Peer Review of Japanese Snow Crab Stocks in 2022

April 30, 2023

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Background

The Fishery Research and Education Agency (FRA) of Japan organized an independent peer review of selected invertebrate stock assessments in 2022. Invited peer reviewers included two external reviewers from the National Oceanic and Atmospheric Association (NOAA) Fisheries' Southwest Fisheries Science Center (Drs. Steve Teo and E.J. Dick). Reviewers were asked to participate in the assessment review meetings and submit peer review reports (this document). Several documents were made available for consideration prior to the review panel meeting, including:

1. FRA-SA2021-RC05-1e Stock assessment and evaluation for North Pacific stock of snow crab
2. FRA-SA2021-RC06-1e Stock assessment and evaluation for Sea of Japan Area A stock of snow crab
3. FRA-SA2021-RC06-2e Stock assessment and evaluation for Sea of Japan Area B stock of snow crab
4. FRA-SA2021-RC04-1e Stock assessment report on winter-spawning stock of Japanese flying squid
5. FRA-SA2021-RC04-2e Stock assessment report on autumn-spawning stock of Japanese flying squid
6. Supplementary material-Estimating MSY of snow crab
7. Supplementary material-Standardized CPUR for Autumn-spawning stock (flying squid)
8. Supplementary material-Standardized CPUR for winter-spawning stock (flying squid)

Other documents made available to the reviewers included electronic copies of presentations given by analysts during the meeting, an article concerning estimation of MSY for snow crab stocks (Shibata et al. 2020), and two reports detailing standardization of the CPUE. The project manager of the peer review requested that the external reviewers prepare and submit pre-review questions to the assessment teams a month in advance of the meeting, to allow them time to organize their responses. Copies of the pre-review questions from Dr. Dick are included here as Appendix A.

Reviewing system

The peer review was conducted the week of November 7th, 2022, via a hybrid meeting format, i.e., attendees present either online or in-person. Pre-review questions were requested well in advance and submitted a month prior to the meeting, and translation services were provided during the meeting itself. I appreciated having the opportunity to prepare questions in advance, as it would have been difficult for the stock assessment teams to prepare meaningful responses during the review meeting. A large fraction of the presentations for each stock were devoted to answering the pre-review questions, which was an efficient use of time and provided an opportunity to explore additional questions as they arose.

Stock assessment review report

1. Snow Crab, North Pacific Stock

   The most recent stock assessment for the North Pacific stock of snow crab was developed using the "Just Another State-Space Stock Assessment Model" (JASAM), producing estimates of abundance, recruitment, natural mortality rates, and exploitation rates from 1997-2020. The stock assessment team presented results of the assessment, and responses to the pre-review questions (Appendix A). A summary of key issues and recommendations is provided in the following paragraphs, with reference to biological data and assumptions, fishery-dependent and fishery-independent data sources, model configuration and estimation procedures, and methods for forecasting yield.

   At the request of the reviewers, a detailed description of methods used to calculate the survey index was included in the stock assessment team's presentation. It was noted that the survey covers the range of the stock as defined for management, but additional research is needed to understand connectivity between the North Pacific management area and adjacent waters. Given that pelagic phases of the life history last for 2-3 months, the possibility of long-range larval dispersal should be considered in such an analysis. Genetic analysis of stock structure would be useful, particularly if there is evidence of genetic differentiation between this and adjacent stocks. However, if it is found that there is no evidence of genetic structure, other factors may affect demography and dynamics support management of the stock at finer spatial scales.

