North Pacific stock of snow crab

Contents

- Biology

  Distribution, Growth

- Stock assessment

  Catch, Bottom-trawl survey,

  Estimation of stock abundance and Natural mortality

- Stock-Recruitment relationship and Future projection

Contents

- **Biology**

  Distribution, Growth

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  Fisheries

  Bottom-trawl survey

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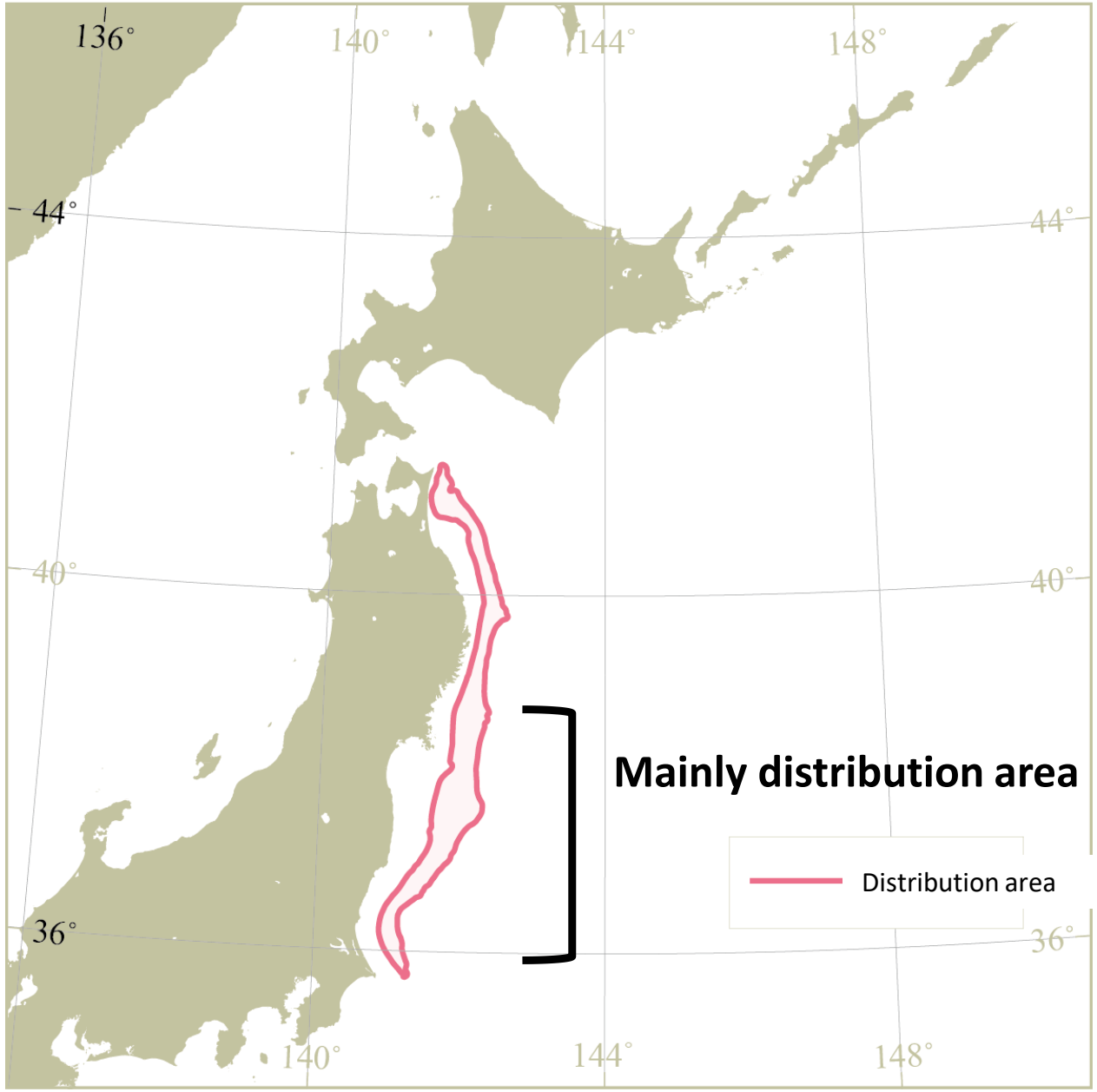
Distribution



Distribution – Reviewer's comment

Response

（1） How was the stock structure and distribution for this stock defined? Is it based on biological evidence or a management unit? If based on biological evidence, please explain. (Teo #1)

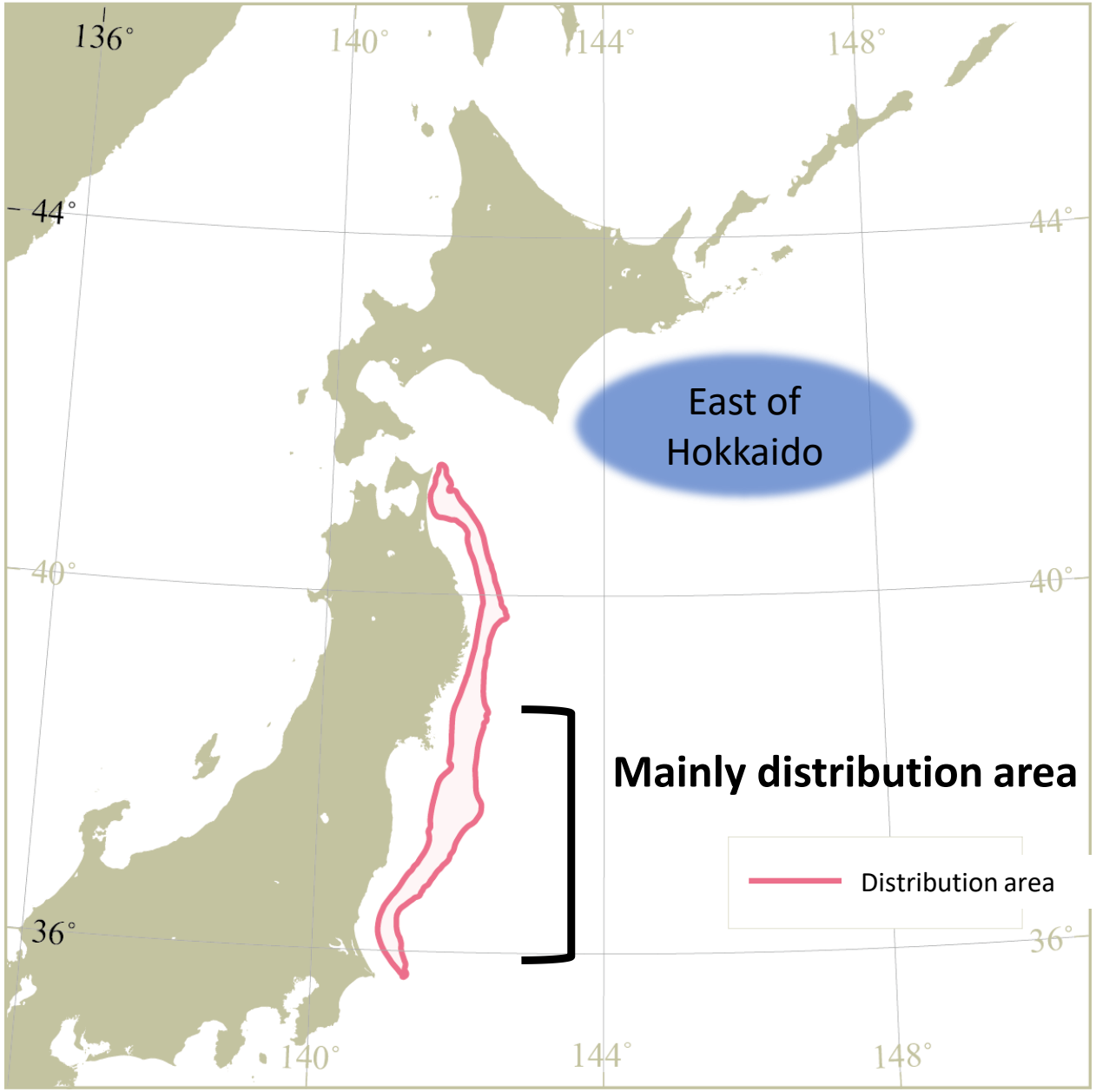
A: It's based on a management unit.

（2） What is the distribution of snow crabs in the western Pacific? Are there snow crab stocks north of Tohoku, in Hokkaido waters? If so, how are they connected to this one? Are there snow crab stocks south of this stock? (Teo #2)

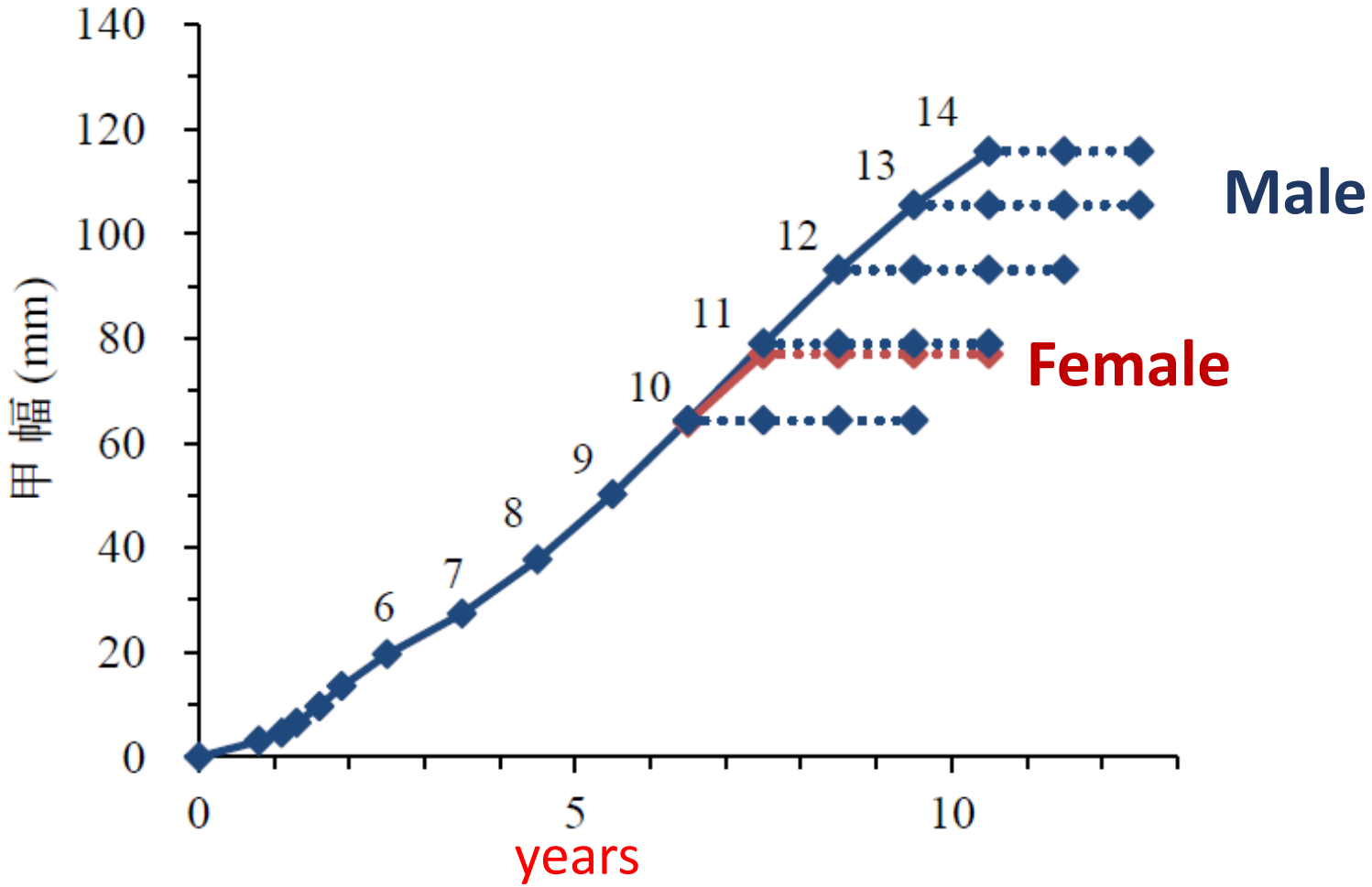
A: There are snow crabs in both northern and southern areas of Tohoku, but it is very low density and fishers do not catch crabs in the areas.

（3） Do the snow crabs move after settlement? (Teo #22)

A: No information. But we think only little.



Growth



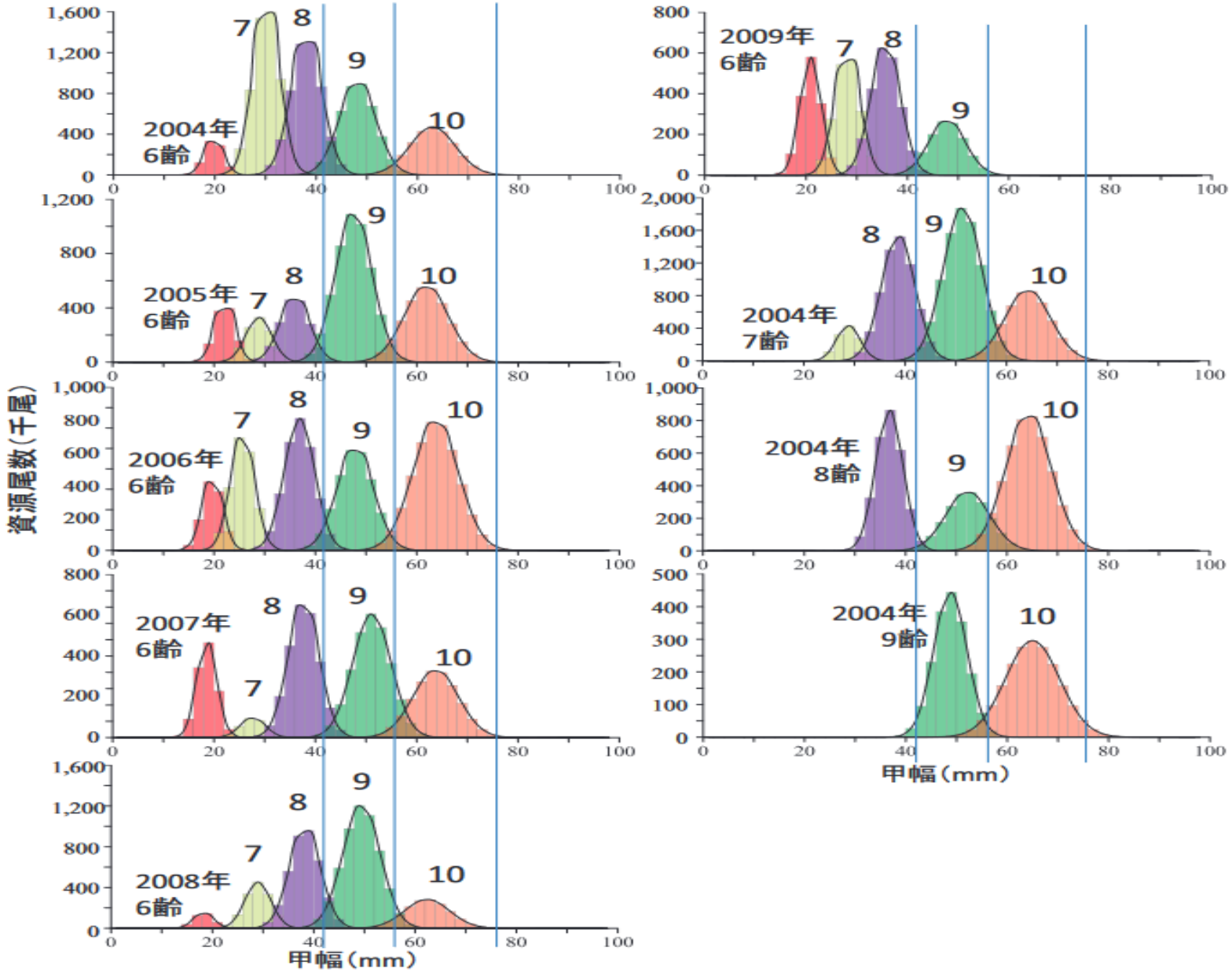
Reviewer's comment

Please provide details on how the size class to age class relationship is set. (Teo #17)

A:A mixed normal distribution is applied to the carapace width composition obtained in the survey, and each instar size class is estimated by slicing method (see next slide).

Growth – Reviewer's comment

Response



Growth – Reviewer's comment

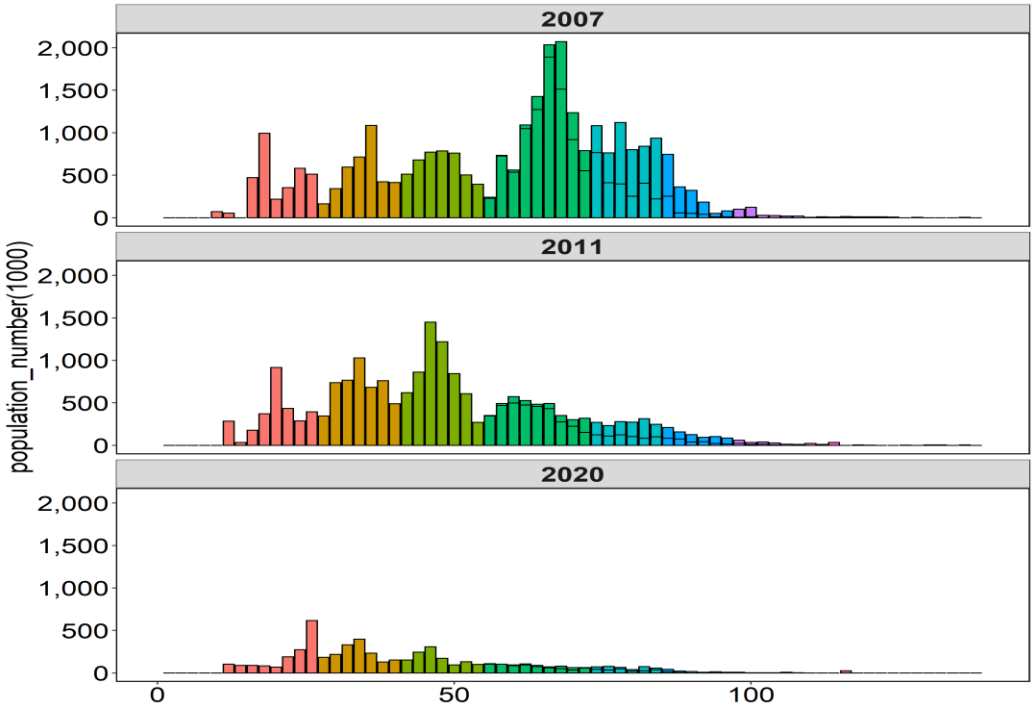
Response

（1）Is there any uncertainty with regards to the size class associated with each age class after recruitment at instar 8? (Teo #16)

A: Yes. But we do not see any major bias in the results of retrospective analysis in the resource analysis model, and we believe that there is no serious problem.

（2）Is my reading correct that the data is sliced into instars before being fit in the model? Or are you fitting to the size data? (Teo #18)

A: As you wrote, sliced into instars before being fit in the model. Figures show carapace width distribution in 2007, 2011 and 2020.



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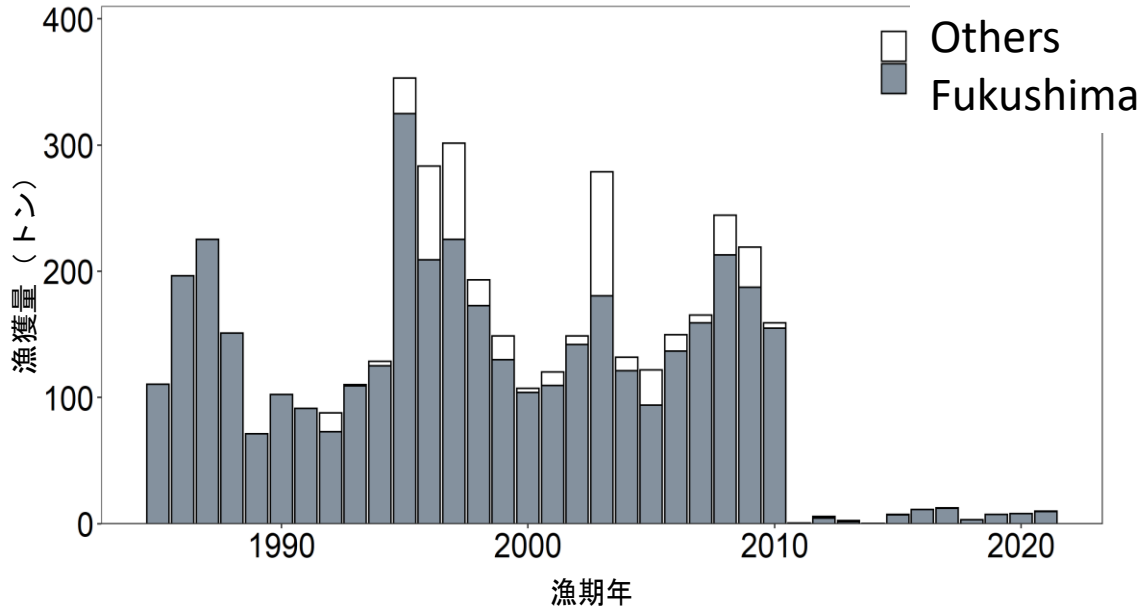
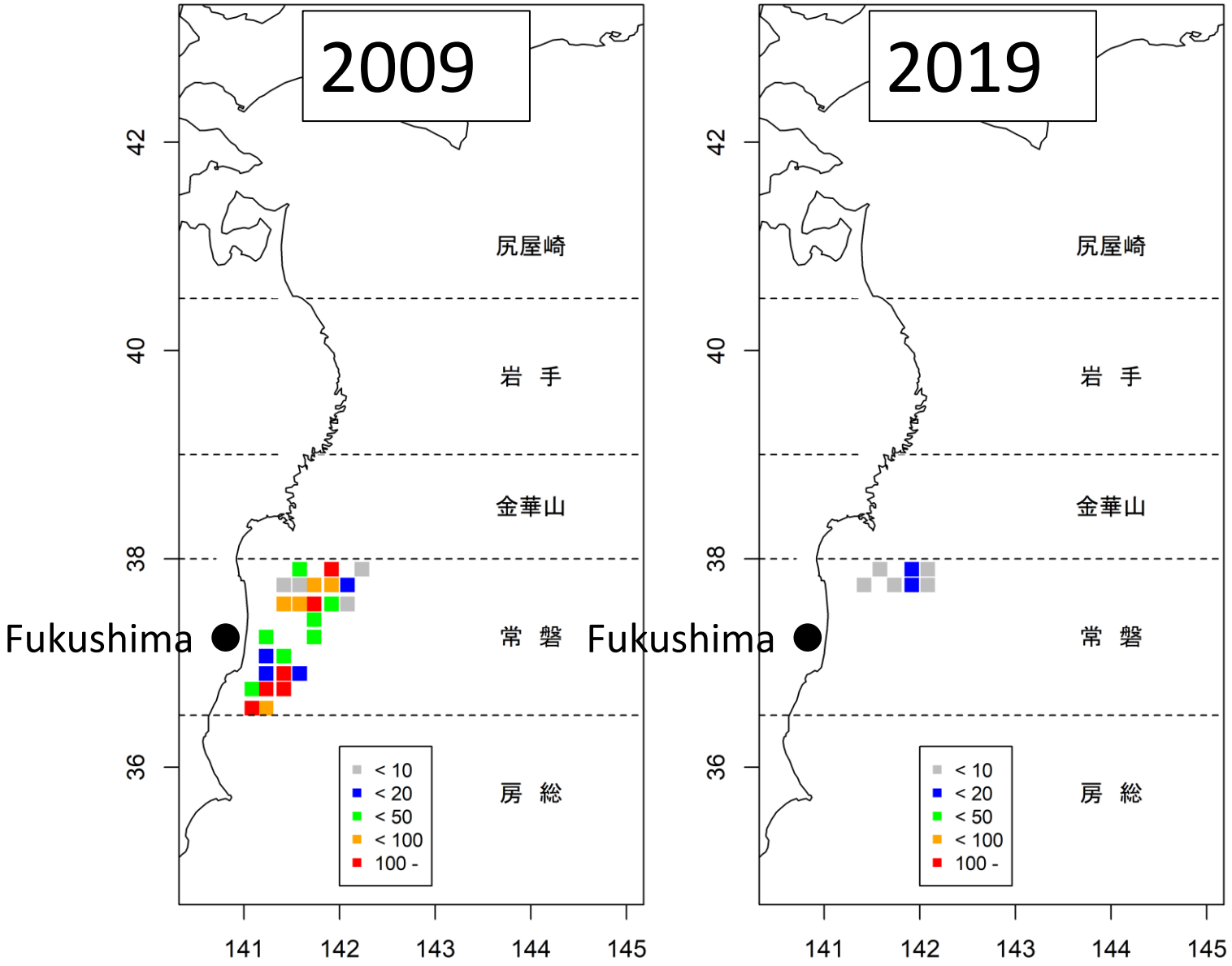
Catch


