Space-time modelling of IPHC Fishery-Independent Setline Survey (FISS) data

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PURPOSE

To provide the Commission with a summary of the results of the 2019 space-time modelling of Pacific halibut survey data (which includes data from other fishery-independent surveys), as well as results of the IPHC fishery-independent setline survey (FISS) expansions in IPHC Regulatory Areas 3A and 3B, and modelling results from fixed and snap gear comparison in Regulatory 2C. Also presented are methods for rationalising the FISS following completion of the final set of expansions in 2019.

BACKGROUND/INTRODUCTION

The IPHC has completed a series of FISS expansions, beginning with a 2011 pilot in IPHC Regulatory Area 2A, and continuing from 2014-19 as follows:

- 2014: Regulatory Areas 2A and 4A
- 2015: Regulatory Area 4CDE eastern Bering Sea flats
- 2016: Regulatory Area 4CDE shelf edge
- 2017: Regulatory Areas 2A and 4B
- 2018: Regulatory Areas 2B and 2C
- 2019: Regulatory Areas 3A and 3B

The purpose of the expansion program has been to fill in the often large gaps in the annually-fished FISS to build a complete picture of Pacific halibut density throughout its range, and thereby reduce bias and improve precision in density indices and other quantities computed from the FISS data.

With the expansions completed in 2019, the intention is to use our improved understanding of the Pacific halibut distribution to re-design the annual FISS. As a result, it is likely that stations that were previously fished annually may require less frequent fishing, and it may be efficient to annually fish some expansion stations that have been surveyed just once to date. This report proposes criteria and methods for evaluating such a FISS rationalisation, and uses Regulatory Area 4B as an example to demonstrate the application of our proposed approach. We envision the rationalisation as an ongoing process: as new data become available each year and relative costs change with time, future designs choices will be re-evaluated and modified to adapt to changing data needs.

Snap gear is increasingly used in the commercial fishery, and allowing vessels using snap gear to participate in the FISS (previously fixed-gear only) increases the number of available vessels. Using a study design that fished each FISS station in Regulatory 2C twice, once with each gear type, provided data for comparing snap and fixed gears, including examining the effect of gear type on weight and numbers per unit effort indices through space-time modelling.

Space-time modelling results for 2019

Revisions to the data inputs for space-time modelling of survey data include: the addition of expansion stations in Regulatory Areas 3A and 3B; the use of direct individual weight measurements of FISS Pacific halibut in computing 2019 station-level WPUE; the application of revised effectiveness criteria for whale depredation for FISS sets; the inclusion of snap-gear data in Regulatory Area 2C modelling; and the inclusion of FISS stations within the area of overlap of US and Canadian maritime claims in Dixon entrance in the estimation of WPUE and NPUE indices in both Regulatory Areas.

Figures 1-2 show time series estimates of O32 WPUE (most comparable to fishery catch-rates) and all sizes NPUE over the 1993-2019 period included in the 2019 space-time modelling. Declines of 4-5% were estimated in all three indices from 2018-19, largely driven by 8-10% declines in Biological Region 3. Equivalent figures for Regulatory Areas are in Appendix A.

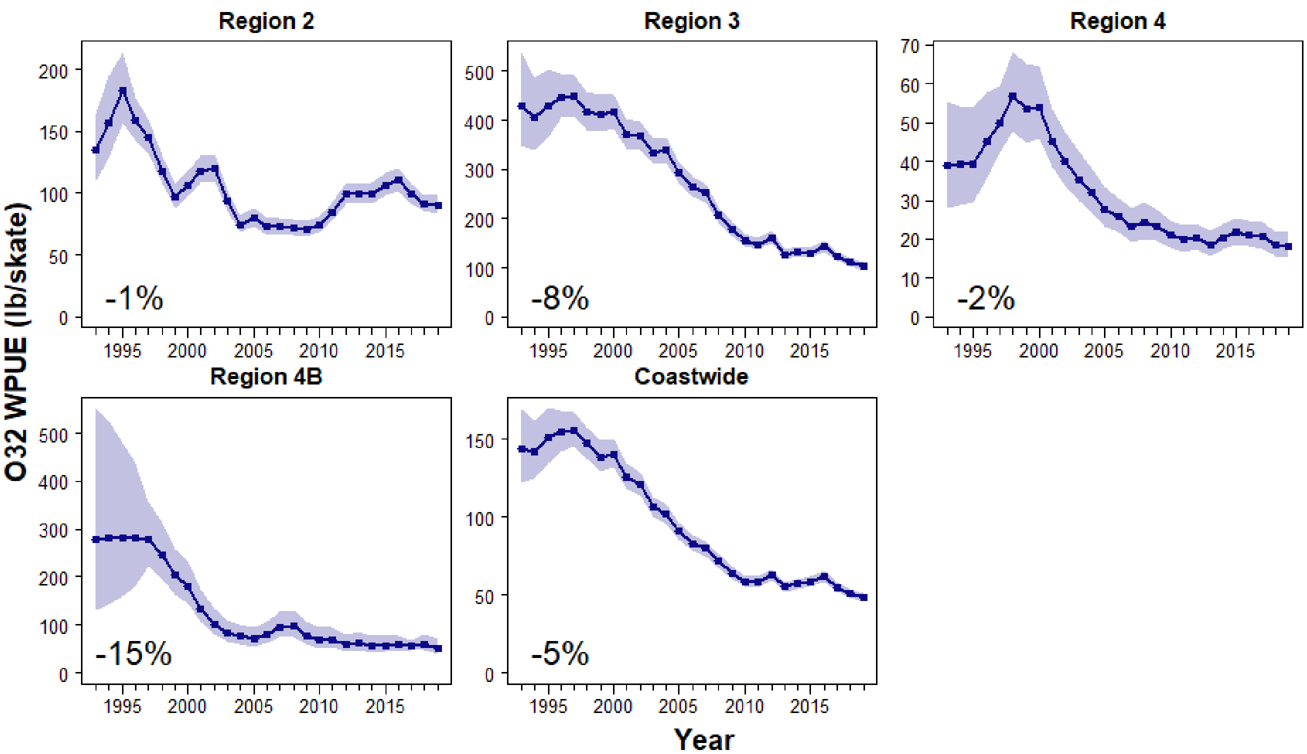

Figure 1. Space-time model output for O32 WPUE for 1993-2019 for Biological Regions. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean O32 WPUE from 2018 to 2019.

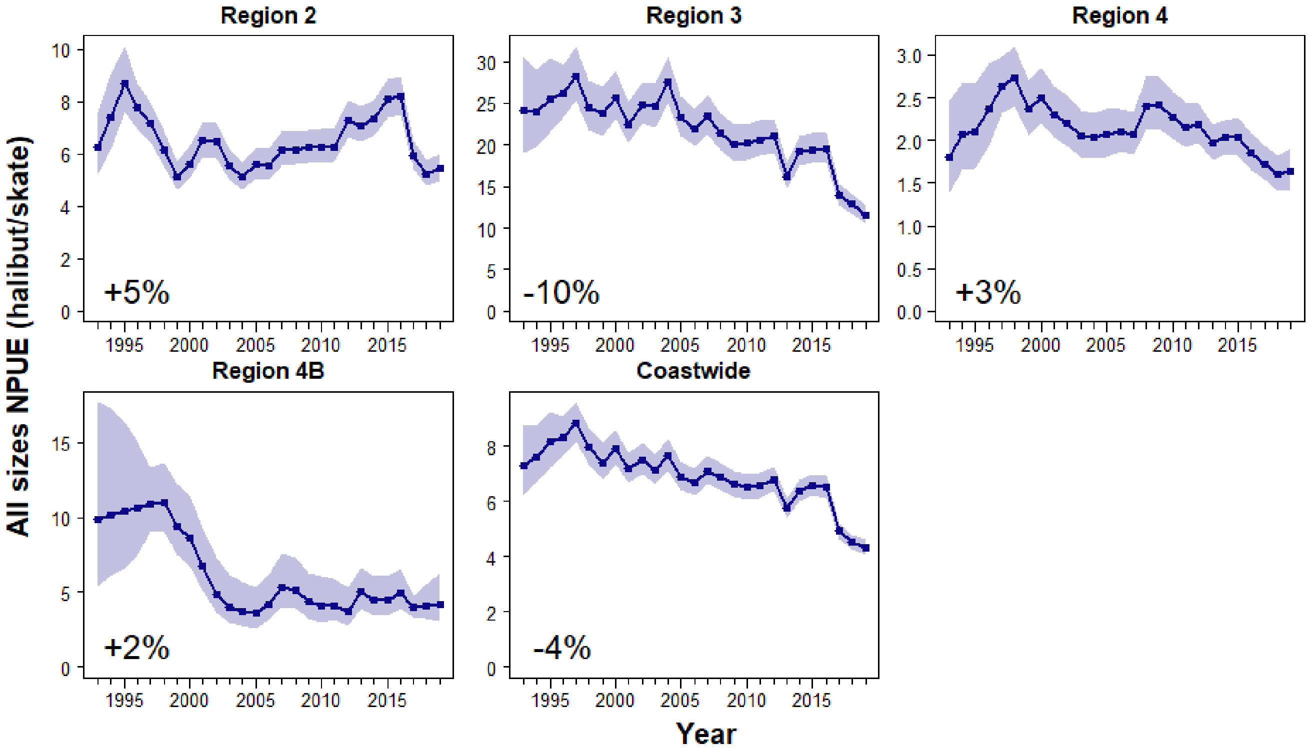

Figure 2. Space-time model output for all sizes NPUE for 1993-2019 for Biological Regions. Filled circles denote the posterior means of all sizes NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean all sizes NPUE from 2018 to 2019.

