Space-time modelling of survey data

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PURPOSE

To provide the Commission with a summary of the results of the 2018 space-time modelling of Pacific halibut survey data (which includes data from the IPHC fishery-independent setline survey (FISS), and other fishery-independent surveys), as well as the detailed results of the FISS expansions in IPHC Regulatory Areas 2A, 2B and 2C conducted in 2018.

BACKGROUND

The IPHC's fishery-independent setline survey (FISS, or "setline survey") of the Pacific halibut stock has been undertaken annually using a 10 nmi fixed grid design since 1998, within depths of 37-503 m (20-275 ftm). This design ensures that, on average, all habitat types within the area covered by the setline survey are sampled in proportion to their occurrence, while fishing the same fixed stations each year reduces uncertainty in any estimates of trends in density indices derived from the setline survey data.

The setline survey design has been augmented each year since 2014 with expansion stations that fill in historical gaps in coverage. These gaps include waters in depths from 18-37 m (10-20 ftm) and 503-732 m (275-400 ftm), along with other previously unsurveyed regions within 37-503 m in each IPHC Regulatory Area. Typically, expansions have taken place in one or two IPHC Regulatory Areas each year:

- 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; and
- 2018: Regulatory Areas 2B and 2C.

In addition to the planned expansions in 2018, setline survey stations were added off the north Washington coast (Regulatory Area 2A) in both 2017 and 2018 in an *ad hoc* expansion that doubled the station density in that region.

INTRODUCTION

In most Regulatory Areas, the IPHC setline survey grid has historically been fished in waters within the 37-503 m (20-275 fm) depth range. Information from commercial fishery data and other fishery-independent sources showed the presence of Pacific halibut down to depths of 732 m (400 fm) and in waters shallower than 37 m. Further, most IPHC Regulatory Areas had gaps in coverage within the standard 37-503 m depth range. The incomplete coverage of Pacific halibut habitat by the historical setline survey had the potential to create bias in estimates of the weight per unit effort (WPUE) and numbers per unit effort (NPUE) density indices used in the stock assessment and management strategy evaluation analyses. For this reason, the IPHC has been undertaking a sequence of setline survey expansions since 2014 (following a 2011 pilot), with stations added to the standard grid to cover all depths (from 0 to 732 m) and habitats not previously sampled in our setline survey. The expansions have involved adding stations to one or two Regulatory Areas each year, and reverting to the historically fished stations for those areas in subsequent years.

In 2018, setline survey expansions took place in Regulatory Areas 2B and 2C. In addition, the *ad hoc* densified grid off the north Washington Coast was repeated after having been fished in 2017 during a hypoxic event. The waters of the Salish Sea in Regulatory Area 2A were also surveyed in 2018 (as they were in 2011, 2014 and 2017), in order to supplement the new expansion FISS stations in the Straits of Juan de Fuca and Georgia within Regulatory Area 2B and provide full coverage of the Salish Sea for the first time.

As in 2016 and 2017, estimates of mean WPUE and NPUE are produced through space-time modelling of Pacific halibut fishery-independent survey data. In 2018, the IPHC's Scientific Review Board (SRB) undertook a review of the space-time model for the third year since its introduction in 2016. The SRB again endorsed its use for the 2018 analysis, as follows:

> IPHC-2018-SRB013-R, Para. 10. *"NOTING that this is the sixth review of the space-time modelling approach, the SRB reiterated its ENDORSEMENT of the approach as cutting-edge and could be widely used. Thus there is a pressing need to publish the space-time modelling approach used for the fishery-independent setline survey data in a peer-reviewed scientific journal."*

In IPHC Regulatory Areas 2A, 2B, 2C and 4B, only IPHC setline survey data are used in the modelling, while models for Regulatory Areas 4A and 4CDE include calibrated data from the NOAA-Fisheries (National Marine Fisheries Service; NMFS) and Alaska Department of Fish and Game (ADFG) fishery-independent trawl surveys. These supplementary data sources are important, due to incomplete coverage of the Bering Sea by the IPHC setline survey. Data from NMFS sablefish longline survey also provide limited information on Pacific halibut density in deeper waters in Regulatory Areas 3A and 3B, although the use of sablefish survey data will be discontinued following completion of setline survey expansions with more complete and comparable data for those Regulatory Areas in 2019. In 2018, NMFS fished an *ad hoc* northern expansion of the annual Bering Sea trawl survey, and ADFG's previously triennial Norton Sound trawl survey was fished for the second consecutive year. Data from both of these sources were included in the modelling (as have previous data from these surveys), improving estimates of Pacific halibut density indices in the northern Bering Sea, and therefore in Regulatory Area 4CDE as a whole.

SPACE-TIME MODELLING RESULTS

No changes were made to the space-time modelling methods in 2018. Along with this year's new survey data, a small amount of additional data were included in the models from a 1995 IPHC random stratified setline survey in IPHC Regulatory Area 2A.

Figure 1 shows time series estimates for O32 WPUE (most comparable to fishery catch-rates) over the 1993-2018 period used in the 2018 space-time modelling. Biological Regions 2, 3 and 4 all showed modest declines from 2017 to 2018, while Region 4B was estimated to a have a 12% increase. Estimated declines from 2017 to 2018 in the NPUE index (Figure 2) of all sizes of Pacific halibut captured by the survey were greatest in Region 2, with Region 4B again showing a small increase. As in 2017, we also modelled the WPUE of all sizes of Pacific halibut captured by the survey, and Figure 3 shows a comparison of space-time model estimates of mean all sizes WPUE and O32 WPUE. It is notable that in all Biological Regions except Region 4B, the two time series converge during 2017 and 2018, a consequence of fewer small (U32) Pacific halibut being captured on the setline survey in the last two years. Space-time model results by IPHC Regulatory Area are shown in the figures in Appendix A.