   A defining event in the fishery was the 2011 Tohoku Earthquake and Tsunami event (hereafter referred to as the Earthquake). Fishery data included a time series of catch, effort, and catch per unit effort (CPUE) from 1997 to present, showing a drastic decline in fishing effort since the Earthquake. Discussion during the review highlighted the increased, but highly variable, estimates of CPUE in years after 2011. However, stock assessment analysts noted that fishing effort since 2011 has been limited in time and area; therefore, commercial CPUE since 2011 is not considered to be a good indicator of stock size since 2011 due to smaller sample sizes, as well as limited temporal and spatial coverage. After further consideration, it was recognized that CPUE prior to the earthquake could still be included in the model, to inform trends in abundance prior to 2011. Should such an approach be taken, I propose analysis of historical catch rates by block (or latitude/depth bins) and perhaps filtering the data using either available habitat information or species composition of the catch. This would reduce the influence of catch rates in areas that are not snow crab habitat on the CPUE trend.

A key element of the stock assessment model (JASAM) is the assumption and estimation of time-varying natural mortality (M). Over the course of the assessed time period, estimated annual M values in the model increase by a factor or 2-3 times. It is clear that allowing for time-varying M improves the model's ability to fit the data. However, as pointed out by Dr. Teo, other un-modeled or otherwise misspecified processes could also explain the patterns in the data, and there is no well-documented relationship between the estimated changes in M and observed biological or environmental drivers. For that reason, continued investigations into alternative hypotheses (e.g. time-varying growth) are encouraged. Other hypotheses that could explain the patterns attributed to increasing M, such as shifts in stock distribution or emigration, were not considered likely by the stock assessment team. The analysts noted that the depth range of the stock has not shifted over time based on survey data. In addition to looking at the range, it would be helpful to plot catch-weighted mean depth as a function of time, again using the survey data.

Treatment of discarded catch in the model was also a topic of frequent discussion during the review. At present, there appears to be no information about fraction of catch that is discarded by instar, or mortality rates of those discarded crabs. The assessment team indicated that discard is implicitly included in M. However, if discard mortality is large, then the assumption that discard is included in M will not accurately characterize total fishing mortality or the stock's projected response to changes in fishing effort ("M" will be higher in years with greater catch and associated discard). Random assignment of onboard observers, with minimum observation periods to avoid short-term modification of fishing behavior, could be used to inform discard rates. Discard mortality (e.g. due to heat shock at the surface) could be initially investigated in a laboratory setting.

It is possible that fitting the stock-recruitment curve outside of the assessment model results in a situation where the replacement line (largely a function of M) is steeper than the slope of the stock-recruitment relationship at the origin? If so, that would indicate serious model misspecification, as such a stock could not persist even in the absence of fishing.

For forecasts, the stock-recruitment relationship was not incorporated in the JASAM framework. Estimates assume a 5-year lag in recruitment, similar to the Sea of Japan stock. The estimates of spawning stock biomass and recruitment from the population dynamics model were fit to a hockey-stick model for stock-recruitment using least squares. Autocorrelation of residuals in recruitment was also considered.

Sensitivity runs to the assumed value of natural mortality (M) in forecasts did not change the outcome. Projections using the current M, lower M, and recent recruitments imply a declining stock even if fishing is stopped altogether. It is possible that fitting the stock-recruitment curve outside of the assessment model resulted in a situation where the replacement line (largely a function of M) is steeper than the slope of the stock-recruitment relationship at the origin. If so, that would indicate serious model misspecification, as such a stock could not persist even in the absence of fishing (consistent with the projections of a declining stock, even in the absence of fishing).

The stock assessment team was asked in the pre-review questions to describe the pros and cons of implementing a male-only fishery. They cited pros as preservation of spawning output, and cons as possible sperm limitation. It was also noted that eggs can be a desirable part of the catch. If it's possible for fleets to target sexes, as noted by the assessment team for the Area A stock, then it might be worth considering how regulations could be structured to reduce total annual mortality of females (e.g. shortened seasons and/or depth restrictions).