In Regulatory Area 2C, data from both fixed and snap gears were used in the modelling. Parameters allowing for different catch rates of the two gears were included in the models, and estimates of WPUE and NPUE series were based on model predictions assuming fixed gear to ensure consistency with other Regulatory Areas. Comparisons of estimates based on data with and without the snap gear data show no meaningful effect of including the snap gear data on either means or uncertainty (Appendix B). Note that these figures do not imply there were no gear differences in catch rates, since we have standardized for gear type by predicting at fixed gear only. Indeed, parameter estimates of gear type differences showed some evidence that snap gear catch rates were lower on average (Table 1), with estimated catch rate ratios of 0.86 for all three indices modelled in 2019 (i.e., we estimate snap gear had 86% of the catch of fixed gear on average). Posterior 95% credible intervals all had an upper limit of 1.00, i.e., no difference in catch rate, so evidence for a difference in gear types was not strong. Although there is no impediment to using these data in generating estimates of indices, with the calibration estimated within the space-time model, the results imply the need to collect additional data comparing fixed and snap gears in order to better understand the relative efficiency of the gears and potential variability over time and space.

Table 1. Posterior estimates of the ratio of snap to fixed gear catch rates for O32 and all sizes WPUE, and all sizes NPUE, from space-time modelling of data from Regulatory Area 2C in 2019.

Variable	Ratio of snap to fixed catch rate	
	Posterior mean	95% credible interval
O32 WPUE	0.86	0.74 – 1.00
All sizes WPUE	0.86	0.75 – 1.00
All sizes NPUE	0.86	0.75 – 1.00

The 2019 FISS expansions in Regulatory Areas 3A and 3B led to improvements in precision and reductions in bias (Appendix C). This was particularly true for Regulatory Area 3A, where the addition of expansion stations to previously very poorly-predicted locations in places like Cook Inlet and Prince William Sound greatly reduced uncertainty (Figures C.1 and C.2).

Methods for FISS rationalisation

The overall goal of the FISS rationalisation is to maintain or enhance data quality (precision and bias), while minimizing the annual scope of the survey, subject to the cost constraints of the FISS budget. Here we propose some precision targets, discuss an approach for reducing the chance of large biases, and note the importance of considering costs in any redesign.

Precision targets

Previously, the IPHC Secretariat had an informal goal of maintaining a coefficient of variation (CV) of no more than 15% for mean WPUE for each IPHC Regulatory Area. Including all expansion data to date, this goal has been achieved in all areas from 2011, the year of the first pilot expansion (Table 2), except Regulatory Area 4B in 2011-14 and 2019 for O32 WPUE and 2011-12 and 2019 for all sizes WPUE, and Regulatory Area 4A in 2016-19 (O32 and all sizes WPUE).

Table 2. Range of coefficients of variation for O32 and all sizes WPUE from 2011-18 by Regulatory Area.

Reg Area	O32 WPUE (2011-19)				All sizes WPUE (2011-18)			
	Lowest CV (%)	Year	Highest CV (%)	Year	Lowest CV (%)	Year	Highest CV (%)	Year
2A	10	2014*	13	2019	10	2014*	13	2019
2B	5	2018*	7	2019	5	2018*	7	2012
2C	5	2018*	6	2012	5	2018*	6	2011
3A	4	2017	5	2011	5	2019	5	2011
3B	7	2019*	8	2015	9	2018	10	2015
4A	12	2014*	18	2019	10	2014*	19	2019
4B	10	2017*	16	2012	10	2017*	16	2012
4CDE	10	2017#	11	2013	5	2015*	6	2019

* Year of FISS expansion in Reg. Area. # Year of NMFS trawl expansion in Reg. Area 4CDE.

Considering Biological Regions, CVs for WPUE in Region 2 and Region 3 were at or below 5% in all years from 2011 (Table 3). Region 4 CVs for WPUE were below 10%, while the smallest region, Region 4B, has some years with CVs above 15% as noted previously. For all sizes NPUE (Table 4), CVs were above 10% in all Regions except Region 4B. Based on this information, constraining the FISS design to produce CVs of 10% or less for Regions 2-4 and 15% for Region 4B should allow for some reduced FISS effort in the former regions, while maintaining low uncertainty in Region 4B.

Table 3. Range of coefficients of variation for O32 and all sizes WPUE from 2011-19 by Biological Region.

Region	WPUE (2011-19)				All sizes WPUE (2011-19)			
	Lowest CV (%)	Year	Highest CV (%)	Year	Lowest CV (%)	Year	Highest CV (%)	Year
2	4	2018*	4	2012	4	2018*	4	2012
3	4	2019*	4	2011	4	2018	5	2011
4	8	2014*	9	2019	5	2014*	9	2019
4B	10	2017*	16	2012	10	2017*	16	2012

* Year of FISS expansion in at least part of the Region.

Table 4. Range of coefficients of variation for all sizes NPUE from 2011-19 by Biological Region.

Region	All sizes NPUE (2011-19)			
	Lowest CV (%)	Year	Highest CV (%)	Year
2	4	2018*	5	2011
3	4	2018*	5	2011
4	5	2014*	8	2019
4B	9	2017*	20	2019

* Year of FISS expansion in at least part of the Region.

Finally, the CV of coastwide, all sizes NPUE (used in the stock assessment) is estimated to be from 3-9% for all years of estimation from 1993 to 2019 (3-4% for 2011-19). This suggests a target of 10% for the CV of this index will ensure that uncertainty is maintained at a low level for this key stock assessment input.

In summary, in order to maintain the quality of the estimates used for the assessment, and for estimating stock distribution, we propose that a rationalised FISS should be designed to meet the following precision targets:

- CVs below 15% for O32 and all sizes WPUE for all Regulatory Areas
- CVs below 10% for O32 WPUE, all sizes WPUE, and all sizes NPUE for Regions 2, 3 and 4
- CVs below 15% for O32 WPUE, all sizes WPUE, and all sizes NPUE for Region 4B
- CVs below 10% for the coastwide, all sizes NPUE index

Reducing the potential for bias

With these targets set, we can proceed to using the space-time modelling to evaluate different FISS designs by IPHC Regulatory Area and Biological Region. However, sampling a subset of stations in any area or region brings with it the potential for bias, when trends in the unsurveyed portion of a management unit (Regulatory Area or Region) differ from the surveyed portion. To reduce the potential for bias, we also looked at how frequently part of an area or region (called a "subarea" here) should be surveyed in order to reduce the likelihood of appreciable bias. For this, we propose a threshold of a 10% absolute change in biomass percentage: how quickly can a subarea's percent of the biomass of a Regulatory Area or Region's change by at least 10%? By sampling each subarea frequently enough to keep down the chance of its percentage changing by more than 10% between successive surveys of the subarea, we reduce the potential for appreciable bias in the Regulatory Area or Region's indices as a whole.

Cost constraints

While there are financial benefits to sampling low-density waters less frequently, reduced sampling frequency in high-density waters will result in a loss of income generated from fish sales. Thus, there are constraints on the how the FISS design can be modified in a given year. Consideration of the effect of FISS operating costs and cost recovery will be part of the final analysis, and is likely to constrain options for reducing annual effort in high-density Regulatory Areas and limit the frequency of surveys in remote, low density regions. Any decisions on future survey designs must account for the relative costs of design options, and be subject to overall budget limitations.