136°
140°
144°
148°
44°
40°
36°
Fukushima
分布域

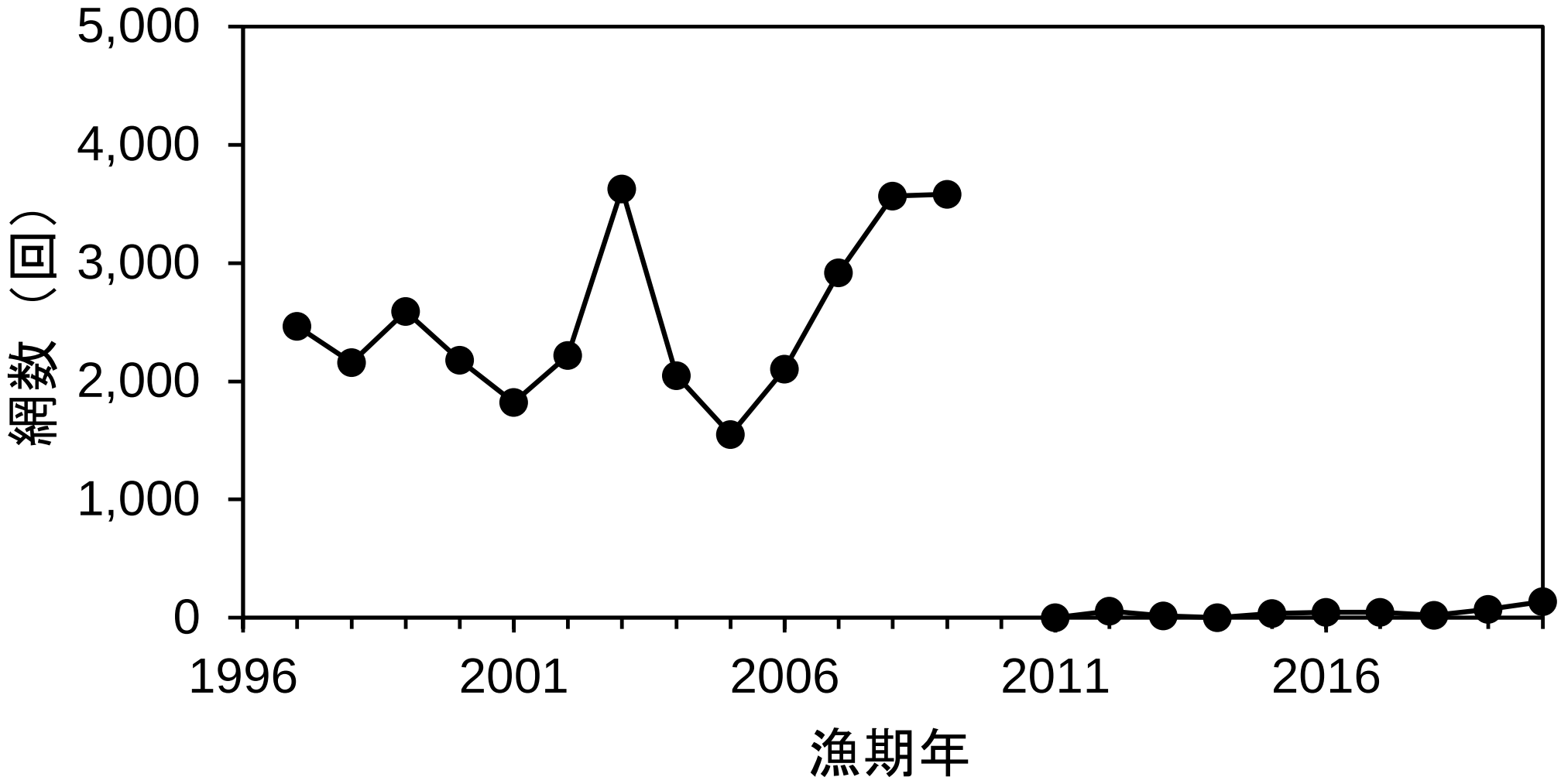

400
300
200
100
0
漁獲量（トン）
1990
2000
2010
2020
漁期年
Others
Fukushima

Fishing ground

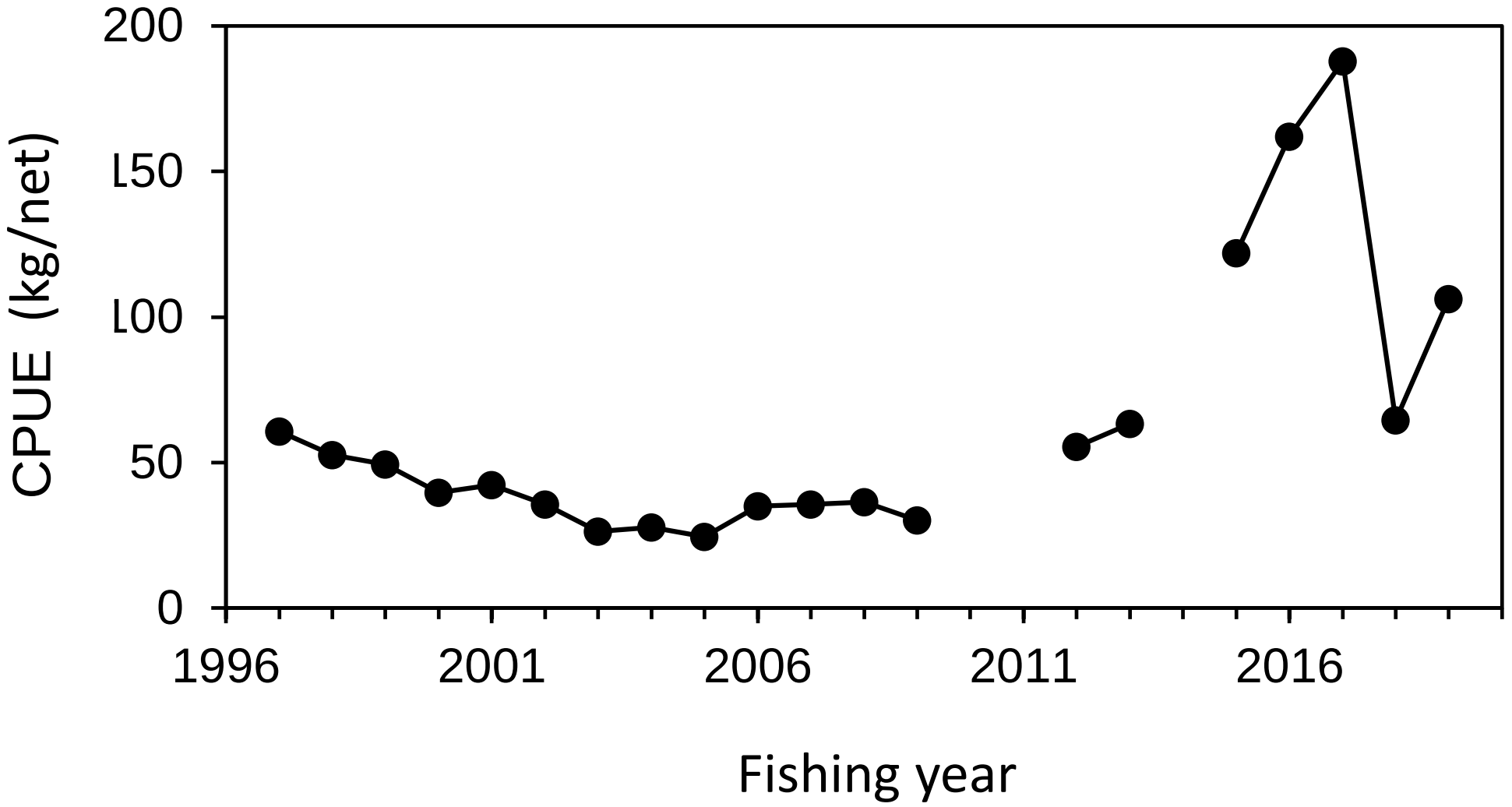


漁場分布図（漁獲量）

Fishing effort



CPUE


200
150
100
50
0
CPUE (kg/net)
1996
2001
2006
2011
2016
Fishing year

Catch and effort – Reviewer's comment

Response

(1)

- Are there potential sources of unaccounted fishing mortality? For example, mis-identified catches, discards? (Teo #14)

A: There is discards but not mis-identified catches. Now we have no data about discard.

- What are the pros and cons of implementing a male-only retention fishery, in addition to requiring minimum sizes and implementing seasonal closures? (Dick #2)

A: For this stock, both sexes are fishing target. Please refer to the opinion of the Sea of Japan stock A for the pros and cons of taking both sexes or only males.

(2)

- Is there any work to examine discard mortality, especially by instar? (Teo #21)
- 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. (Dick #5)

A: That is a subject of future study. In the model of this stock, discard mortality is included in M.

Catch and effort – Reviewer's comment

Response

（1） 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? (Dick #3)

A: No. Because fishermen are towing nets in waters up to 600 m in depth, we believe there are no unused waters.

（2） Are there fisheries that do not target snow crab but historically catches snow crab as bycatch? Are these fisheries discarding snow crabs after 2010 due to regulations? If so, what is the time series of effort for these fisheries? (Teo #15)

A: As wrote before, there are some bycatch but we have no data. There has been no increase in discards since the Earthquake.

Catch and effort – Reviewer's comment

Response

- 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? (Dick #13)

A: In response to this comment, Supplemental Material 2 was incorrectly stated. I'll fix it. Correctly, we substituted the missing year of 1999 with the average of 1997 and 1998, the equally missing year of 2002 with the average of 2001 and 2003, and the missing year of 2007 with the average of 2008 and 2010.

CPUE– Reviewer's comment

（1） In Fig 4-2, the commercial trawl CPUE suggests an increase in abundance after 2010. Although the commercial operations after 2010 have been severely affected, this is nevertheless evidence that the survey may not be picking up the same signal as the commercial CPUE. (Teo #10)

A: A: Since the snow crab fishery in the Tohoku region after the Earthquake has been conducted in a very limited time and sea area, we think it is problematic to use CPUE as an index of stock size. See slide 18.

（2） On page 8, Section 4.2, it was stated that the commercial CPUE was based on non-zero effort. This is typically not a good idea. Please show the proportion of effort that is zero catch and a CPUE that includes the zero-catch effort, and compare with the original CPUE presented. (Teo #11)

If the commercial CPUE, after including the zero-catch effort, shows an alternative trend, it may be important to show a sensitivity model run with the commercial CPUE. (Teo #12)

A: The trend would then change if the effort were the total number of nets, including the number of nets that the Fukushima fishing boats could not catch. Due to the small number of nets, the fluctuations have increased, but this is not a situation where CPUE has increased in recent years. See slide 19, 20.

（3） 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. Could the CPUE trend prior to 2011 be included in the model? (Dick #6)

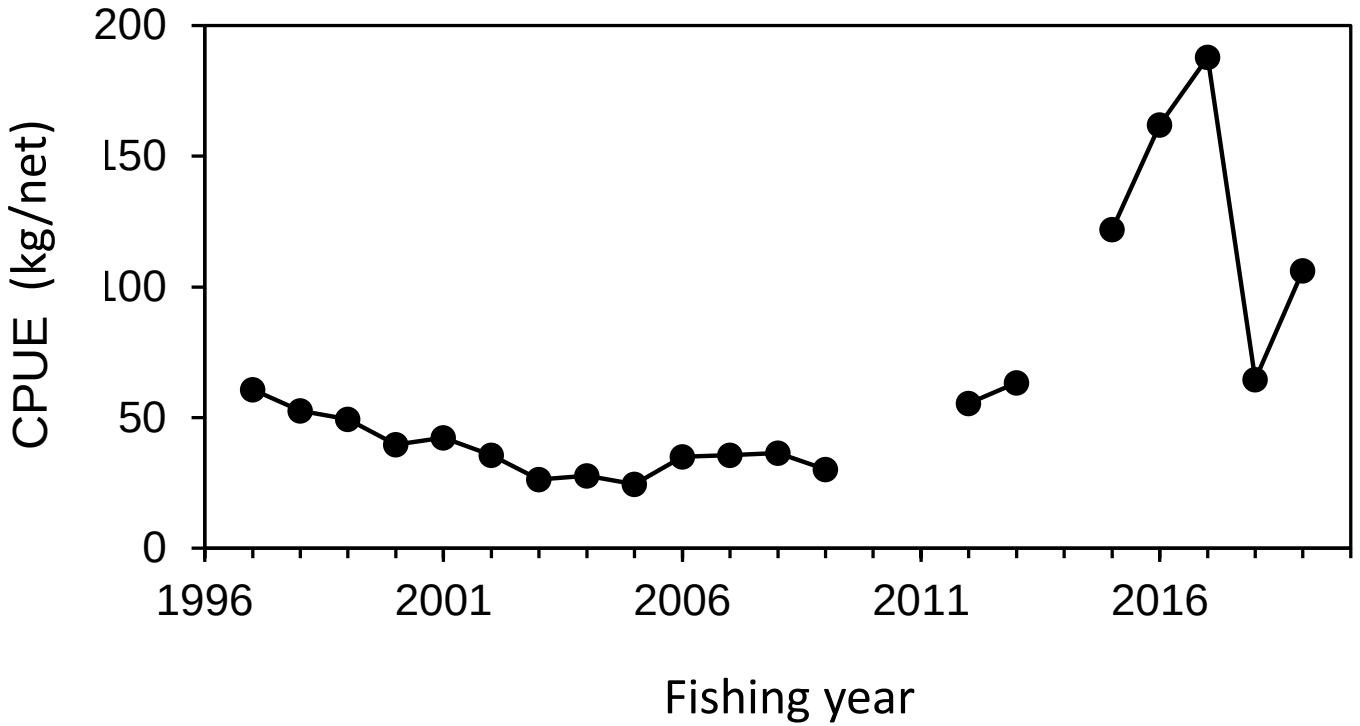
A: As wrote (1), we regard the CPUE after the Earthquake is irregular, we do not think inclusion of CPUE to

CPUE– Reviewer's comment

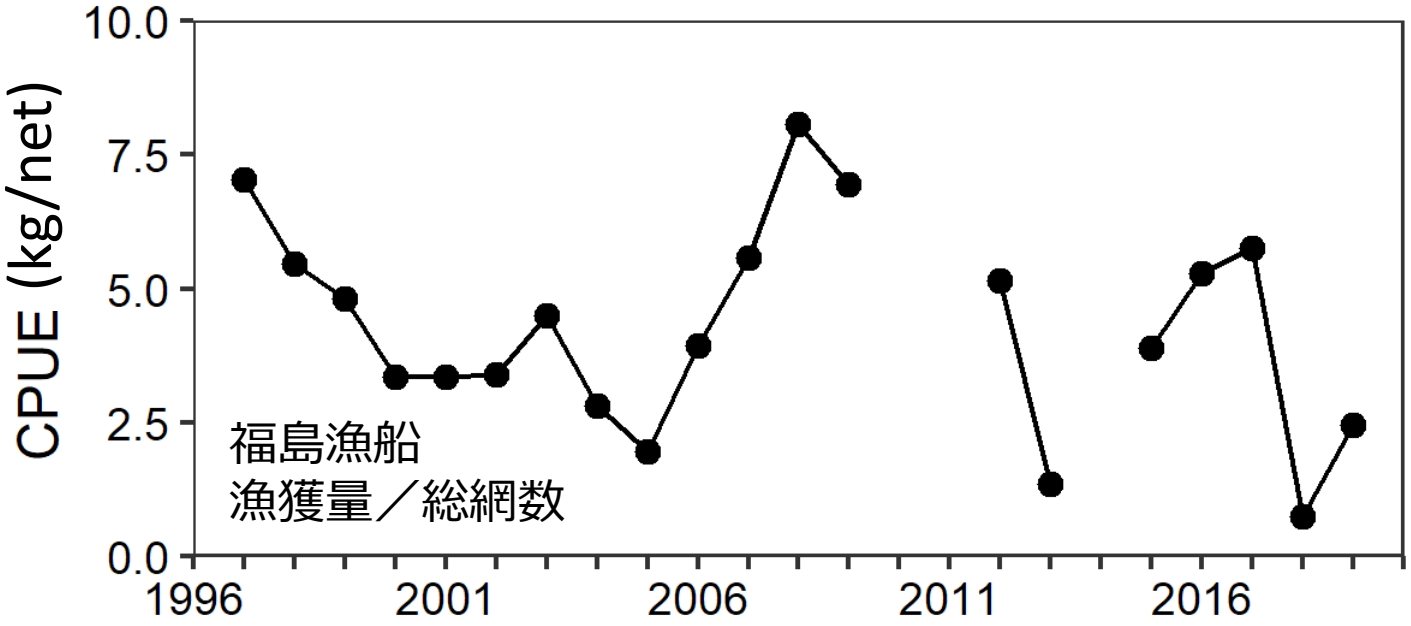
Response

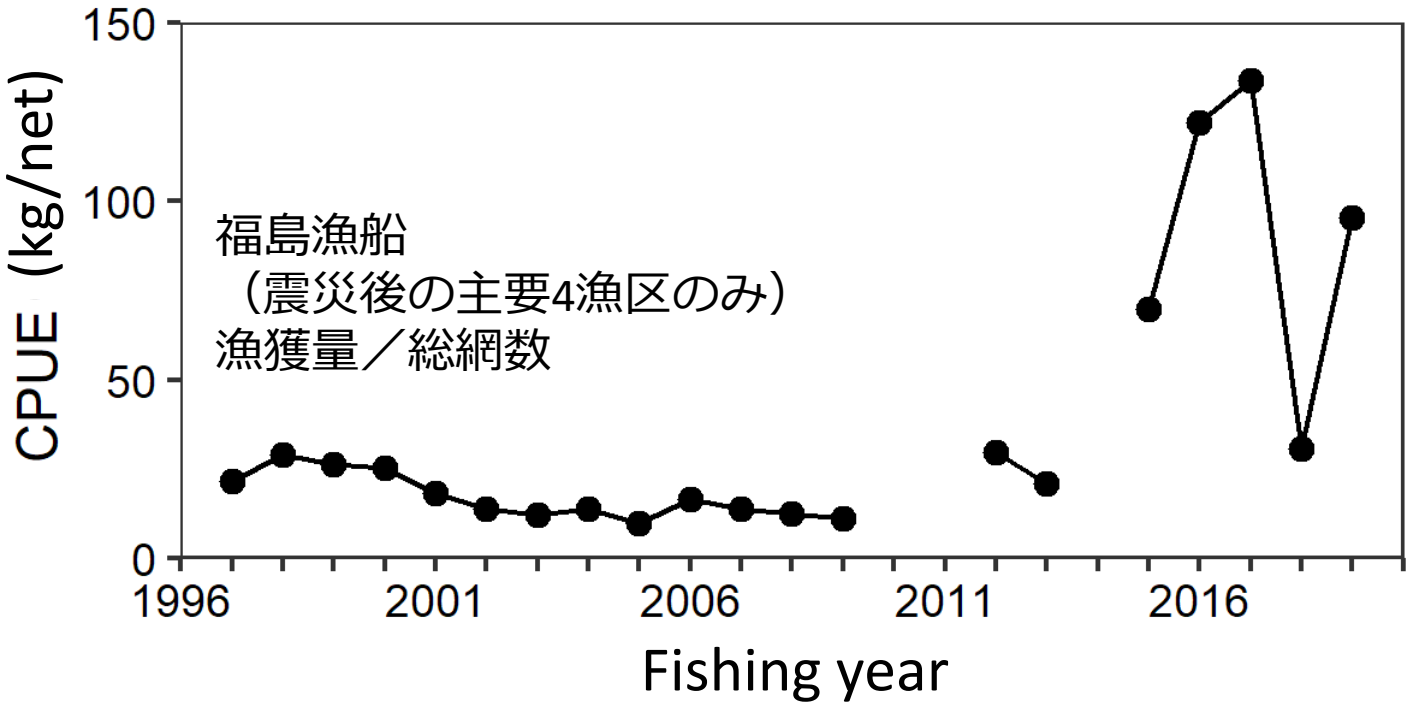
（1） In Fig 4-2, the commercial trawl CPUE suggests an increase in abundance after 2010. Although the commercial operations after 2010 have been severely affected, this is nevertheless evidence that the survey may not be picking up the same signal as the commercial CPUE. (Teo #10)

A: Since the snow crab fishery in the Tohoku region after the Earthquake has been conducted in a very limited time and sea area, we think it is problematic to use CPUE as an index of stock size.

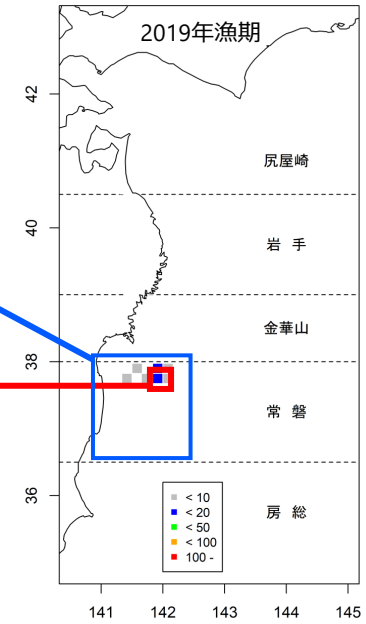


Response

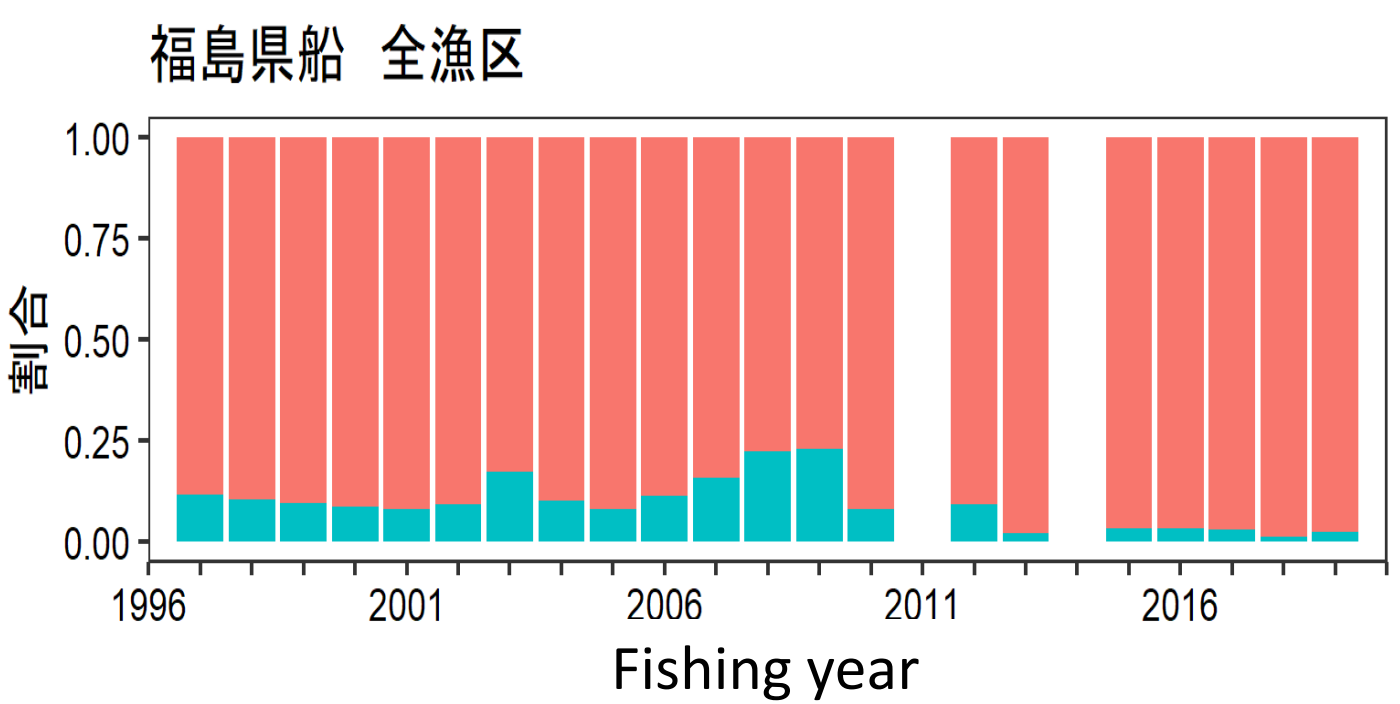




CPUE including the zero-catch data of Fukushima fishing boats are also shown.



Response

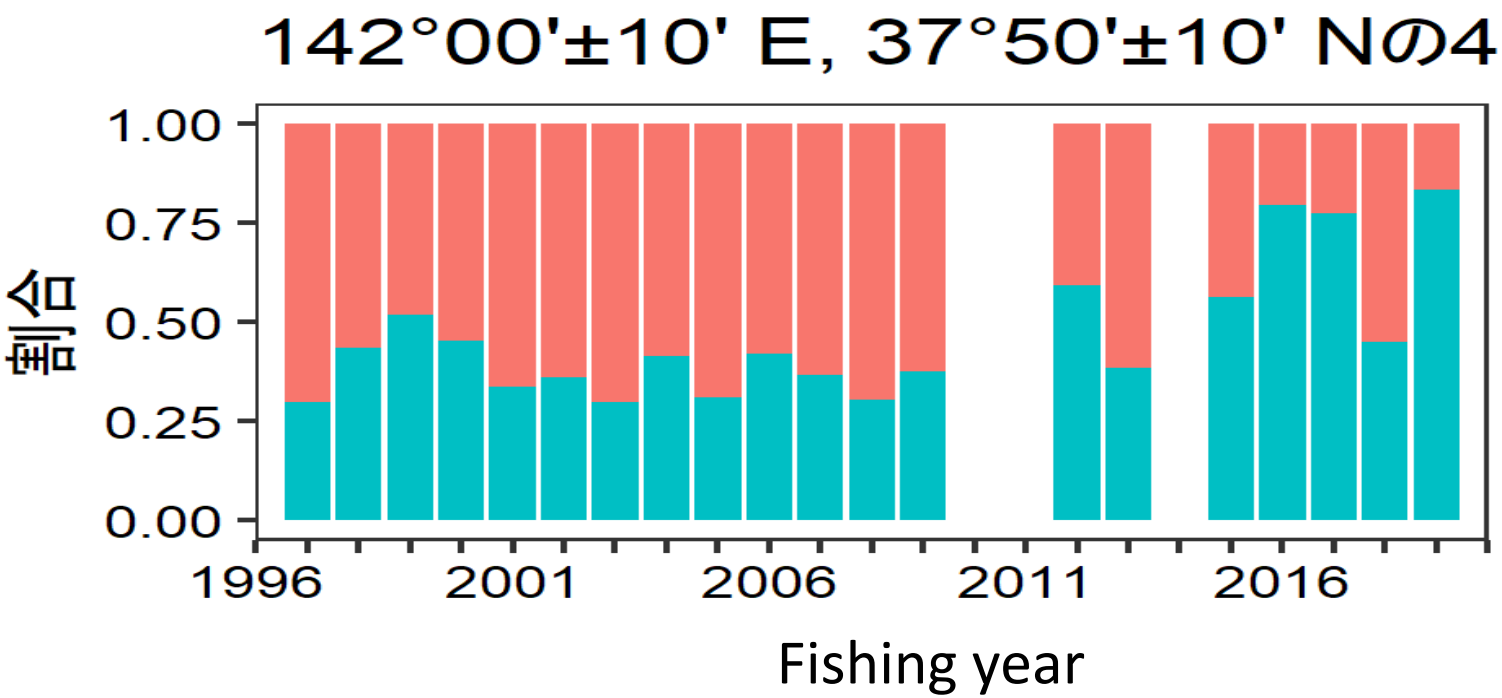


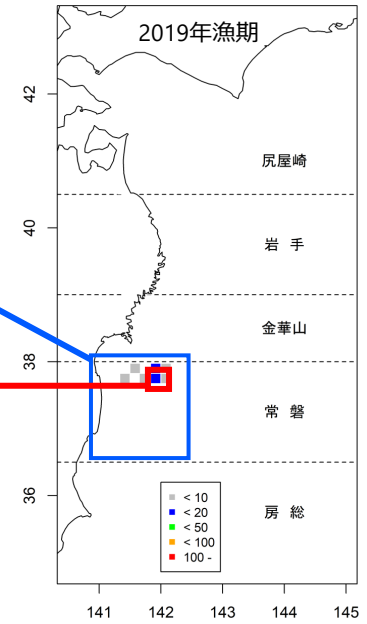
努力量

Negative

positive

The ratio of nonzero-catch data of Fukushima fishing boats





CPUE– Reviewer's comment

Response

（3） 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.

