	1,841	2,605	4,615	5,114	4,728	5,110	6,250	4,577	3,212	3,822	2,838

Stock population at the beginning of the fishing season (thousands)

Instar	Maturity	Category	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
12th	IM	Soft shells	9,516	8,501	8,340	7,717	12,988	14,539	19,715	14,241	22,004	14,799	15,935	13,193	14,910
	M	Soft shells	2,535	2,265	2,222	2,056	3,460	3,874	5,253	3,794	5,862	3,943	4,246	3,515	3,972
	M	Hard shells	2,175	1,845	1,616	1,553	1,423	2,380	2,778	3,756	2,778	4,143	2,918	3,072	2,570
13th	M	Soft shells	5,985	5,776	5,160	5,062	4,684	7,883	8,825	11,967	8,644	13,356	8,983	9,673	8,008
	M	Hard shells	1,010	1,316	1,666	2,357	4,176	4,627	4,278	4,623	5,655	4,142	2,906	3,458	2,568

Stock abundance at the beginning of the fishing season (tons)

Instar	Maturity	Category	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
12th	IM	Soft shells	3,550	3,171	3,111	2,879	4,844	5,423	7,354	5,312	8,207	5,520	5,944	4,921	5,561
	M	Soft shells	946	845	829	767	1,291	1,445	1,959	1,415	2,187	1,471	1,584	1,311	1,482
	M	Hard shells	876	744	651	626	574	959	1,120	1,514	1,120	1,669	1,176	1,238	1,036
13th	M	Soft shells	4,357	4,205	3,757	3,685	3,410	5,739	6,425	8,712	6,293	9,723	6,540	7,042	5,830
	M	Hard shells	807	1,051	1,331	1,883	3,337	3,697	3,418	3,694	4,518	3,309	2,322	2,763	2,052

Standing stock population at the time of survey (thousands)

Instar	Maturity	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
9th	IM	15,198	13,159	17,340	18,261	17,435	15,046	11,941	10,839	13,709	21,671
10th	IM	17,533	17,499	15,151	19,966	21,025	20,074	17,324	13,749	12,480	15,785
11th	IM	21,420	18,917	18,881	16,347	21,542	22,685	21,659	18,692	14,834	13,465
	M	2,268	2,010	1,984	1,739	2,218	2,368	2,282	1,989	1,593	1,429
12th	IM	11,429	10,266	9,067	9,049	7,835	10,325	10,873	10,381	8,959	7,110
	M	3,125	2,842	2,463	2,481	2,156	2,792	2,979	2,863	2,508	2,010
13th	M	3,383	3,934	3,054	2,625	1,934	2,723	3,677	4,625	4,741	2,627

Stock population at the beginning of the fishing season (thousands)

Instar	Maturity	Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
12th	IM	Soft shells	13,394	11,828	11,806	10,222	13,470	14,185	13,543	11,688	9,276	8,420
	M	Soft shells	3,568	3,151	3,145	2,723	3,589	3,779	3,608	3,114	2,471	2,243
	M	Hard shells	2,828	2,571	2,229	2,245	1,950	2,527	2,696	2,591	2,269	1,818
13th	M	Soft shells	9,050	8,130	7,180	7,166	6,205	8,176	8,610	8,221	7,094	5,630
	M	Hard shells	3,061	3,560	2,763	2,375	1,750	2,463	3,327	4,185	4,290	2,377

Stock abundance at the beginning of the fishing season (tons)

Instar	Maturity	Category	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
12th	IM	Soft shells	4,996	4,412	4,404	3,813	5,024	5,291	5,052	4,360	3,460	3,141
	M	Soft shells	1,331	1,175	1,173	1,016	1,339	1,410	1,346	1,162	922	837
	M	Hard shells	1,140	1,036	898	905	786	1,018	1,086	1,044	915	733
13th	M	Soft shells	6,589	5,919	5,227	5,217	4,517	5,952	6,268	5,985	5,165	4,099
	M	Hard shells	2,446	2,844	2,208	1,897	1,398	1,968	2,658	3,344	3,428	1,899

Italic values are forecasts. 13th instar values are based on direct estimation. Values for standing stock population by instar are estimated assuming that capture efficiency by trawl net size is constant, and that the stock populations of juvenile instars are underestimated compared to the actual populations. The standing stock population in the 9th instar for each year and in the 10th instar in 1999 are equal for males and females.

Recruitment in number is the standing stock population of immature individuals in the 11th instar.

Supplementary Table 2-4. Stock abundance, catch in weight (fishing year), exploitation rate, and fishing coefficient (F) for males at the beginning of the fishing season by category

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stock abundance (tons)	Soft shells	8,853	8,221	7,696	7,331	9,545	12,607	15,738	15,439	16,687	16,714	14,067	13,274	12,873
	Hard shells	1,684	1,795	1,982	2,509	3,910	4,656	4,538	5,208	5,638	4,979	3,498	4,001	3,087
	Total	10,536	10,016	9,679	9,840	13,455	17,263	20,275	20,647	22,325	21,693	17,565	17,275	15,960

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Catch in weight (tons)	Soft shells	1,029	891	955	1,002	919	865	1,113	1,018	939	604	727	618	619
	Hard shells	913	1,114	1,220	1,282	1,469	1,776	1,512	1,829	1,887	1,935	1,572	1,516	1,532
	Total	1,942	2,004	2,176	2,284	2,387	2,641	2,625	2,848	2,826	2,539	2,299	2,134	2,151

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Exploitation rate (%)	Soft shells	11.6	10.8	12.4	13.7	9.6	6.9	7.1	6.6	5.6	3.6	5.2	4.7	4.8
	Hard shells	54.2	62.1	61.6	51.1	37.6	38.1	33.3	35.1	33.5	38.9	44.9	37.9	49.6
	All	18.5	20.0	22.4	23.2	17.7	15.2	12.9	13.7	12.6	11.6	13.0	12.3	13.4

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fishing coefficient (F)	Soft shells	0.124	0.115	0.133	0.147	0.101	0.071	0.073	0.068	0.058	0.037	0.053	0.048	0.049
	Hard shells	0.781	0.969	0.956	0.715	0.471	0.480	0.405	0.433	0.408	0.492	0.597	0.476	0.686
	All	0.204	0.223	0.255	0.264	0.195	0.166	0.139	0.148	0.135	0.124	0.140	0.132	0.145

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Stock abundance (tons)	Soft shells	12,915	11,506	10,804	10,046	10,880	12,653	12,666	11,506	9,546	8,076
	Hard shells	3,586	3,880	3,106	2,802	2,184	2,986	3,744	4,388	4,342	2,632
	Total	16,501	15,386	13,910	12,848	13,064	15,639	16,410	15,894	13,888	10,708

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Catch in weight (tons)	Soft shells	558	358	361	356	359	358	104	159	158	*104*
	Hard shells	1,558	1,585	1,472	1,335	1,244	1,311	1,408	1,410	1,252	*868*
	Total	2,116	1,942	1,833	1,691	1,603	1,669	1,513	1,569	1,411	*1,513*

		2012	2013	2014	2015	2016	2017	2018	2019	2020
Exploitation rate (%)	Soft shells	4.3	3.1	3.3	3.5	3.3	2.8	0.8	1.4	1.7
	Hard shells	43.5	40.8	47.4	47.6	56.9	43.9	37.6	32.1	28.8
	All	12.8	12.6	13.1	13.1	12.2	10.6	9.2	9.8	10.4

		2012	2013	2014	2015	2016	2017	2018	2019	2020	F2018-2020
Fishing coefficient (F)	Soft shells	0.044	0.032	0.034	0.036	0.034	0.029	0.008	0.014	0.017	0.130
	Hard shells	0.570	0.525	0.642	0.647	0.843	0.578	0.472	0.388	0.340	0.400
	All	0.137	0.135	0.141	0.141	0.131	0.113	0.097	0.104	0.107	0.103

Italic values are forecasts. F 2018-2020 indicates the average of F in 2018 to 2020 (current F).