Analytical methods

We propose examining the effect of subsampling a management unit on precision as follows:

- Identify subareas within each management unit and select priorities for future sampling
- Generate simulated data for all FISS stations based on the output from the most recent space-time modelling
- Fit space-time models to the 1993-2018 observed data augmented with 1 to 3 additional years of data, where the design over those three years reflects the sampling priorities identified above

Extending the modelling beyond three years is not considered worthwhile, as we expect further evaluation undertaken following collection of data during the 1-3 year time period to influence design choice to subsequent years.

Ideally, a full simulation study with many replicate data sets would be used, but this is impractical for the computationally time-consuming spatio-temporal modelling. Instead, "simulated" sample data sets for the future years will be taken from the 2000 posterior samples from the most recent year's modelling. Each year's simulated data will have to be added and modelled sequentially, as subsequent data can improve the precision of prior years' estimates, meaning the terminal year is often the least precise (given a consistent design). If time allows, the process can be repeated with several simulated data sets to ensure consistency in results, although with large enough sample sizes (number of stations) in each year, we would expect even a single fit to be informative.

Example: IPHC Regulatory Area 4B

Regulatory Area 4B was chosen as an example for discussion as it is a relatively small area (and so models are quite quick to run), can be divided into fairly distinct subareas based on the 2017 expansion results, and is likely to benefit from a redesign as it has a high potential for exceeding CV targets and is costly to survey. We began by dividing Regulatory Area 4B into three subareas based on the results of the 2017 expanded FISS (Figure 2):

1. West of Kiska Is. At present, a relatively low density subarea, but one that previously had much higher densities of Pacific halibut. (57 stations)
2. East of Kiska Is, and west of Amchitka Pass, including Bowers Ridge. Also at present a low density subarea, but one largely unsurveyed before 2017. (73 stations)
3. East of Amchitka Pass. Currently, a subarea of relatively high density and stability, although with higher density in the past. (73 stations)

In recent years, the bulk of the 4B stock (70-80%, Figure 3) is estimated to have been in Subarea 3. With standard deviations typically increasing with the mean for this type of data, focusing FISS effort on this subarea in future surveys may succeed in maintaining target CVs, while reducing net cost. However, Subarea 1's percentage of the biomass can also change by relatively large amounts over short time frames, with absolute changes of over 10% over as little as 3-4 years (Table 4). This also should be accounted for in a three-year design plan.

We augmented the 1993-2018 data with simulated data sets for 2019-22. For 2019, the planned FISS design was used, while the following designs were considered for subsequent years:

- 2019: Planned FISS fished (standard 89-station 4B FISS)
- 2020: Only Subarea 3 fished (73 stations)
- 2021: Only Subarea 3 fished (73 stations)
- 2022a: Only Subarea 3 fished (73 stations)
- 2022b: Only Subarea 1 fished (57 stations)
- 2022c: Subareas 1 and 2 fished (130 stations)

The three options for 2022 allow either a continuation of Subarea 3 only (2022a), Subarea 1 only to reduce the chance of bias due to changes in density in Subarea 1 over the three years since 2019 (2022b), and a third option (2022c) in case 2022b leads to CVs above the 15% target. The third option is also precautionary in that while there is apparent stability in Subarea 2's biomass percentage (Figure 3 and Table 5), most of Subarea 2 has been surveyed just once, in the 2017 expansion. Therefore, this stability can be at least partly attributed to a lack of data reducing the potential for rapid change in its biomass percentage. As a precautionary approach, a more frequent FISS for Subarea 2 than implied by the estimates in Table 5 could be implemented initially, with further evaluation once more data are available.

Table 5. For each year, the number of years until at least a 10% absolute change in estimated biomass percentage is observed.

Subarea	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
1	9	8	7	4	3	4	3	13	12	7	5	4	4
2	17	21	20	19	18	19	≥ 19	16	16	14	13	12	11
3	6	5	4	3	2	4	11	10	11	11	10	9	8
Subarea	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
1	7	6	4	3	4	3	≥ 7	≥ 6	≥ 5	≥ 4	≥ 3	≥ 2	≥ 1
2	≥ 13	≥ 12	≥ 11	≥ 10	≥ 9	≥ 8	≥ 7	≥ 6	≥ 5	≥ 4	≥ 3	≥ 2	≥ 1
3	6	6	4	3	4	3	3	≥ 6	≥ 5	≥ 4	≥ 3	≥ 2	≥ 1

Table 6 presents the estimated CVs for each of the space-time model inputs listed above for 2020-22, along with those from the 2018 model fit to observed 1993-2018 data only. The three fits based on surveying only Subarea 3 in 2020-22 (rows 3, 4 and 5 of Table 6) all lead to CVs below the 15% target. However, surveying only Subarea 1 instead of Subarea 3 in 2022 was insufficient to meet the target, with a CV of 17% estimated in 2022. Adding Subarea 2 brought the 2022 CV down to 14%, now below the target.

Table 6. Estimated coefficients of variation (%) by data input for Regulatory Area 4B. Proposed target CV is 15%.

Data input	2017	2018	2019	2020	2021	2022
1993-2018 data	9	14				
+ 2019-20 simulated data	9	13	12	10		
+ 2019-21 simulated data	10	13	13	11	12	
+ 2019-22a simulated data	9	12	12	10	12	14
+ 2019-22b simulated data	9	12	12	10	11	*17*
+ 2019-22c simulated data	9	11	11	9	9	14

The next step would be to calculate the relative costs of each option. Fishing both Subareas 1 and 2 in 2022 would be expensive, with likely high vessel charter costs together with low catches offsetting those costs. It may be desirable to explore other options for 2022, such as pairing Subareas 1 and 3, and fishing Subarea 2 (probably together with Subarea 3) in a later year.

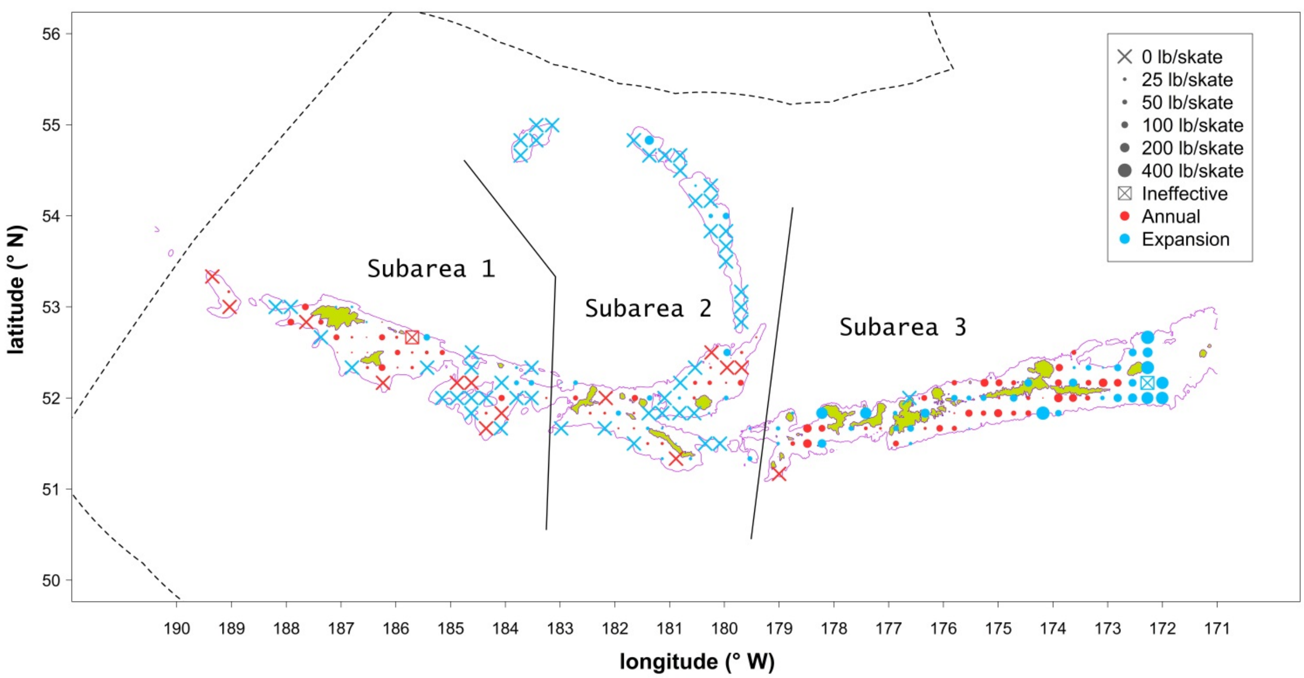

Figure 2. Map of 2017 the FISS expansion design in IPHC Regulatory Area 4B showing the subareas used in the analysis.