2. Snow Crab, Sea of Japan Area A

The most recent stock assessment for the snow crab stock in the Sea of Japan (Area A) was developed using a modified (forward calculation) cohort analysis, bottom trawl fishery data, and bottom trawl surveys. This approach produced estimates of abundance, recruitment, natural mortality rates, and exploitation rates from 1999-2021. The stock assessment team presented results of the assessment, and responses to the pre-review questions (Appendix A). A summary of key issues and recommendations is provided in the following paragraphs, with reference to biological data and assumptions, fishery-dependent and fishery-independent data sources, model configuration and estimation procedures, and methods for forecasting yield. Areas A and B were described as administrative boundaries, with no evidence of stock structure. However, regulations in each area are different, as are the characteristics of the vessels in each area.

The stock assessment team began the review with a summary of the fishery and management areas. It was noted that the fishery in Area A is characterized by larger vessels, longer trips (3-5 days), larger annual catches, and higher prices. In contrast, Area B has smaller vessels, shorter trips (typically 1 day), smaller overall catches, and lower prices. A key source of uncertainty in these areas is the lack of information about catch by foreign fleets, and connectivity between snow crabs in other parts of the Sea of Japan. If foreign fleets are harvesting unknown amounts from the same stock, it will be difficult to estimate long-term sustainable yields using data from Areas A and B alone. This is one of the largest sources of uncertainty for the stock, as biased estimates of catch will affect estimates of population scale.

During a discussion of possible sensitivity analyses to the scale of foreign catch, it was noted that Korean catch is male-only. This suggests that studying the mortality rate of discarded females is key to understanding impacts of Korean fleets on stock productivity. If discarded females had a high survival rate, that would reduce the impacts of foreign catch on total egg production, and would increase confidence in model results based solely on data from Areas A and B.

When inquiring about alternative hypotheses to time-varying M, the idea of shifts in stock distribution was brought up, and whether the survey might be affected by such a shift. The assessment team confirmed that the survey covers the vast majority of the stock's depth distribution. This is based on observations from beam trawls fishing in deeper depths.

In response to questions from both reviewers regarding the ability to report fishing effort by sex, it was explained that fishers can target sexes by depth and location. This explains the discrepancy between reported number of casts, in light of differences in the duration of the fishing season (231 days for males and 55 days for females).

An interesting feature of the model for Area A in the Sea of Japan is the combination of factors contributing to the transition rates among instars. The transition rate includes natural mortality, bycatch from the domestic fleet, catch by foreign fleets, changes in juvenile catchability, and movement (emigration and immigration). Presumably this is due to the fact that most of these processes are not observed. Continuing studies to quantify these factors is encouraged, particularly those which could be observed such as bycatch rates.

It appears that there is interest in using time-varying M for all snow crab stocks. Responses to questions about this assumption often included the observation of improved fits to the data. This is expected due to the increase in the number of parameters in the model, but does not by itself suggest that time-varying M is the mechanism driving patterns in the data. Other possible explanations include time-varying growth, shifts in population distribution, and/or availability of the stock to the fishery. Each of these alternative hypotheses should be explored and their impacts to management advice evaluated. If M is defined as including foreign catch, then fluctuations in foreign catch could 'drive' changes in M, and reduce the chances of detecting environmental factors affecting M.

I recommend exploring integrated analysis models for this stock (c.f. Turnock and Rugalo, 2015). The combination of a strong cohort signal in the size composition data and a long-term index of abundance (1970-present) would allow for simultaneous estimation of natural mortality and stock-recruitment parameters, recruitment deviations, growth parameters, and gear selectivity. It was encouraging to hear from the stock assessment team that there are plans to evaluate a new model (perhaps a state-space implementation), as this would allow for exploration of time-varying growth as an alternative to the hypothesis of time-varying M. As noted by the assessment team, this would also require standardization of long-term indices.

Given that fishers can target sexes by depth and location, it is also possible to evaluate impacts to stock status under a range of sex-specific harvests. Alternative management decisions (i.e. varying duration of female fishing season) could be included in forecasts, evaluating projected stock size under alternative sex-specific catches.