Supplementary Table 2-5. Standing stock population at the time of trawl surveys, stock population at the beginning of the fishing season, stock abundance, catch in weight (fishing year), exploitation rate, fishing coefficient (F), and SSB for females based on cohort analysis

Standing stock population at the time of survey (thousands)

Instar	Maturity	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
9th	IM	10,737	9,935	16,719	18,716	25,380	18,333	28,326	19,052	20,514	16,984	19,194	17,242	15,227
10th	IM	12,601	12,362	11,439	19,251	21,550	29,223	21,109	32,615	21,936	23,620	19,555	22,100	19,853
11th	M	30,401	22,912	20,520	18,439	26,492	31,749	42,504	37,012	48,309	39,609	39,548	34,413	35,249

Stock population (thousands) and stock abundance (tons) in the 11th instar (kuroko) at the beginning of the fishing season

	Instar	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stock Population	11th	27,970	21,080	18,879	16,965	24,374	29,210	39,106	34,053	44,446	36,442	36,386	31,661	32,430
Stock abundance	11th	4,924	3,753	3,370	3,034	4,360	5,218	6,987	6,088	7,947	6,546	6,511	5,666	5,808

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Catch in weight (tons)	1,591	1,264	1,309	1,502	1,726	1,862	1,823	1,945	2,085	1,515	1,660	1,780	1,663
Exploitation rate (%)	32.1	33.9	39.2	50.0	40.0	36.0	26.3	32.3	26.5	23.5	25.8	31.8	29.0
Fishing coefficient (F)	0.388	0.414	0.497	0.693	0.511	0.446	0.306	0.390	0.308	0.268	0.298	0.382	0.342

SSB (tons)

Instar	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
11th	3,359	2,467	2,033	1,501	2,588	3,308	5,099	4,082	5,782	4,935	4,780	3,824	4,077

Standing stock population at the time of survey (thousands)

Instar	Mature	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
9th	IM	15,198	13,159	17,340	18,261	17,453	15,046	11,941	10,839	13,709	21,671
10th	IM	17,533	17,499	15,151	19,966	21,025	20,074	17,324	13,749	12,480	15,785
11th	M	33,150	29,698	29,106	25,877	30,540	33,418	33,884	30,436	25,708	22,682

Stock population (thousands) and stock abundance (tons) in the 11th instar (kuroko) at the beginning of the fishing season

	Instar	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Stock Population	11th	30,500	27,323	26,779	23,808	28,099	30,746	31,175	28,002	23,652	20,868
Stock abundance	11th	5,398	4,836	4,740	4,214	4,973	5,442	5,518	4,956	4,186	3,694

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	F 2018-2020
Catch in weight (tons)	1,627	1,277	1,386	1,303	1,360	1,116	1,291	917	802	*753*	
Exploitation rate (%)	30.1	26.4	29.2	30.9	27.3	20.5	23.4	18.5	19.1		
Fishing coefficient (F)	0.359	0.307	0.346	0.370	0.319	0.229	0.266	0.205	0.213		0.228

SSB (tons)

Instar	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
11th	3,771	3,559	3,354	2,911	3,614	4,326	4,227	4,040	3,385	*2,941*

Italic values are forecasts. F 2018-2020 indicates the average of F in 2018 to 2020 (current F).

SSB is the stock abundance after the fishing season ends.

Values for standing stock population by instar are estimated assuming that capture efficiency by trawl net size is constant, and that the stock populations of juvenile instars are underestimated compared to the actual populations.

The standing stock population in the 9th instar for each year and in the 10th instar in 1999 are equal for males and females.

Recruitment in number is the standing stock population of individuals in the 10th instar.

Supplementary Table 2-6. Stock abundance, catch in weight (fishing year), exploitation rate, and fishing coefficient (F) for soft shells, hard shells, females, and the total of all categories at the beginning of the fishing season

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Stock abundance (tons)	Soft shells	8,853	8,221	7,696	7,331	9,545	12,607	15,738	15,439	16,687	16,714	14,067	13,274	12,873
	Hard shells	1,684	1,795	1,982	2,509	3,910	4,656	4,538	5,208	5,638	4,979	3,498	4,001	3,087
	Female	4,924	3,753	3,370	3,034	4,360	5,218	6,987	6,088	7,947	6,546	6,511	5,666	5,808
	Total	15,460	13,769	13,049	12,874	17,815	22,482	27,262	26,735	30,272	28,239	24,077	22,941	21,768

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Catch in weight (tons)	Soft shells	1,029	891	955	1,002	919	865	1,113	1,018	939	604	727	618	619
	Hard shells	913	1,114	1,220	1,282	1,469	1,776	1,512	1,829	1,887	1,935	1,572	1,516	1,532
	Female	1,591	1,264	1,309	1,502	1,726	1,862	1,823	1,945	2,085	1,515	1,660	1,780	1,663
	Total	3,533	3,268	3,484	3,786	4,114	4,503	4,447	4,793	4,911	4,055	3,959	3,914	3,814

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Exploitation rate (%)	Soft shells	11.6	10.8	12.4	13.7	9.6	6.9	7.1	6.6	5.6	3.6	5.2	4.7	4.8
	Hard shells	54.2	62.1	61.6	51.1	37.6	38.1	33.3	35.1	33.5	38.9	44.9	37.9	49.6
	Female	32.1	33.9	39.2	50.0	40.0	36.0	26.3	32.3	26.5	23.5	25.8	31.8	29.0
	All	22.9	23.7	26.7	29.4	23.1	20.0	16.3	17.9	16.2	14.4	16.4	17.1	17.5

		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
F	Soft shells	0.124	0.115	0.133	0.147	0.101	0.071	0.073	0.068	0.058	0.037	0.053	0.048	0.049
	Hard shells	0.781	0.969	0.956	0.715	0.471	0.480	0.405	0.433	0.408	0.492	0.597	0.476	0.686
	Female	0.388	0.414	0.497	0.693	0.511	0.446	0.306	0.390	0.308	0.268	0.298	0.382	0.342
	All	0.259	0.271	0.311	0.348	0.263	0.224	0.178	0.198	0.177	0.155	0.180	0.187	0.193