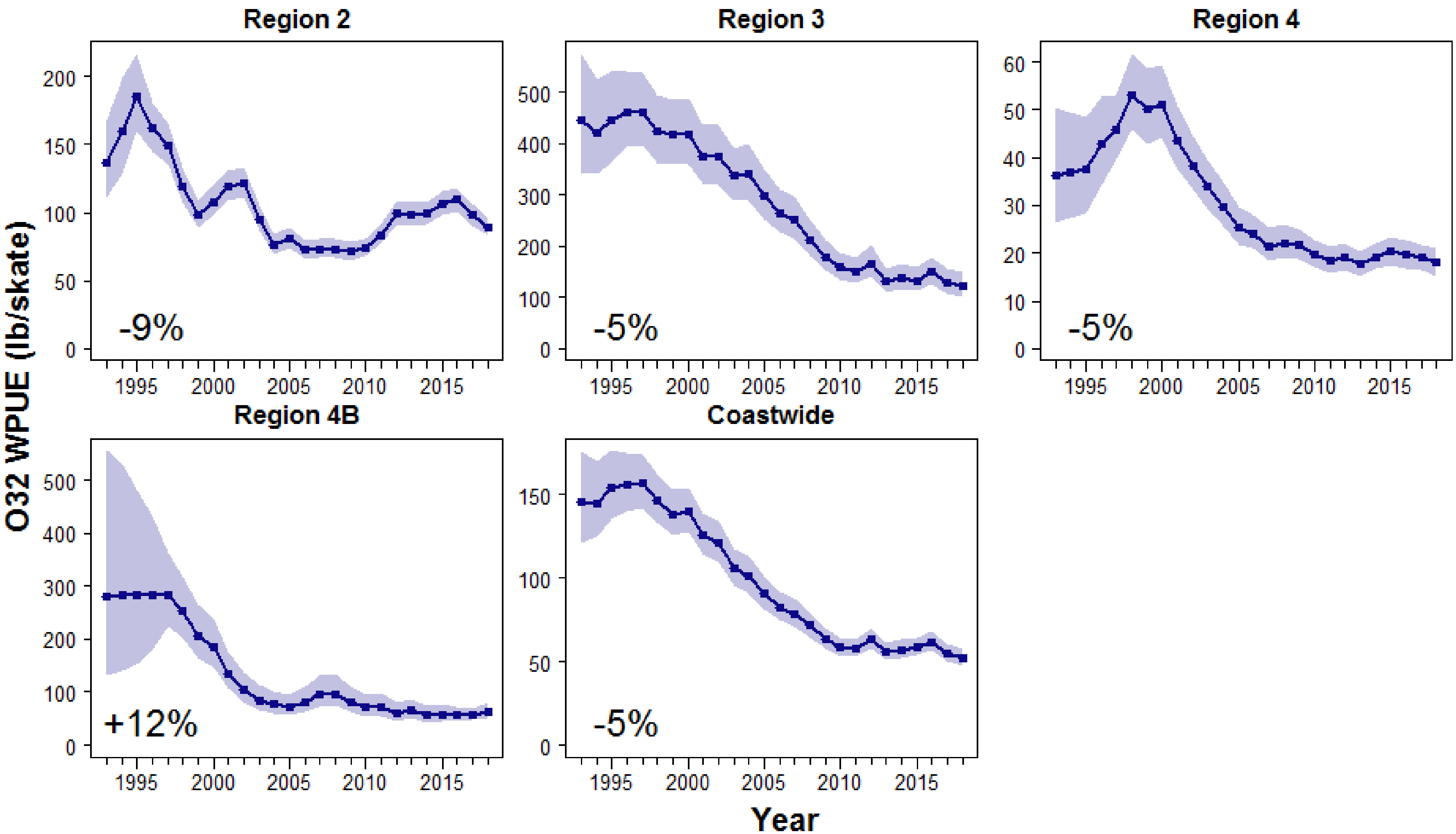

Figure 1. Space-time model output for O32 WPUE for 1993-2018 for Biological Regions. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean O32 WPUE from 2017 to 2018.

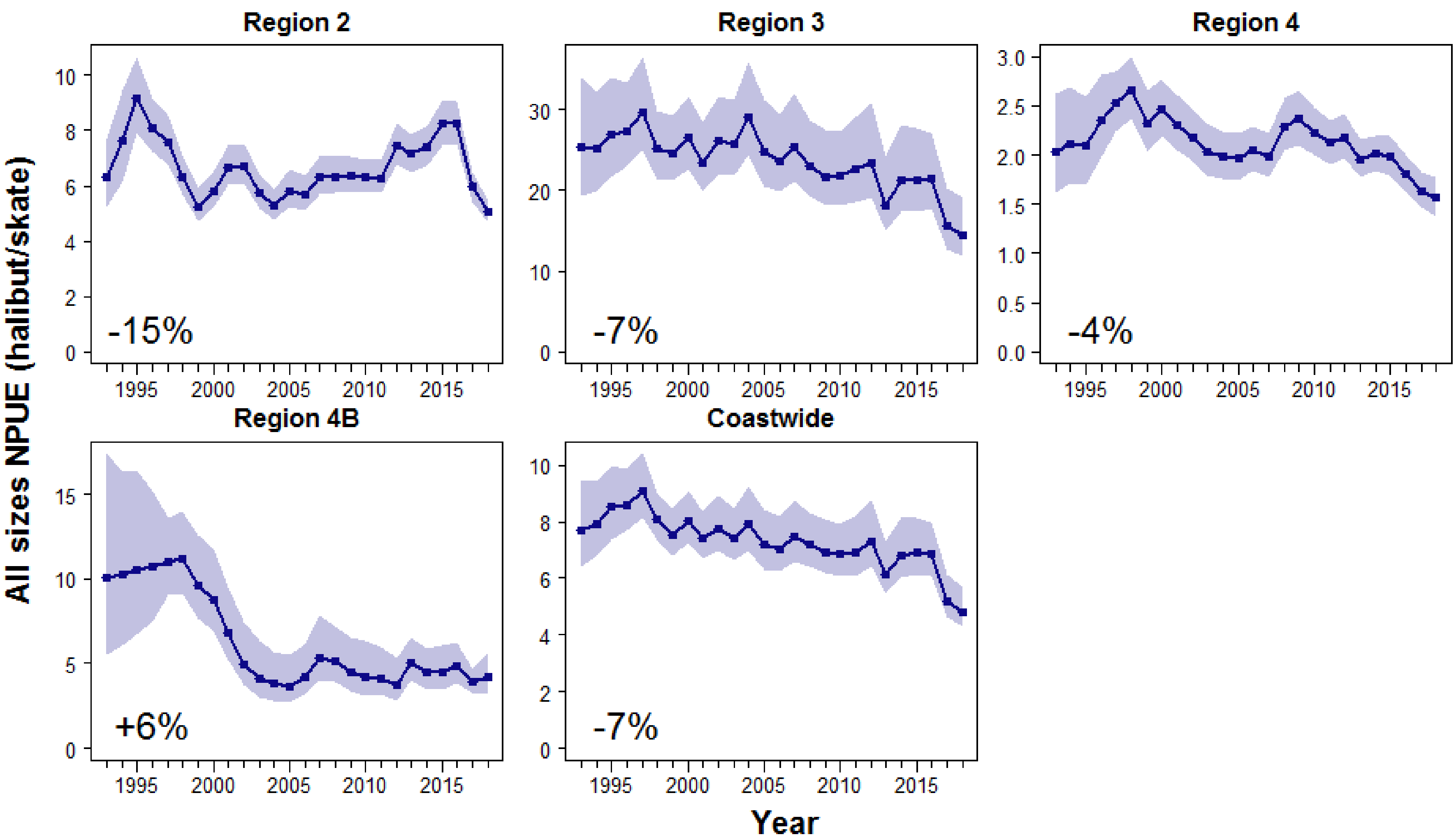

Figure 2. Space-time model output for all sizes NPUE for 1993-2018 for Biological Regions. Filled circles denote the posterior means of all sizes NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean all sizes NPUE from 2017 to 2018.