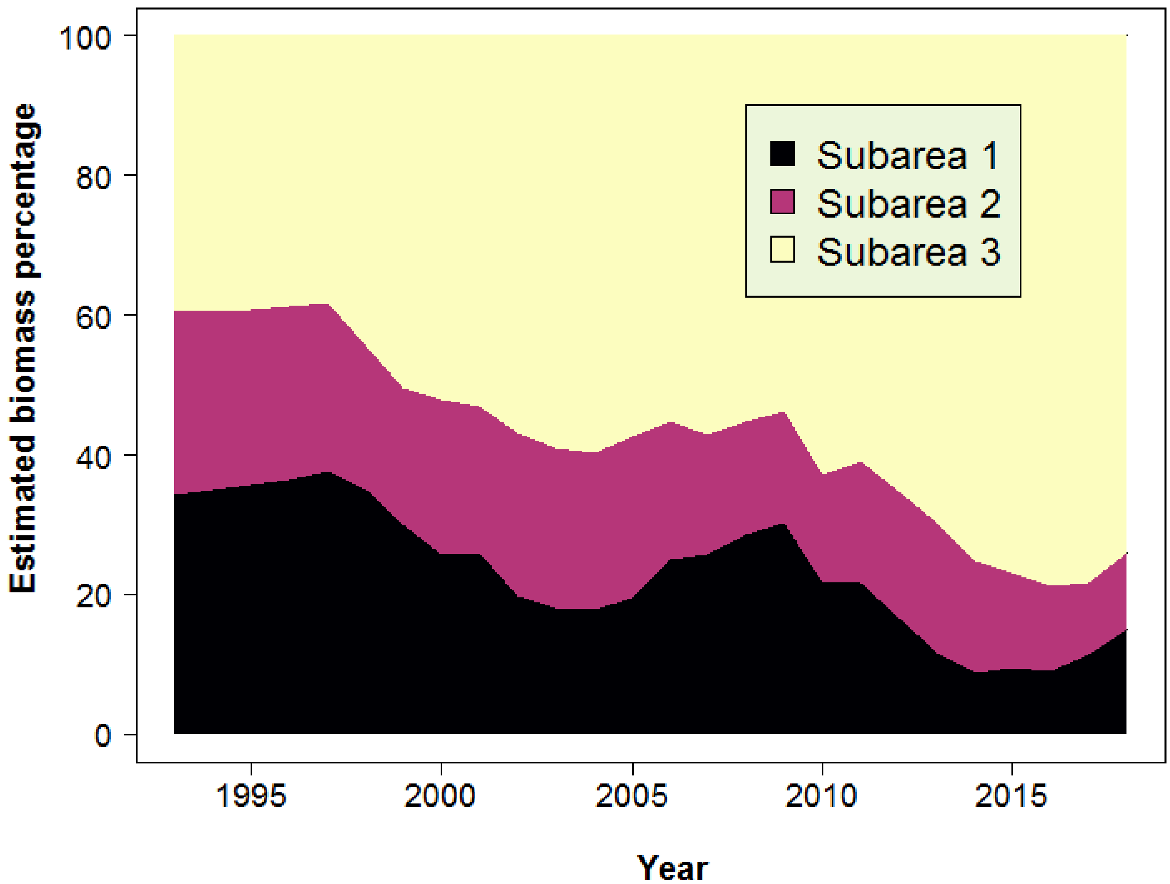

Figure 3. Estimated Regulatory Area 4B biomass % by subarea and year.

Other Regulatory Areas

Like Regulatory Area 4B, we identified subareas in Regulatory Areas 2A and 4A based largely on geographic biomass distribution and developed priorities using the precision and bias criteria described above. Regulatory Areas 2B, 2C, 3A and 3B represent the core of the Pacific halibut stock, with generally high density throughout. It was therefore more difficult to identify subareas based on density, geographic regions, or biological differences. Instead, IPHC FISS regions were considered as subareas, and sampling priorities were based on the density and temporal variability of these. Specifically, we considered designs in which two FISS region per year were omitted from the six regions in Regulatory 2B, the eight regions in Regulatory 3A and the five regions in Regulatory 3B, and where two of the three FISS regions in Regulatory 2C were fished. Those regions with either the highest densities in recent years, or (in the case of Regulatory Area 3B), with densities that varied greatly over short time periods, were prioritized for annual sampling, while other FISS regions can be sampled on a rotating basis. As described above, the proposed designs for each Regulatory Area in 2020 were evaluated to ensure that precision and bias criteria were met. The full proposal for 2020 is shown in Figure 4. This represents a minimum design that will meet the data quality criteria for analytical purposes, and comprises approximately 1150 stations, fewer than in recent years. Other stations can be added to the design if there are specific needs beyond those criteria, such as for sampling efficiency, cost recovery, biological sampling, and environmental monitoring.

Figure 4 includes a proposal for fishing the full 10 nmi grid along the Regulatory Area 4CDE edge in 2020 (last fished in 2016). While it may be possible to reduce FISS sampling and still meet precision/bias targets, we note that ecosystem conditions have been anomalous in the Bering Sea for several years, making the Pacific halibut distribution more difficult to predict in unsurveyed habitat. Indeed, recent NMFS trawl surveys in the northern Bering Sea have shown a generally increasing trend in that region, but over the last three years, deeper waters in the north covered by the FISS grid have been unsampled. The IPHC is interested in better understanding density trends and possible links with Pacific halibut in Russian waters in the Bering Sea, and the data obtained from sampling the full FISS grid in 2020 would help greatly in achieving these goals.

RECOMMENDATION/S

That the Commission:

1) **NOTE** paper IPHC-2019-IM095-07 Rev_1, which provided the Commission with a summary of the results of the 2019 space-time modelling of Pacific halibut survey data (which includes data from other fishery-independent surveys), as well as results of the IPHC fishery-independent setline survey (FISS) expansions in IPHC Regulatory Areas 3A and 3B, and modelling results from fixed and snap gear comparison in Regulatory 2C. Also presented were methods for rationalising the FISS following completion of the final set of expansions in 2019.

2) **ENDORSE** the proposed minimum FISS design for 2020 (provided in Figure 4), while recognizing that it will be subject to potential modification (addition of FISS stations) to meet the Commissions general objective of revenue neutrality.