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Stock abundance (tons)	Soft shells	12,915	11,506	10,804	10,046	10,880	12,653	12,666	11,506	9,546	8,076
	Hard shells	3,586	3,880	3,106	2,802	2,184	2,986	3,744	4,388	4,342	2,632
	Female	5,398	4,836	4,740	4,214	4,973	5,442	5,518	4,956	4,186	3,694
	Total	21,900	20,223	18,650	17,062	18,038	21,081	21,928	20,850	18,075	14,402

		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Catch in weight (tons)	Soft shells	558	358	361	356	359	358	104	159	158	104
	Hard shells	1,558	1,585	1,472	1,335	1,244	1,311	1,408	1,410	1,252	868
	Female	1,627	1,277	1,386	1,303	1,360	1,116	1,291	917	802	753
	Total	3,743	3,219	3,219	2,993	2,963	2,784	2,804	2,486	2,212	1,725

		2012	2013	2014	2015	2016	2017	2018	2019	2020
Exploitation rate (%)	Soft shells	4.3	3.1	3.3	3.5	3.3	2.8	0.8	1.4	1.7
	Hard shells	43.5	40.8	47.4	47.6	56.9	43.9	37.6	32.1	28.8
	Female	30.1	26.4	29.2	30.9	27.3	20.5	23.4	18.5	19.1
	All	17.1	15.9	17.3	17.5	16.4	13.2	12.8	11.9	12.2

		2012	2013	2014	2015	2016	2017	2018	2019	2020	F 2017-2019
F	Soft shells	0.044	0.032	0.034	0.036	0.034	0.029	0.008	0.014	0.017	0.013
	Hard shells	0.570	0.525	0.642	0.647	0.843	0.578	0.472	0.388	0.340	0.400
	Female	0.359	0.307	0.346	0.370	0.319	0.229	0.266	0.205	0.213	0.228
	All	0.187	0.173	0.189	0.193	0.179	0.142	0.137	0.127	0.131	0.131

Italic values are forecasts. F 2018-2020 indicates the average of F in 2018 to 2020 (current F).

Appendix 3 Direct Estimation Method for Standing Stock

Bottom-trawl surveys were conducted by the Tanshu Maru (Hyogo) from May 6 to June 28, 2021, in the western Sea of Japan in depths of 190 m to 550 m. This area was divided into 8 sub-areas in the same manner as the offshore bottom-trawl area (in addition, off Hamada was divided into east and west sub-areas), and divided into 3 depth layers, to configure 139 survey sites across a total of 23 layers (Supplementary Figure 3-1). Trawl nets with a wing end spread of 17 m during towing were used, and towing time was generally 30 minutes.

Measurements were performed for all snow crabs (males: 9,308 individuals, females: 9,246 individuals) in the catches. In males, propodus width was measured in addition to carapace width, and maturation status (pre/post terminal molt) was determined. For females, carapace width was measured, and the condition of the abdomen and presence/absence of internal egg masses was recorded to determine if individuals were immature, 10th instar (pre-primiparous), or 11th instar (multiparous).

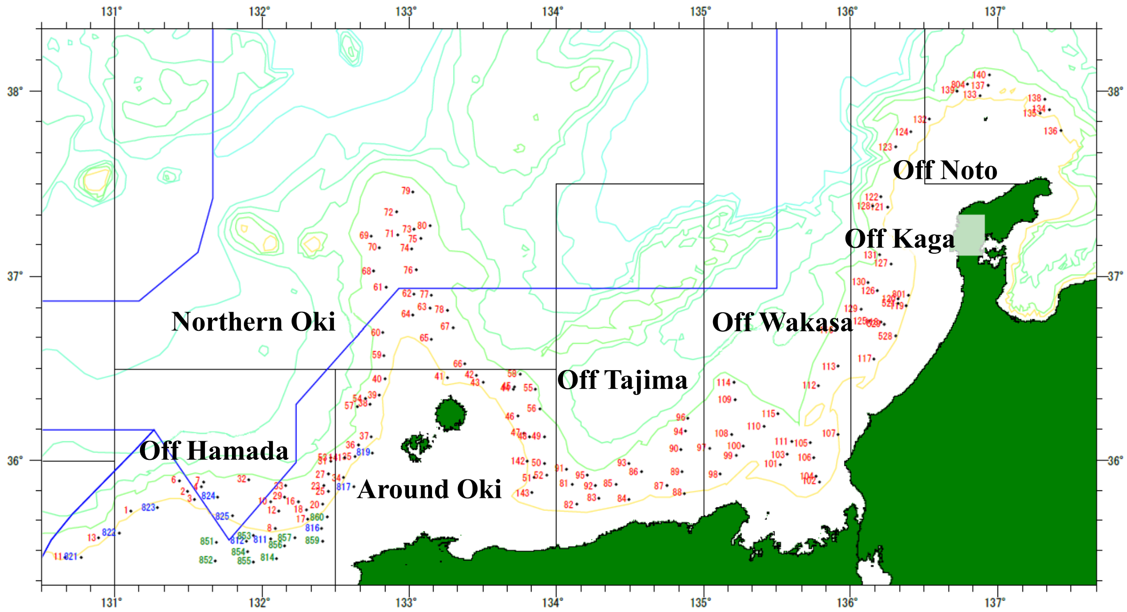
Carapace width composition was estimated using the swept-area method from the catch in number by sex and by maturation status for each survey site (carapace width class interval was 2 mm, and capture efficiency was 0.442). The new style of trawl nets has been used since 2015, and from this year, the capture efficiency of new style nets compared to the old style nets was assumed to be 0.6, 0.8, and 1 for the 9th instar or younger, 10th instar, and 11th instar and older, respectively (Appendix 4). A compound normal distribution was fitted to the estimated values for carapace width composition by sex and by maturation status to perform instar stratification (Supplementary Table 2-1).

Carapace width composition by area and by sex is shown in Supplementary Figure 3-2. Mature individuals (post terminal molt), such as males with large claws and 11th instar females, are commonly found in the west area, including off Hamada every year.