Could the CPUE trend prior to 2011 be included in the model? (Dick #6)

A. We would like to use commercial fishing data (CPUE) in the assessment model after considering standardized CPUE.

Contents

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Survey data - Reviewer's comment

Response

- The most important piece of information into the assessment is that the survey CPUE has continued to be flat or lower after 2010, even though the fishery catch has been close to 0. Therefore, it is very important to look at this survey closely. Please explain in detail the survey design, especially if there were any changes over time, and how the index was calculated. (Teo #5)

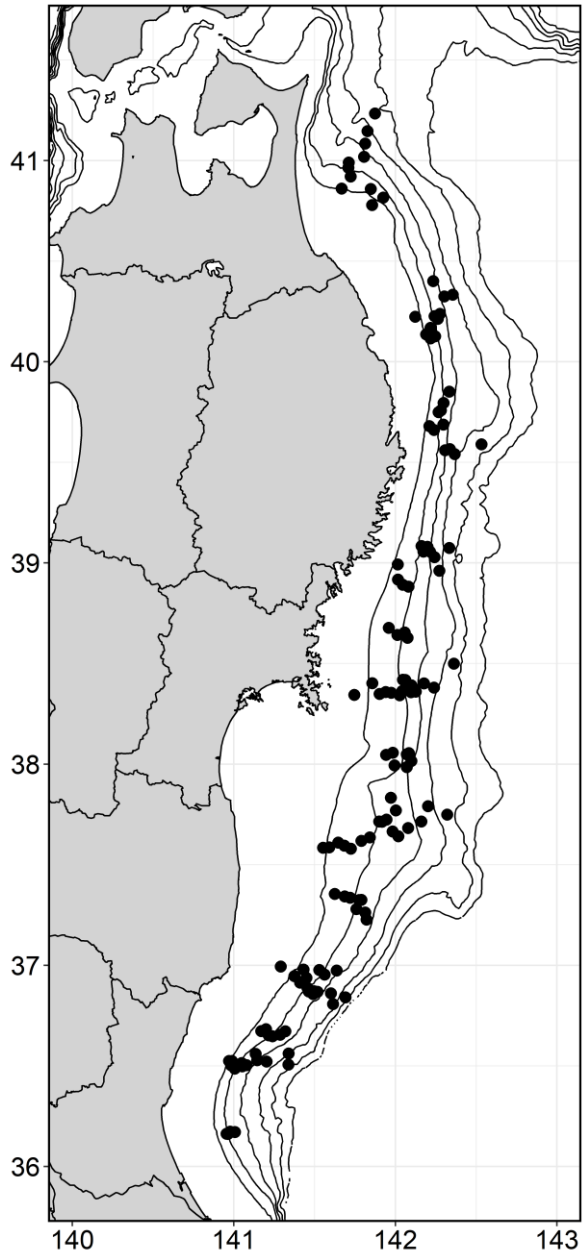
A: The survey design has not been changed since 1997.

The survey area covers the distribution area of this stock over

8 instar.

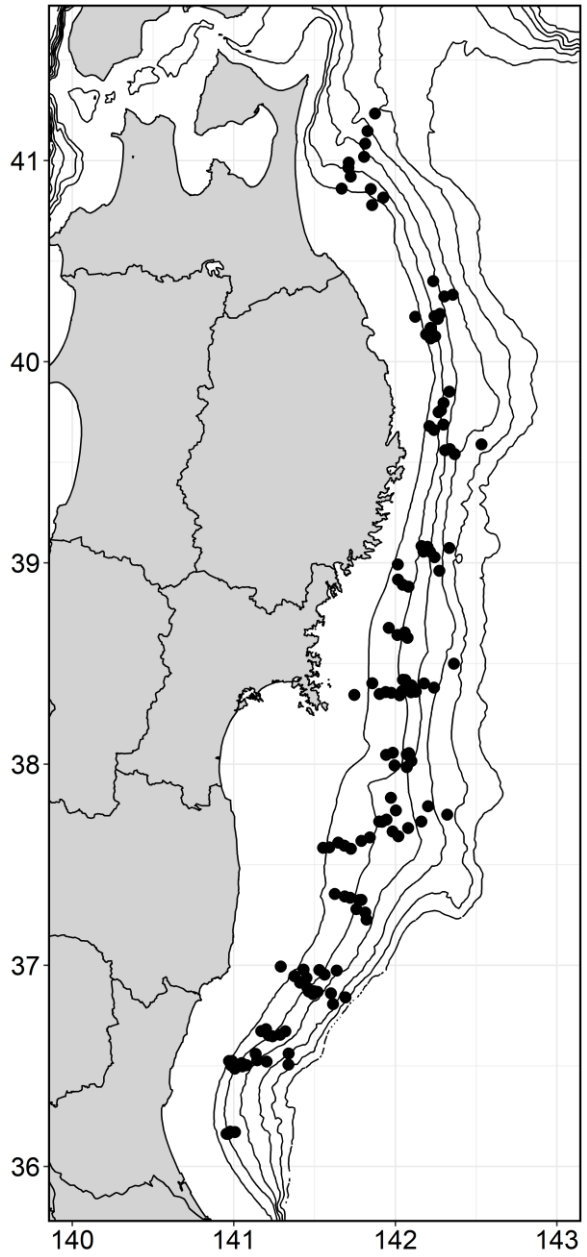
The method to calculate the index is described the following slides

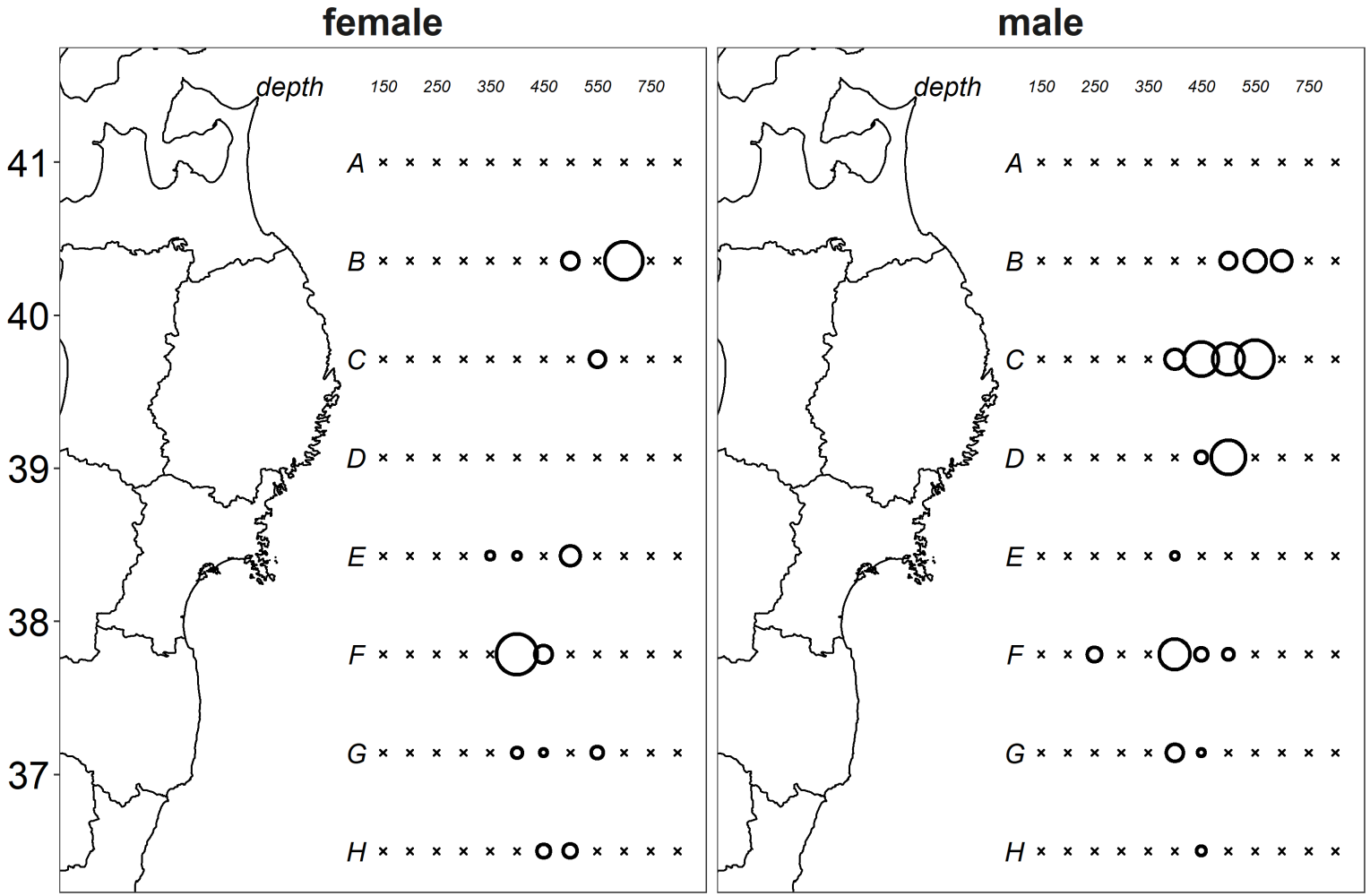
Bottom-trawl survey

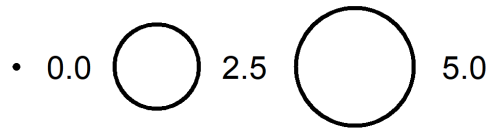


Since 1997, bottoming trawl surveys have been conducted on a research vessel (Waka
The survey points are at a depth of 150 ~ 900 m, and in the vicinity of the main fishing

Bottom-trawl survey







The survey is conducted on
example, in 2020, a total of
samples were collected fro

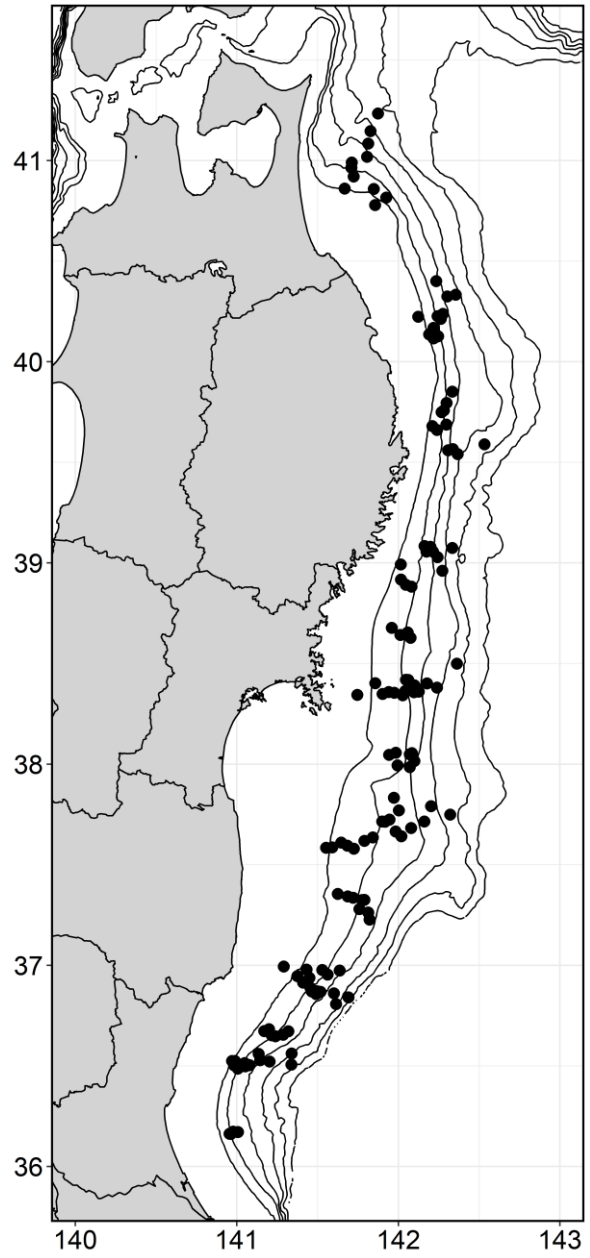
Survey data - Reviewer's comment

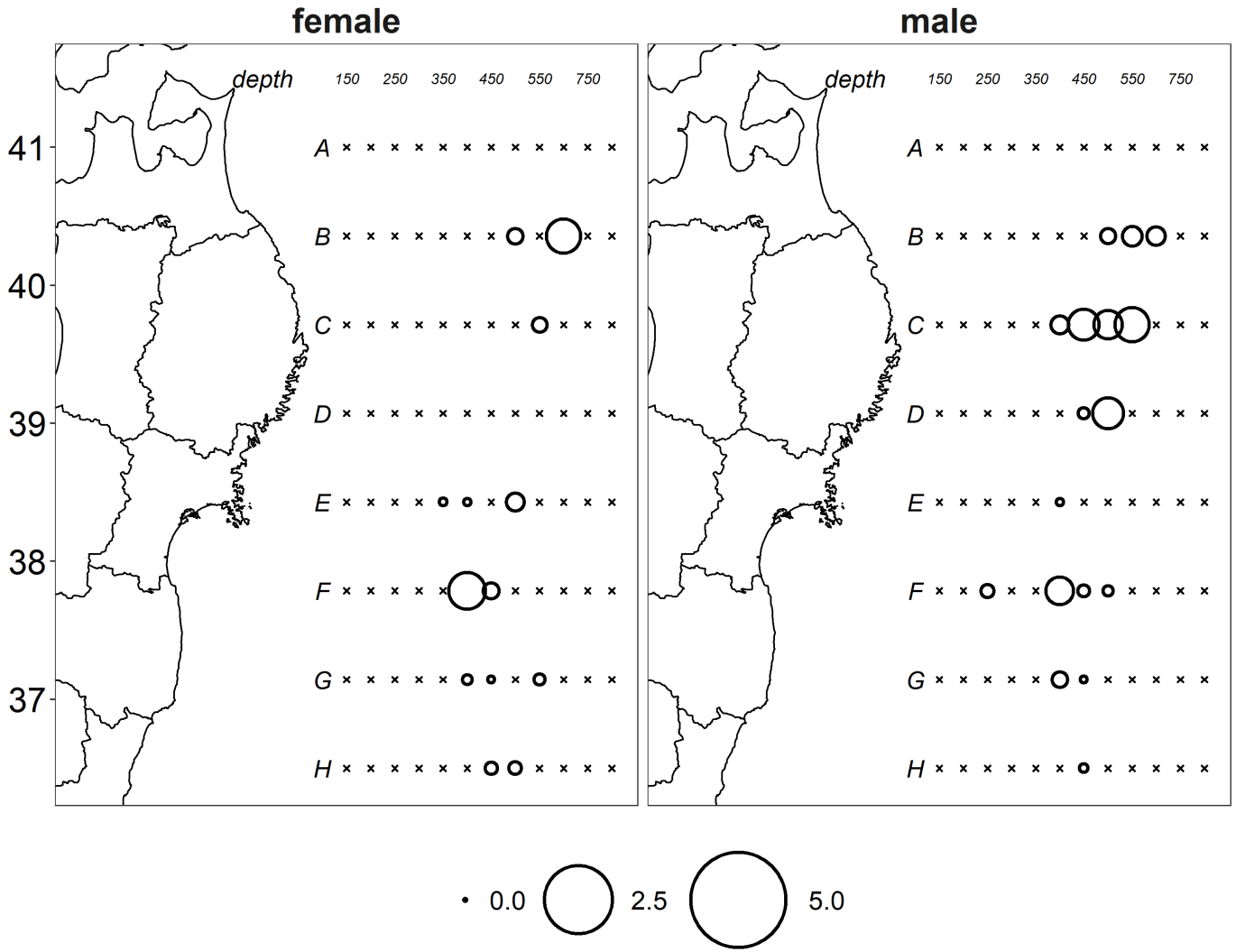
- Is there evidence to show that the survey covers the entire distribution of the stock, especially after 2010? For example, in Supplementary Fig 3, it would be useful to see where there was effort but no catch. (Teo #8)

A: In this study, the range of carapace width collected was 20 ~ 140 mm, covering all carapace width ranges from instar 8 onward.

In addition to the main fishing area off the coast of Fukushima Prefecture, we have surveyed a wide range of areas and water depths, which we believe covers the distribution range of the northern Pacific stock of snow crabs. See the following slide.

Bottom-trawl survey





Survey data - Reviewer's comment

- Given the increasing temperature and the sensitivity of snow crabs to temperature, the distribution of all or part of the population is likely to change over time (northwards or deeper). Has there been any work to investigate this possibility? (Teo #3)

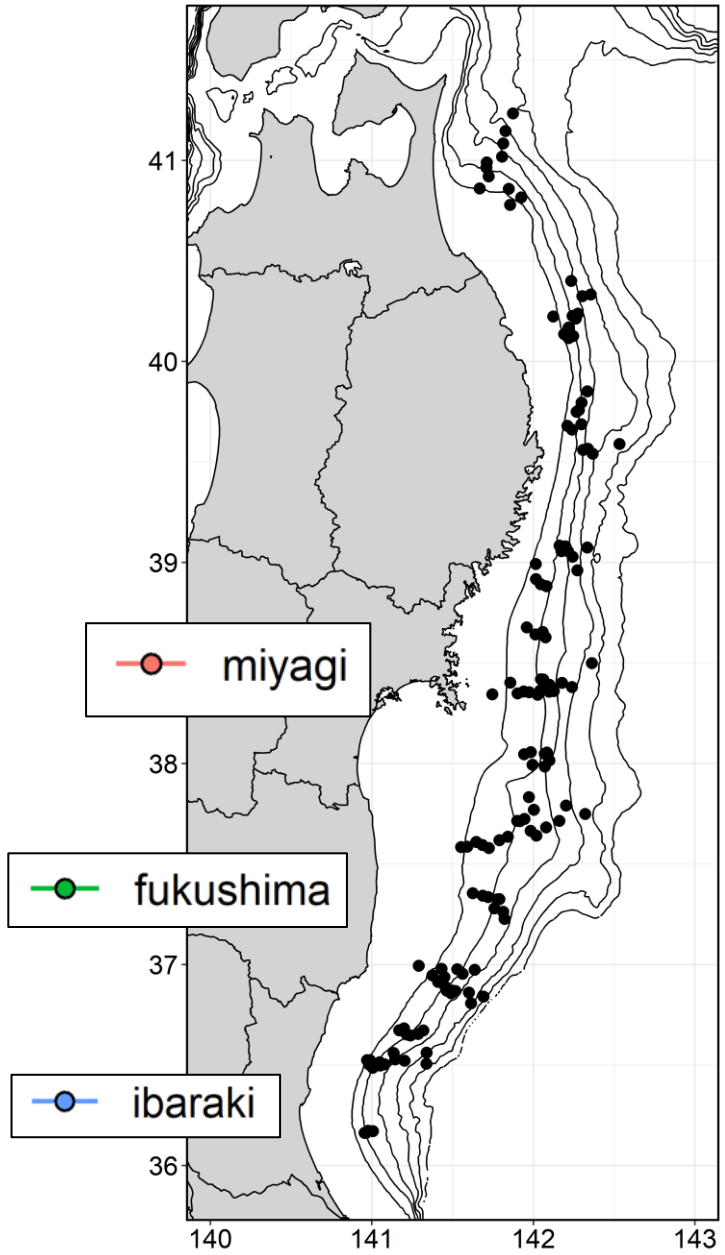
A: Bottom temperature in the distribution area of snow crabs is actually increasing (see slide 29). The movement to northwards or deeper area was not observed until now (see slide 30), although more research is needed. So, our surveys cover the distribution range of the northern Pacific stock of snow crabs (see slide 31).

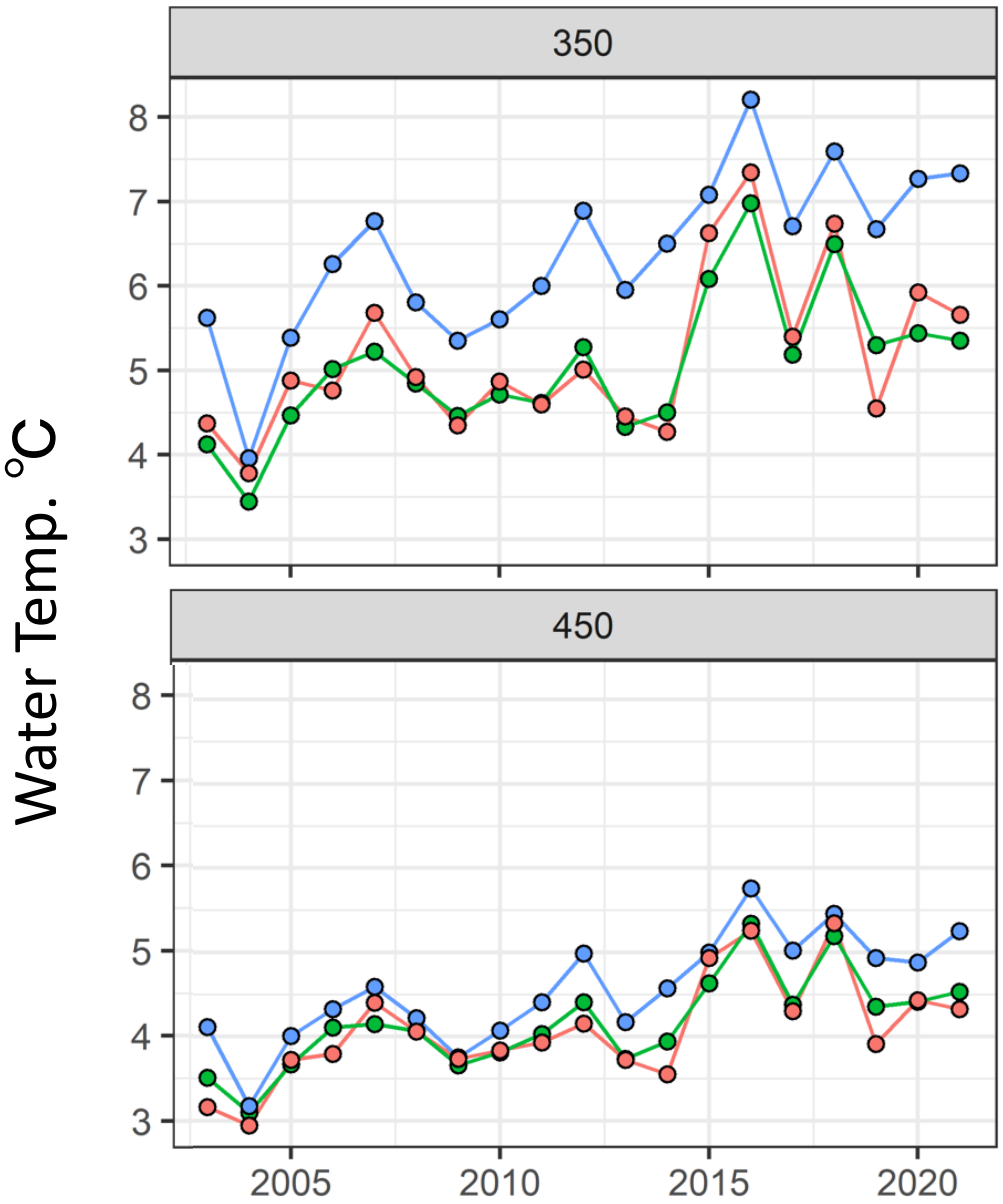
- An alternative hypothesis to an increasing M is that the distribution of the stock is changing and moving out of the survey range. Is there any evidence for or against this hypothesis? (Teo #4)

A: Based on our surveys, movement, if any, is limited. Therefore, the surveys seem to cover the distribution range of snow crabs (See slide 32).

Survey data - Reviewer's comment

Response



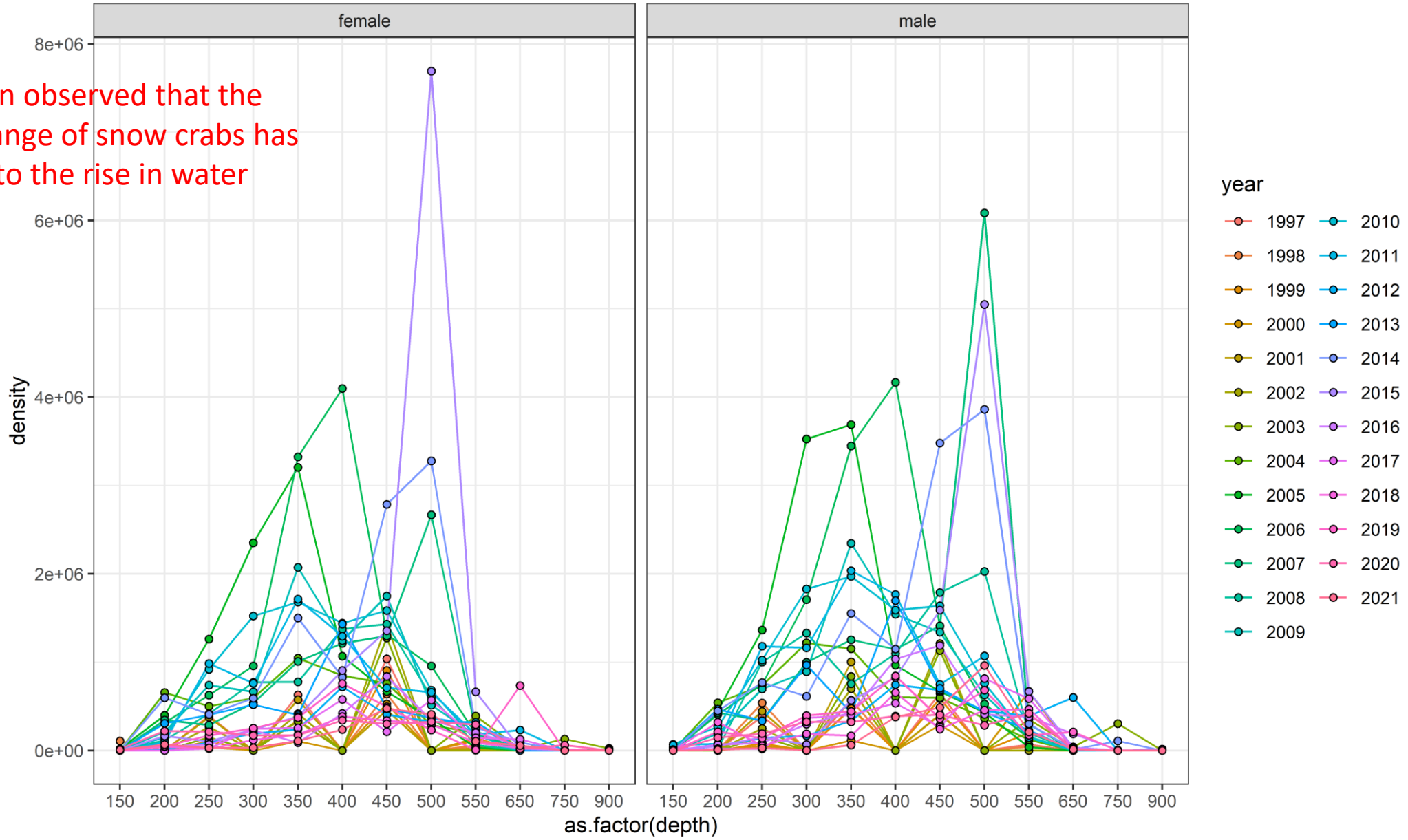


Survey results show that the water temperature at depths of 350 m and 450 m, which is the main fishing ground for snow crabs, has risen in recent years.