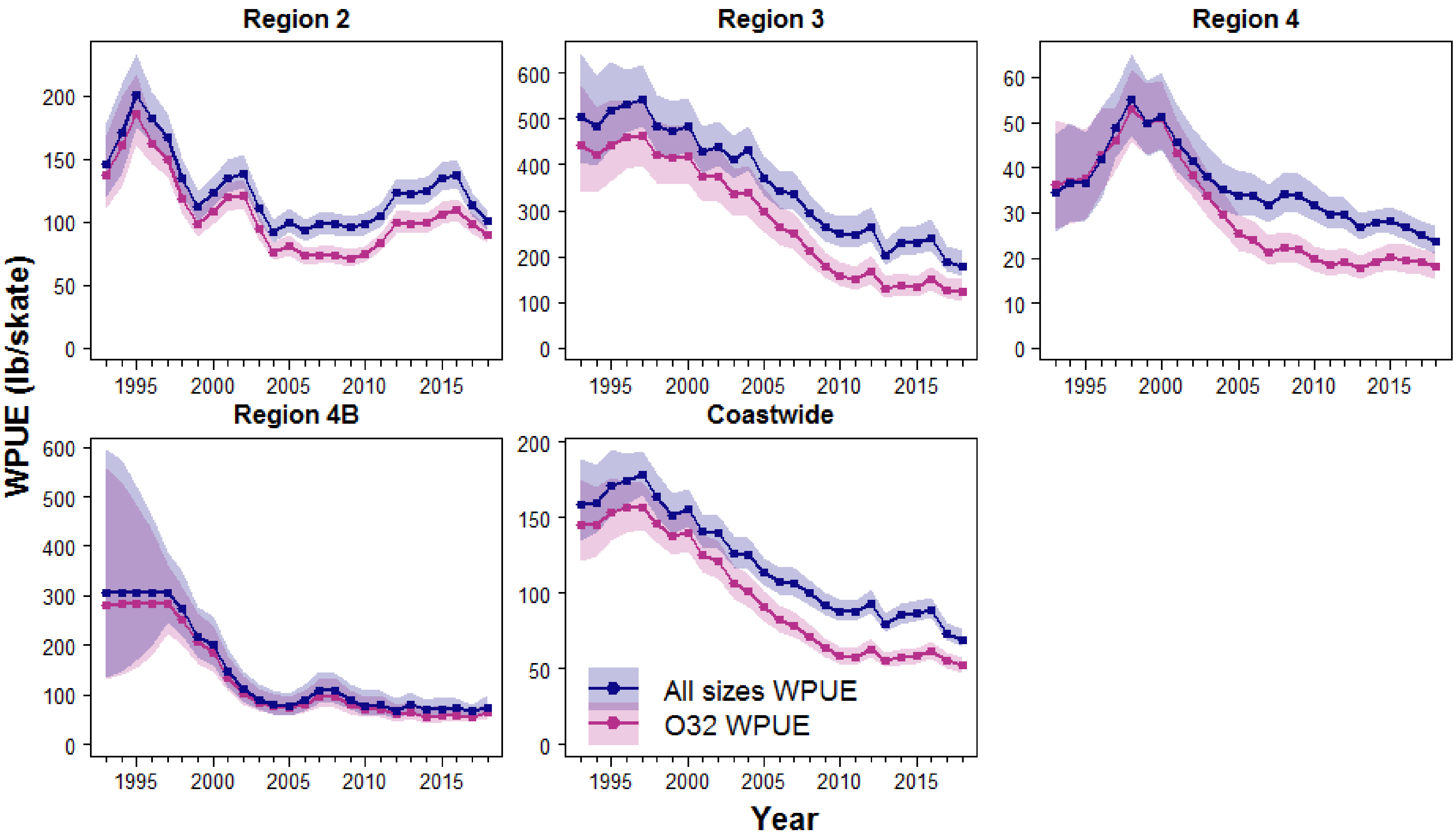

Figure 3.Comparison of space-time model output for O32 and all sizes WPUE for 1993-2018 for Biological Regions. Filled circles denote the posterior means for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate.

RESULTS OF THE IPHC FISHERY-INDEPENDENT SETLINE SURVEY (FISS) EXPANSIONS

In IPHC Regulatory Area 2B, expansion stations were added to large areas of previously unsurveyed habitat (Figure 4), including the region east of Haida Gwaii, the fjords and coastal waters of the British Columbia mainland, and the Straits of Georgia and Juan de Fuca (Salish Sea). In newly surveyed regions, higher than average catch rates were found at stations near Haida Gwaii and around the north BC coast and fjords, while Pacific halibut catch was near zero in the Strait of Georgia.

Overall, the average catch rate was lower over the entire expanded setline survey than on the historically fished stations: raw, unadjusted O32 WPUE was 72.1 lb/skate over all 2018 stations, but 82.0 lb/skate for those previously fished. On its own, this does not imply the previous space-time model estimates were biased, as that depends on what the model had predicted in newly surveyed areas. However, because most of the Strait of Georgia in particular was far from observed data in prior years, the predictions there previously approached the Regulatory Area 2B mean (after allowing for year and depth effects). The new information showing very low densities in the Strait of Georgia means that these predictions were likely too high, resulting in positive bias in previous estimates of density indices for IPHC Regulatory Area 2B. The new information from the expanded survey has allowed this bias to be corrected in estimates of WPUE and NPUE indices (Appendix B, Figures B.1 and B.2). Refitting the model to the data while excluding 2018 expansion data allows us to obtain an estimate of the bias the indices would have had without the setline survey expansion. For mean O32 WPUE, the 2018 estimate using the full data was 78.3 lb/skate, while the estimate without expansion data was 91.0 lb/skate, meaning the latter has an estimated positive bias of 16.2%. The estimate without expansion data is outside the 95% posterior credible interval of 70.0-87.2 lb/skate for O32 WPUE based on all data. The posterior probability of observing a mean O32 WPUE index of 91.0 lb/skate or greater is less than 4 in 1000, meaning this value is an implausible estimate of mean O32 WPUE given our understanding of halibut density from the full 2018 setline survey data.

The uncertainty in the estimates also decreased in 2018, as shown by the narrower 95% posterior credible intervals for the revised estimates (Appendix B, Figures B.1 and B.2). With the new expansion data, coefficients of variation (CVs) for both mean O32 WPUE and all sizes NPUE now range from 6-10% for the period of the current 10 nmi grid design (1998 onwards), compared to CVs of 9-12% for estimates obtained in 2017 prior to the expansion.

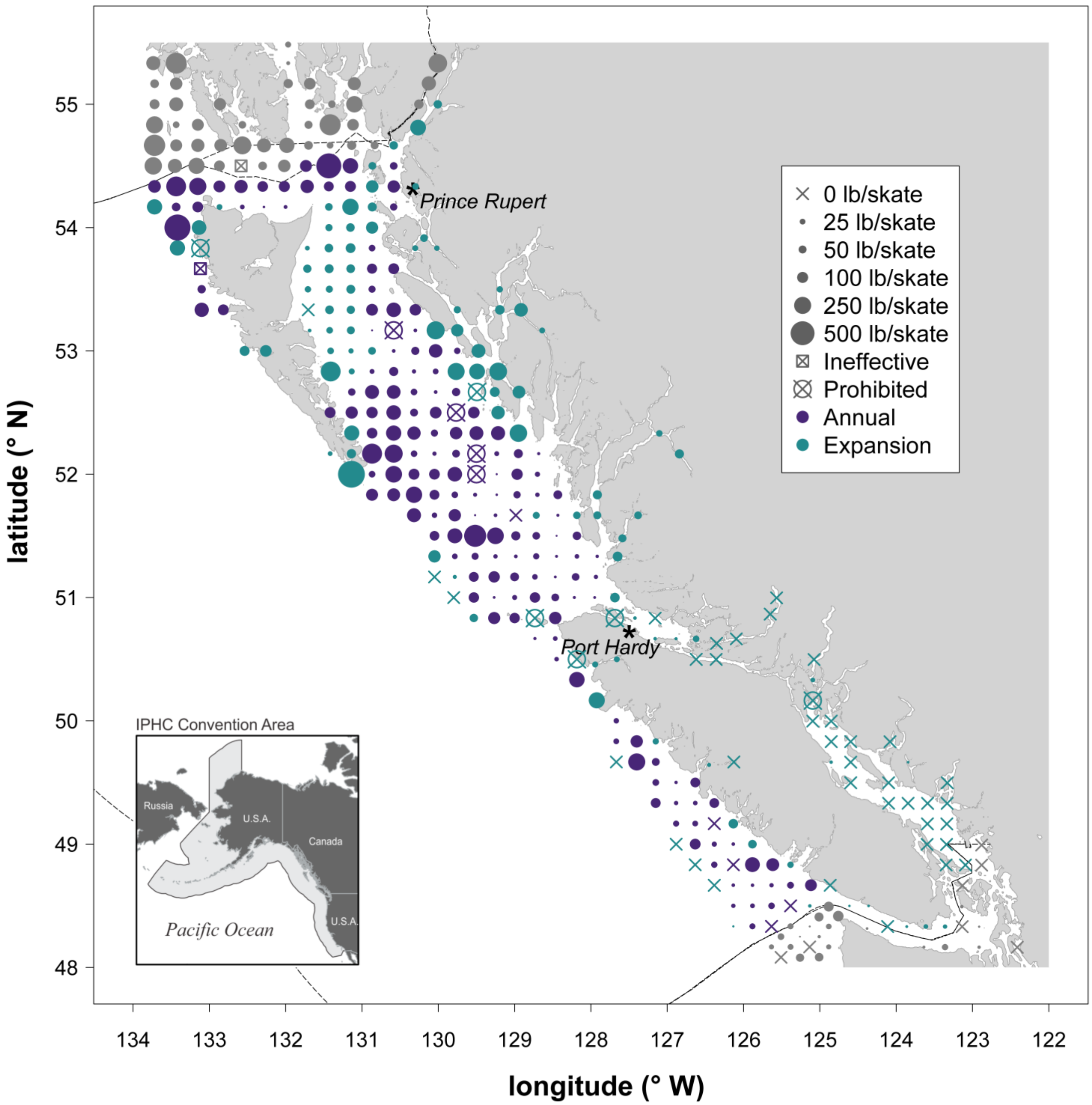

Figure 4. Map of setline survey station locations in IPHC Regulatory Area 2B. For circular symbols, the area of the circle is proportional to raw, unadjusted O32 WPUE. Gray symbols denote setline survey stations that are counted as being outside of IPHC Regulatory Area 2B.