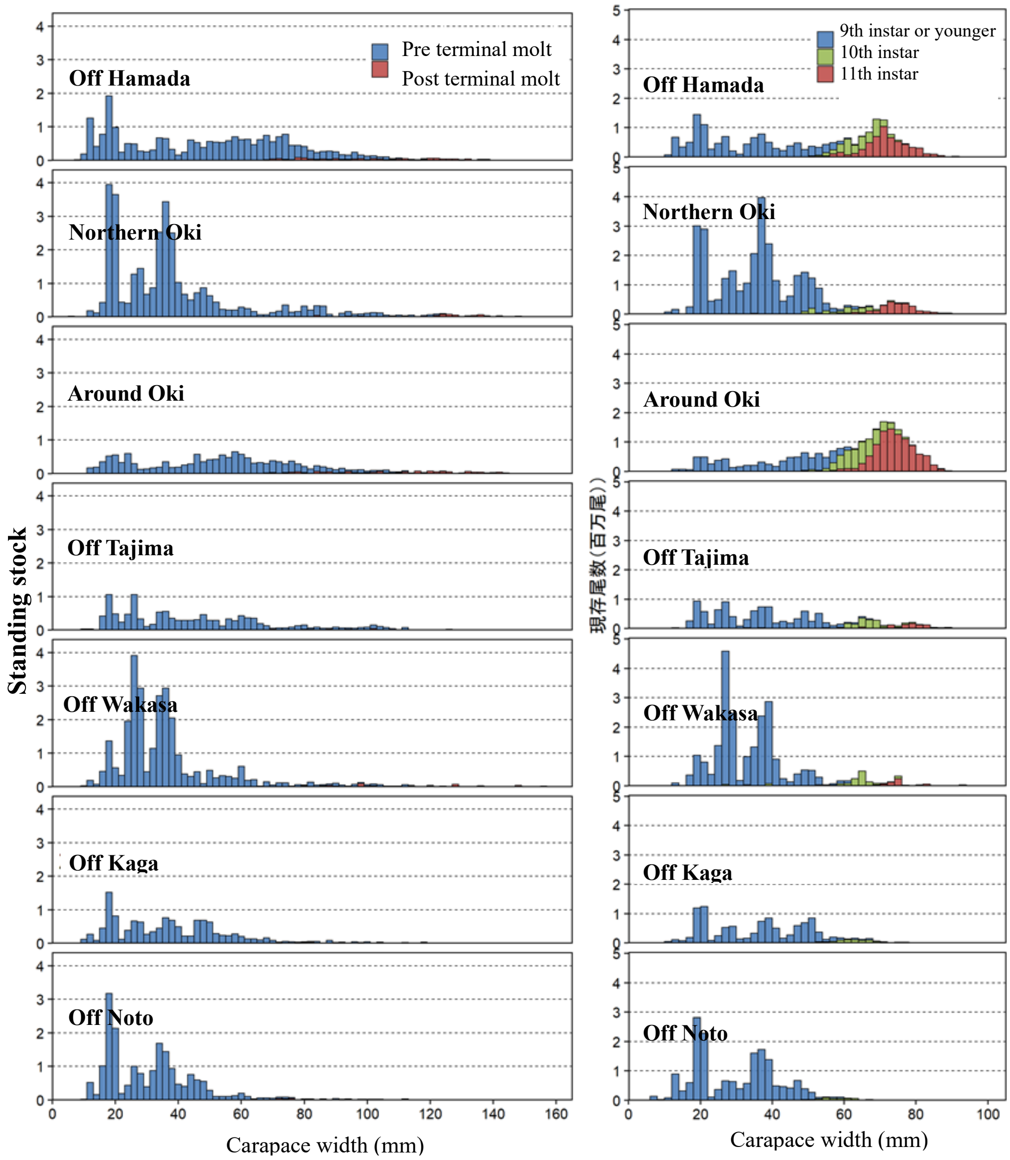
The standing stock of males (carapace width of 90 mm or more) and females (11th instar) estimated from trawl surveys for 2021 decreased significantly for both groups from 2020, and reached record lows (Supplementary Figure 3-3). Standing stock of males showed a slight increase off Tajima, but decreased in all other areas. Most of the changes in standing stock over time occur west of Oki (off Hamada, around Oki, and north of Oki). In 2021, 71% of the standing stock of males was found west of Oki. The proportion was even higher for females at 91% in 2021.

Trawl surveys have been conducted since 2011 by the Japan Sea Regional Fisheries Research Laboratory (Tanshu Maru) and the Shimane Prefecture Fisheries Technology Center (Shimane Maru) off Hamada and around the west side of Oki in depths of 160 m to 190 m (Supplementary Figure 3-4). Standing stock population by instar shows extremely low levels of fishable instars, and high levels of instars too young to be catch targets (Supplementary Figure 3-4). Even if standing stock in depths of 190 m or shallower is included in Area A, the contribution to catch in weight forecasts is extremely small. Stock distribution in waters of 190 m or shallower is influenced by the distribution of cold water off Hamada, but most of the stock in this area is considered to migrate to deeper waters as they mature. Surveys must continue to be conducted in this area to understand yearly changes in snow crab distribution.

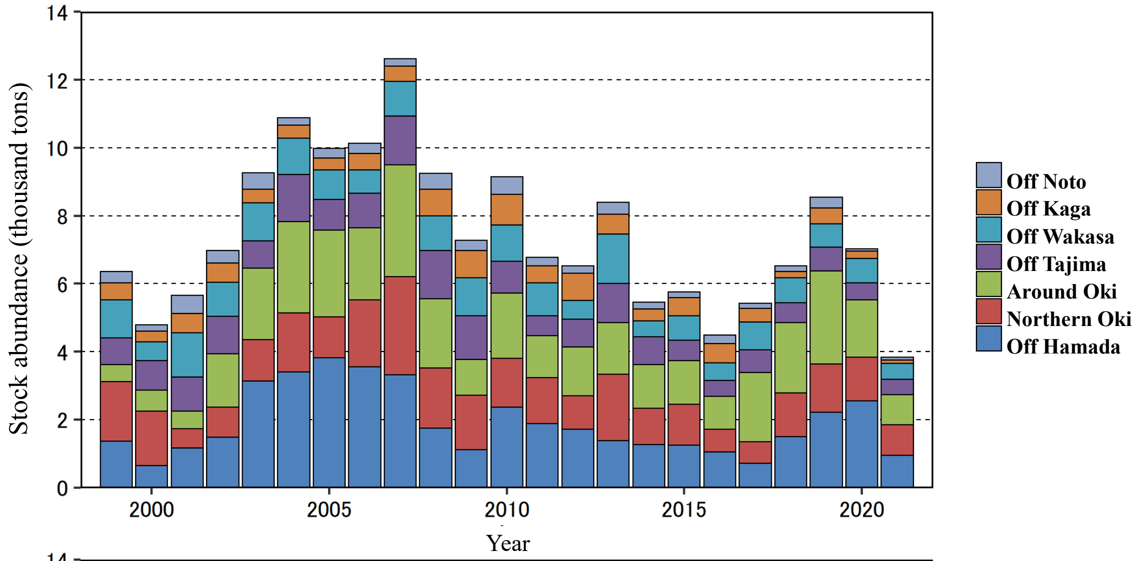
In the western part of the Sea of Japan, concrete blocks have been placed to form conservation zones which make operations using bottom-trawl nets impossible. Currently, it is difficult to estimate the standing stock across all conservation zones. Meanwhile, the population of female crabs is expected to increase inside of these conservation zones, and trawl surveys have shown that recruitment will increase based on the stock-recruitment relationship, and trawl surveys have also shown some stock emerging from these conservation zones. The effects of these conservation zones are reflected in the calculations for ABC in this evaluation.