Survey data - Reviewer's comment

Response

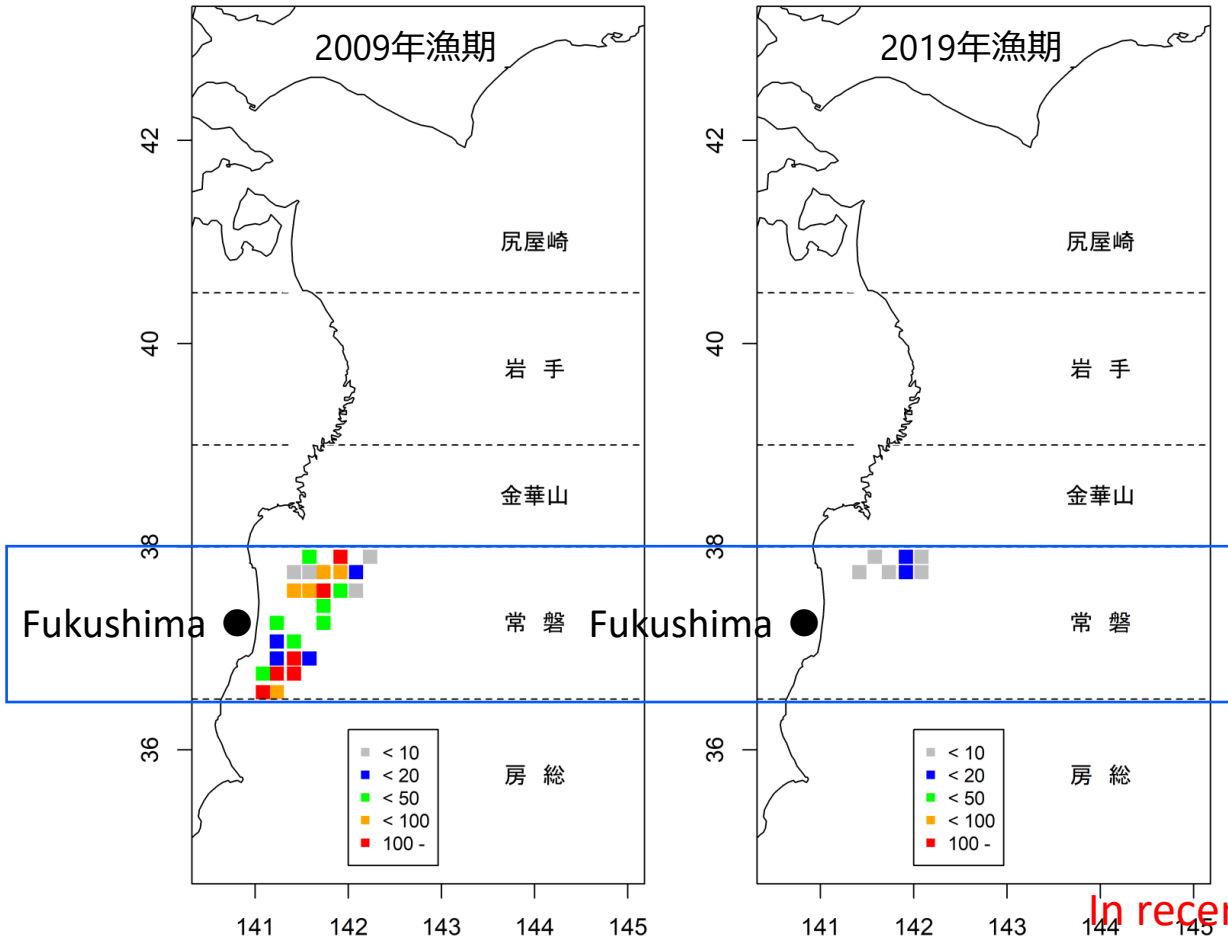
It has not been observed that the distribution range of snow crabs has changed due to the rise in water temperature.

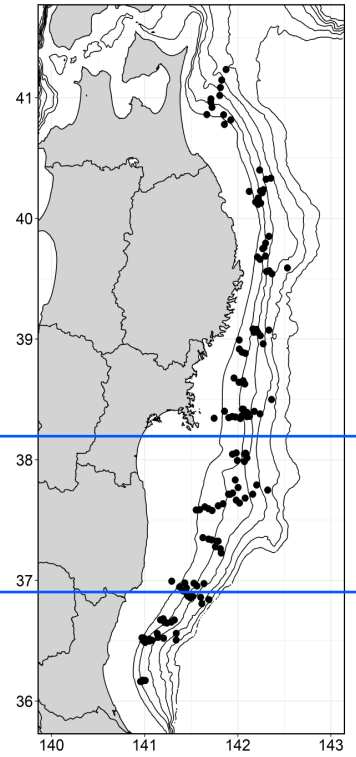


Survey data - Reviewer's comment

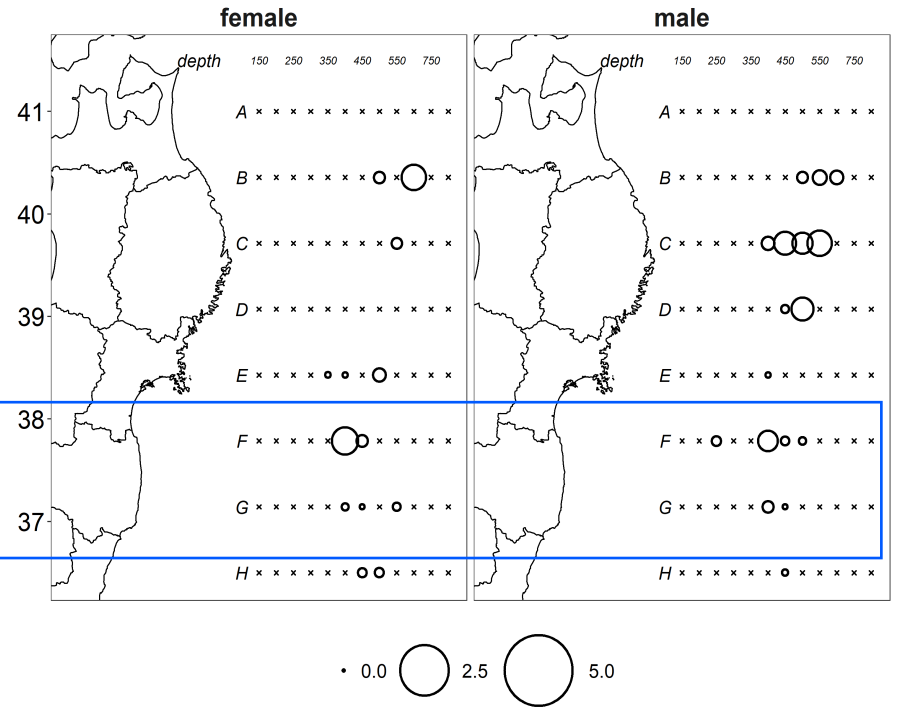
Response

- Are there logbook data for the bottom trawl fishery? If so, please compare the distribution of catch and effort (including zero catch) of the fishery versus the distribution of the survey (both overall and annually). (Teo #7)



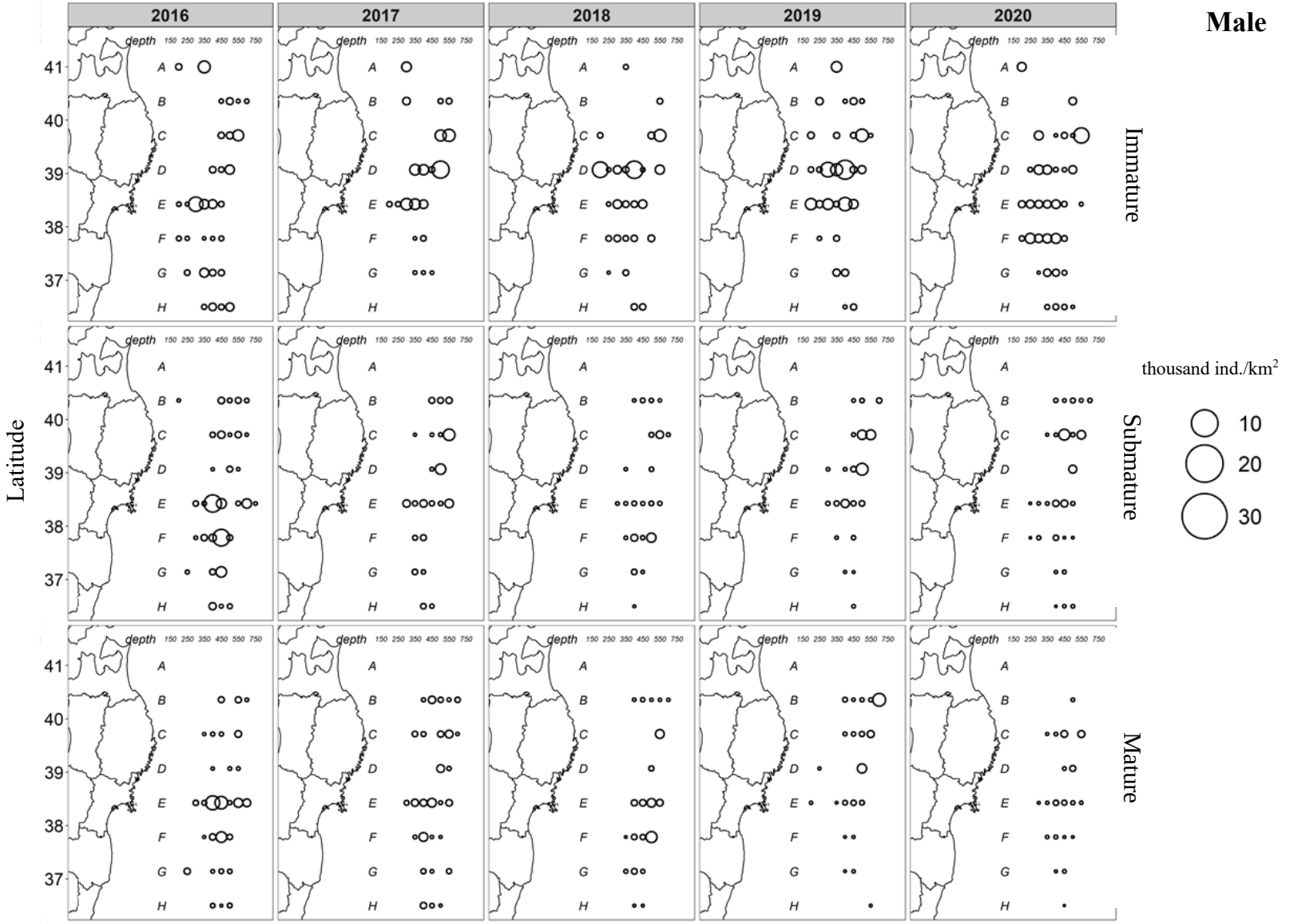


2020

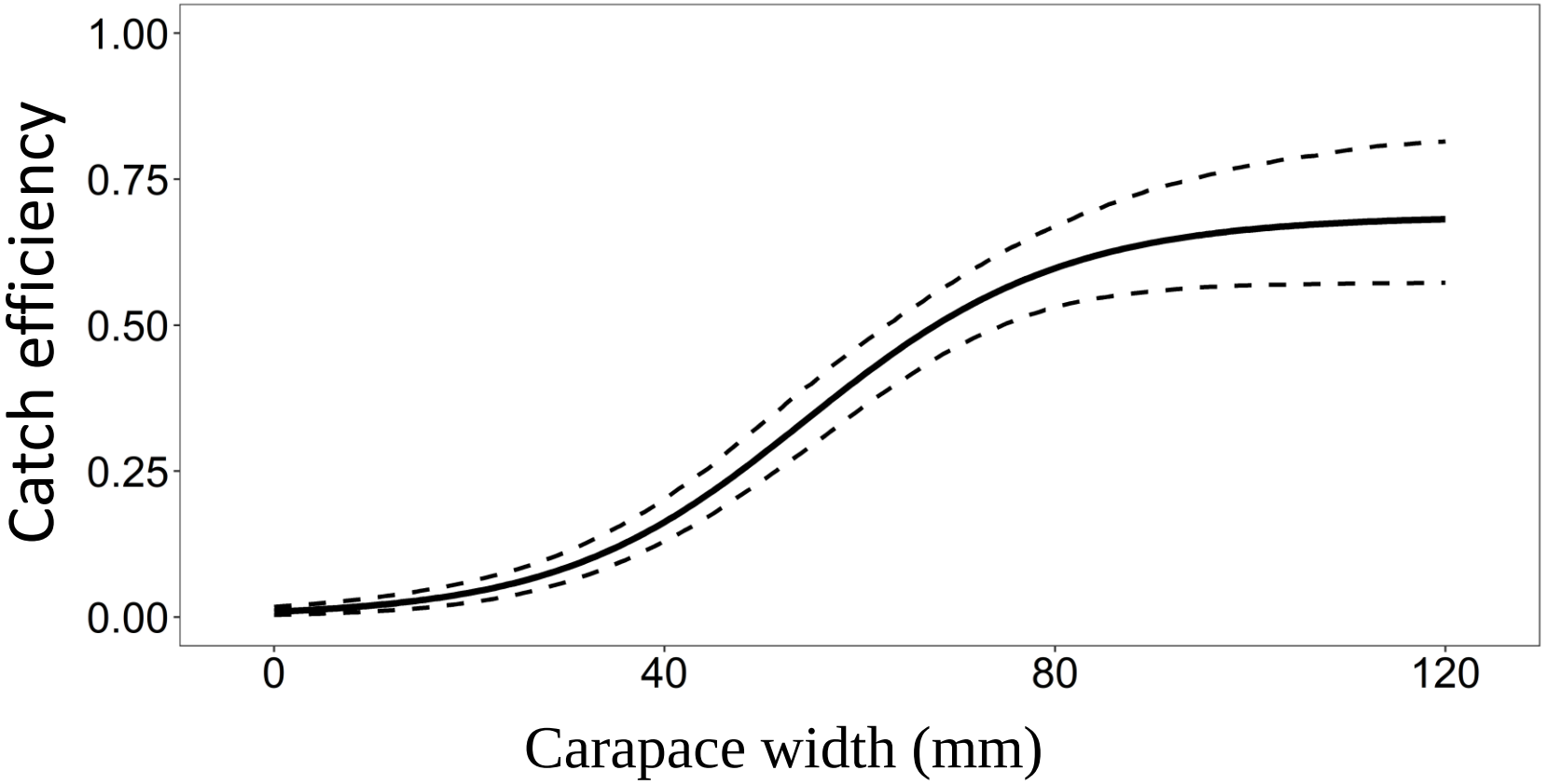


In recent years, the fishing ground of commercial fisheries and the survey positions are almost the same off the coast of Fukushima Prefecture.

Survey data



Supplementary Figure 3-4. 2016 to 2020 Crab density of males by survey sites



Supplementary Figure 2-2. Carapace width vs. catch efficiency

Reviewer's comment

Response

- Are there observations to support the catch efficiency curve in Suppl Fig 2-2?
  (T

We show the curve with observations from Hattori et al 2014.

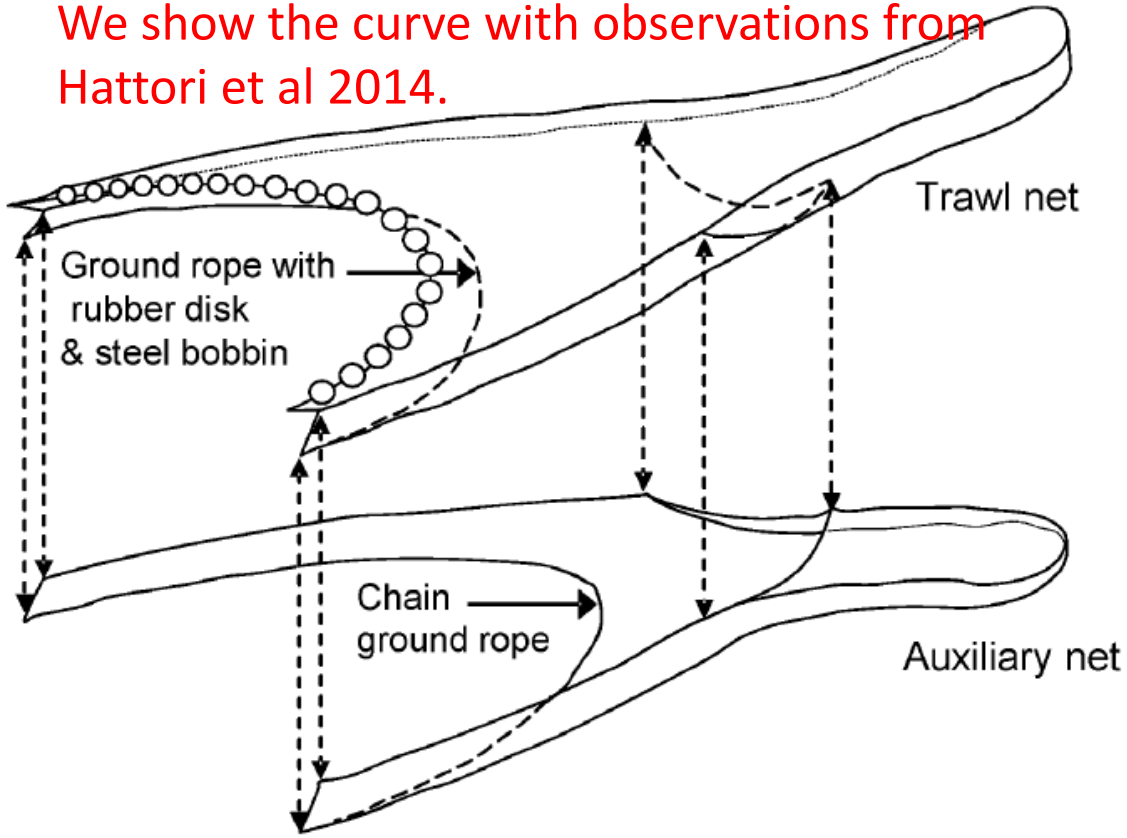


Fig. 3 Schematic illustration of the experimental trawl net composed of the *Wakataka Maru* trawl net and the auxiliary net. This figure is cited from Somerton and Otto (1999).[6]

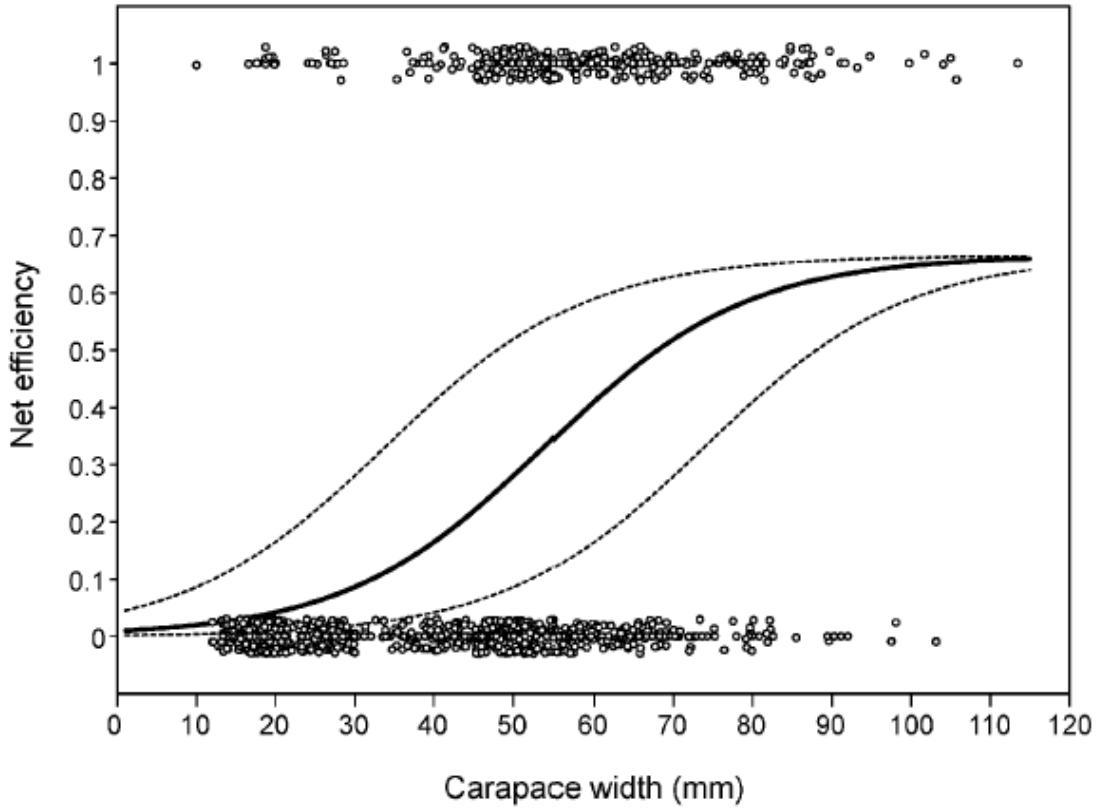
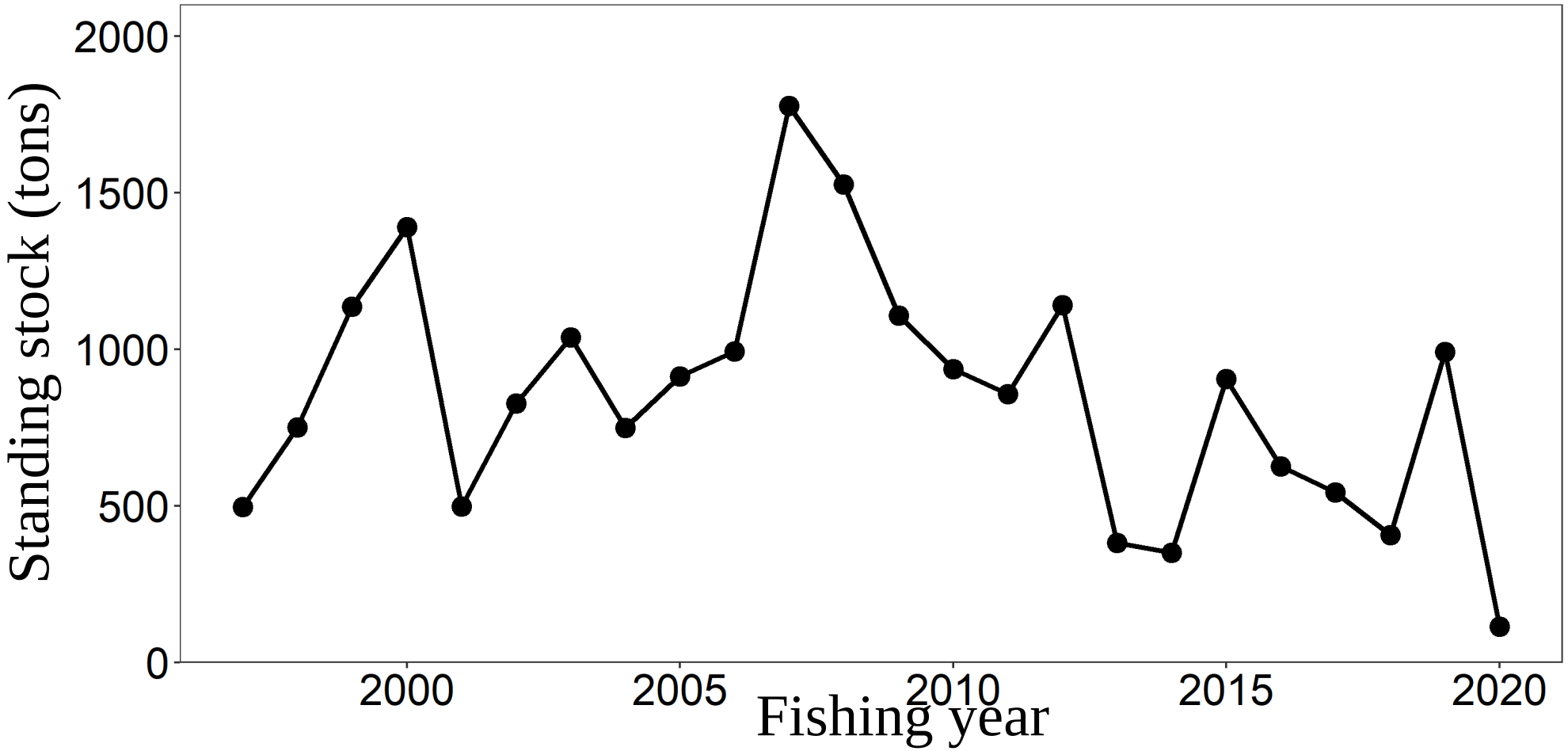


Fig. 5 Estimated net efficiency with the carapace width of snow crab *Chionoecetes opilio*. Broken lines indicate 95% confidence interval. Data plots are scattered around 0 and 1 by adding small random values.