During the review, there was a discussion of how the reported probabilities of SSB exceeding reference points currently do not include parameter uncertainty. I propose that uncertainty in the stock-recruitment parameters for the Ricker curve can be integrated into the forecast simulations by drawing 10,000 pairs from the bivariate covariance matrix (representing parameter uncertainty), and then drawing a random lognormal recruitment deviation for each set of parameters draws. Evidence of density-dependent cannibalism was cited as justification for the Ricker curve, in addition to selection of a Ricker shape by AICc. However, a transition to an integrated analysis model could automatically include parameter uncertainty and recruitment variability into the forecasts.

Given the known difficulties with selecting among stock-recruitment relationships, as well as evidence of density-dependent cannibalism, would it be wise to select a Ricker stock-recruitment model for all Japanese snow crab stocks?

There was discussion of why Fmsy in Figure 4-10 was greater than Fmax, and the stock assessment team indicated it was going to investigate. This is worth investigating, because the fishing mortality rate that maximizes yield per recruit (Fmax) does not take into account reductions in spawning output associated with stock depletion, resulting in Fmax > Fmsy. Dr. Teo suggested it might be due to the choice of stock-recruitment relationship, as opposed to a Beverton-Holt or hockey stick model.

3. Snow Crab, Sea of Japan Area B

The most recent stock assessment for the snow crab stock in the Sea of Japan (Area B) was developed using an estimate of stock abundance derived from pot survey data and a proxy fishing mortality rate. This approach produced estimates of abundance by sex from 1998-2020. The stock assessment team presented results of the assessment, and responses to the pre-review questions (Appendix A). A summary of key issues and recommendations is provided in the following paragraphs, with reference to biological data and assumptions, fishery-dependent and fishery-independent data sources, model configuration and estimation procedures, and methods for forecasting yield. Areas A and B were described as administrative boundaries, with no evidence of stock structure. However, regulations in each area are different, as are the characteristics of the vessels in each area.

In addition to the differences between Areas A and B that were noted in the review of the Area A assessment, it was noted during the Area B review that, in general, this area has less available data, the sea bed is rocky and steeply sloped, and fishing regulations are customized to this region. Although “data-poor” relative to other snow crab stocks, the availability of biomass estimates from a fishery-independent survey is an incredibly useful source of information for the Area B stock.

Connectivity between the stocks was also discussed. It is believed that juveniles migrate. Larval dispersal is unknown, and genetic research is underway. It may be possible to infer at least the direction of larval dispersal from models of ocean currents if those are available.

Logbook data were presented for the time period 1978-2021. These data were used to calculate average kilograms per net by sex and year (Figure 4-8 in the assessment report). The average catch rates display considerable interannual variability, with a long-term increasing trend. It seemed like the logbook data could be refined to account for differences in effort among smaller and larger vessels, or, estimated only for vessels of similar size. Currently, fishing effort is the number of casts. If vessel tonnage or other factors related to catch per cast are known, this could be used to link logbooks to vessel size, and the index could be standardized to remove changes over time in differences in average vessel size. If data on species composition of the catch, either by haul or trip, are available from logbooks, then it might be possible to further restrict hauls used for the index to those that catch snow crab and co-occurring species, and to exclude hauls with species that might be counter-indicators of snow crab habitat.

As the abundance estimates from the pot survey are critical to yield recommendations, I recommend using all available sources to validate estimates of abundance. For example, obtaining the data from the beam trawl survey conducted since 2016 would allow for comparison of the estimates of stock abundance from the beam trawl survey to the estimates from the pot survey. The beam trawl data could also potentially inform recruitment. Alternatively, the pre-review comments described how underwater visual survey transects (e.g. ROV or perhaps AUV due to the depth) could be used to estimate crab densities, with pot or other gear types used to verify size, sex, and maturity. The assessment team noted that video observation has been used to evaluate catch efficiency. However, the pre-review suggestion was focusing on an independent source of density information, one that would not rely on assumptions about pot gear efficiency. It would be useful to have a direct measure of density to evaluate potential bias in pot survey density estimates.