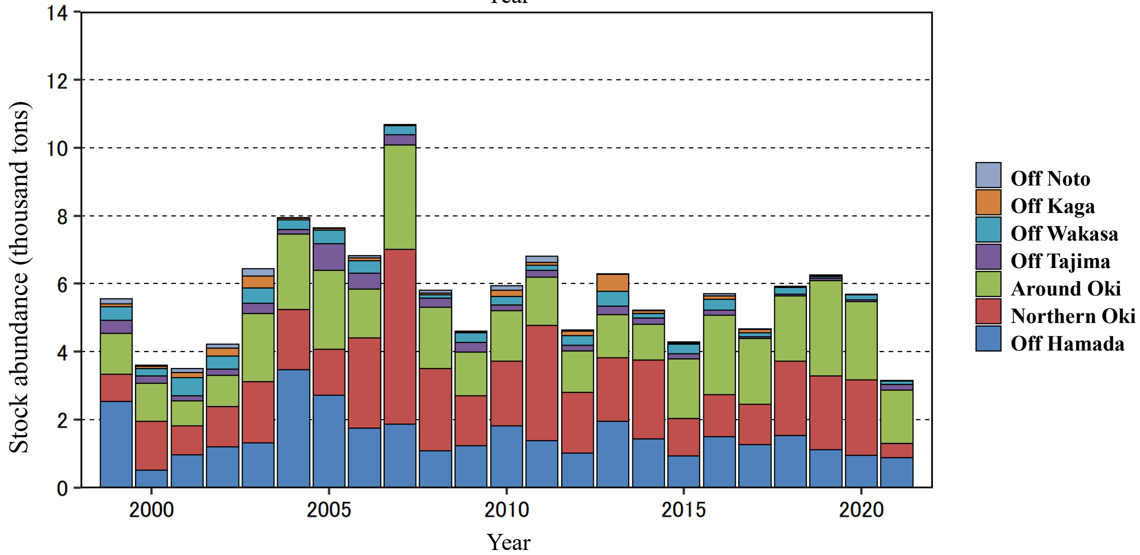


Supplementary Figure 3-1. Trawl survey areas
Numbers indicate survey sites, and the yellow line near the coast indicates the 200-m isobath.



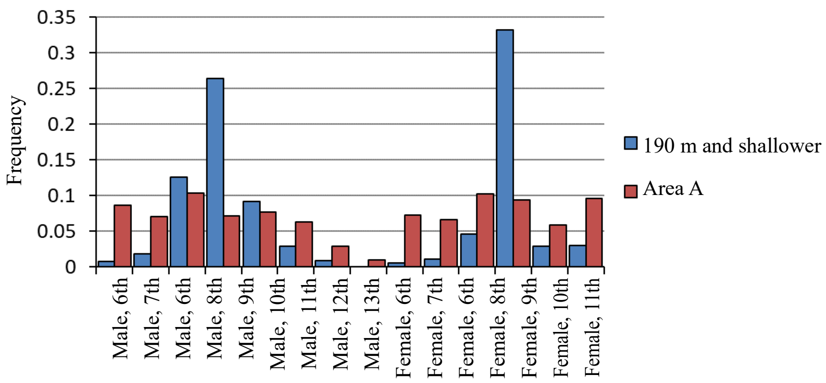
Supplementary Figure 3-2. Carapace width composition by area estimated from trawl surveys (left: males, right: females)





Supplementary Figure 3-3. Standing stock by area estimated from trawl surveys

These graphs show standing stock of males with a carapace width of 90 mm or more (top), and females in the 11th instar (bottom).



Supplementary Figure 3-4. Instar composition of the standing stock population in depths of 190 m and shallower

Appendix 4 Difference in Capture Efficiency of New Style and Old Style Trawl Nets

(Cooperation: Demersal Fish Group 2, Demersal Fish Resources Division)

Demersal Species Stock Surveys for Sea of Japan Snow Crabs were conducted by the Tanshu Maru (499 tons) using NT-4 style bottom-trawl nets (old style nets) until 2014. Since 2015, smaller NOB-81 bottom-trawl nets (new style nets) have been used, which have made fishing operations run smoothly even when using 350 ton class vessels, such as the replacement for the Tanshu Maru (358 tons). In order to determine the difference in capture efficiency between old style and new style nets, parallel surveys were conducted with old style and new style nets in 2014 and 2015.

These parallel surveys were conducted in late September of 2014 and 2015 at 16 survey sites in the waters east and west of the Oki Islands. In 2014, surveys were conducted with old style nets first, then the vessel returned to port and changed its net before continuing surveys. In 2015, the new style net surveys were conducted first. The lines of both styles of nets were towed at the same depth along a parallel course.

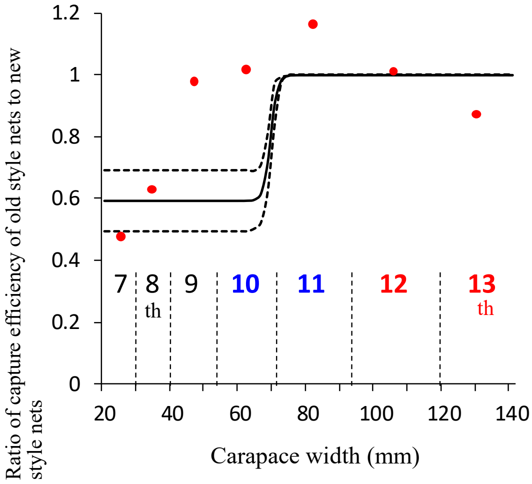
Both the old style and new style nets captured males with a carapace width of 10 mm or more to 150 mm or more, and females with a carapace width of 10 mm or more to 90 mm or more. A Gaussian function was fitted to the carapace width composition by sex and by net style, with consideration for the differences in distribution of snow crabs encountered by both types of nets at the same site during the survey, and a generalized logistic equation was assumed for the differences in capture efficiency by carapace width for both types of nets to estimate the parameters.

Results showed that the ratio of capture efficiency (fx) of old style nets to new style nets was 1 for carapace widths of 70 mm or more (11th to 13th instar), which means no difference between net styles, but was 0.6 for carapace widths of 70 mm or less (6th to 10th instar) (solid black line and equation in Supplementary Figure 4-1). Next, we calculated the yearly transition rate (ratio of the stock population in instar (i) for year (y) against the stock population in instar (i+1) for year (y+1)) using the actual stock population by year and by instar from trawl surveys, and determined the difference of the transition rates in 2004 to 2014, when old style nets were used for surveys, and the transition rate in 2015, when new style nets were introduced (red dots in Supplementary Figure 4-1). Transition rates for the 7th and 8th instars decreased to 0.46 and 0.65, respectively, in 2015 compared to rates up to 2014, which were close to the estimates in our model. Meanwhile, values for the 9th and 10th instars were 0.96 and 1.04, respectively, which were different from the estimates in our model. Actual values for the 11th to 13th instars from trawl surveys are scattered, but are inferred to be around 1.