There were no large gaps in historical setline survey coverage in IPHC Regulatory Area 2C, and the 2018 expansion stations were spread throughout the area (Figure 5). As with Regulatory Area 2B, mean raw, unadjusted O32 WPUE was lower on the full set of 2018 stations (195.4 lb/skate) than on the subset of previously fished stations (215.9 lb/skate). Unlike in Regulatory 2B, space-time model estimates for prior years were able to accurately predict catches at newly surveyed locations: revised 2018 estimates are generally very close to those estimated in 2017 (Figures B.3 and B.4), with only some evidence of a small negative bias in the absence of expansion data for O32 WPUE (Figure B.3, 2018 estimates slightly higher in most years). For recent years, there is some divergence between the two estimates of the time series for all sizes NPUE (Figure B.4). This is most likely due to the influence of the very low value of the estimated all sizes NPUE index in 2018 on prior years, through the strong correlation between successive years' Pacific halibut density at each station location in Regulatory Area 2C (the estimate of the temporal correlation parameter is 0.95).

Inclusion of data from the expansion stations has greatly reduced uncertainty in the estimates of density indices in Regulatory Area 2C, with much narrower 95% intervals from the 2018 modelling than from the 2017 modelling conducted prior to the expansion (Figures B.3 and B.4). CVs for the period from 1998 onwards have been reduced from 8.1-8.5% to 5.6-6.7% for O32 WPUE with the addition of the expansion data and to 6.5-9.7% from over 13% in all years for total NPUE. One reason for this is the improvement in the data informing the estimates of depth covariate parameters (defining the relationship between catch rates and depth) in the model. Prior to 2018, we used NMFS sablefish longline survey data help index Pacific halibut in deeper waters. Estimated density indices from that survey were generally close to zero. The six expansion stations in waters deeper than 503 m (275 ftm) had mean O32 WPUE of 73 lb/skate, much lower than the overall average for Regulatory 2C, but not close to zero. Some of the predictions at more remote locations in Regulatory Area 2C inlets, particularly in Lynn Canal in the north, had very high uncertainty in previous modelling, and having direct observations in these inlets also contributed to reducing overall uncertainty.

In 2017, setline survey catches off the north Washington Coast were affected by a large hypoxic zone present during the period of the setline survey. This was not the case in 2018 (Figure 6), allowing for a clearer comparison of the *ad hoc* dense grid stations with the annually fished stations. The raw, unadjusted mean O32 WPUE on annually fished stations within the region covered by the dense grid was 26.4 lb/skate in 2018, while the mean on the dense grid expansion stations was 28.0 lb/skate. Addition of the dense grid expansion stations had no meaningful effect on space-time model estimates of O32 WPUE in Regulatory Area 2A (Figure B.5): differences between estimates made with and without the dense grid expansion data were very small relative to the overall uncertainty in the estimates.

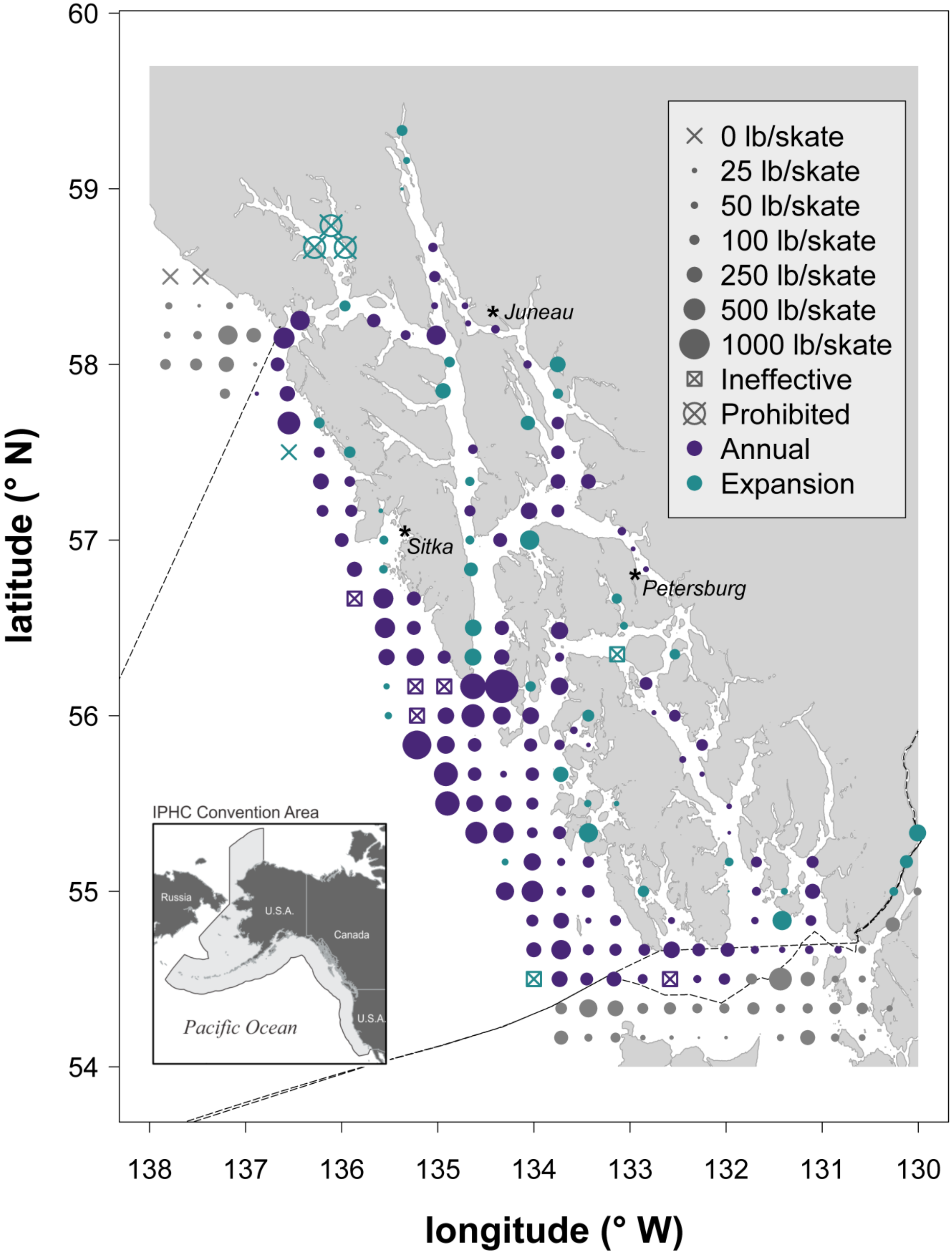

Figure 5. Map of setline survey station locations in IPHC Regulatory Area 2C in 2018. For circular symbols, the area of the circle is proportional to raw, unadjusted O32 WPUE. Gray symbols denote survey stations counted as outside of IPHC Regulatory Area 2C.