Another option that was discussed to evaluate the biomass estimates from the pot and beam trawl surveys is to model the entire Sea of Japan (Areas A & B) as one stock, in addition to modeling Area A as is currently done. An estimate of the biomass in Area B could then be calculated as the biomass of Areas A and B combined, minus the biomass of Area A.

Growth in Area B is assumed to be the same as growth in Area A due to a lack of data from Area B. An investigation of growth in Area B should be conducted to evaluate the validity of this assumption.

Initially, it was not clear to this reviewer how population status was determined. The stock assessment team explained that a target level for the abundance index (in units of kg/net) was defined using a cumulative normal distribution fit to the time series of the index. While this approach does not provide information about how large the stock is relative to Bmsy, it is a reasonable approach, with limit values in place to prevent large declines in catch rates relative to historical values.

Estimates of stock size from the surveys are reported without measures of uncertainty. Since yields are based on the product of stock biomass and a proxy for Ftarget (F30%spr), both quantities could be expressed with uncertainty, allowing for communication of uncertainty in catch recommendations to managers.

Overall comments for snow crab assessments

Overall, the quality of the three assessments for snow crab stocks examined during the review, as well as the presentations given by the assessment teams, were excellent. I appreciate and recognize that the assessment teams spent considerable time and effort addressing numerous pre-review questions, and found their answers to be informative and reasonable.

References

Turnock, B. and L. Rugalo. 2015. Stock Assessment of eastern Bering Sea snow crab. https://www.fisheries.noaa.gov/resource/data/2015-alaska-crab-stock-assessment-and-fishery-evaluation-report.

Appendix A

Pre-review questions regarding three stock assessments for snow crab in fiscal year 2021

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Several documents were made available for consideration prior to the panel meeting. These included assessments for the following three stocks of snow crab in fiscal year 2021:

1. North Pacific stock
2. Sea of Japan Area A stock
3. Sea of Japan Area B stock

A published research paper was also provided (Shibata et al. 2020), describing a method for estimation of maximum sustainable yield for snow crab using a state-space assessment model with time-varying natural mortality. The purpose of this document is to provide questions in advance of the review based on the materials provided, such that the assessment teams can prepare responses for the review panel meeting, currently scheduled for November 2022.

Questions relevant to all snow crab stock assessments

1. Assumptions regarding natural mortality are consistent for Areas A and B (M is time-invariant, but different for immature and mature individuals), but differ for the North Pacific stock (M is time-varying, and assumed to be the same for immature and mature individuals). Further justification of the biological and/or environmental basis for these differences would be helpful.
2. What are the pros and cons of implementing a male-only retention fishery, in addition to requiring minimum sizes and implementing seasonal closures?

Questions specific to the assessment for the North Pacific stock of snow crab (fiscal year 2021)

3. The fishing grounds are described as relatively deep for this stock, i.e. 150 - 400 m. Do snow crabs occupy depths greater than that, and if so, is it possible that a significant fraction of larger crabs are unavailable to the fishery? This would suggest using a “dome-shaped” selectivity curve in the assessment model.
4. Figure 2-2 shows carapace width as a function of age. Is growth estimated outside of the assessment model? If so, how much variability in growth was observed over space and time? Cronin-Fine and Punt (2022) found that M estimation was improved if growth was known (and specified correctly in the model), but spawning stock biomass was better estimated when growth was also estimated in the model.