Model estimates and actual values from trawl surveys for the 9th and 10th instars showed different values for the difference in capture efficiency for both net styles. The reason for this may be because the model used parallel operation data from areas with a hard and stable sea floor where towing is easy, unlike actual trawl surveys which are often in complex areas like muddy sea floors where towing is not easy, so we believe that things like mud being trapped in the nets led to a higher capture efficiency. Next, investigations and adjustments were completed before the 2016 trawl surveys regarding factors like warp length in order to ensure stable towing with the new style nets across a diverse range of bottom conditions. Therefore, we decided to correct the capture efficiency of the new style nets based on 2017 trawl survey data. For the 9th instar, a ratio of 0.6 was chosen for the capture efficiency ratio of old style nets to new style nets, based on the results from parallel operations. For the 10th instar, we assumed a ratio of 0.8 because it is the intermediate value between 0.6 and 1. This was chosen because the majority of results from parallel operations were 0.6, and the remainder were 1 (Supplementary Figure 4-1), and because 2017 trawl surveys showed no significant difference in the stock population compared to the population up to 2016, when capture efficiency was unusually high.

The ratio of capture efficiency of old style nets to new style nets by instar and capture efficiency by instar, as discussed above, are shown in Supplementary Table 4-1.

$$f_x = 0.593 + \frac{0.407}{1 + exp(68.7 - 0.998x)}$$



Supplementary Figure 4-1 The ratio of capture efficiency of old style nets to new style nets, estimated from parallel surveys and actual trawl survey results

The solid black line indicates a generalized logistic equation from parallel surveys, and the red dots indicate the values for each instar from actual trawl surveys in 2015.

Supplementary Table 4-1. Capture efficiency of old style nets by instar, ratio of capture efficiency of old style nets to new style nets, and capture efficiency of new style nets

	6th	7th	8th	9th	10th	11th	12th	13th
Capture efficiency of old style nets	0.442	0.442	0.442	0.442	0.442	0.442	0.442	0.442
Ratio of capture efficiency of old style nets to new style nets	0.6	0.6	0.6	0.6	0.8	1	1	1
Capture efficiency of new style nets	0.265	0.265	0.265	0.265	0.354	0.442	0.442	0.442

All values apply to both sexes.

Appendix 5 Catch in weight of Sea of Japan Area A snow crabs

Catch in weight of snow crabs in Sea of Japan Area A was summarized (Supplementary Table 5-1).

Catch in weight in Area A peaked in the 1960s and 1970s, and changes in commercial size category composition of catches were seen during this period. The waters surrounding the Oki islands, which were the main fishing grounds in that period, had a high ratio of large hard shells in the mid-1960s. When this ratio declined, the ratio of cheaper, smaller hard shells and soft shells, which were previously dumped back into the sea, increased through 1970 (Ogata 1974). The increase in dependence on these cheaper commercial size categories allows us to infer that stock conditions had become worse at the peak in 1970 compared to during the 1960s.

References

T. Ogata (1974) Notes on the Ecology and Fisheries of the Zuwai Crab, Chionoecetes opilio (O. Fabricius) in the Japan Sea. Fisheries Research Series, 26, Japan Fisheries Resource Conservation Association, Tokyo, pp. 64.

Supplementary Table 5-1. Catch in weight of snow crabs in Sea of Japan Area A (tons)

Year	Area A total (calendar year)	Area A offshore trawl (fishing year)	South Korea (calendar year)
1954	8,573		
1955	8,501		
1956	7,721		
1957	9,079		
1958	10,274		
1959	10,039		
1960	12,468		
1961	12,041		
1962	13,841		
1963	14,568		
1964	14,600		
1965	10,228		271
1966	9,641		403
1967	9,275		756
1968	10,811		435
1969	11,194		253
1970	14,234	11,265	247
1971	12,172	10,834	494
1972	12,056	7,980	132
1973	8,205	5,689	355
1974	6,434	4,024	340
1975	4,767	3,378	100
1976	4,308	3,091	9
1977	4,619	3,162	144
1978	4,367	3,158	228
1979	4,424	3,185	155
1980	4,035	2,911	193
1981	4,187	2,813	125
1982	3,529	2,329	73
1983	3,577	2,307	183
1984	3,015	1,885	6
1985	2,932	1,361	14
1986	2,591	1,278	9
1987	2,096	1,334	4
1988	1,929	1,131	10
1989	1,863	1,081	3
1990	1,806	1,044	3

Year	Area A total (calendar year)	Area A offshore trawl (fishing year)	South Korea (calendar year)
1991	1,691	903	2
1992	1,621	935	11
1993	1,880	1,215	94
1994	2,424	1,424	98
1995	2,490	1,541	79
1996	2,631	1,602	133
1997	2,938	1,959	815
1998	3,282	2,418	459
1999	3,415	2,733	1,134
2000	3,521	2,472	756
2001	3,501	2,514	1,001
2002	3,735	2,891	896
2003	4,155	3,132	1,889
2004	4,698	3,600	2,605
2005	4,120	3,402	3,240
2006	4,841	3,706	4,062
2007	4,978	3,891	4,817
2008	4,434	3,115	3,019
2009	3,913	2,808	2,372
2010	4,058	3,060	2,606
2011	3,810	3,016	2,567
2012	3,822	2,822	2,317
2013	3,550	2,458	1,868
2014	3,271	2,439	2,411
2015	3,123	2,284	1,917
2016	2,996	2,242	1,570
2017	2,774	2,126	1,869
2018	3,213	2,225	1,449
2019	2,386	1,894	1,251
2020	2,416	1,777	-

*Area A total in 2020 is approximate.
*The percentage of Area A within South Korea's catch in weight is unknown.

Appendix 6 Method for Calculating Abundance Indices Using Japanese logbooks for the offshore trawlers

Abundance indices based on Japanese logbooks for the offshore trawlers were summarized (Supplementary Figure 6-1, Supplementary Table 4-1).

Records in logbooks report catch in weight and number of nets by month and by sub-area (latitude and longitude are recorded in a 10 minute grid). Based on these, CPUE (U) in month (i), sub-area (j) is expressed in the following equation:

$$U_{i,j} = \frac{C_{i,j}}{X_{i,j}}$$

In the equation above, C is catch in weight, and X is effort (number of nets).

The abundance index (P) in the aggregation unit (year, fishing season, etc.) is expressed as the total CPUE in the following equation:

$$P = \sum_{i=1}^{I} \sum_{j=1}^{J} U_{i,j}$$

The relationship between the effective fishing effort (X'), catch in weight (C), and abundance index (P) in the aggregation unit is expressed in the following equation:

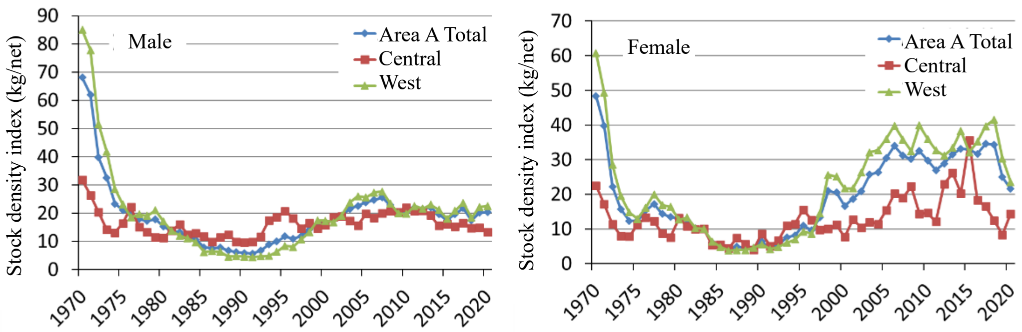
$$P = \frac{CJ}{X'} \text{ therefore } X' = \frac{CJ}{P}$$