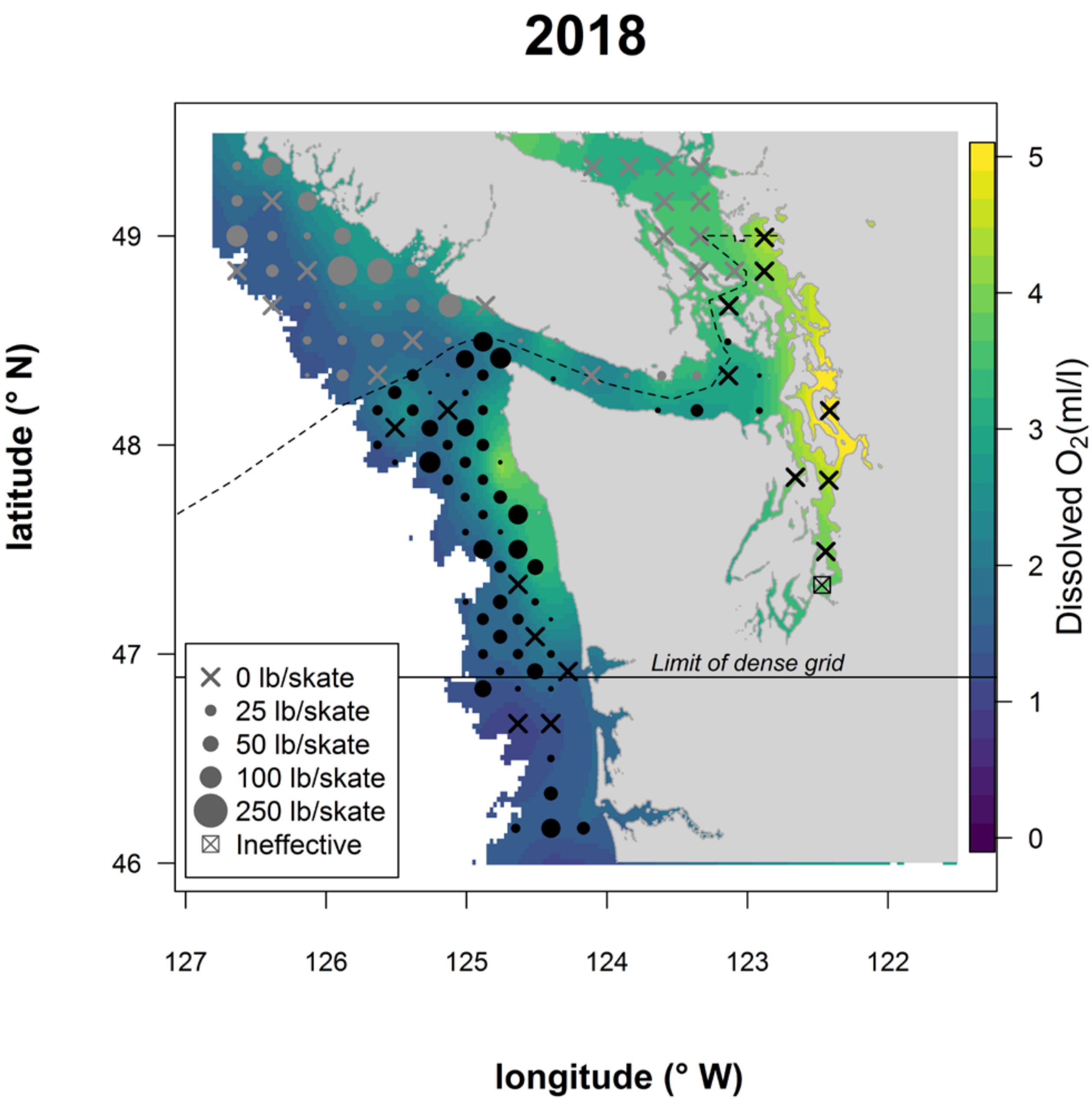

Figure 6. Map of dissolved oxygen in northern IPHC Regulatory Area 2A in 2018, with symbols showing raw, unadjusted O32 WPUE from the 2018 setline survey. Gray symbols denote setline survey stations outside of IPHC Regulatory Area 2A.

OTHER SPACE-TIME MODELLING WORK IN 2018

At the 12th Session of the IPHC SRB meeting (IPHC–2018–SRB012–R) in June 2018, results were reviewed from two analyses exploring changes to the setline survey data analysis methods, or the space-time model inputs. In the first, data from Regulatory Area 2B were analysed to determine if the use of counts of all species on 20-hooks per skate were sufficient for accurate estimation of the hook competition standardisation adjustment factors, given the change to applying these at the station level in 2016 instead of the Regulatory Area level, as done in prior years. Regulatory Area 2B has a 100% hook counts, allowing us to compare model output from the use of 20 and 100% counts. No meaningful differences were found, and the conclusion was that the use of 20-hook counts on IPHC setline surveys was sufficient.

The second analysis looked at the effect of including environmental covariate data (specifically, bottom temperature and dissolved oxygen) on estimates of the O32 WPUE index for space-time models for Regulatory Area 2A. While there was strong evidence of relationships between WPUE and dissolved oxygen, the inclusion of this variable in the models did not have a meaningful effect on estimates of the indices or associated estimates of uncertainty. The SRB stated the following in their June 2018 review:

> IPHC–2018–SRB012–R, Para 10. "*The SRB AGREED that, while dissolved oxygen (DO) levels improved space-time model fits to setline survey data, the results were not compelling or widespread enough (i.e. small effect size estimates) to warrant routine inclusion in the stock assessment process or WPUE/NPUE standardization. DO results could be reported at annual meetings*."

APPENDIX A
Space-time modelling results by IPHC Regulatory Area

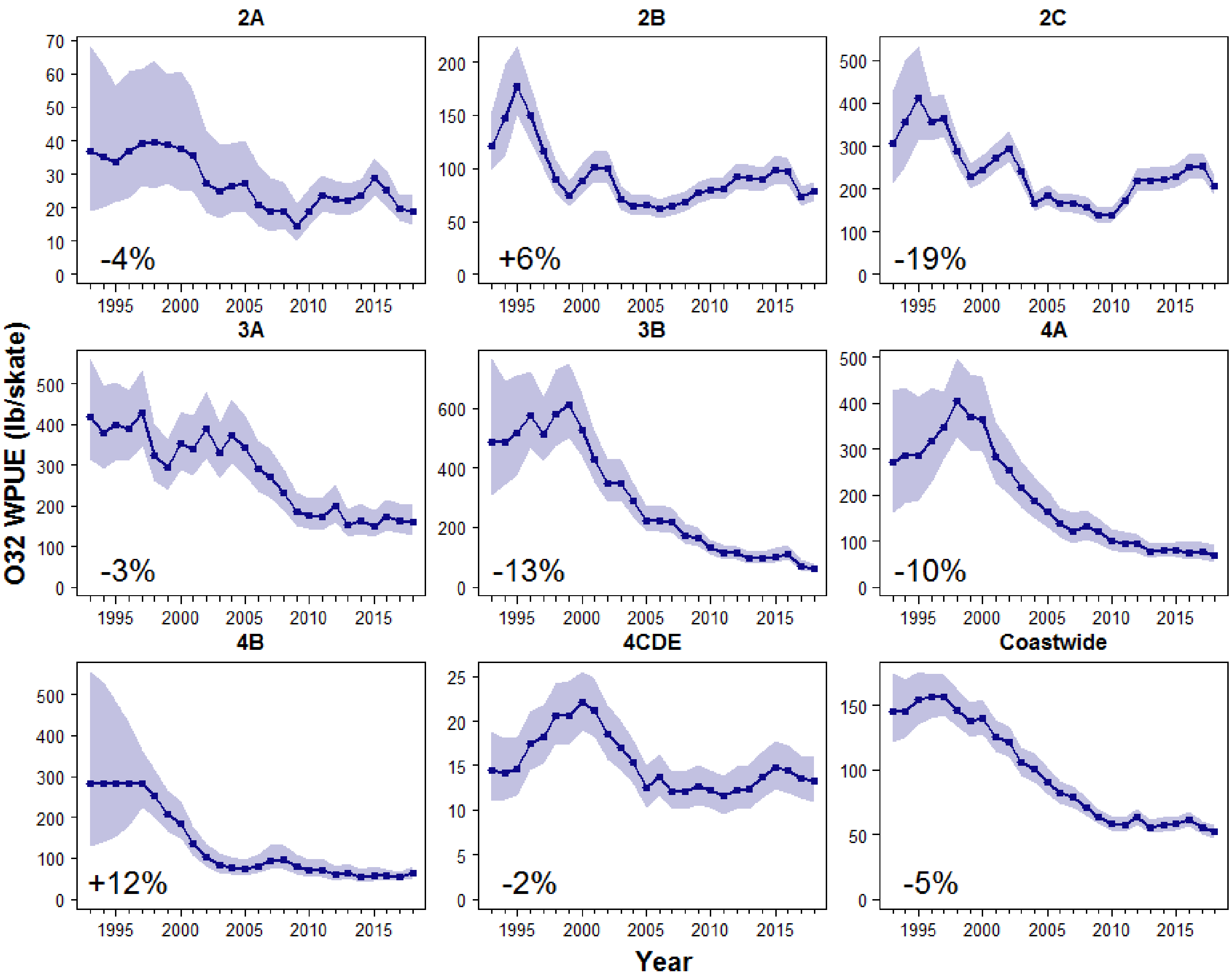

Figure A.1. Space-time model output for O32 WPUE for 1993-2018. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean O32 WPUE from 2017 to 2018.