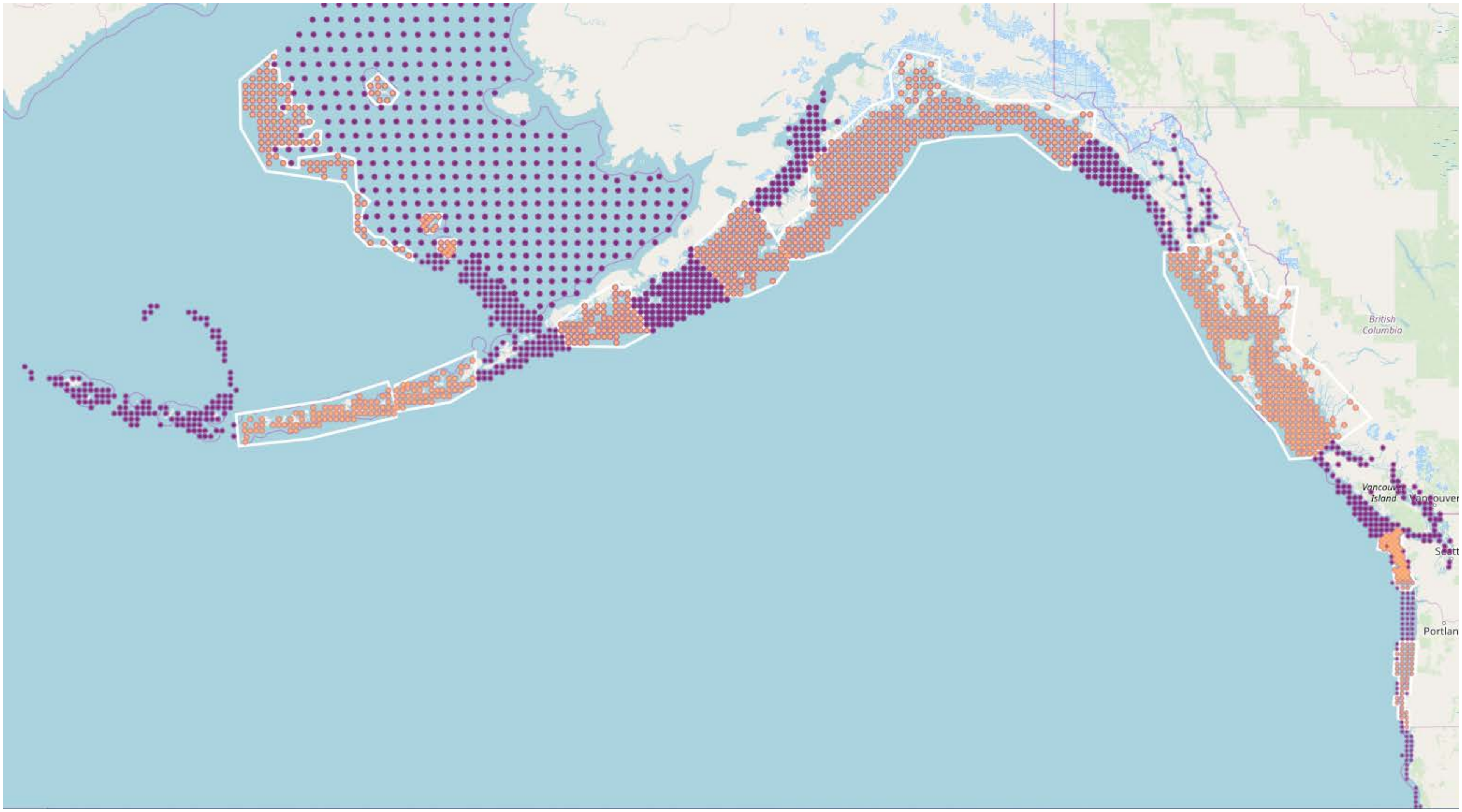

Figure 4. Proposed minimum FISS design in 2020 (orange circles). Purple circles on the 10 nmi FISS grid are optional for meeting data quality criteria, while purple circles on a 20 nmi grid in the Bering Sea will be sampled by the 2020 NMFS trawl survey used for indexing Pacific halibut density in Regulatory Area 4CDE.

APPENDIX A

Space-time modelling results by IPHC Regulatory Area

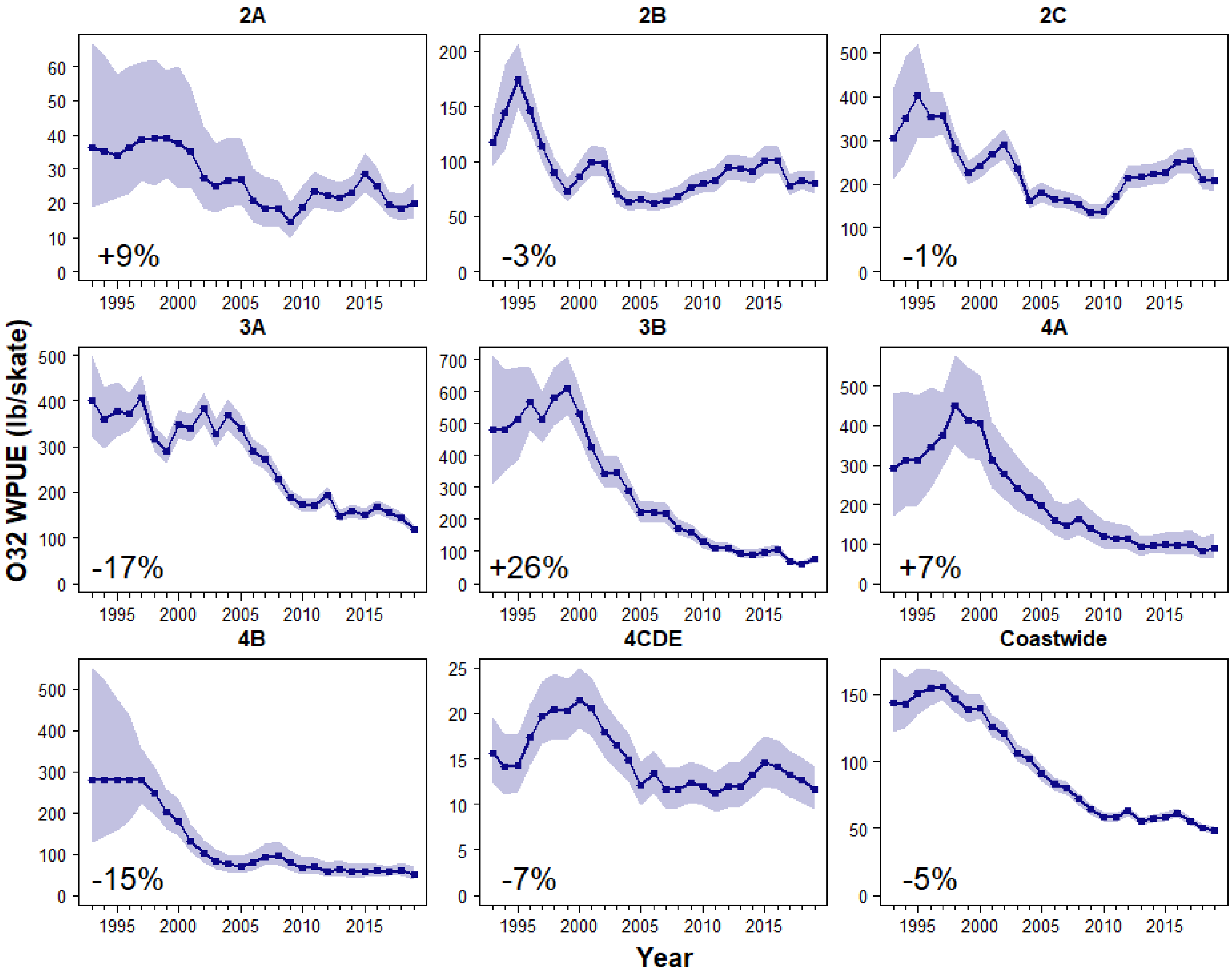

Figure A.1. Space-time model output for O32 WPUE for 1993-2019. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean O32 WPUE from 2018 to 2019.