In the above equation, J is the actual number of sub-areas with catch, and the stock density index (D) is calculated by dividing the stock abundance index (P) by the number of sub-areas with catch (J).

$$D = \frac{P}{J} = \frac{C}{X'}$$

In this stock, the effort is the total number of nets from non-zero catch data in logbooks. This stock is the most important species for offshore trawlers with limited fishing season, therefore, most hauls during the fishing season are non-zero catches by operations targeting this stock (Inoue and Harada, unpublished data). Accordingly, there is only a small difference in calculated values such as stock density index whether effort is calculated as the number of non-zero catches, or as the total number of nets during the fishing season.

For this species, it is thought that the influence on changes such as the expansion or contraction of the distribution area due to changes in stock abundance is small, so the stock density index, which does not take into account the number of sub-areas, is used as a long-term abundance index value.



Supplementary Figure 6-1. Area A stock density indices(West: west of Tajima, Central: east of Wakasa)

Appendix 7 CSC key updates for Hyogo catches

In this stock, the catch in number by instar for the entire area is estimated based on the results of market surveys conducted in Hyogo, Tottori and Kyoto. In Hyogo, instar composition stratification of catches is based on catch in weight by commercial size category (CSC) and CSC-instar keys (hereinafter referred to as "CSC keys"). Periodic review of CSC keys can provide us with a more accurate understanding of catch in number by instar. Therefore, CSC keys for age stratification for the past 10 years (2010 to 2020) were reviewed this financial year, with the cooperation of the Tajima Fisheries Technology Institute, Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries.

Catch in number by instar for this area is shown in Figure 7-1. Results of CSC review led to changes for catch in number, mainly by allocating the catch of 12th instar hard shells to the catch of 13th instar hard shells. In addition, the catch in number for 12th and 13th instar soft shells also changed slightly, but soft shells are only a small proportion of total catch in number, so the change in catch in number was small.

In order to see the impact of Hyogo CSC key revisions on stock assessment results, yearly rates of change for stock abundance by commercial size category and F were determined for both before and after CSC key review (Table 7-1). Rates of change for stock abundance ranged from -0.6% to 0.9%, and rates for F ranged from -1.0% to 0.8%. The 12th and 13th instar hard shell groups are plus groups which have already completed their terminal molts, so we don't expect weight changes related to growth. In addition, the transition rate and natural mortality coefficient of hard shells for cohort analysis remain the same regardless of instar, so as long as there are no weight changes for the hard shell CSC, the impact on the stock assessment results is small. Therefore, we used the catch in number by instar after the Hyogo CSC key review for stock assessment in this financial year.

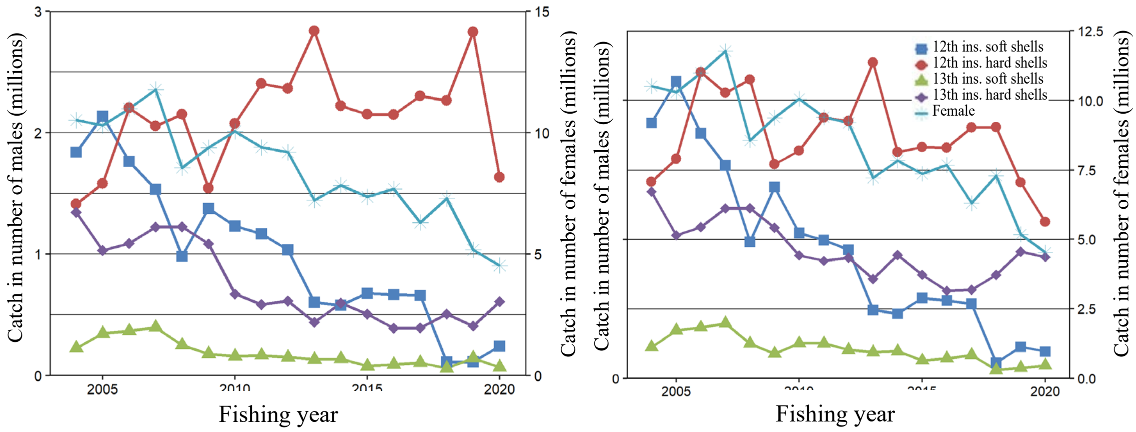


Fig. 7-1. Catch in number by instar in this area

Comparison of before (left) and after (right) the Hyogo CSC key review.

Table 7-1. Rate of change in stock abundance and F due to CSC key review (%)

Fishing year	Stock abundance			F		
	Soft shells	Hard shells	Female	Soft shells	Hard shells	Female
1999	0.1	-0.2	0.1	-0.1	0.2	-0.1
2000	0.0	-0.5	-0.1	0.0	0.8	0.1
2001	0.0	-0.4	0.0	0.0	0.7	0.0
2002	0.0	-0.2	0.0	-0.1	0.2	0.0
2003	-0.1	-0.1	0.0	0.1	0.1	0.0
2004	0.0	-0.1	0.1	0.0	0.1	-0.2
2005	0.1	-0.2	0.1	-0.1	0.3	-0.1
2006	0.1	-0.3	0.2	-0.1	0.4	-0.2
2007	0.2	-0.3	0.2	-0.2	0.3	-0.2
2008	0.1	-0.3	0.0	-0.1	0.3	0.0
2009	0.0	-0.6	0.1	0.0	0.8	-0.1
2010	0.1	-0.4	0.0	-0.1	0.5	-0.1
2011	0.1	0.0	0.1	-0.1	0.0	-0.1
2012	0.1	0.3	0.0	-0.1	-0.4	0.0
2013	0.0	0.2	0.0	0.0	-0.3	0.0
2014	-0.1	0.5	-0.2	0.1	-0.6	0.2
2015	-0.1	0.4	-0.1	0.1	-0.6	0.2
2016	0.0	0.5	0.0	0.0	-0.7	0.0
2017	0.0	0.4	0.0	0.0	-0.5	0.0
2018	0.0	0.2	0.0	0.0	-0.3	0.0
2019	-0.1	0.1	-0.2	0.1	-0.2	0.3
2020	-0.1	0.9	-0.1	0.1	-1.0	0.1
2021	0.0	0.4	-0.1	0.1	-0.5	0.1

Appendix 8 Decline in Standing Stock in Waters North of Oki and Off Hamada

The results of stock assessment for this financial year show that the standing stock of catch targets has declined significantly since 2020, specifically, there was a remarkable decrease in females in the waters north of Oki (offshore trawl fishery sub-area, hereinafter referred to as “sub-area”) (Appendix 3, Supplementary Figure 3-3). Clarification of the factors behind the decline of this stock is expected to improve the accuracy of future forecasts, and to provide knowledge for more effective management. We investigated the factors behind the decline of this stock through comparison of habitats using a distribution model, and by visualizing the exploitation rate by sub-area based on the Japanese logbooks for offshore trawlers (catch reports).