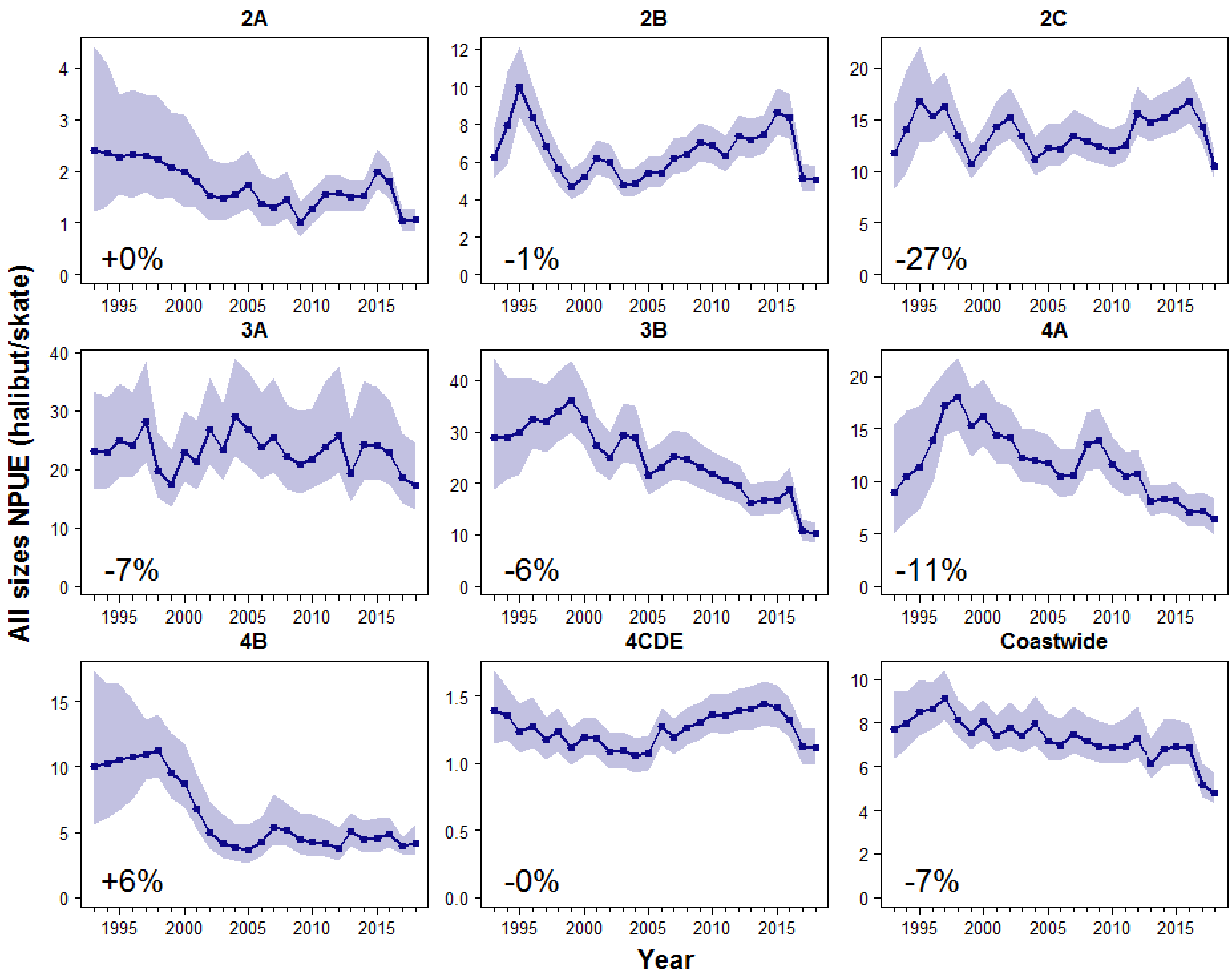

Figure A.2. Space-time model output for total NPUE for 1993-2018. Filled circles denote the posterior means of total NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean total NPUE from 2017 to 2018.

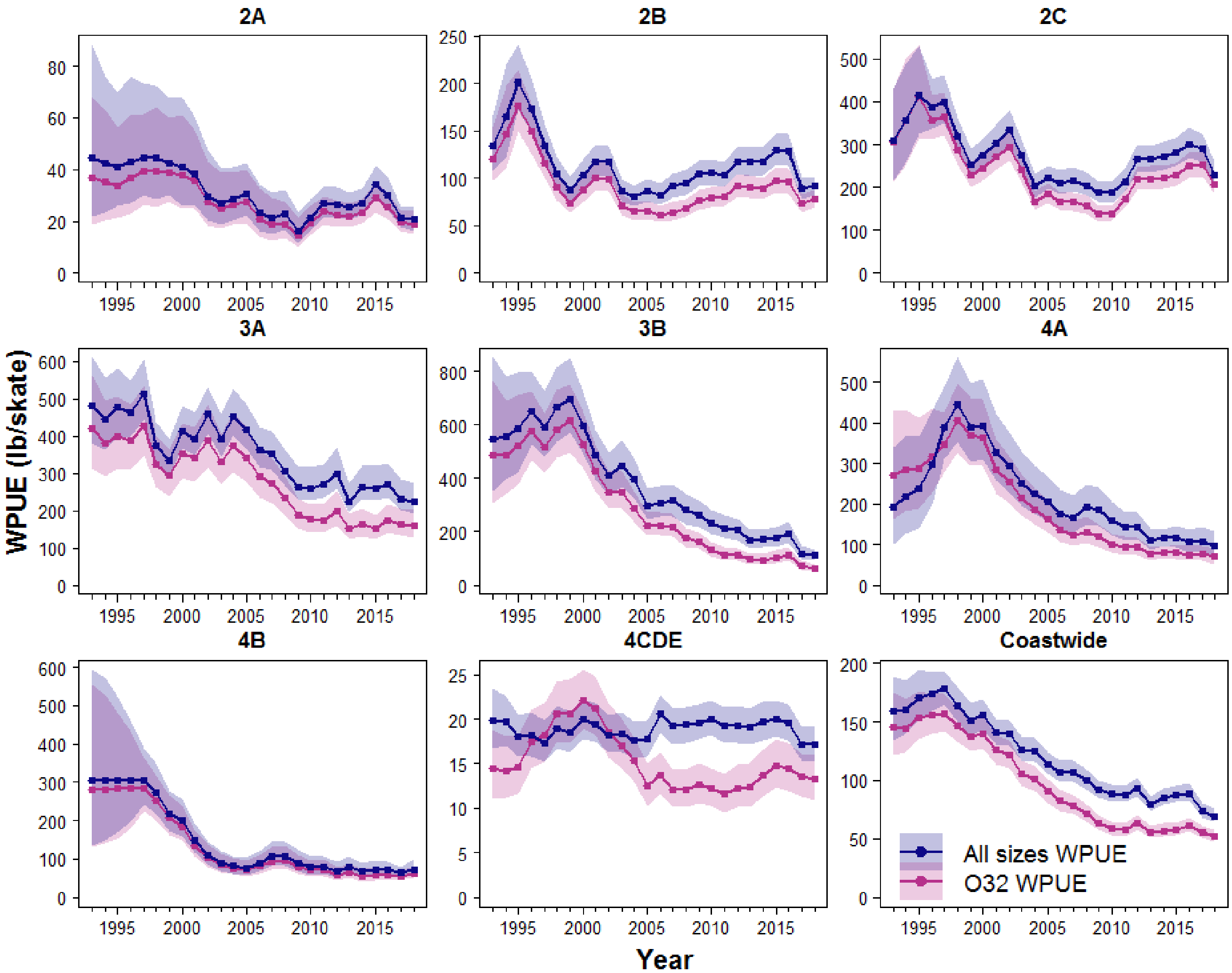

Figure A.3. Comparison of space-time model output for O32 and total WPUE for 1993-2018. Filled circles denote the posterior means for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate.