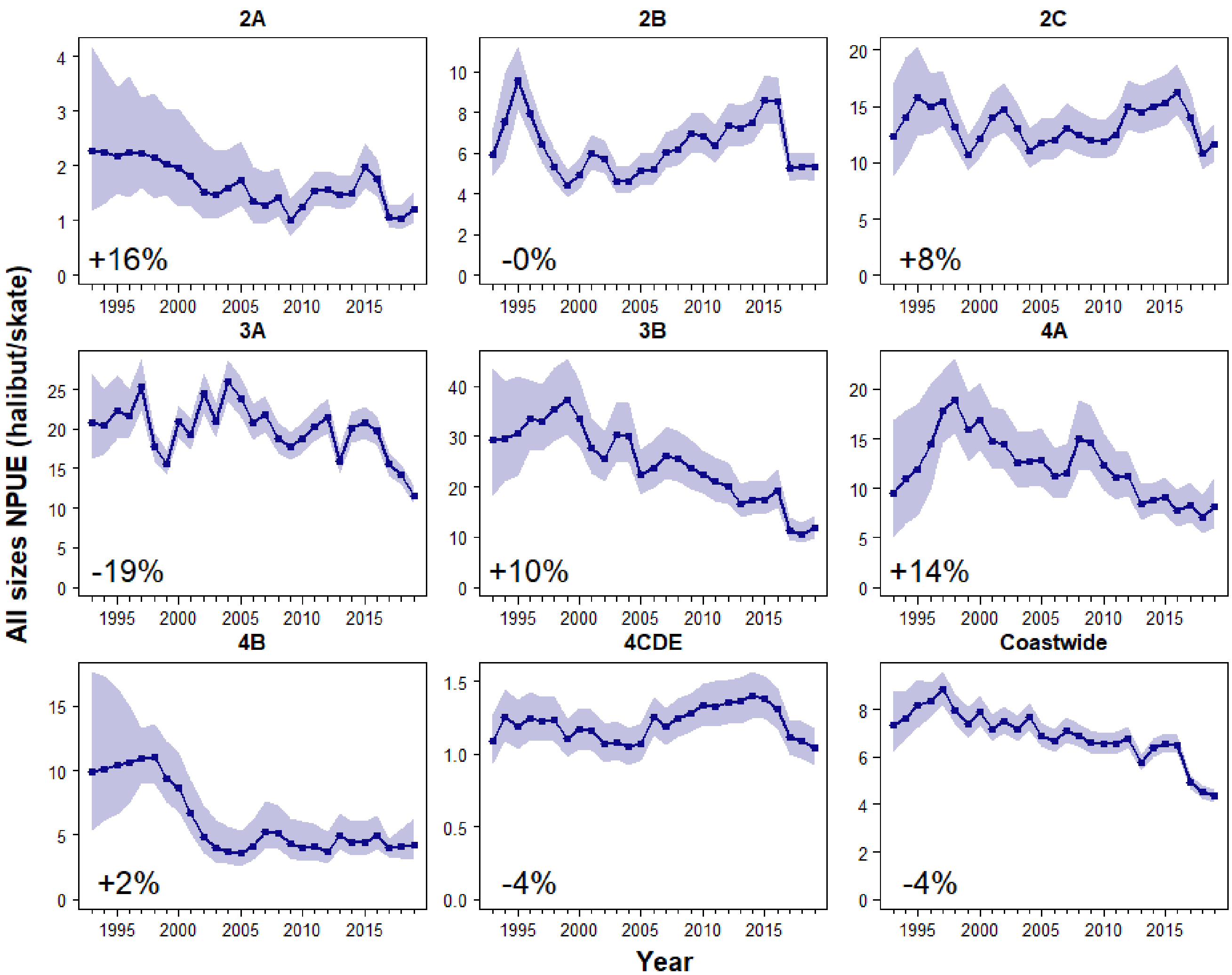

Figure A.2. Space-time model output for total NPUE for 1993-2019. Filled circles denote the posterior means of total NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean total NPUE from 2018 to 2019.

APPENDIX B

Space-time modelling results for Regulatory Area 2C with and without snap gear data.

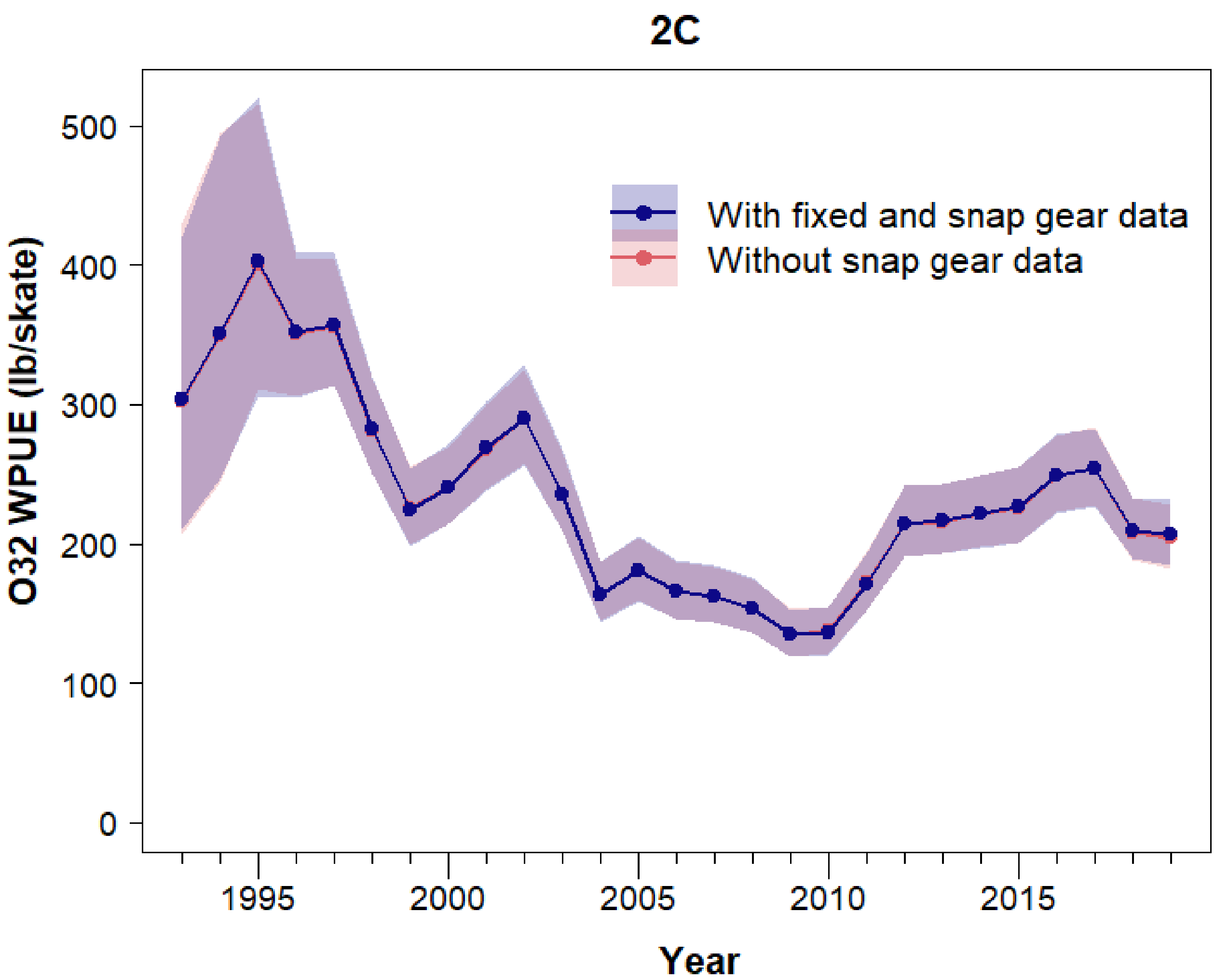

Figure B.1. Space-time model output for O32 WPUE for 1993-2019 for Regulatory Area 2C, comparing output from models with and without snap gear data. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate.

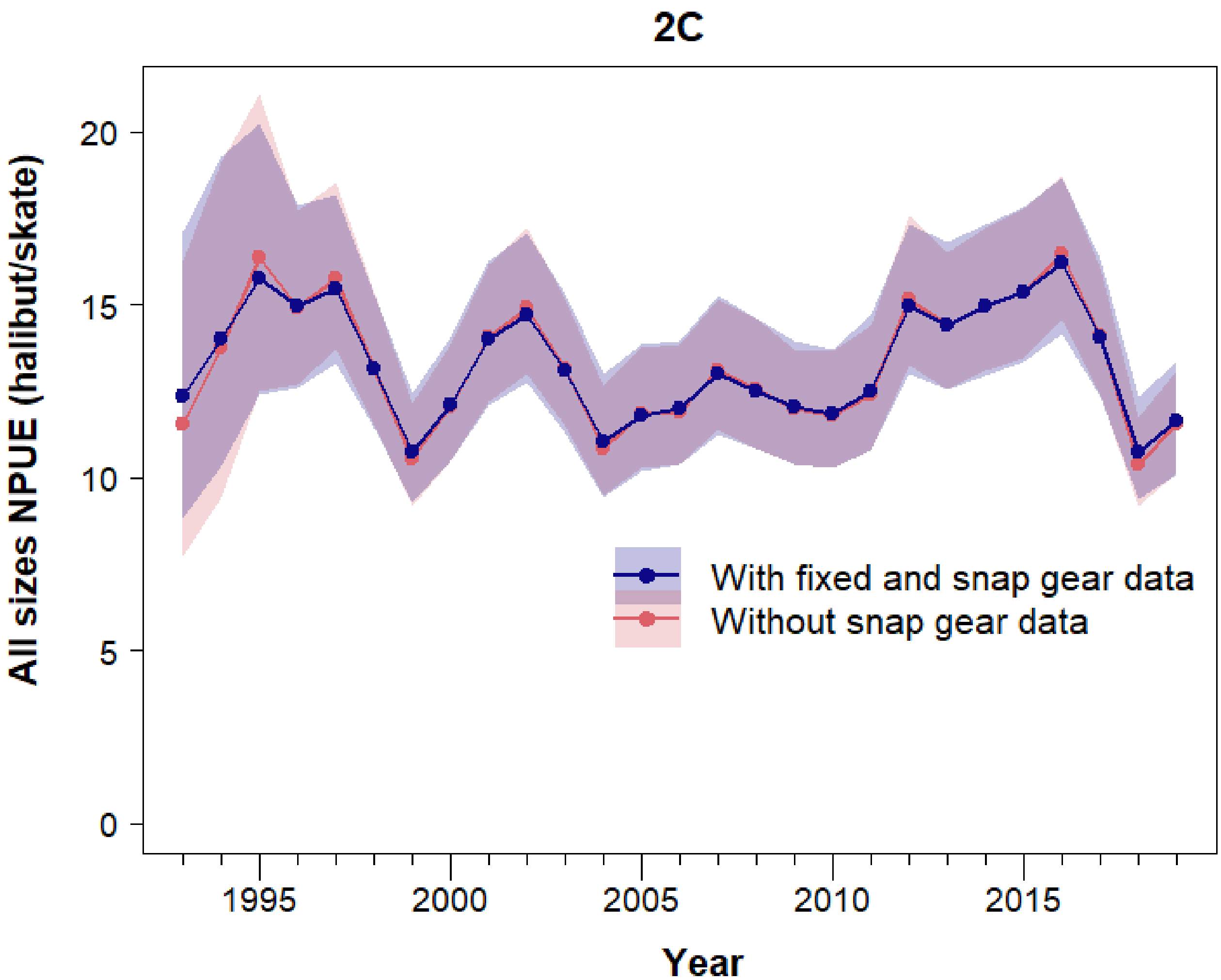

Figure B.2. Space-time model output for all sizes NPUE for 1993-2019 for Regulatory Area 2C, comparing output from models with and without snap gear data. Filled circles denote the posterior means of all sizes NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate.