Hattori et al., 2014

Survey data


Standing stock (tons)
2000
1500
1000
500
0
2000
2005
2010
2015
2020
Fishing year

Survey data – Reviewer's comment

- What is the estimated uncertainty (e.g., CV) of the survey index in Fig 4-1 and Table 4-1? (Teo #6)

- 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. (Dick #9)

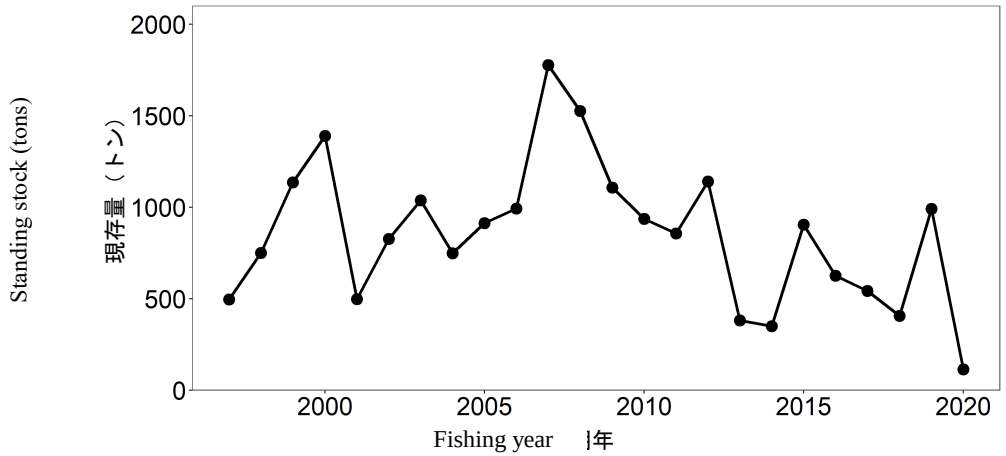
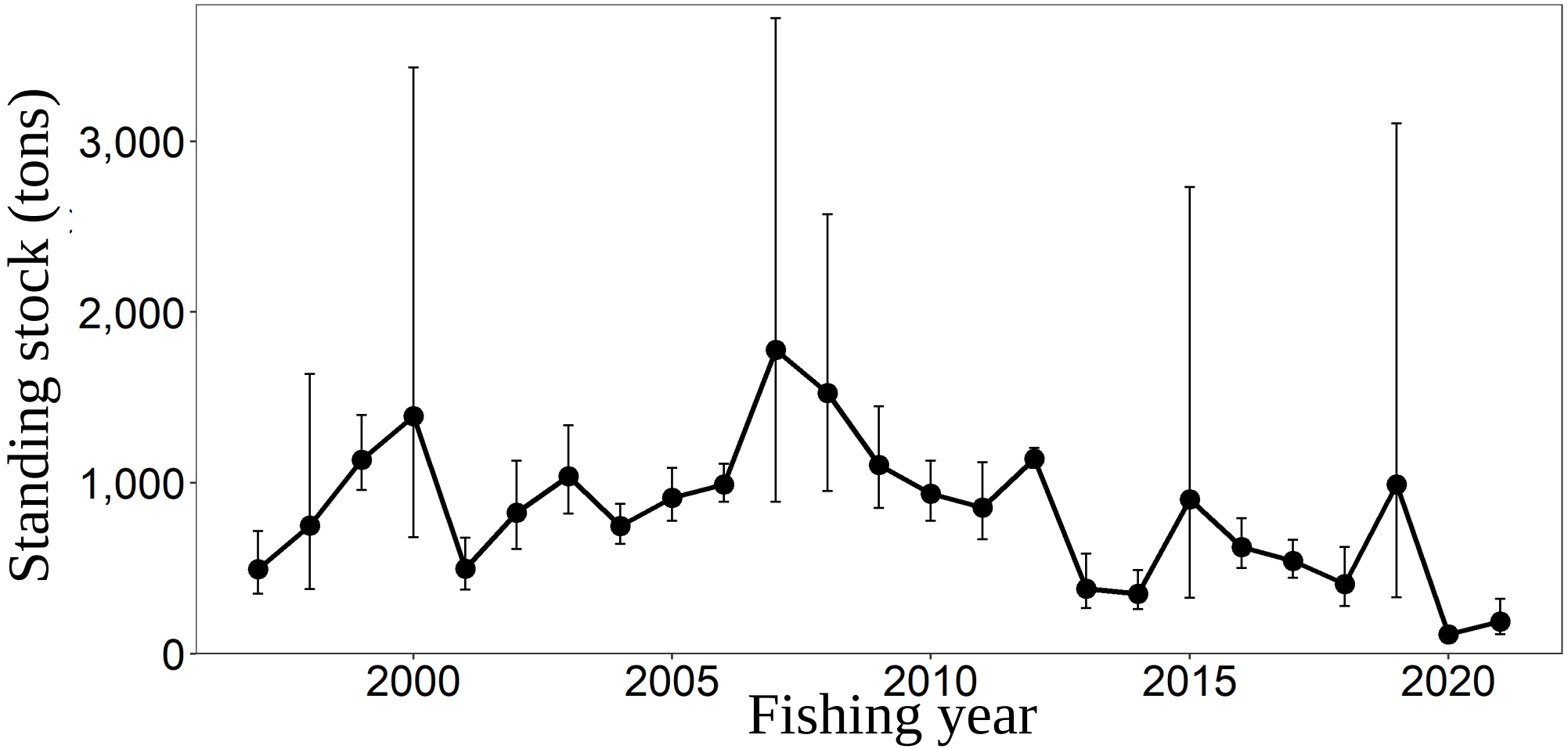


Fig. 4-1. Trends in standing stock based on bottom-trawl surveys

Survey data

Response



Survey data

instar	sex	Maturity	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
8	Male	IM	0.187	0.552	0.474	0.128	0.301	0.308	0.252	0.205	0.352	0.196	0.081	0.190	0.392	0.248	0.406	0.207	0.222	0.461	0.186	0.386	0.259	0.190	0.339	0.241
9	Male	IM	0.488	0.444	0.160	0.531	0.638	0.309	0.333	0.229	0.252	0.193	0.141	0.206	0.211	0.200	0.162	0.240	0.318	0.338	0.218	0.286	0.354	0.278	0.335	0.199
10	Male	IM	0.353	0.459	0.298	0.421	0.133	0.308	0.308	0.176	0.304	0.230	0.576	0.328	0.194	0.240	0.203	0.175	0.238	0.287	0.538	0.289	0.246	0.321	0.184	0.204
10	Male	M	0.861	0.695	0.414	0.420	0.423	0.388	0.243	0.167	0.357	0.193	0.648	0.281	0.171	0.224	0.237	0.284	0.412	0.348	0.741	0.229	0.196	0.263	0.472	0.282
11	Male	IM	0.424	0.518	0.382	0.551	0.267	0.427	0.338	0.194	0.336	0.192	0.809	0.494	0.170	0.296	0.345	0.050	0.301	0.570	0.787	0.319	0.315	0.714	0.396	0.357
11	Male	M	0.422	0.410	0.568	0.431	0.612	0.300	0.220	0.239	0.249	0.179	0.696	0.353	0.182	0.196	0.285	0.282	0.311	0.345	0.772	0.228	0.226	0.360	0.249	0.241
11	Male	IM	0.416	0.333	0.380	0.880	0.319	0.490	0.404	0.204	0.273	0.188	0.706	0.571	0.350	0.238	0.378	0.043	0.368	0.716	0.762	0.482	0.404	0.761	0.614	0.442
11	Male	M	0.244	0.595	0.414	0.880	0.329	0.232	0.279	0.246	0.242	0.174	0.795	0.403	0.244	0.195	0.258	0.185	0.347	0.349	0.765	0.323	0.235	0.459	0.486	0.304
12	Male	IM	0.578	0.405	0.251	0.820	0.293	0.386	0.575	0.304	0.240	0.216	0.371	0.678	0.282	0.331	0.575	0.038	0.342	0.547	0.725	0.430	0.402	0.474	0.785	0.519
12	Male	M	0.292	0.555	0.481	0.834	0.306	0.289	0.262	0.286	0.322	0.228	0.701	0.587	0.224	0.247	0.271	0.167	0.532	0.325	0.542	0.278	0.274	0.371	0.835	0.302
13	Male	IM	0.656	0.716	0.528	0.544	0.816	0.721	0.577	0.467	0.556	0.364	0.491	0.820	0.538	0.451	0.770	0.424	0.619	0.464	0.000	0.000	0.000	0.662	0.619	0.000
13	Male	M	0.478	0.395	0.603	0.815	0.218	0.331	0.234	0.383	0.554	0.289	0.357	0.490	0.354	0.382	0.259	0.059	0.745	0.353	0.360	0.468	0.352	0.642	0.862	0.386
14	Male	M	0.284	0.666	0.616	0.932	0.591	0.452	0.528	0.528	0.442	0.354	0.824	0.672	0.438	0.397	0.436	0.011	0.803	0.526	0.553	0.699	0.708	0.758	0.881	0.771
8	Female	IM	0.357	0.476	0.630	0.516	0.397	0.257	0.393	0.171	0.378	0.194	0.118	0.210	0.327	0.209	0.395	0.304	0.170	0.499	0.233	0.504	0.241	0.300	0.280	0.269
9	Female	IM	0.451	0.455	0.212	0.511	0.578	0.265	0.221	0.176	0.216	0.205	0.153	0.219	0.166	0.200	0.176	0.279	0.334	0.356	0.330	0.286	0.447	0.255	0.444	0.200
10	Female	IM	0.327	0.364	0.266	0.346	0.326	0.351	0.243	0.218	0.264	0.263	0.379	0.351	0.183	0.331	0.202	0.225	0.250	0.275	0.541	0.256	0.245	0.239	0.265	0.180
11	Female	M	0.511	0.817	0.167	0.207	0.469	0.448	0.340	0.268	0.242	0.217	0.625	0.222	0.429	0.348	0.379	0.259	0.291	0.319	0.936	0.303	0.345	0.373	0.937	0.396

Survey data

Response

- In Suppl Table 2-1, I assume the 4 categories for 11th instar crabs are for the M & IM & 74-80 & 80-86 cm categories. Is that correct? (Teo #9)

Supplementary Table 2-1. Population size by instar from bottom-trawl surveys (no consideration of catch efficiency)

Instar	Sex	Maturity	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
8	M	IM	166	931	63	30	525	199	246	553	1,677	735	467	406
9	M	IM	434	266	546	79	565	548	784	693	816	2,652	1,140	1,255
10	M	IM	705	273	834	509	136	987	1,456	1,640	1,423	2,873	4,102	1,757
10	M	M	94	147	107	73	30	276	190	217	153	356	752	259
11	M	IM	142	47	343	239	108	369	216	143	445	252	889	623
11	M	M	47	75	102	69	123	171	184	124	192	260	798	408
11	M	IM	85	74	213	254	99	97	124	101	298	190	528	545
11	M	M	88	77	189	103	92	148	191	193	258	266	1,023	485
12	M	IM	68	86	146	262	129	106	156	63	185	97	260	579
12	M	M	122	164	293	546	156	242	244	228	283	304	829	621
13	M	IM	8	6	65	61	14	30	28	5	8	8	14	78
13	M	M	76	185	76	351	95	113	160	74	105	253	193	395
14	M	M	64	56	45	300	45	75	82	28	34	90	52	122
8	F	IM	144	505	145	14	427	144	268	501	1,446	643	299	359
9	F	IM	380	107	385	93	536	331	608	500	780	2,733	1,119	1,140
10	F	IM	689	177	686	332	77	1,494	667	1,184	1,289	2,844	2,368	1,249
11	F	M	861	1,413	2,455	1,286	688	1,566	2,031	1,695	1,542	1,472	2,130	822

Yes

Survey data – Reviewer's comment

Response

（1） Are there any other sources of data that may be used as an abundance index? For example, trap data like the Sea of Japan stocks? (Teo #13)

（2） 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. (Dick #10)

Contents

- Biology
  - Distribution, Growth
- **Stock assessment**
  - Fisheries
  - Bottom-trawl survey
  - **Estimation of stock abundance and Natural mortality**
- Stock-Recruitment relationship and Future projection

Biomass estimation

- JASAM, “just another state-space stock assessment model” (Shibata et al. 2021)
- Estimate the stock abundance of the snow crab off Tohoku considering interannual variations in M and p.

JASAM

Result of estimation

- Biomass
- SSB
- Recruitment
- Fishing mortality
- Natural mortality
- Terminal molt probability

Future projection and Calculation ABC

（1） What is the sigma_M and sigma_rec? (Teo #28)

$$\ln(M_{t+1}) \sim \text{Normal}(2\ln(M_t) - \ln(M_{t-1}), \sigma_M^2) \quad (6)$$

$$\ln(N_{a=8,j=0,t+1}) \sim \text{Normal}(\ln(N_{a=8,j=0,t}), \sigma_{rec}^2)) \quad (7)$$

The number of σM is 0.03 (=exp(-3.498)) and σrec is 0.31(=exp(-1.167)). See also slide 69.

（2） Am I correct to think of recruits in the model as N_8 (N at instar-8), which is age-3? (Teo #25)

→ 「Age-5」

Reviewer's comment

Response

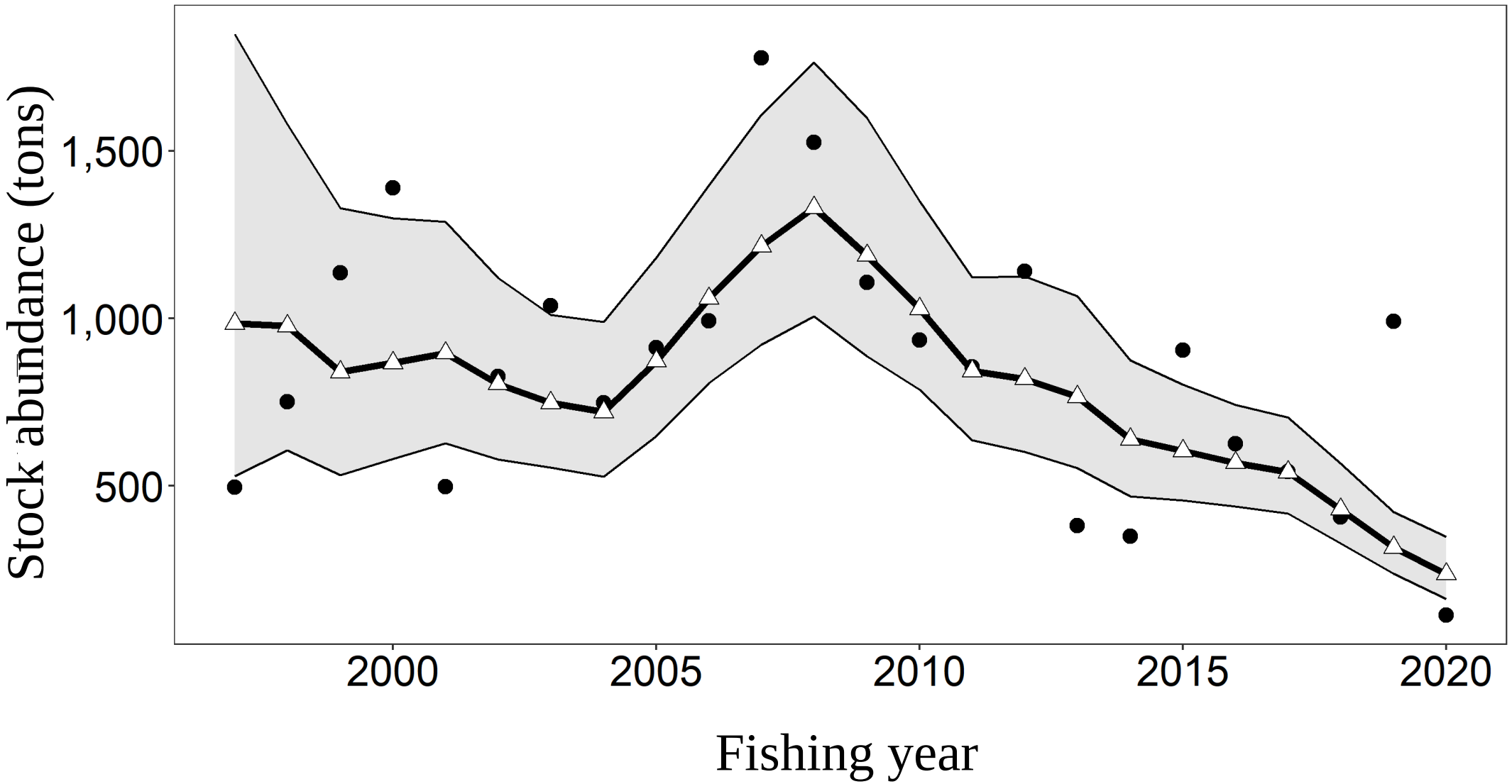
- Is the catch efficiency equation developed by Hattori et al. (2014; Supp. Fig. 2-2) used to calculate the annual standing stock size in the bottom trawl survey (Fig. 4-1)? If so, does it make sense to use the same equation, again, in the population dynamics model (i.e. equations 27-33)?

  Yes. The parameters of catch efficiency equation are not estimated in stock assessment. The parameter value are referred from Hattori et al.,2014.

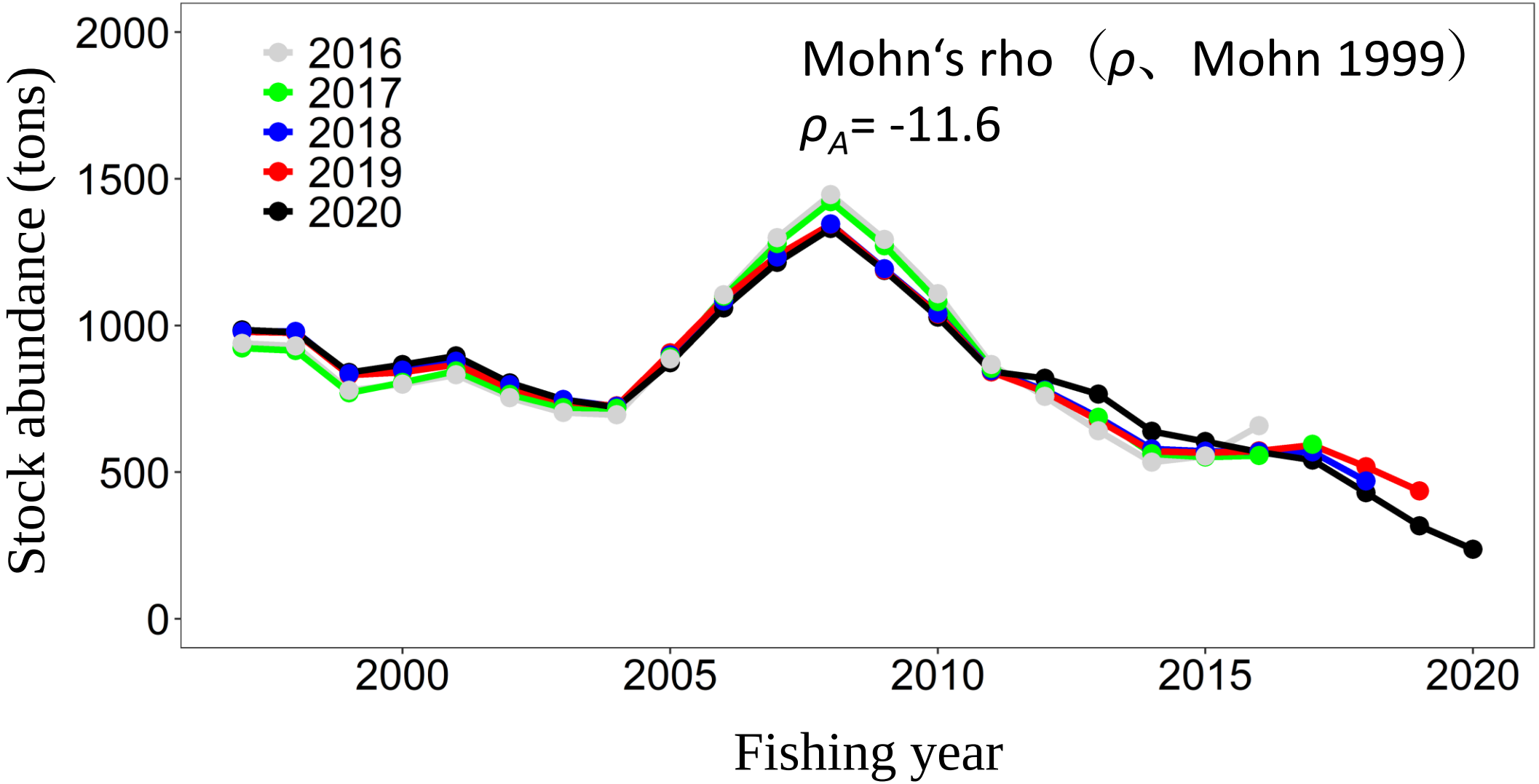
- If the dynamics model is fit to survey estimates that have already been adjusted for catch efficiency, and the catch efficiency curve is part of the dynamics calculations, then the assessment would be adjusting for catch efficiency twice. (Dick #11)

  The catch efficiency equation is used just once for number at instar estimated by JASAM.

Biomass

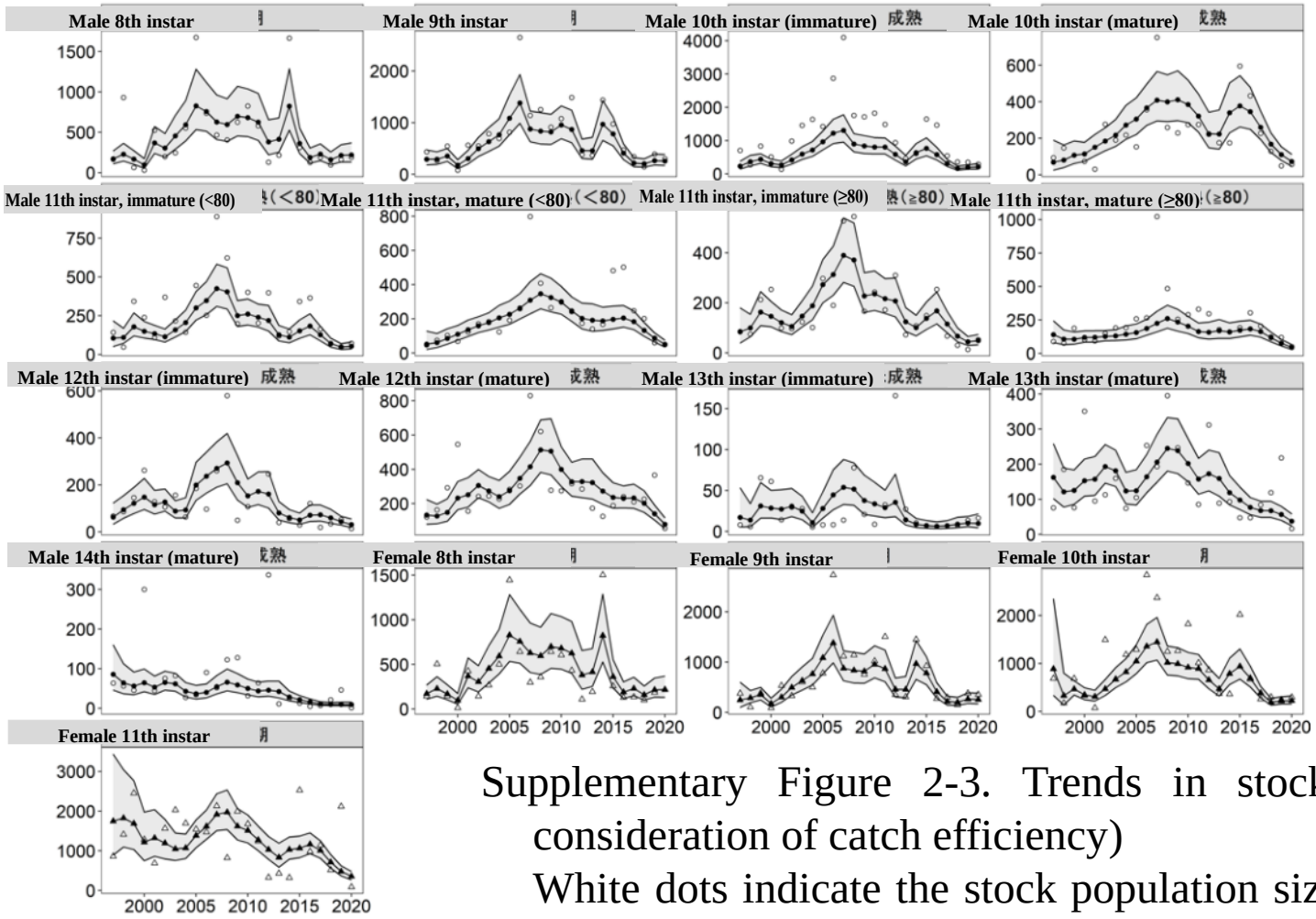

Stock abundance (tons)
1,500
1,000
500
2000
2005
2010
2015
2020
Fishing year

Biomass


Mohn‘s rho（ρ、Mohn 1999）
ρ_A= -11.6
2016
2017
2018
2019
2020
Stock abundance (tons)
2000
1500
1000
500
0
2000
2005
2010
2015
2020
Fishing year

Reviewer's comment

- In Suppl Fig 2-3, please plot the CVs of the observations as well. (Teo #32)



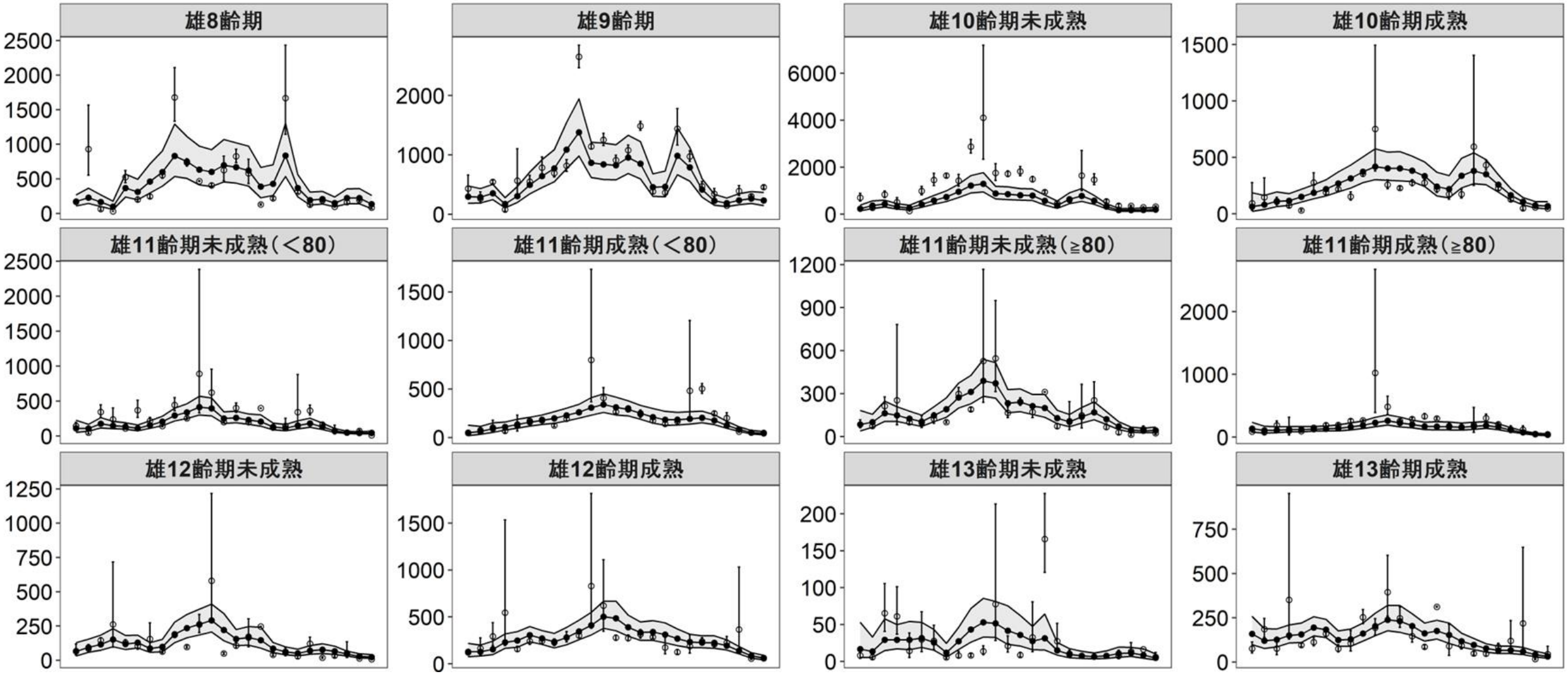
See next slide.