APPENDIX B

The effect of IPHC fishery-independent setline survey (FISS) expansions on space-time modelling results by IPHC Regulatory Area

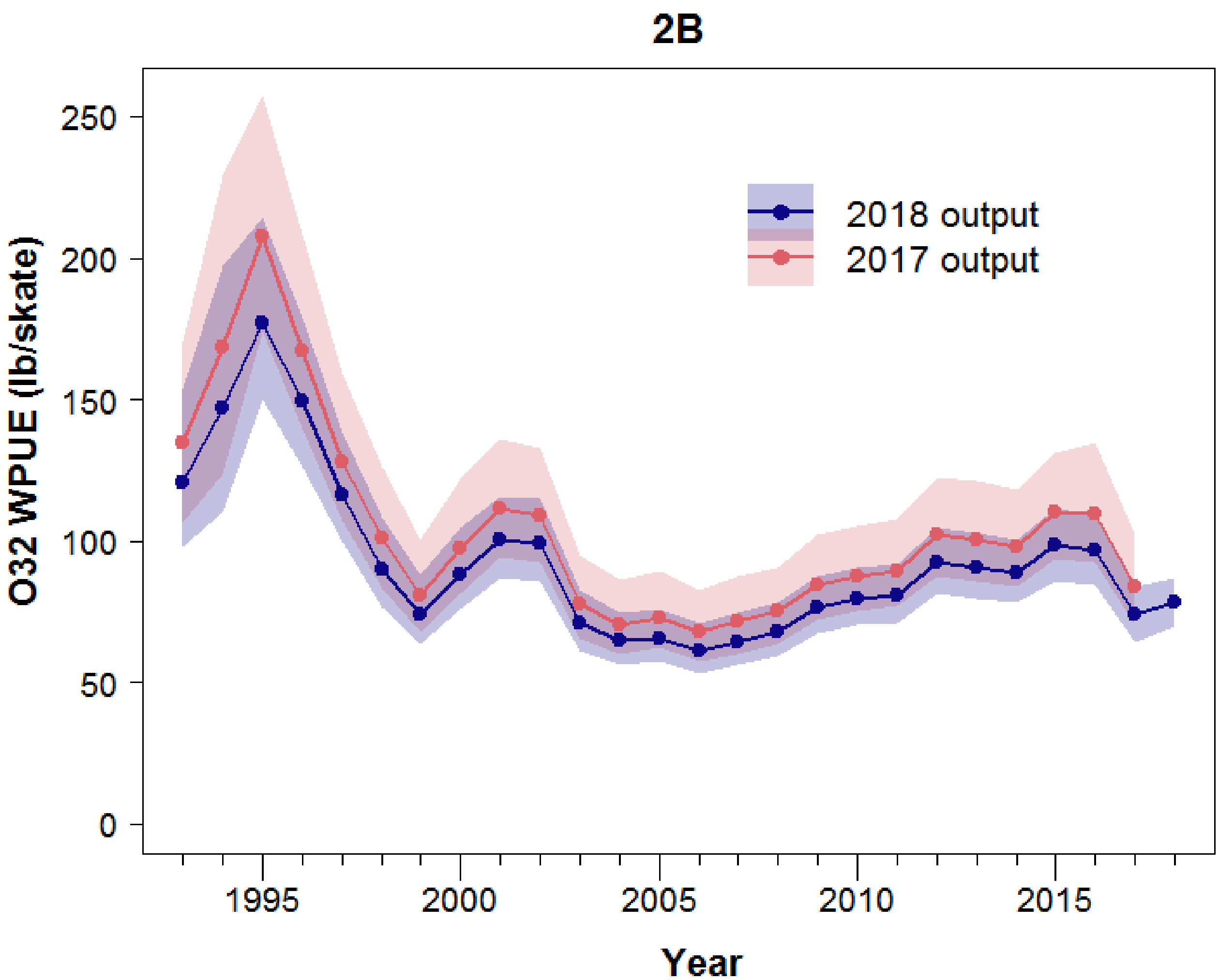

Figure B.1. Time series of posterior means of average O32 WPUE in IPHC Regulatory Area 2B from space-time modelling undertaken in 2018, compared with model output from 2017 modelling. The shaded regions show 95% posterior credible intervals.

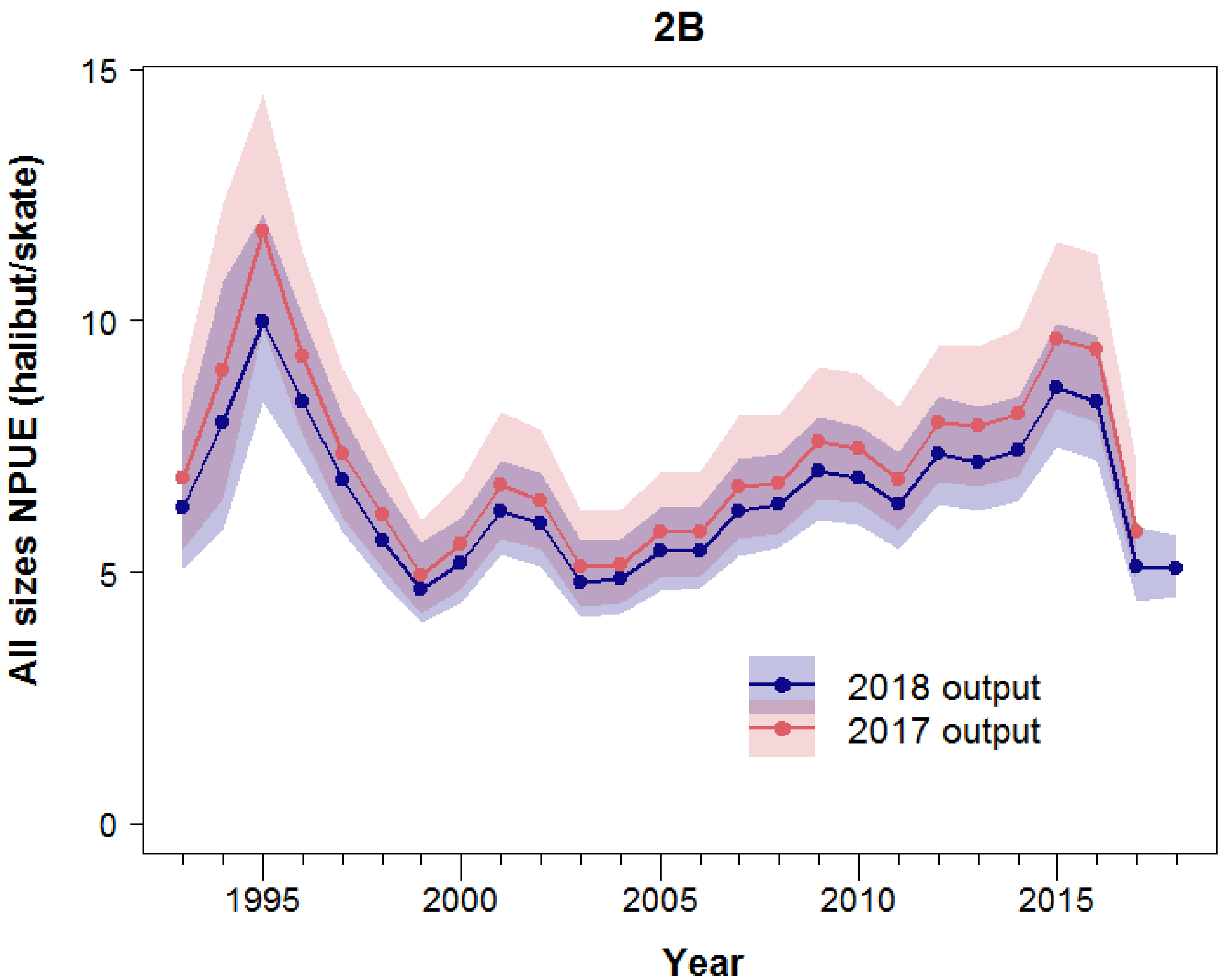

Figure B.2. Time series of posterior means of average all sizes NPUE in IPHC Regulatory Area 2B from space-time modelling undertaken in 2018, compared with model output from 2017 modelling. The shaded regions show 95% posterior credible intervals.