APPENDIX C

The effect of 2019 FISS expansions on space-time modelling results by IPHC Regulatory Area

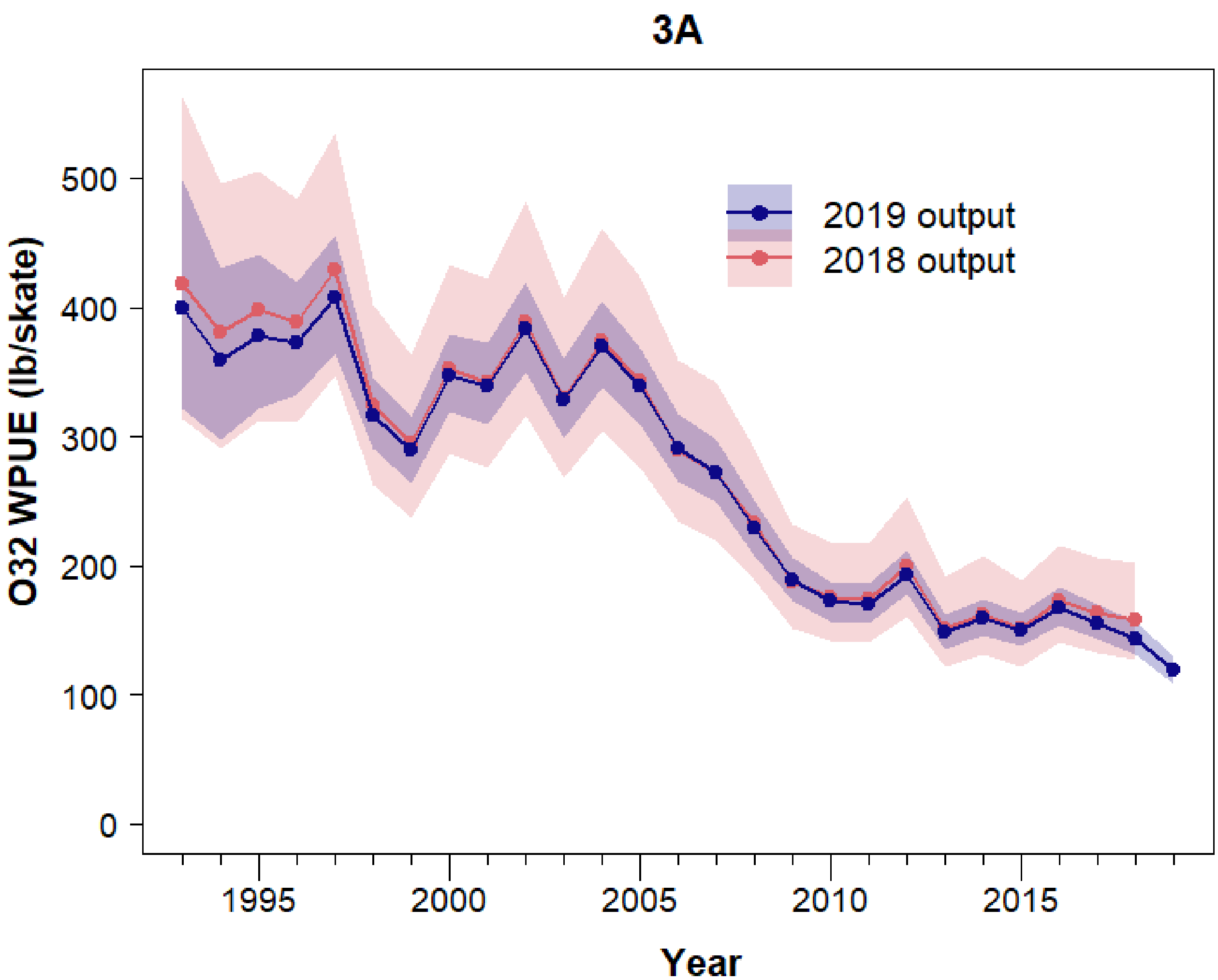

Figure C.1. Time series of posterior means of average O32 WPUE in Regulatory Area 3A from space-time modelling undertaken in 2019, compared with model output from 2018 modelling. The shaded regions show 95% posterior credible intervals.

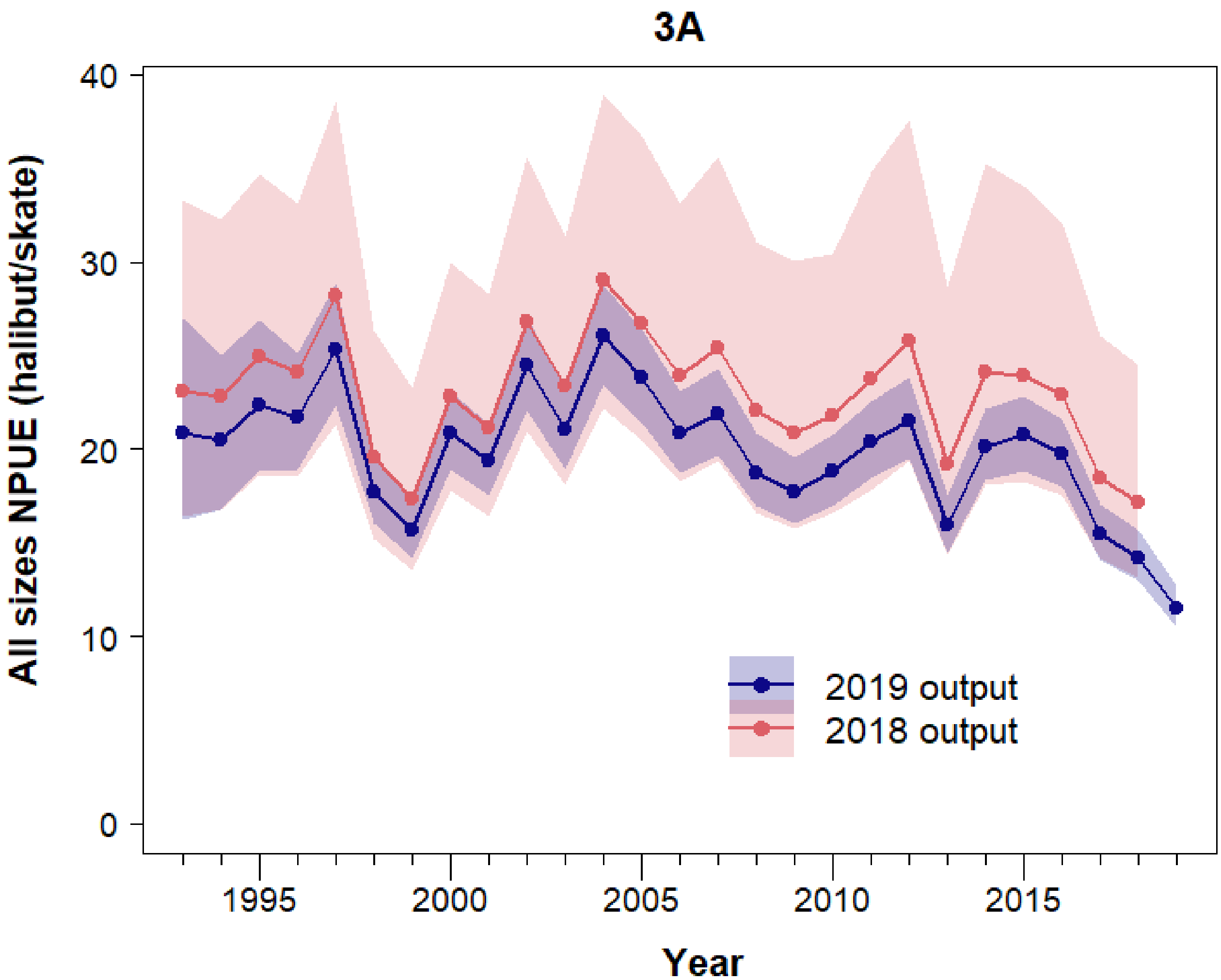

Figure C.2. Time series of posterior means of average all sizes NPUE in Regulatory Area 3A from space-time modelling undertaken in 2019, compared with model output from 2018 modelling. The shaded regions show 95% posterior credible intervals.