Supplementary Figure 2-3. Trends in stock population size by sex and by instar (no consideration of catch efficiency)
White dots indicate the stock population size based on bottom-trawl surveys, and black dots indicate stock population size based on JASAM estimates. The shaded area indicates the 95% confidence interval for estimated values for stock abundance.

Reviewer's comment

Response

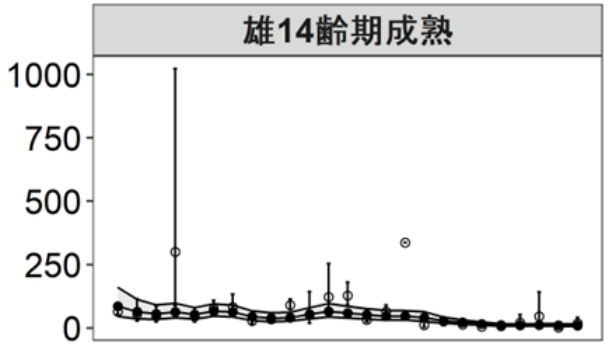
- In Suppl Fig 2-3, please plot the CVs of the observations as well. (Teo #32)

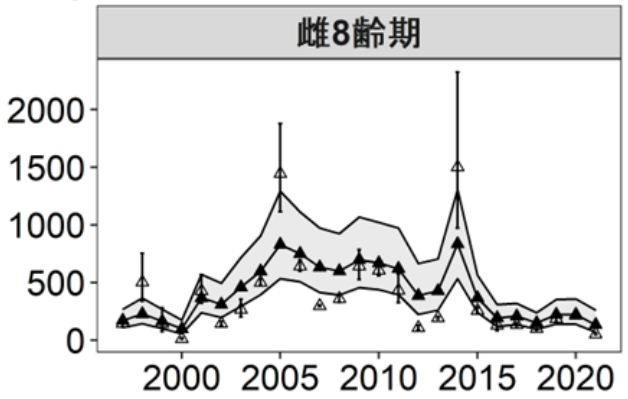


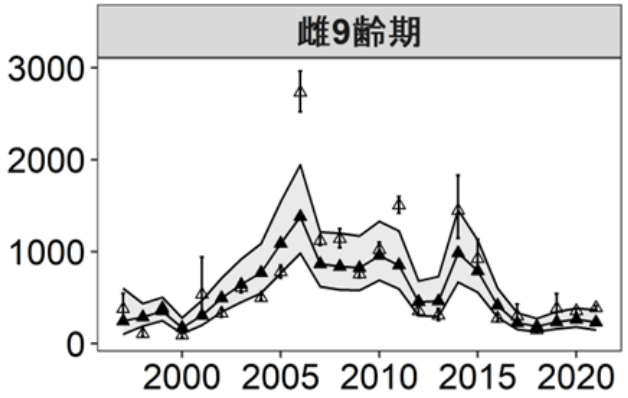
Reviewer's comment

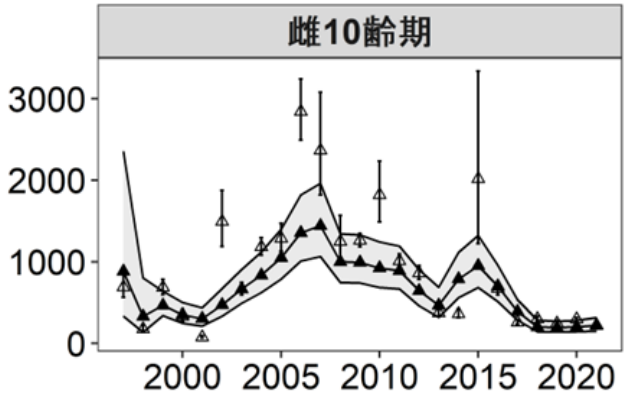
Response

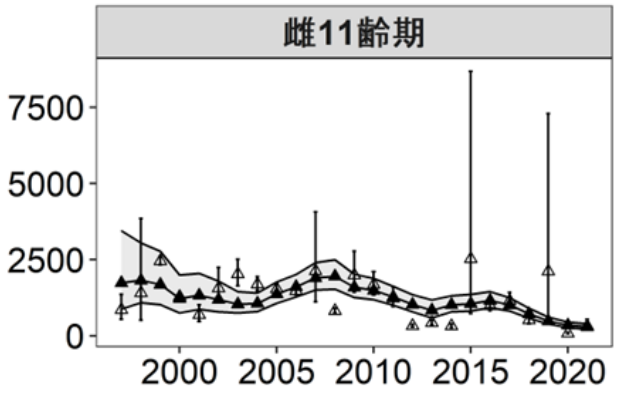
- In Suppl Fig 2-3, please plot the CVs of the observations as well. (Teo #32)





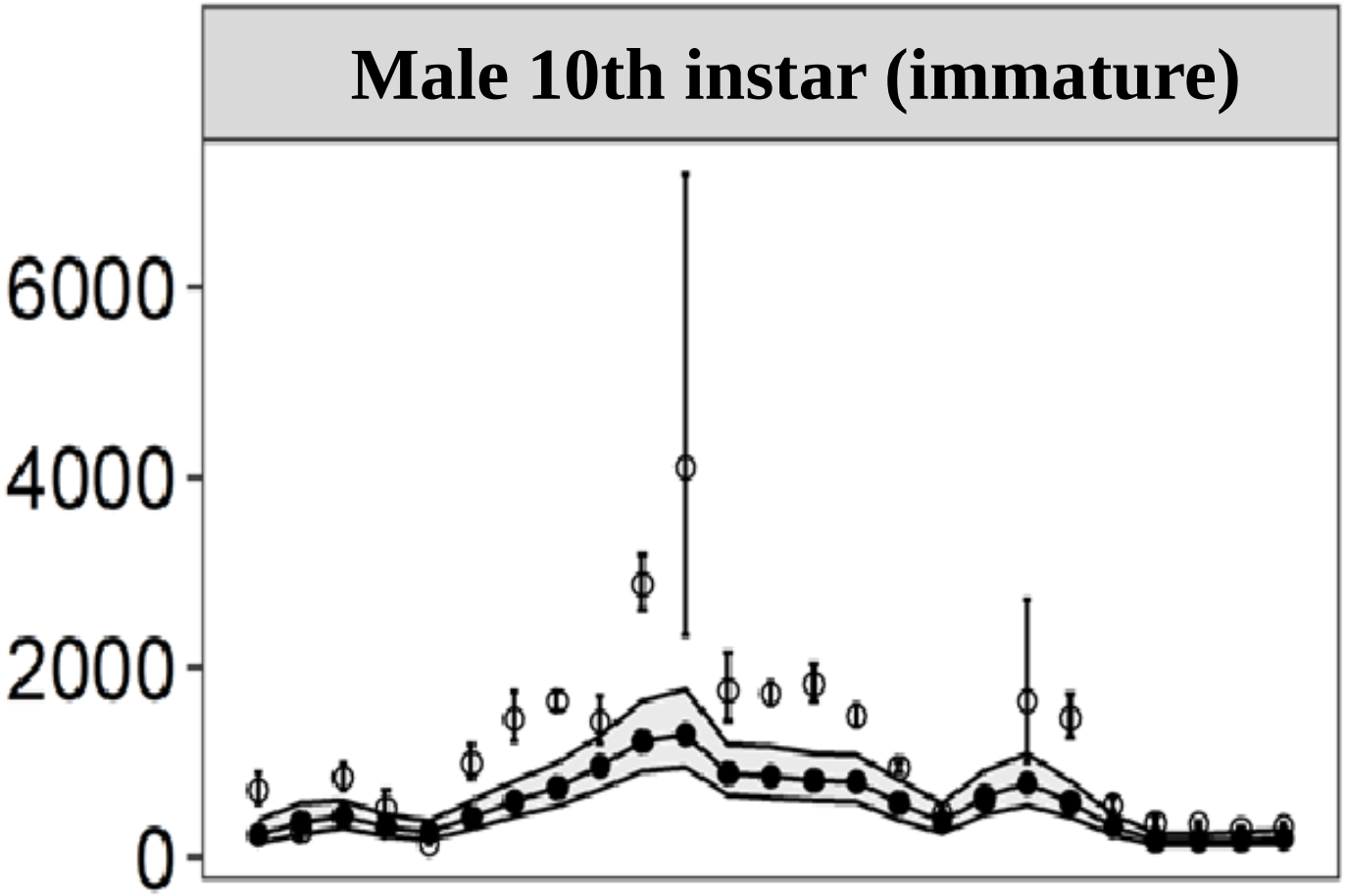






Reviewer's comment

- There seems to be a positive residual pattern for Male_10_immat and a negative one for Male_10_mat. Is there some reason for this? (Teo #33)

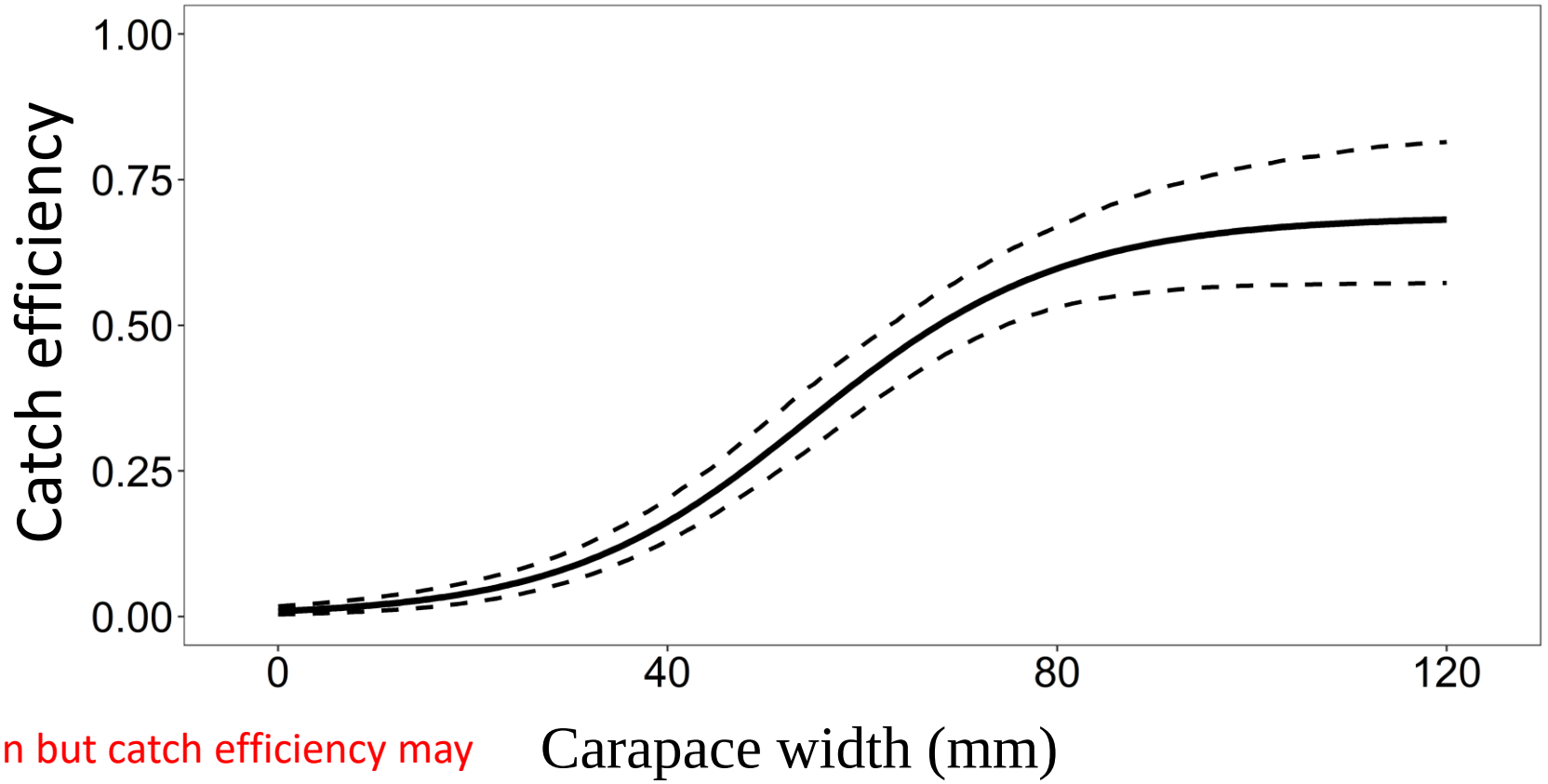


There is no clear reason but catch efficiency may effect.(see also next slide.)

Reviewer's comment

Response

- There seems to be a positive residual pattern for Male_10_immat and a negative one for Male_10_mat. Is there some reason for this? (Teo #33)

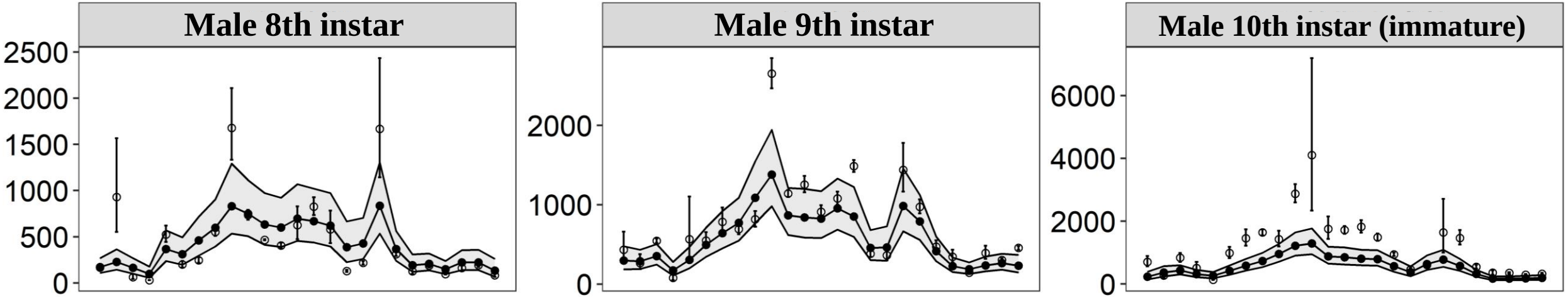


There is no clear reason but catch efficiency may effect. See also eqs.32 of Shibata et al., 2021. The fitting of each instar is effected by the catch efficiency.

Reviewer's comment

Response

- There seems to be a positive residual pattern for Male_10_immat and a negative one for Male_10_mat. Is there some reason for this? (Teo #33)

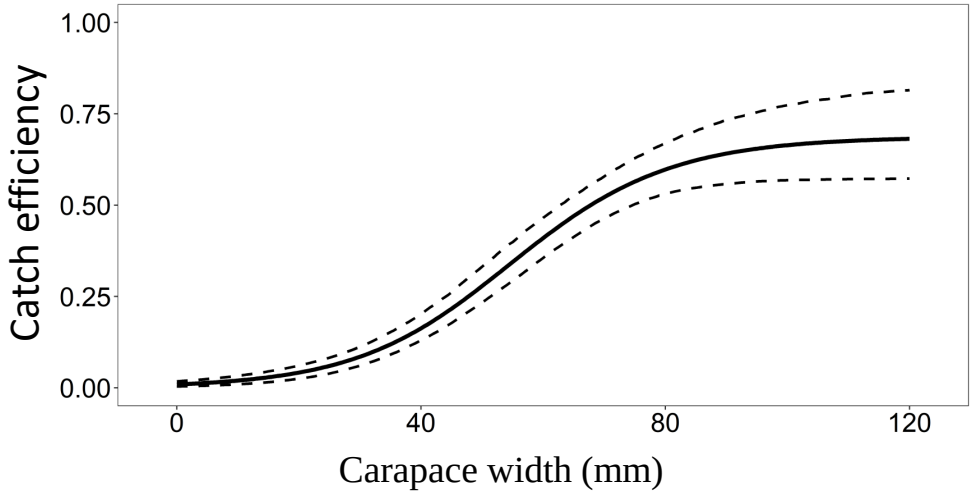


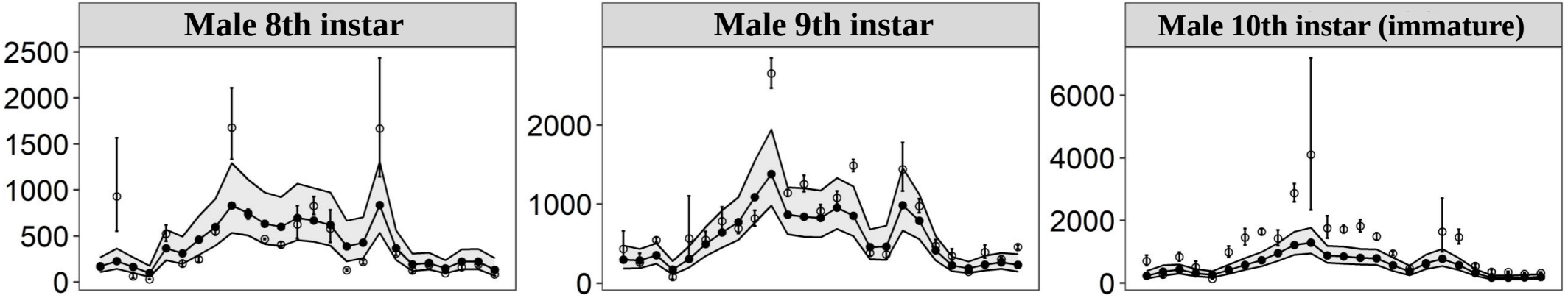
These are observation(n) and estimates(q*N) each instar. Here q is catch efficiency.

Reviewer's comment

Response

- There seems to be a positive residual pattern for Male_10_immat and a negative one for Male_10_mat. Is there some reason for this? (Teo #33)

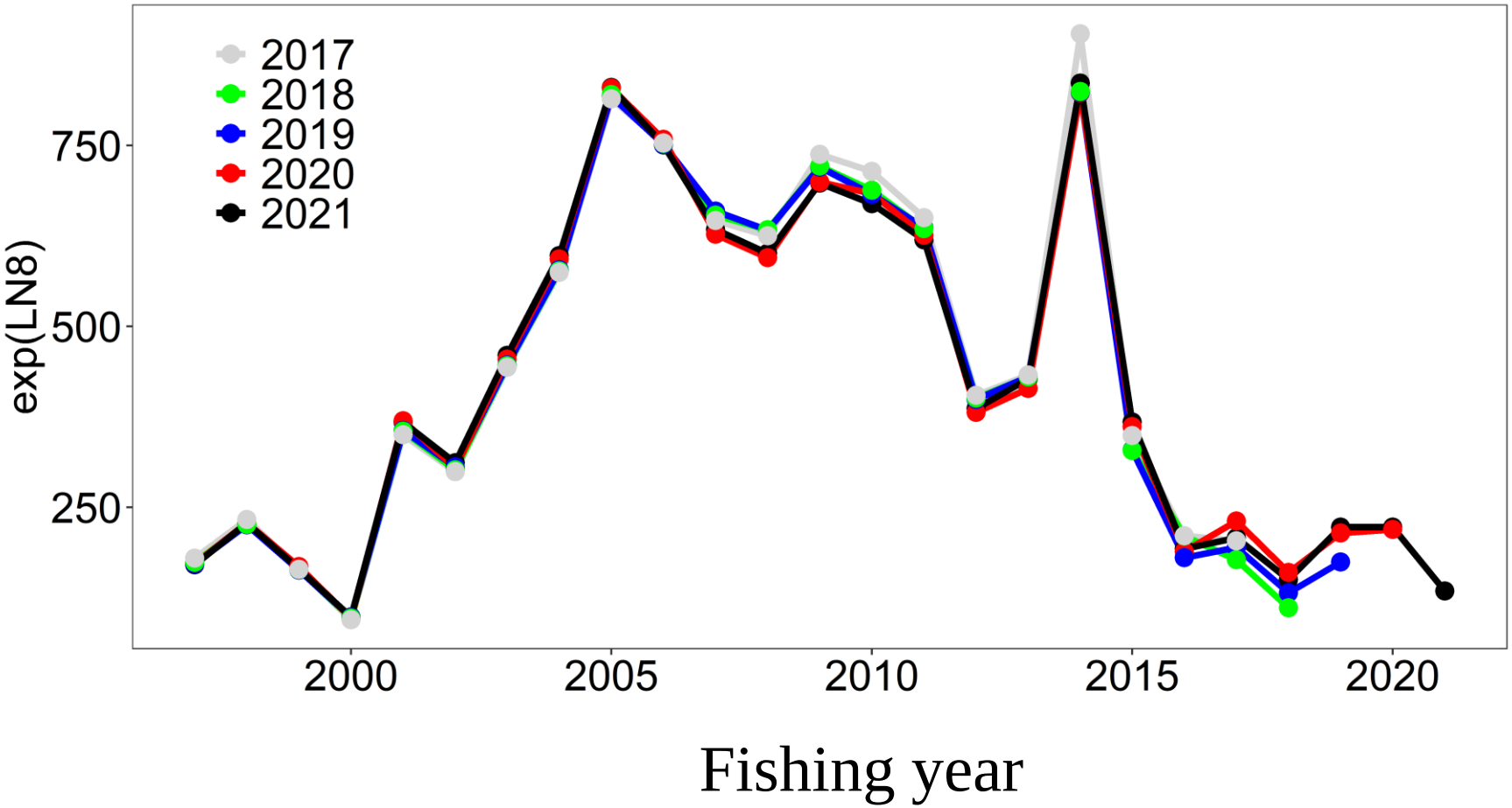




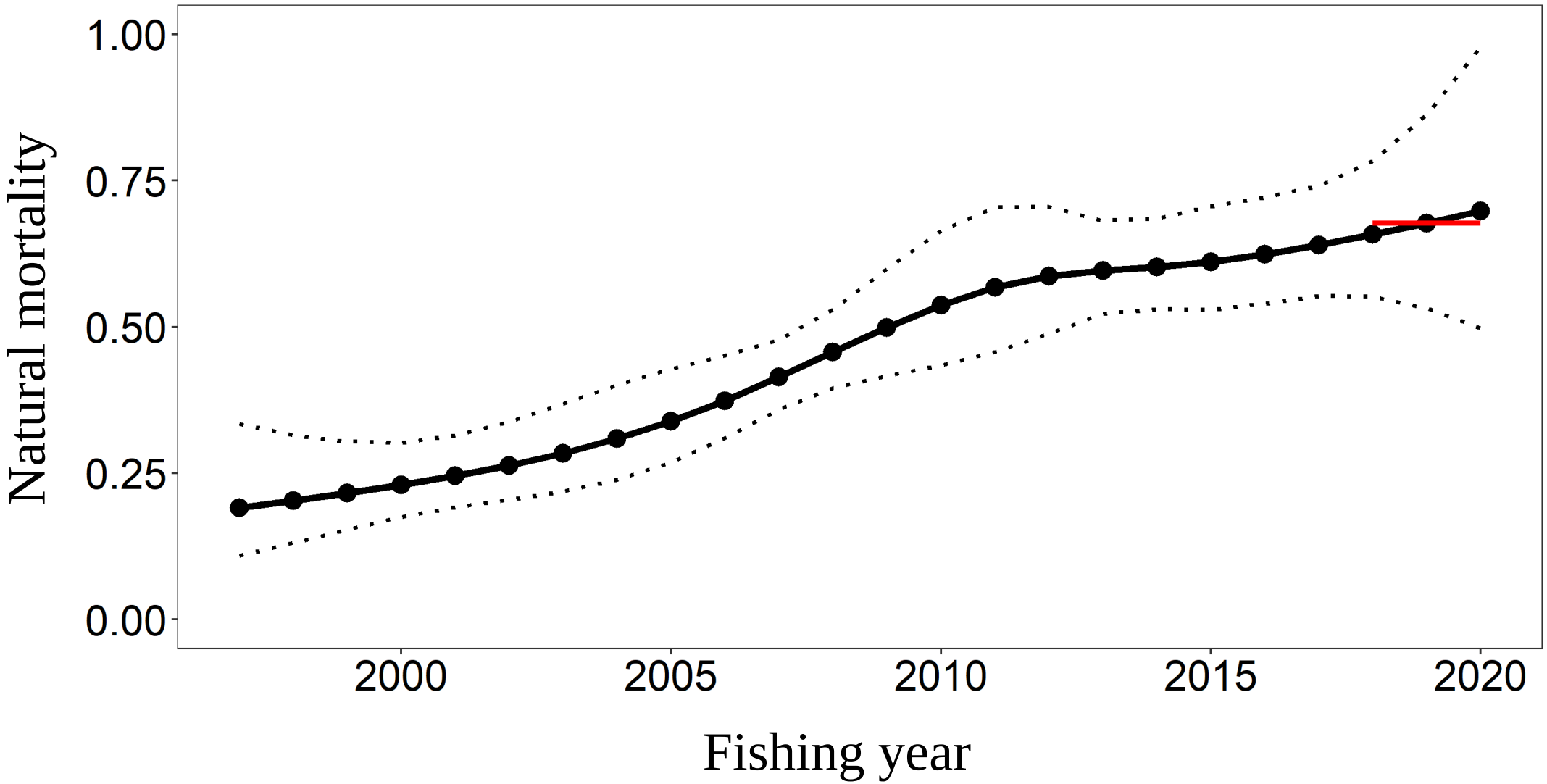
Reviewer's comment

Response

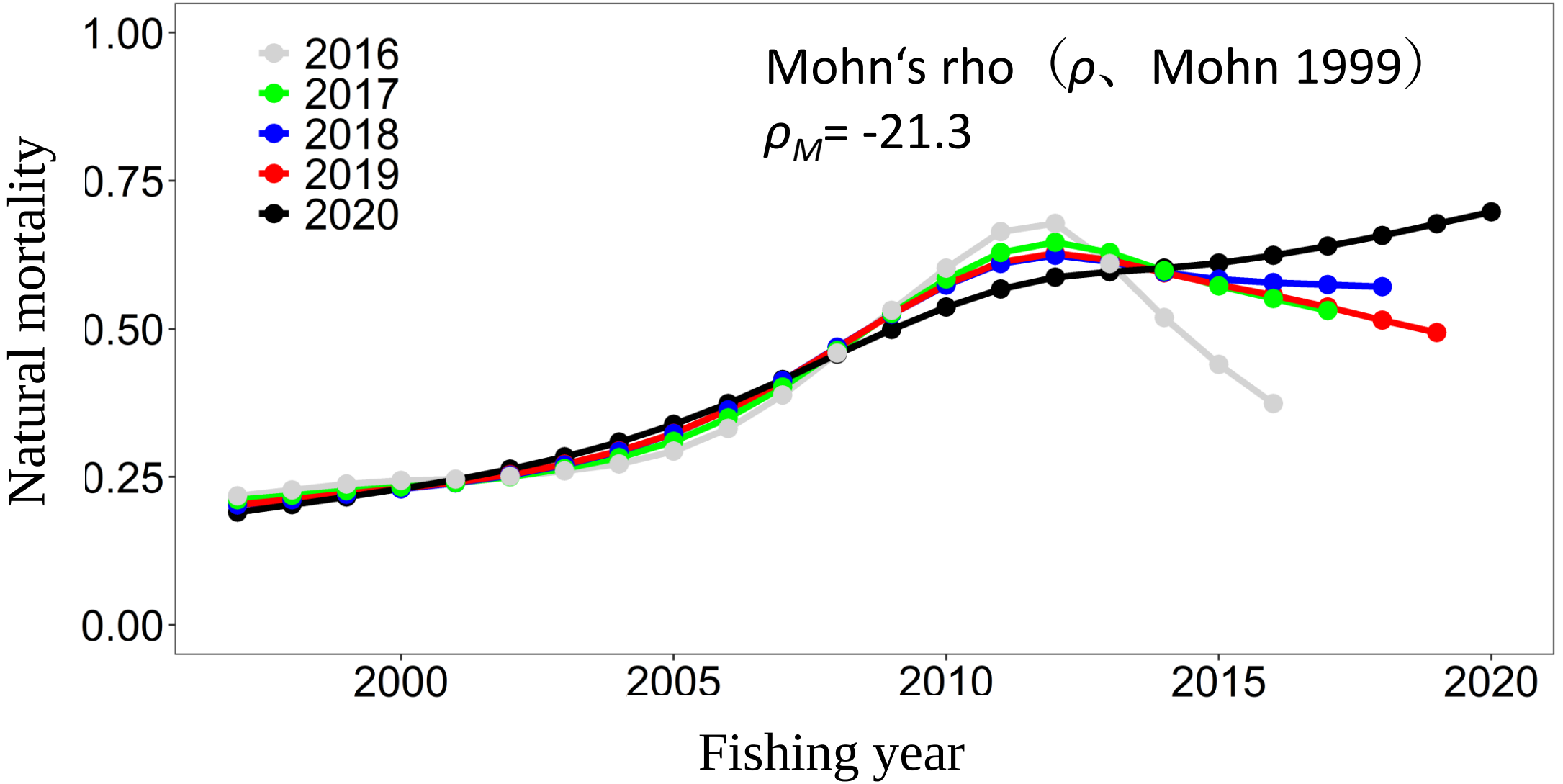
- Please plot the retrospective pattern for recruitment (i.e. N_8). (Teo #26)