Our investigation used the trawl survey results used for stock assessment in this area (Demersal Species Stock Surveys for Sea of Japan Snow Crabs, Appendix 3), in addition to data from surveys conducted from 2018 to 2021 at 527 sites, specifically capture in number, latitude and longitude, and depth for female crabs (11th instar), and ocean floor slope angle and terrain indices (Topographic Position Index, TPI) calculated from 0.25 minute (approx. 300 m) mesh data in the General Bathymetric Chart of the Oceans (GEBCO). Catch in weight of female snow crabs by year and by sub-area was obtained from catch reports.

We constructed our model using a generalized additive model (GAM) with a negative binomial distribution for error structure, and in addition to the effects of each Year, we assumed the following splines: Depth, Slope, TPI, Latitude/Longitude, and the interactions between Latitude/Longitude and Year, and Depth and Year.

The following model was selected through the best subset approach based on AIC:

$$N \sim \text{Year} + s(\text{Depth}) + s(\text{Slope}) + s(\text{Latitude, Longitude}) + \text{Year} \times s(\text{Latitude, Longitude})$$

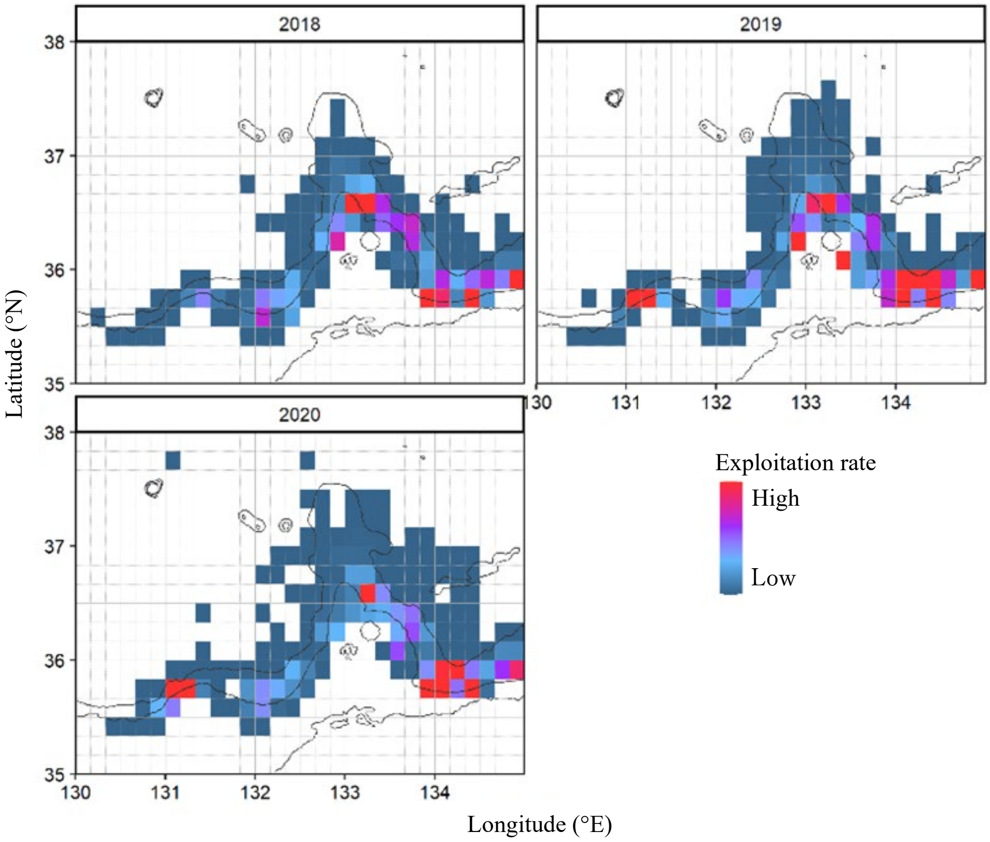
Because our best model did not include the interaction between Depth and Year, we believe that the impact of yearly changes in depth on stock distribution is not significant for females. Meanwhile, because the interaction between Latitude/Longitude and Year was included in our best model, we expect to see differences in stock distribution by area for each cohort.

Using the standing stock forecasts for each fishery management sub-area (10 minute grid) for each year based on the distribution model, we forecasted the stock abundance by sub-area for each fishing year, and divided the catch in weight by year and by sub-area based on catch reports to estimate the exploitation rate by sub-area for each year (Supplementary Figure 8-1). The exploitation rate by sub-area was high in the waters north of Oki in 2018 and 2019, but showed trends of decline across all areas in 2020. Therefore, it is unlikely that the rapid decline in stock abundance was due to excessive fishing pressure.

The points discussed above indicate that the rapid decline in fishable stock is, 1. probably not due to changes in distribution depth layers, and 2. not due to overfishing. We will continue to investigate the reasons behind the rapid decline of this stock in 2021.

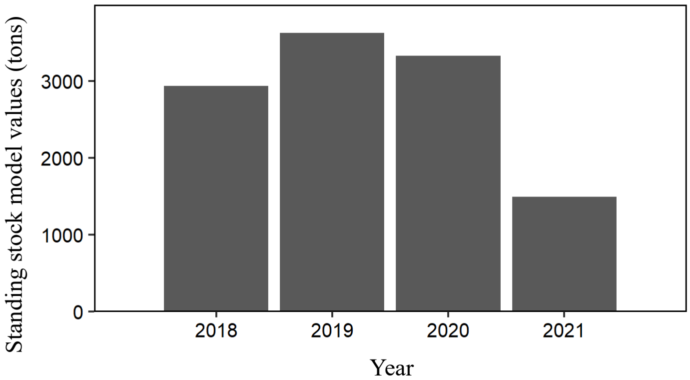
The standing stock forecast for the waters north of Oki was calculated based on the distribution model, and we re-confirmed that the stock declined from 2020 to 2021 (Supplementary Figure 8-2).

Meanwhile, standing stock based on the distribution model showed a smaller decrease than standing stock based on the swept-area method. Bias caused by deviation in fixed sites by depth layer was standardized based on the distribution model, which may have resulted in more accurate forecasts. In the future, we will also investigate the effectiveness of standing stock forecasts based on the distribution model for male crabs, and we will consider including it in our evaluations.



Supplementary Figure 8-1. Changes over time in exploitation rate of females (11th instar) based on the distribution model

The exploitation rate was calculated based on standing stock forecasts by year and by fishery management area, and catch in weight by fishing year and by sub-area from catch reports.



Supplementary Figure 8-2. Changes over time in standing stock of females in the waters north of Oki (at the time of surveys, akako) based on the distribution model

These values are different than standing stock based on the swept-area method used in the stock assessment for this financial year.