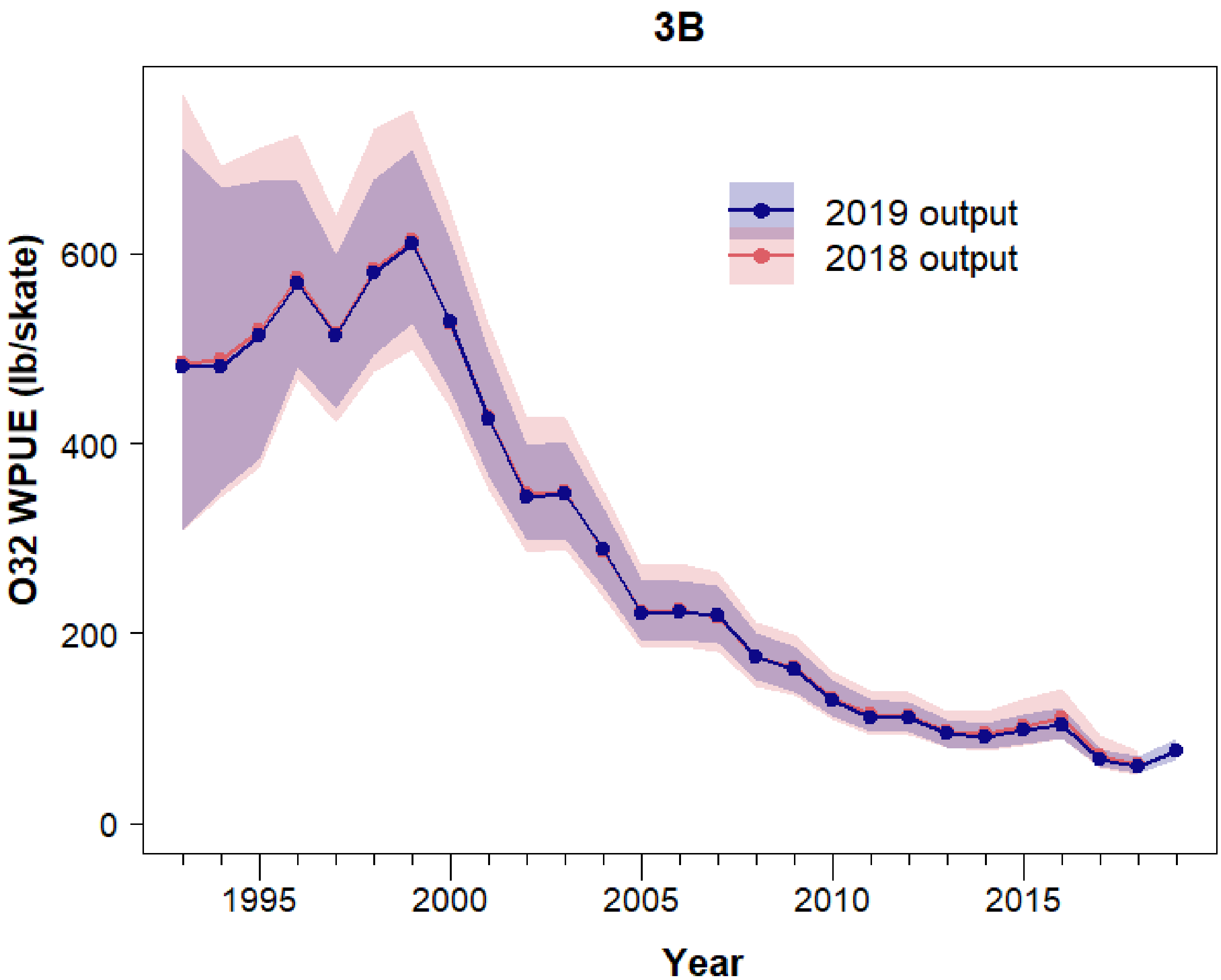

Figure C.3. Time series of posterior means of average O32 WPUE in Regulatory Area 3B from space-time modelling undertaken in 2019, compared with model output from 2018 modelling. The shaded regions show 95% posterior credible intervals.

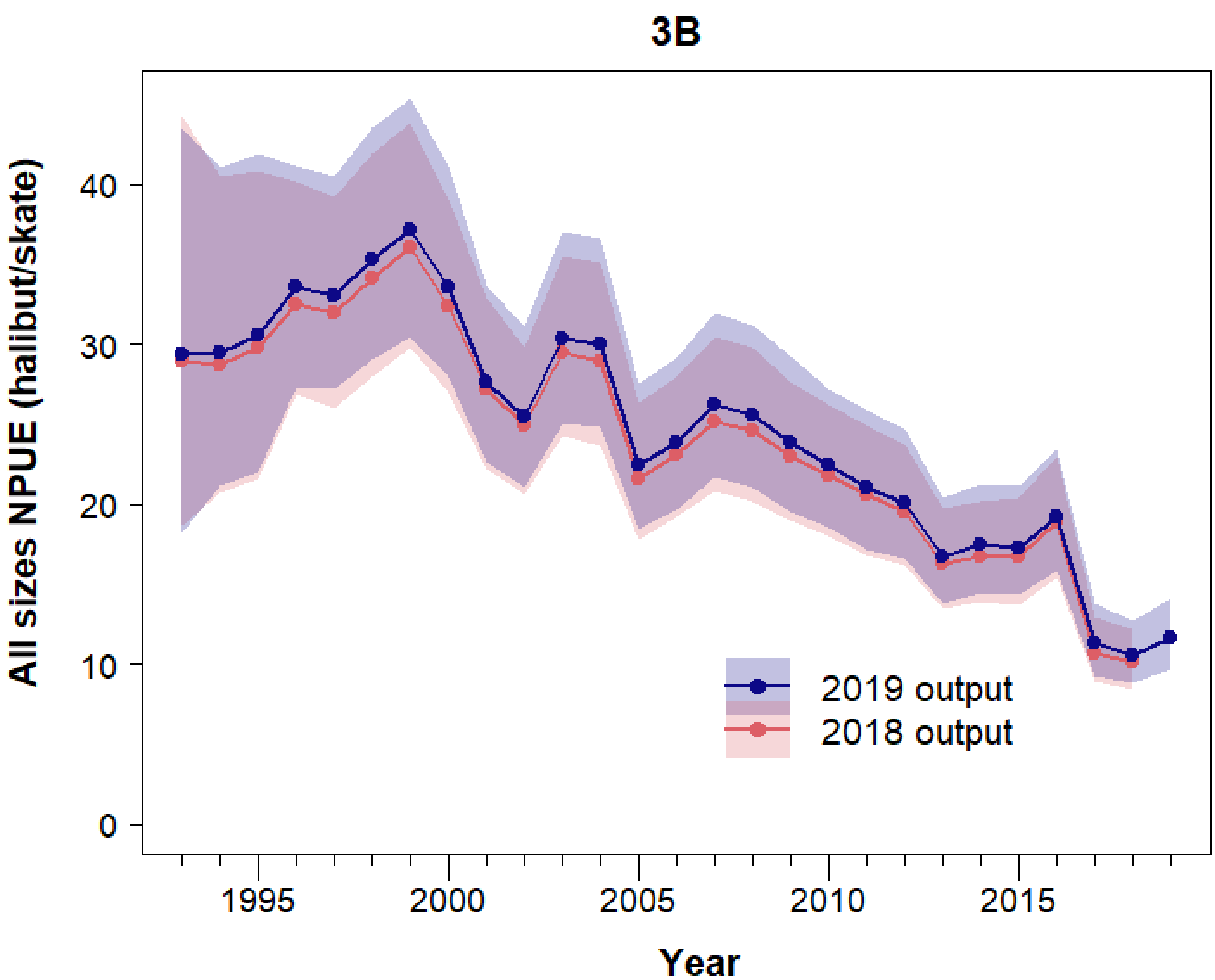

Figure C.4. Time series of posterior means of average all sizes NPUE in Regulatory Area 3B from space-time modelling undertaken in 2019, compared with model output from 2018 modelling. The shaded regions show 95% posterior credible intervals.