5. How is discard mortality accounted for in the model, i.e. what fraction of small males and immature females discarded at sea are assumed to survive? Do foreign fisheries catch this stock? Sources of fishing mortality that are not accounted for in the model (discards, unreported catch) will bias reference points and forecasts.
6. CPUE was calculated using offshore trawler data from Fukushima, and it appears that this time series was not used in the model due to changes after the earthquake (2011). Could the CPUE trend prior to 2011 be included in the model?
7. If the depth distribution of the stock extends beyond the fished area, could the observed increases in bottom temperature result in adults moving outside the fishing grounds? Movement outside of the fished area could be interpreted by the model as an increase in M. How much survey effort occurs outside of the depths of the fishing fleet, and is there any evidence of movement associated with changes in temperature?
8. In the report, the model appears to operate on an annual time step. The estimates of M are described as representing December 1st to December 1st of the following year. However, catches are represented as July to June of the following year. Can you clarify why the time step has different definitions for these two quantities, and how that is accounted for in the model?
9. What are the annual coefficients of variation (CVs) for the bottom trawl survey? Please plot error bars around the point estimates in Figure 4-1 and provide a table with the point estimates and CVs for each year of the survey.
10. Is the survey treated as a relative index of abundance, i.e. only providing trend information, or is it assumed to be an unbiased estimate of total stock size (an absolute index of abundance). Since catch efficiency never reaches 100% (Supp. Fig. 2-2), it seems like the survey is treated as an absolute index.
11. Is the catch efficiency equation developed by Hattori et al. (2014; Supp. Fig. 2-2) used to calculate the annual standing stock size in the bottom trawl survey (Fig. 4-1)? If so, does it make sense to use the same equation, again, in the population dynamics model (i.e. equations 27-33)? If the dynamics model is fit to survey estimates that have already been adjusted for catch efficiency, and the catch efficiency curve is part of the dynamics calculations, then the assessment would be adjusting for catch efficiency twice.
12. The estimate of M used in 2020 and for forecasts was 0.677 based on the average of 3 recent years. The retrospective patterns in M (Supp. Fig. 2-6) show that removing the most recent year of data reduces the 3-year average for M to roughly 0.55, suggesting that there is considerable uncertainty in current M. How sensitive are future forecasts calculations to the assumed value of M, i.e. how much do they change if current M is assumed to be 0.55?
13. Annual catch in number by instar is an input to the assessment model, estimated from catch in weight, carapace width composition data, and average weights by instar. However, these data were only available for three years (1999, 2003, and 2007). Years without data were imputed using the closest year. This is potentially problematic, since it introduces correlations in the fraction of individuals within a given instar across years. A way to test this would be to remove each of the three years of data (1999, 2003, and 2007), one at a time, and replace it with data from the closest remaining year. Are model results very sensitive to this approach?
14. The model assumes parameters of the terminal molt rate follow a random walk (Eq. 24) and estimates that terminal molt probabilities increase over time (Supp. Table 6-1). Since

growth ceases after the terminal molt, this suggests that average weights of individuals in the catch should decline over time (i.e. more crabs stop growing sooner), and the number of individuals for a given catch in weight should increase. Is this consistent with the observed average weights in the catch or survey data?

<u>Questions specific to the assessment for the Sea of Japan Area A stock of snow crab (fiscal year 2021)</u>