Natural mortality (M)



Natural mortality (M)



Reviewer's comment

Response

- 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. (Dick #1)

  If M is constant, it is difficult to explain time-varying stock size with F=0 (i.e., keep to decrease…) for North pacific stock. So, we tried to estimate time-varying M. Bottom water temperature may be too high to live for snow crab.

- Is there any work to independently examine if the natural mortality of this stock has increased substantially? For example, tagging experiments? (Teo #20)

  We tried a mark-recapture experiment, but marked individual has not been caught again. Maybe the fishing effort is too small to catch again.

Reviewer's comment

Response

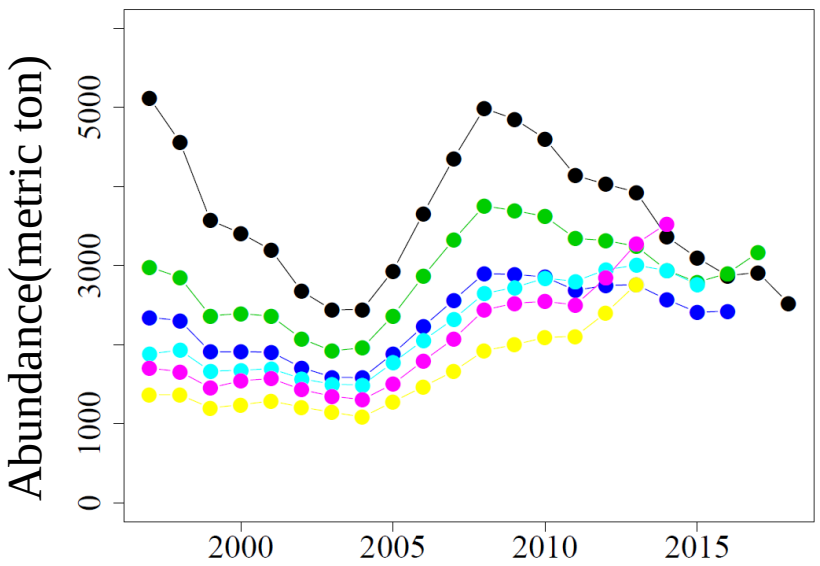
- In the Shibata et al. (2020) paper, the M is modelled as M_g,t but in the assessment, it is M_t. Is my reading correct that the M is modelled differently? If so, please explain why. The model described in the paper is actually a bit easier to understand. What are the other differences? (Teo #24)

The equation in Shibata et al., 2021 is correct, although the equation in paper of assessment is wrong. But the model is same for both. It was just description failure.

Reviewer's comment

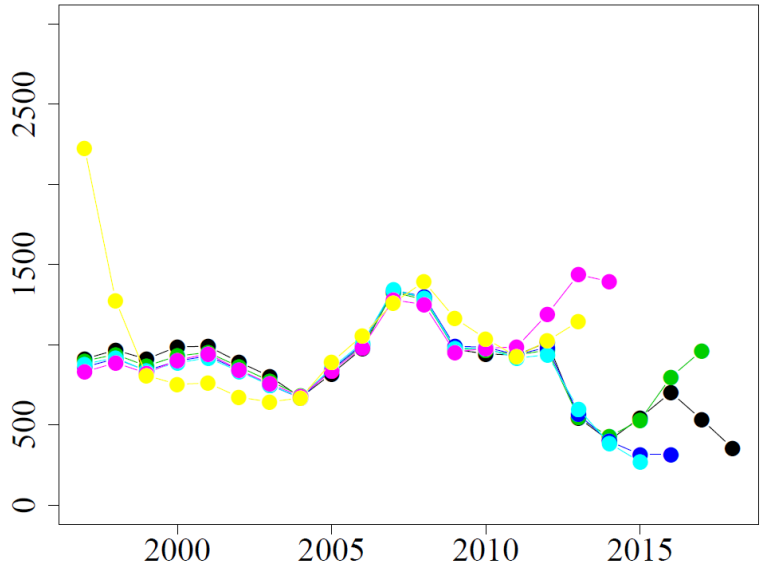
- It would useful to examine a model with constant estimated M, and compare the recruitment and other parameters from the base case model. (Teo #30)

M=constant



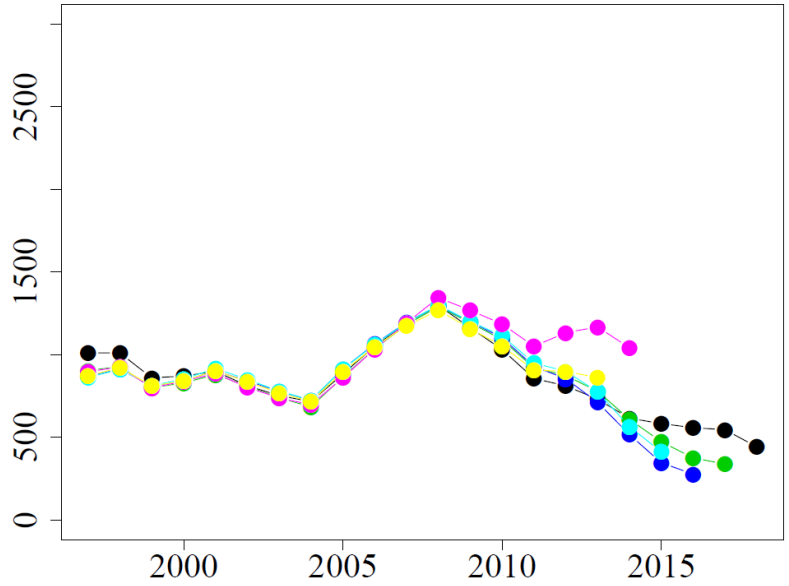
ρ_{future}=-8.5

M=first order difference



ρ_{future}=66.3

M=second order difference



ρ_{future}=-5.8

Although the definition of ρ_future is described in Shibata et al., 2021, it evaluates performance of future prediction. If M is constant or first-order difference, the performance is wrong.

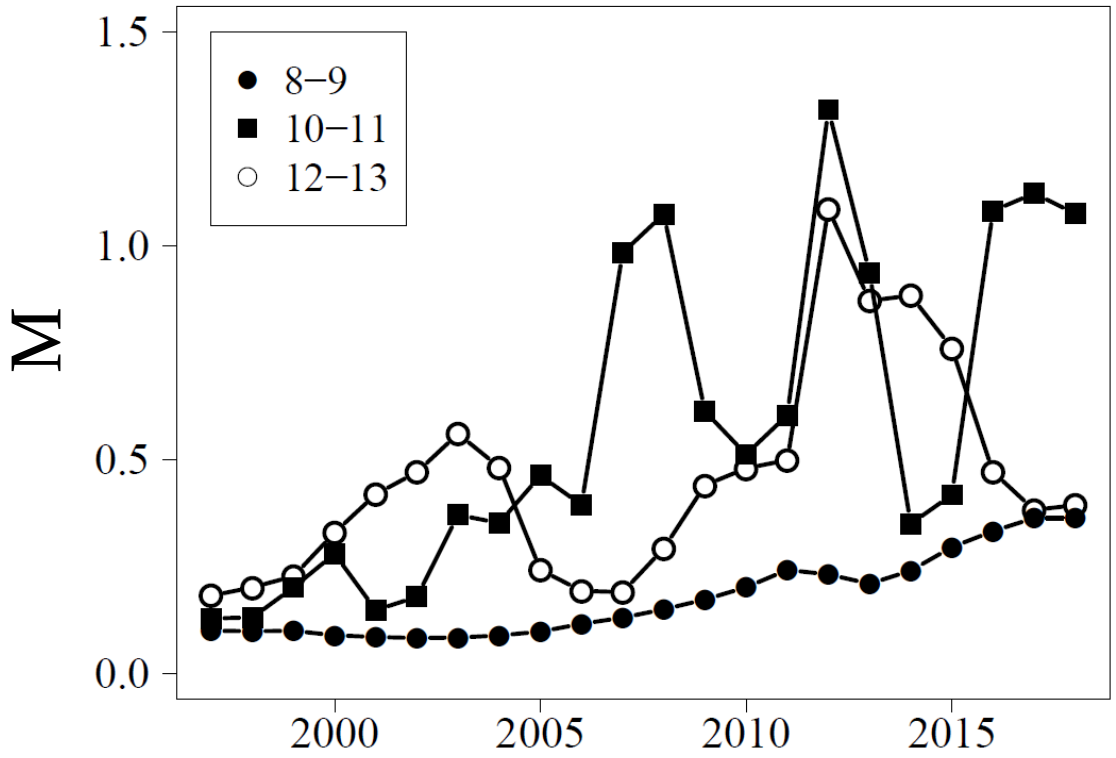
Reviewer's comment

Response

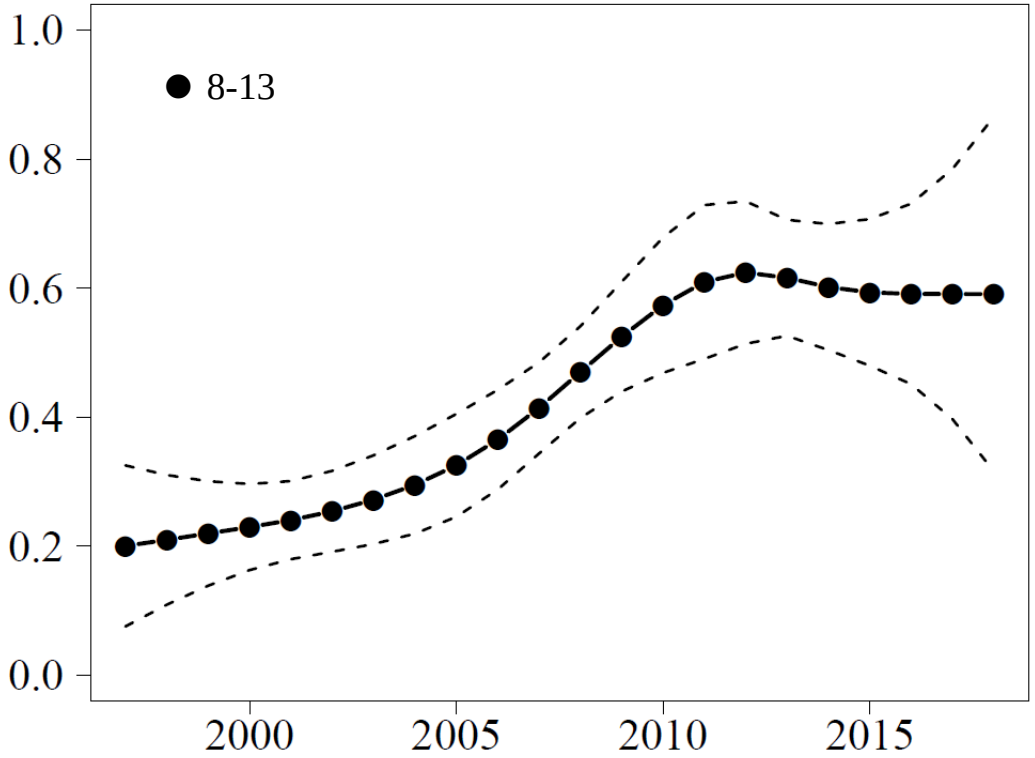
- Another possibility is to allow a step change in M and/or recruitment after 2010, and see if that is reasonable. I am just wondering if the model wants to have a step change in some unmodelled or mis-specified process and is simply putting most of the model misfits onto M. (Teo #31)

Step change model is included in first order difference model.

M=first order difference



M=second order difference



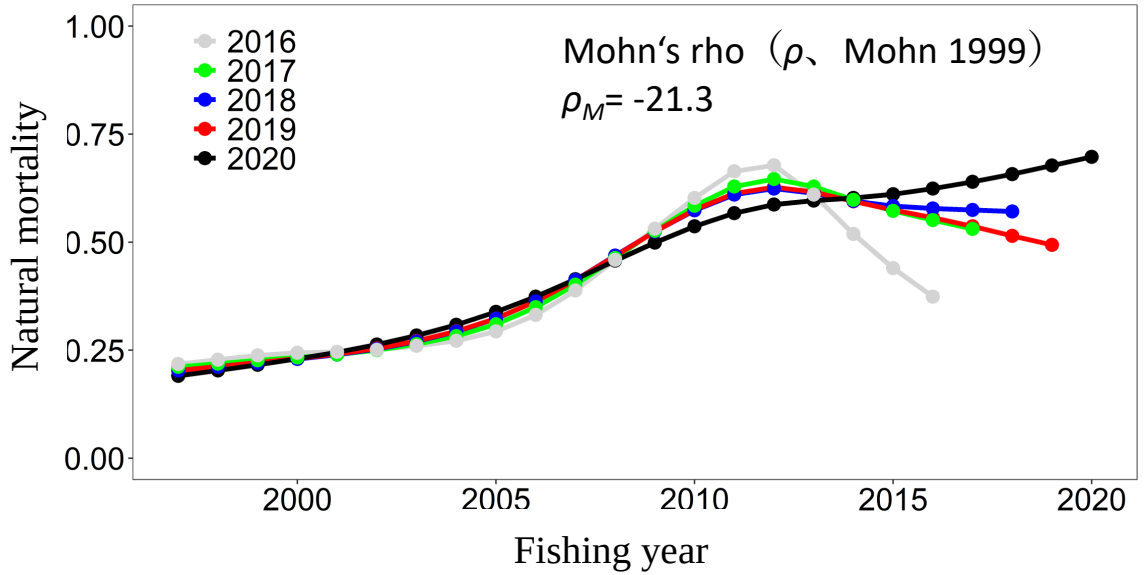
Reviewer's comment

Response

- There is a clear retrospective pattern for this model, especially for M.
- The obvious hypothesis is that the mismatch between catch and CPUE after 2010 is the cause of the retrospective. Has there been an attempt to see if this hypothesis is correct? For example, is there still a retrospective pattern if the model ended in 2010 and you do a retrospective from there. (Teo #27)

Natural mortality (M)

56

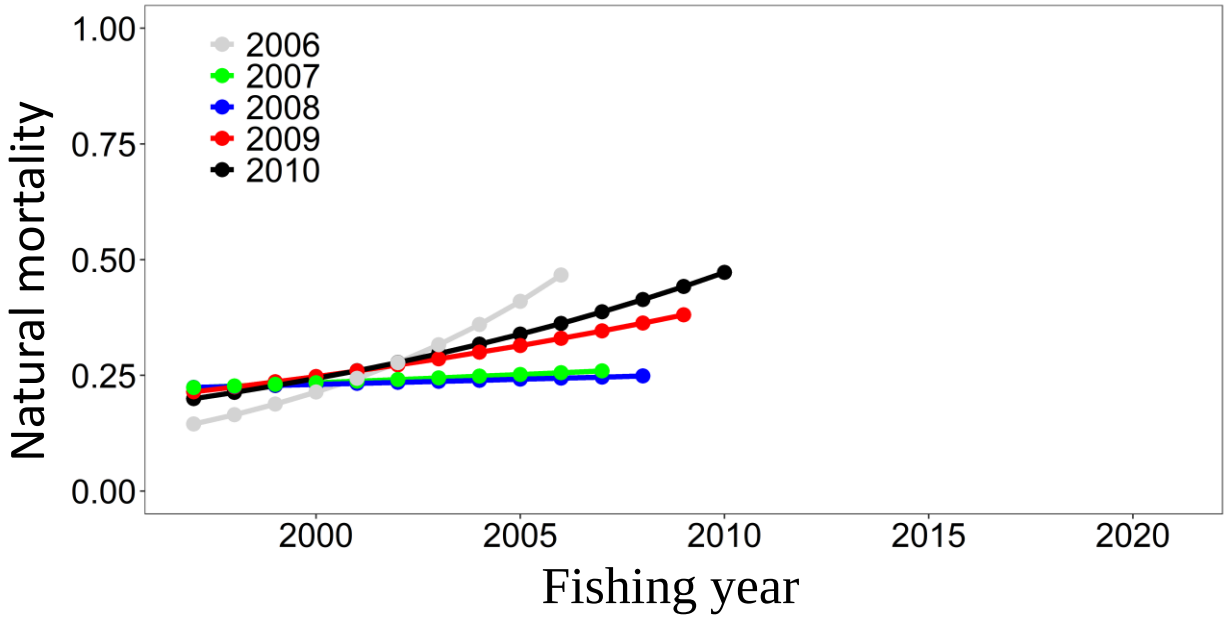


Reviewer's comment

Response

- There is a clear retrospective pattern for this model, especially for M.
- The obvious hypothesis is that the mismatch between catch and CPUE after 2010 is the cause of the retrospective. Has there been an attempt to see if this hypothesis is correct? For example, is there still a retrospective pattern if the model ended in 2010 and you do a retrospective from there. (Teo #27)

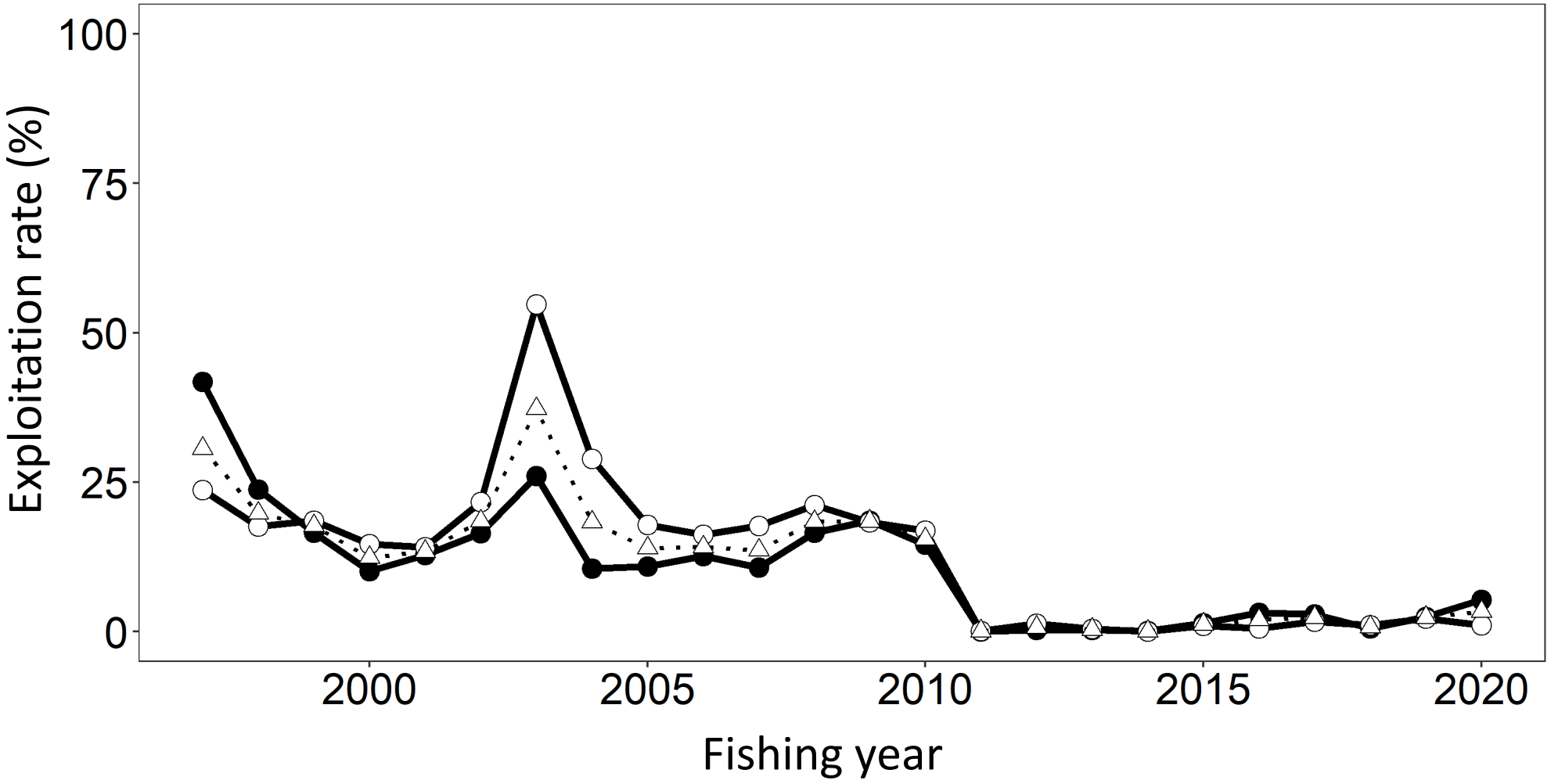
M starts to increase before the Earthquake (i.e., 2011).



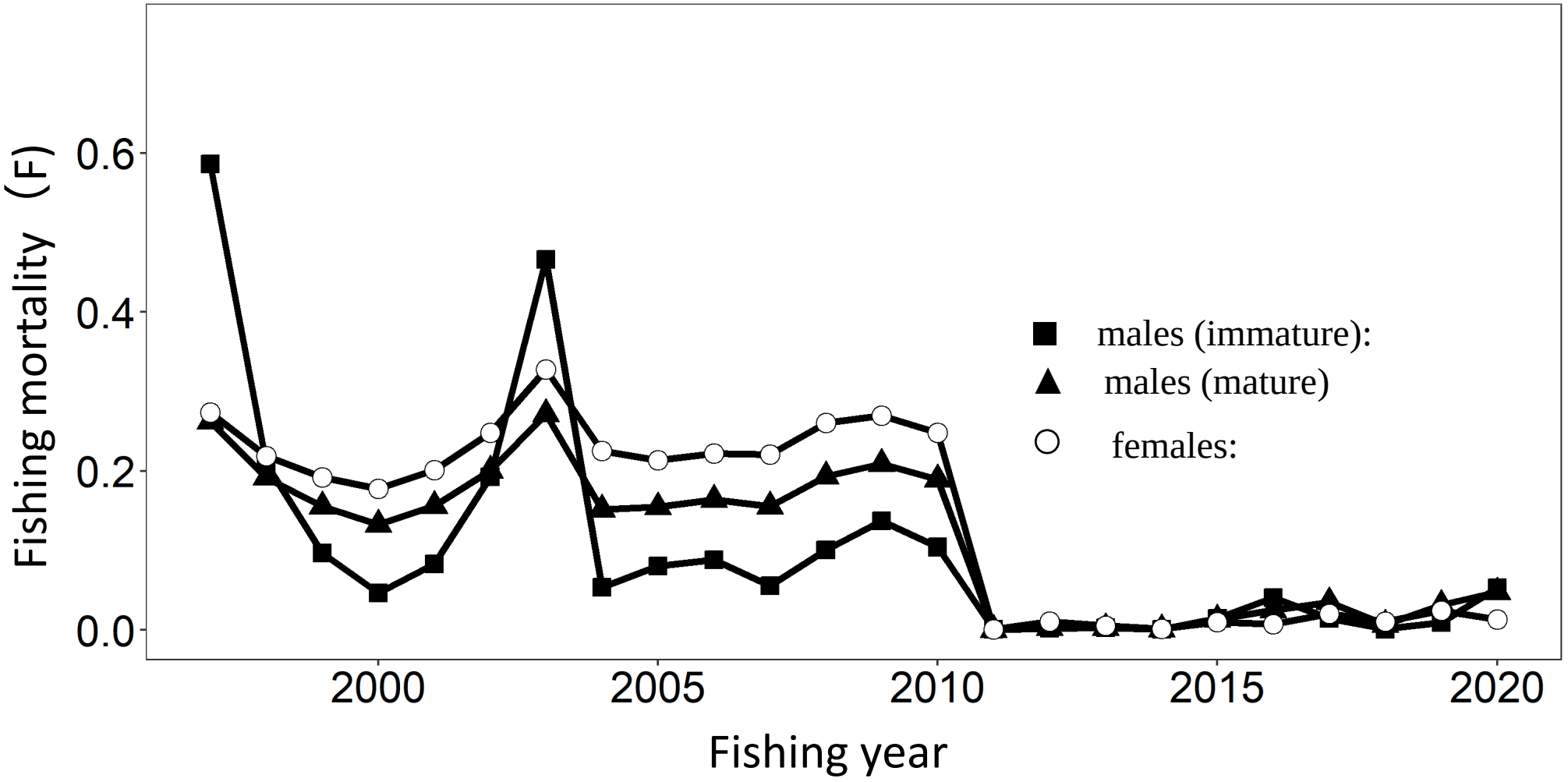
Reviewer's comment

- 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? (Dick #8)

Fishing mortality (F)



Fishing mortality (F)



Terminal molt probability

- 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? (Dick #14)

Yes, it is consistent with the observation.
See also next slide.