15. In the description of fishing effort, "effective effort" is reported by sex (55,000 casts for males, and 31,000 for females). Can you describe why effective effort differs so much by sex?
16. Figure 4-10 indicates that Fmsy (vertical dotted line) is greater than Fmax (the F that maximizes yield per recruit) for both males and females. Can you describe why the estimate for Fmsy is greater than Fmax for both sexes? Typically, Fmax ≥ Fmsy because Fmax does not account for the stock-recruitment relationship.
17. The reported probabilities that SSB will exceed the reference point account for recruitment variability, but do not account for parameter uncertainty. Therefore, the derived probabilities underestimate the variability in recruitment. Estimates of uncertainty in the stock-recruitment parameters for the Ricker curve could be integrated into the forecast simulations by drawing 10,000 pairs from the bivariate covariance matrix (representing parameter uncertainty), and then drawing a random lognormal recruitment deviation for each set of parameters draws.
18. To account for bycatch mortality in the forecasts, a proportionality constant (alpha=0.5) is used to relate the bycatch coefficient to the fishing mortality rate, and applied to the 8th and 9th instar. Does this imply that instars less than 8 are not contacted by the gear, and if so, is that consistent with observations of the fishing fleet?
19. Reported catches could be scaled to reflect rough estimates of South Korean catch based on ratios of total catch by each country shown in Fig. 7-1. Alternative assumptions about the fraction of South Korean catch that comes from the Japanese EEZ could be explored to determine the sensitivity of model outcomes to possible sources of unreported catch.
20. The transition rate for mature individuals (Appendix 2, equation 2) assumes 100% capture efficiency. Does the stock extend outside the fished area, or deeper than fishing gear is deployed by the fleet? Does the average size of individuals continue to increase for depths deeper than the fishing grounds? This would result in a dome-shaped pattern in catch efficiency, and an assumption of 100% efficiency could underestimate the stock size.
21. The unit of effort for the logbook index is the number of nets. Do tow durations differ systematically among vessels, areas, or other factors? If so, this could bias the CPUE calculation used to derive the index.
22. I recommend exploring integrated analysis models for this stock (c.f. Turnock and Rugalo, 2015). The combination of a strong cohort signal in the size composition data and a long-term index of abundance (1970-present) would allow for simultaneous estimation of natural mortality and stock-recruitment parameters, recruitment deviations, growth parameters, and gear selectivity.

Questions specific to the assessment for the Sea of Japan Area B stock of snow crab (fiscal year 2021)

23. This assessment uses a proxy for F_{MSY} ($F_{SPR30\%}$) and an estimate of stock biomass derived from a pot survey to inform catch estimates. Density is calculated per set, representing 20 baited pots mounted at 100-m intervals. It's not clear from the assessment report how catch from baited pot gear (which attracts nearby crabs) is converted to a density.
24. Since 2016, a beam trawl survey has been conducted to estimate stock abundance, and notably recruitment, which is not well estimated by pot survey data. How do the estimates of stock abundance compare for instars that are well-sampled by both gears?
25. Underwater visual survey transects (e.g. ROV or perhaps AUV due to the depth) could be used to estimate crab densities, with pot or other gear types used to verify size, sex, and maturity. Has this approach been considered for estimation of snow crab abundance?
26. An F30% SPR value is reported for males (0.20). Typically, SPR is a function of lifetime egg production and represents the ratio of egg production under fished conditions to egg production in unfished conditions. How is the spawning potential ratio calculated for the males?
27. The method for determining the population level and current stock status is not clear. For example, Supp. Fig. 7-2 shows population level in percent. What is the basis for 100% of the population level? The reference appears to have been left out of the caption, and I could not determine the method from the text in the report.
28. How likely is it that Sea of Japan areas A & B are a single biological stock? The reports indicate that regulations differ between the areas, but the dynamics may be strongly linked by dispersal of larvae. Are there data on prevailing currents during pelagic larval stages, genetic testing, or other information to help understand the degree of connectivity between these two stocks?

Literature Cited

Shibata, Y., J. Nagao, Y. Narimatsu, E. Morikawa, Y. Suzuki, S. Tokioka, M. Yamada, S. Kakehi, and H. Okomura. 2021. Estimating the maximum sustainable yield of snow crab (*Chionoecetes opilio*) off Tohoku, Japan via a state-space stock assessment model with time-varying natural mortality. Population Ecology 63:41-60.

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Hattori, T., M. Ito, Y Shibata, T. Yano and Y. Narimatsu. 2014. Net efficiency of a bottom trawl survey for snow crab *Chionoecetes opilio* off the Pacific coast of northern Honshu, Japan. NIPPON SUISAN GAKKAISHI. 80. 178-184.

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