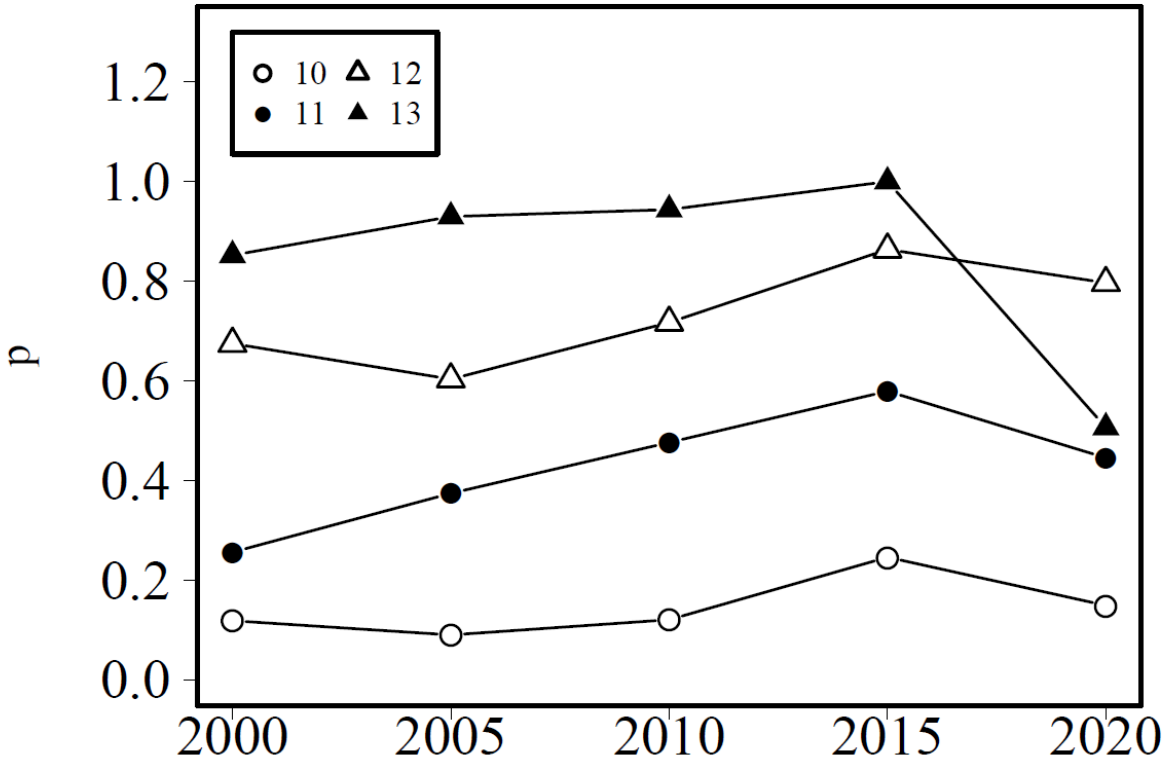
Supplementary Table 6-1. Terminal molt rate estimated by JASAM

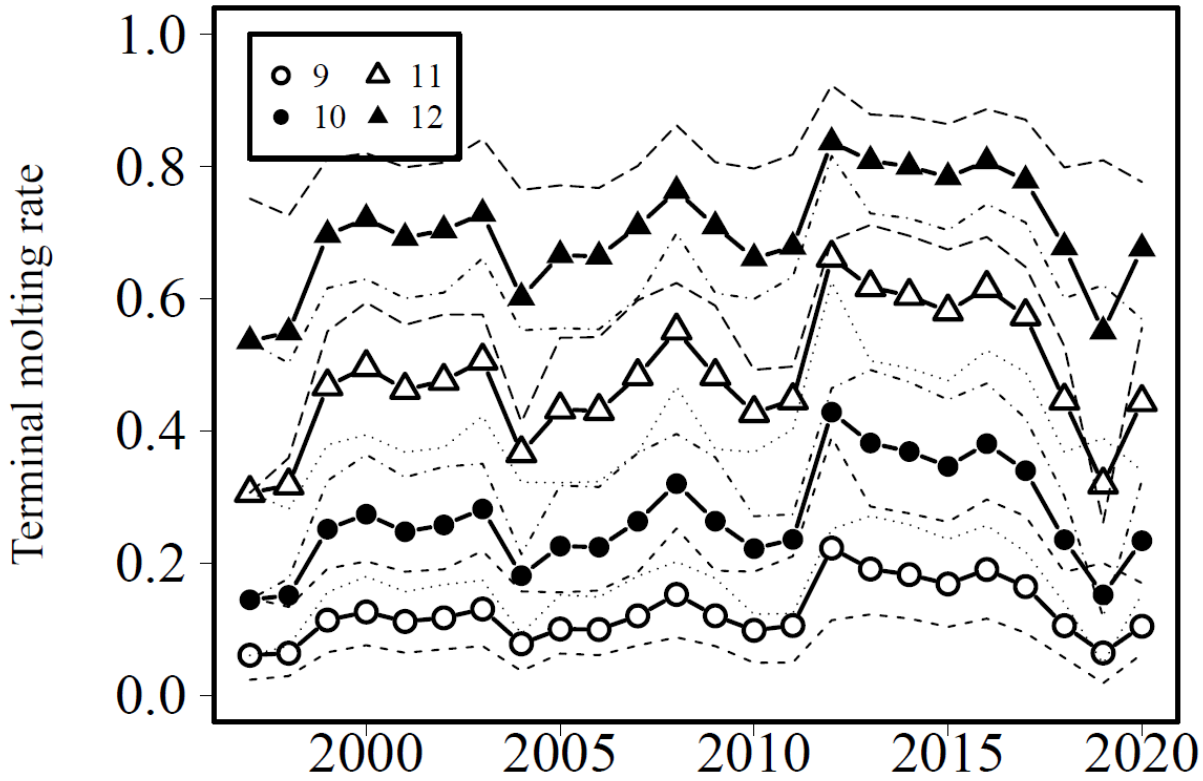
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	200
9th instar	0.06	0.06	0.11	0.13	0.11	0.12	0.13	0.08	0.10	0.10	0.12	0.1
10th instar	0.14	0.15	0.25	0.27	0.25	0.26	0.28	0.18	0.23	0.22	0.26	0.3
11th instar	0.31	0.32	0.47	0.50	0.46	0.48	0.51	0.37	0.43	0.43	0.48	0.5
12th instar	0.54	0.55	0.70	0.72	0.69	0.70	0.73	0.60	0.67	0.66	0.71	0.7

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	202
9th instar	0.12	0.10	0.11	0.22	0.19	0.18	0.17	0.19	0.16	0.11	0.06	0.1
10th instar	0.26	0.22	0.24	0.43	0.38	0.37	0.35	0.38	0.34	0.24	0.15	0.2
11th instar	0.48	0.43	0.45	0.66	0.62	0.60	0.58	0.62	0.57	0.45	0.32	0.4
12th instar	0.71	0.66	0.68	0.84	0.81	0.80	0.78	0.81	0.78	0.68	0.55	0.6

Terminal molt probability

The left is ratio of observed terminal molted snow crab each instar and right one is estimates of terminal molt probability.





Models – Reviewer's comment

Response

- I am used to thinking of crab assessments as using size-structured models because aging is not possible. However, in this case, the size classes are assumed to match ages after recruitment at instar-8, and the model is more of an age-structured model with some stage structure for terminal molting. Is there any inclusion of uncertainty in the model for uncertainty in the size to age class relationship? (Teo #23)

  No, the uncertainty is not considered in JASAM.

- Would it be appropriate to change the modelling approach to more of a length-structured model? (Teo #36)

  It will be a next step of JASAM. On the other hand, because the performance of retrospective analysis is good (Shibata et al., 2021), we think the priority of development of length structured model is not so high now.

Reviewer's comment

Response

- Is there a table of all the estimated parms and their uncertainty? (Teo #29)

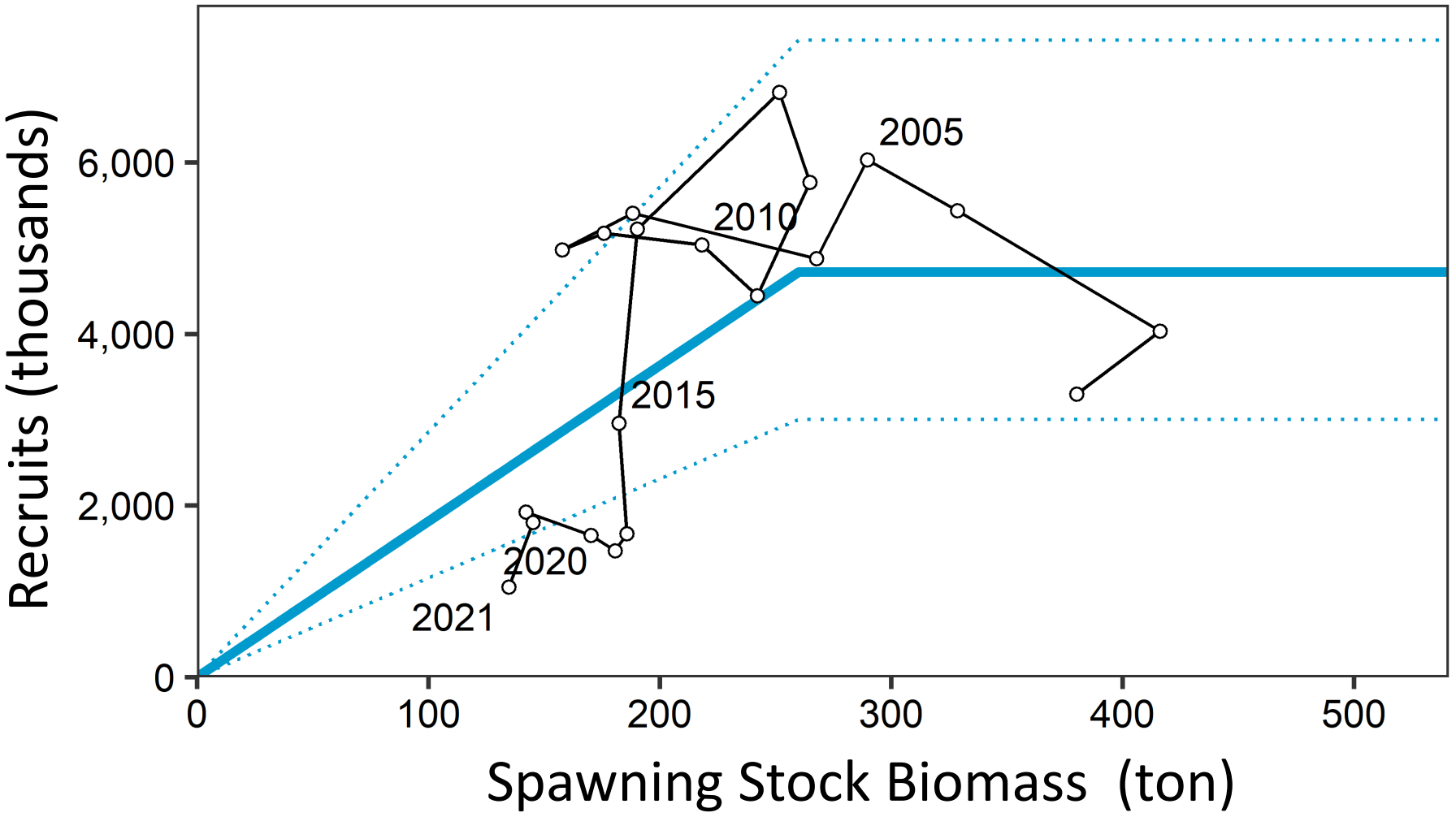
Parameters	Estimates	SE	Either male or female
$\ln\left((\sigma^F{}_{k=1})^2\right)$	-0.152	0.262	Male
$\ln\left((\sigma^F{}_{k=2})^2\right)$	-1.396	0.384	Male
$\ln\left((\sigma^F{}_{k=3})^2\right)$	-1.568	0.920	Female
$T_{\sigma^F{}_{k=1}}$	-5.297	0.981	Male
$T_{\sigma^F{}_{k=2}}$	-6.080	0.382	Male
$T_{\sigma^F{}_{k=3}}$	-5.471	0.413	Female
$\ln\left(\sigma^2{}_{M,g}\right)$	-3.498	1.126	Both
$\ln\left(\tau^2{}_{a=11,u=0}\right)$	-0.665	0.280	Male
$\ln\left(\tau^2{}_{a=11,u=1}\right)$	-0.816	0.201	Male
$\ln\left(\tau^2{}_{a=12,u=0}\right)$	-0.910	0.383	Male
$\ln\left(\tau^2{}_{a=12,u=1}\right)$	-1.216	0.228	Male
$\ln\left(\tau^2{}_{a=13,u=0}\right)$	-0.237	0.207	Male
$\ln\left(\tau^2{}_{a=13,u=1}\right)$	-1.186	0.241	Male
$\ln\left(\tau^2{}_{a=14,u=1}\right)$	-0.234	0.160	Male
$\ln\left(\tau^2{}_{a=11,u=1}\right)$	-1.264	0.426	Female

Parameters	Estimates	SE	Either male or female
$\ln\left(N_{a=9,u=0,t=1997}\right)$	6.937	0.234	Male
$\ln\left(N_{a=10,u=0,t=1997}\right)$	6.238	0.247	Male
$\ln\left(N_{a=10,u=1,t=1997}\right)$	5.053	0.519	Male
$\ln\left(N_{a=11,u=0,t=1997,74-80}\right)$	5.235	0.365	Male
$\ln\left(N_{a=11,u=1,t=1997,74-80}\right)$	4.522	0.461	Male
$\ln\left(N_{a=11,u=0,t=1997,80-86}\right)$	4.966	0.387	Male
$\ln\left(N_{a=11,u=1,t=1997,80-86}\right)$	5.474	0.281	Male
$\ln\left(N_{a=12,u=0,t=1997}\right)$	4.639	0.335	Male
$\ln\left(N_{a=12,u=1,t=1997}\right)$	5.389	0.261	Male
$\ln(N_{a=13,u=0,t=1997})$	3.314	0.582	Male
$\ln\left(N_{a=13,u=1,t=1997}\right)$	5.565	0.228	Male
$\ln\left(N_{a=14,u=1,t=1997}\right)$	4.917	0.314	Male
$\ln\left(N_{a=9,u=0,t=1997}\right)$	6.770	0.457	Female
$\ln\left(N_{a=10,u=0,t=1997}\right)$	7.574	0.502	Female
$\ln\left(N_{a=11,u=1,t=1997}\right)$	8.294	0.338	Female
$\ln\left(\beta_1\right)$	-0.040	0.059	Both
$\ln\left(\sigma_{\beta_0}\right)$	-0.686	0.585	Both
$T_{\rho,k=1}$	2.856	0.604	Both
$T_{\rho,k=3}$	-1.265	0.233	Both
T_r	-0.143	0.101	Both
$\ln\left(\sigma^2{}_{rec}\right)$	-1.167	0.201	Both
μ_ω	-0.788	0.086	Both
$\ln\left(\sigma^2{}_{\omega}\right)$	-1.219	0.324	Both

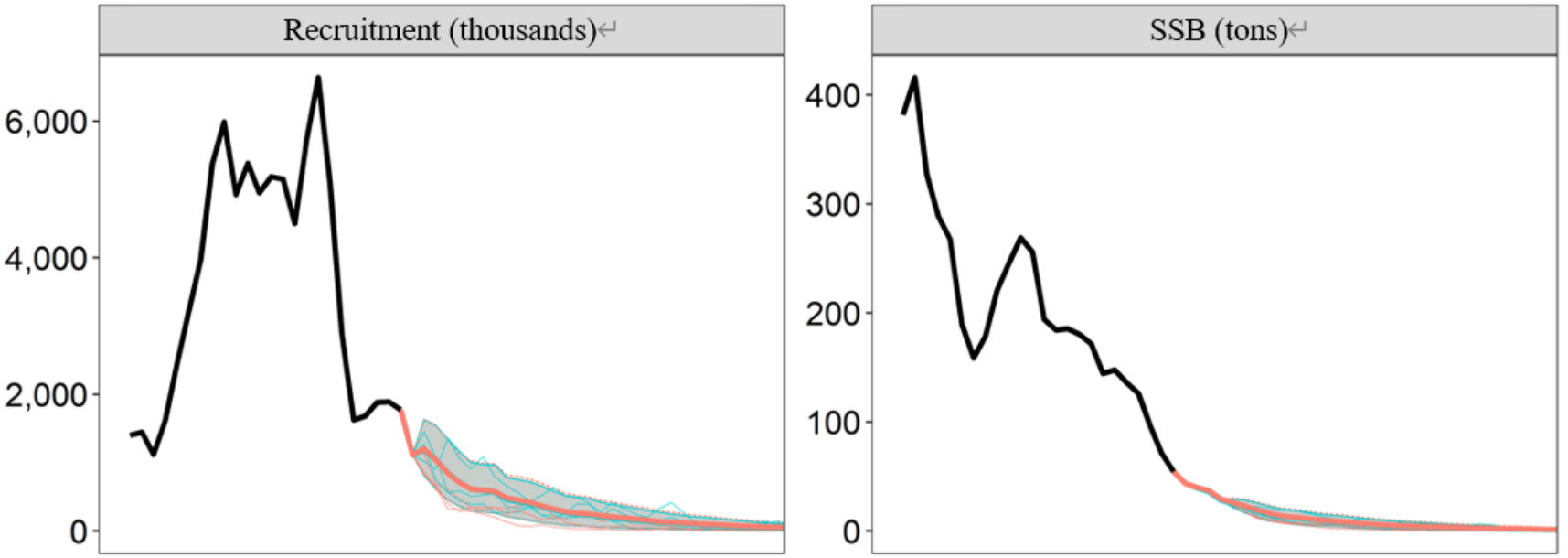
Contents

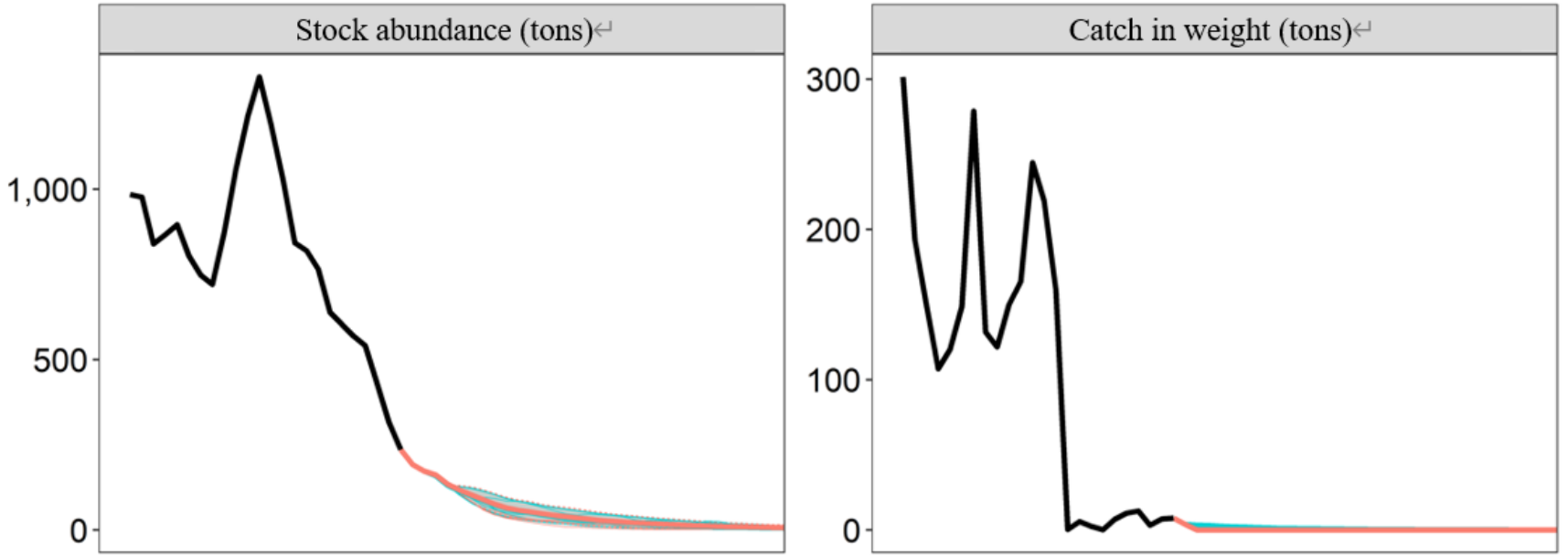
- Biology
  Distribution, Growth
- Stock assessment
  Fisheries
  Bottom-trawl survey
  Estimation of stock abundance and Natural mortality
- **Stock-Recruitment relationship and Future projection**

Stock-Recruitment relationship



Projection under current Natural mortality





M is too high and recruits is too small to maintain snow crab stock even if F=0.

F= 0

F=average (2018-2020)

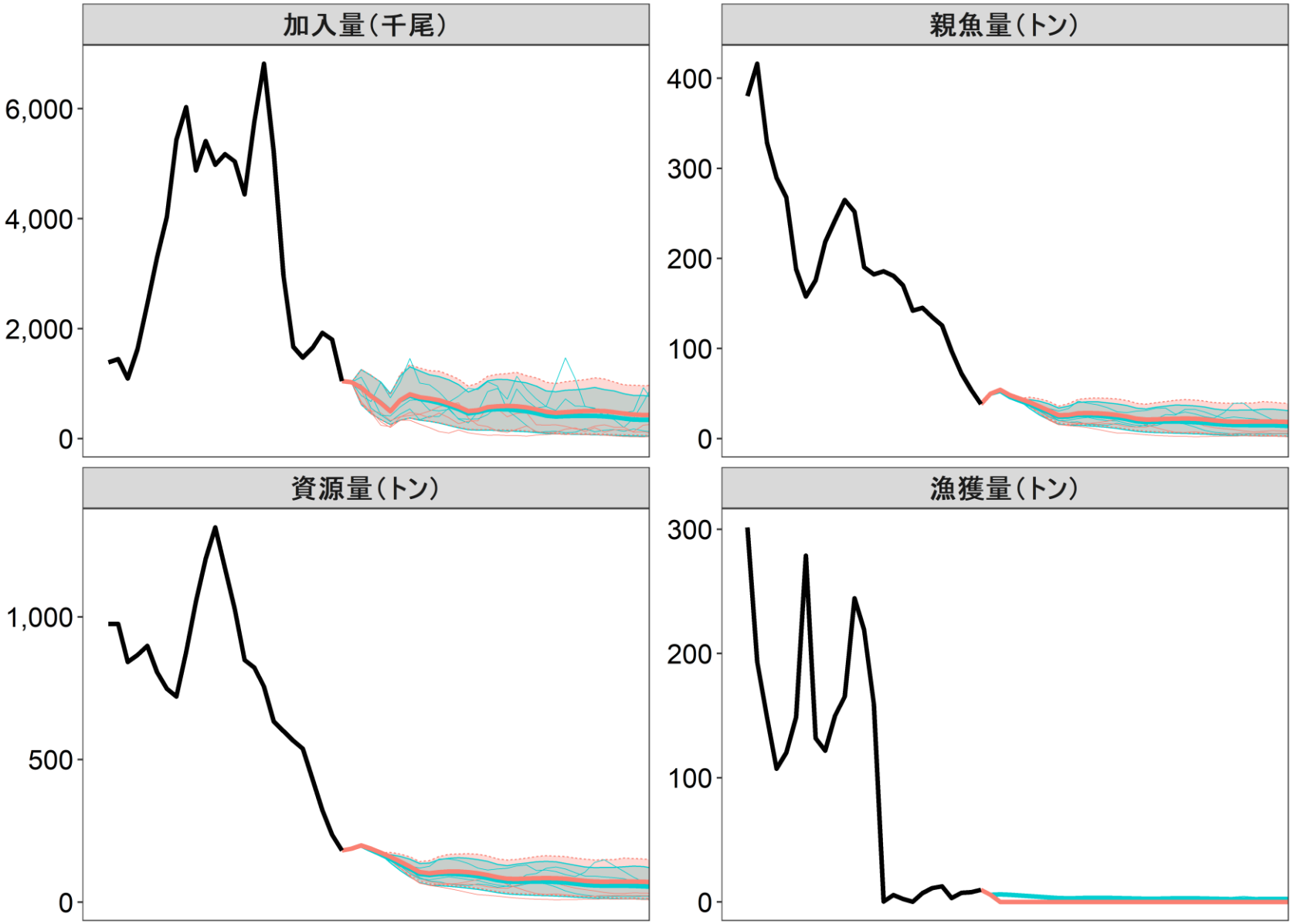
Future projection – Reviewer's comment

- 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? (Dick #12)

Even if M is 0.55, the stock size keep to decrease. See next slide.

Future projection – Reviewer's comment

Response



This is the case when M = 0.55.

F= 0

F=average (2018-2020)

Reviewer's comment

Response

- In general, is uncertainty in the assessment results important for the management of this stock? (Teo #35)

Yes. We would like to proceed with research to reduce the uncertainty.
For example, we believe that improving scientific surveys, models, clarifying the factors behind recent declines, and the effects of changes in the environment such as water temperature are also important in reducing uncertainty in stock assessment.