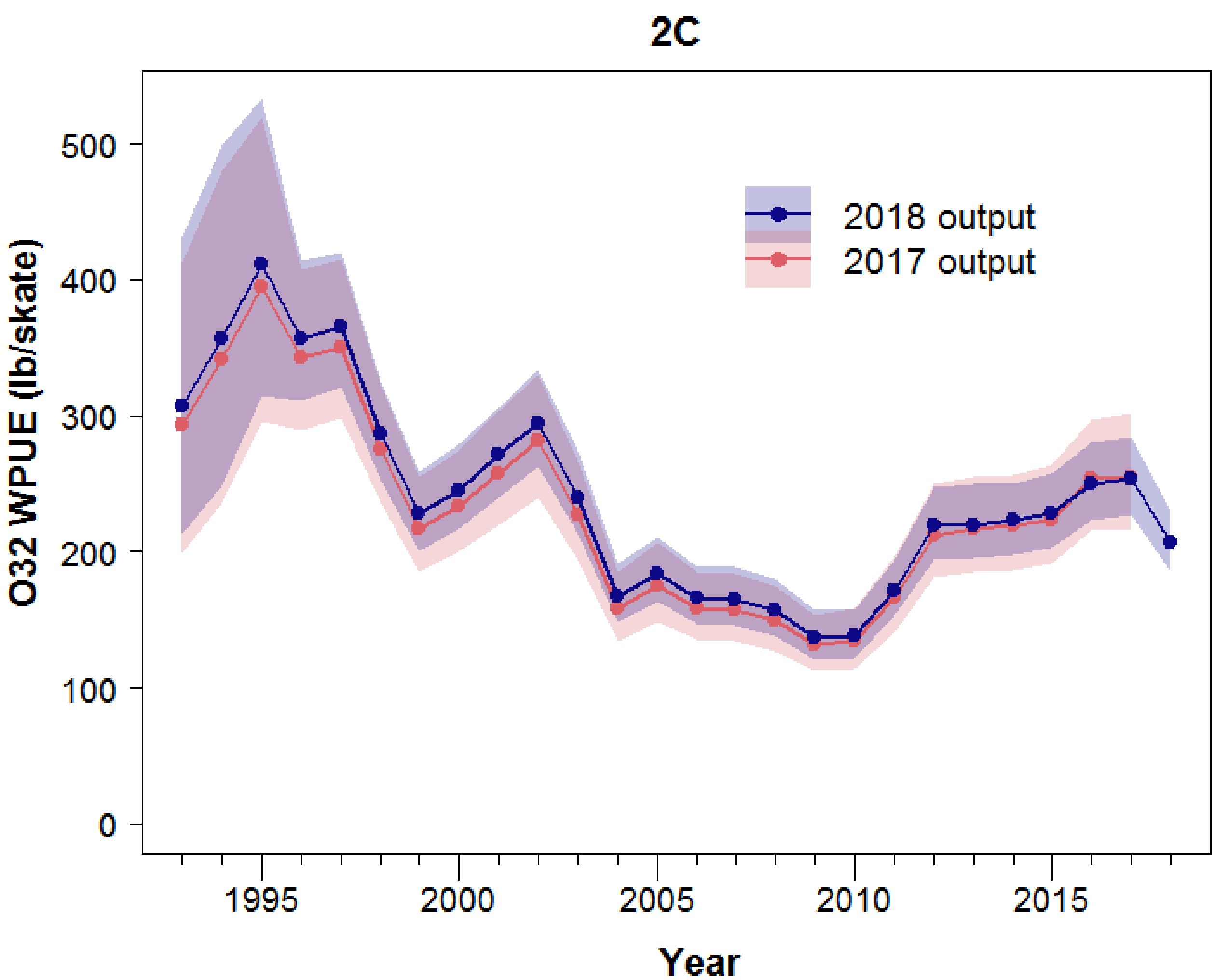

Figure B.3. Time series of posterior means of average O32 WPUE in IPHC Regulatory Area 2C from space-time modelling undertaken in 2018, compared with model output from 2017 modelling. The shaded regions show 95% posterior credible intervals.

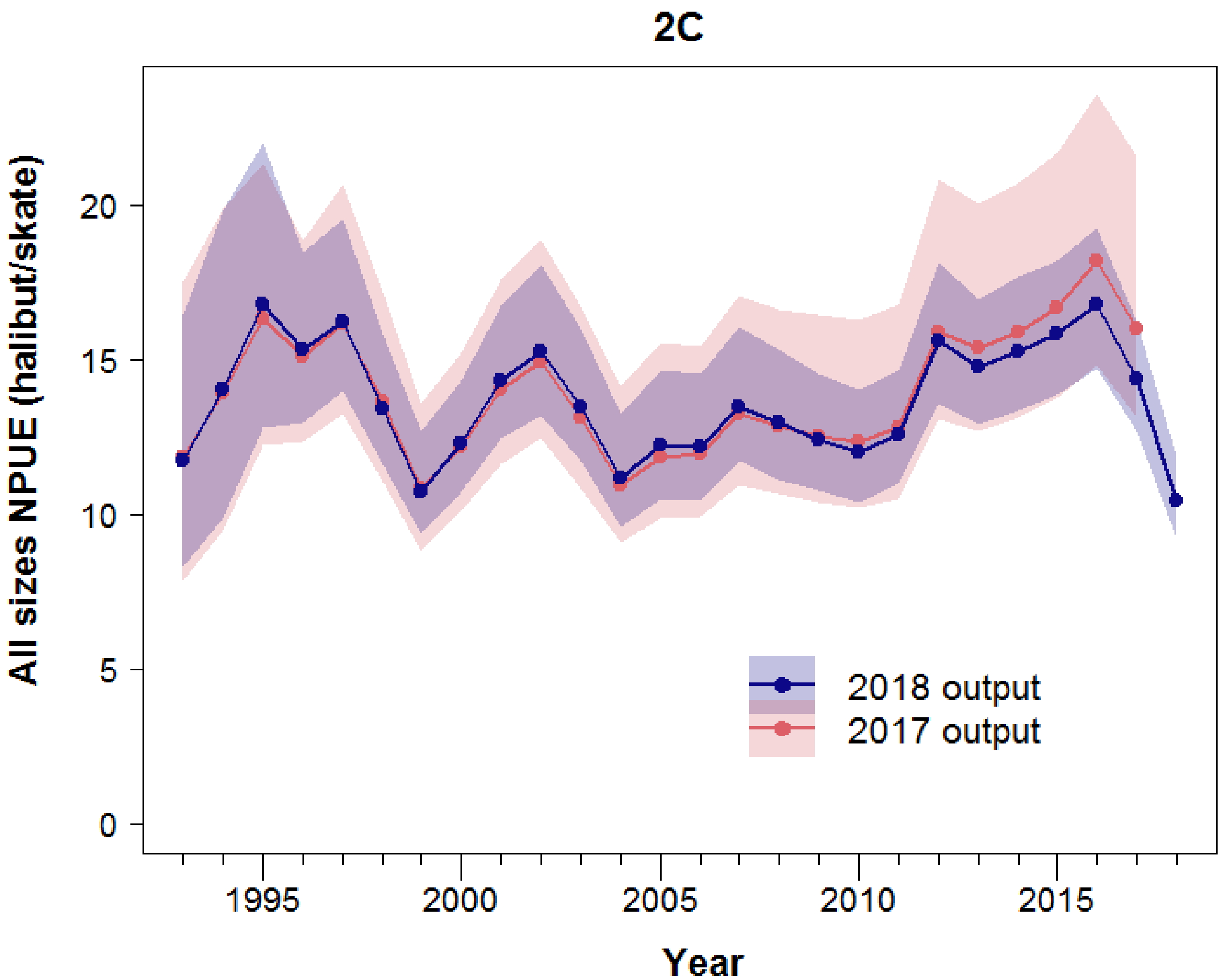

Figure B.4. Time series of posterior means of average all sizes NPUE in IPHC Regulatory Area 2C from space-time modelling undertaken in 2018, compared with model output from 2017 modelling. The shaded regions show 95% posterior credible intervals.

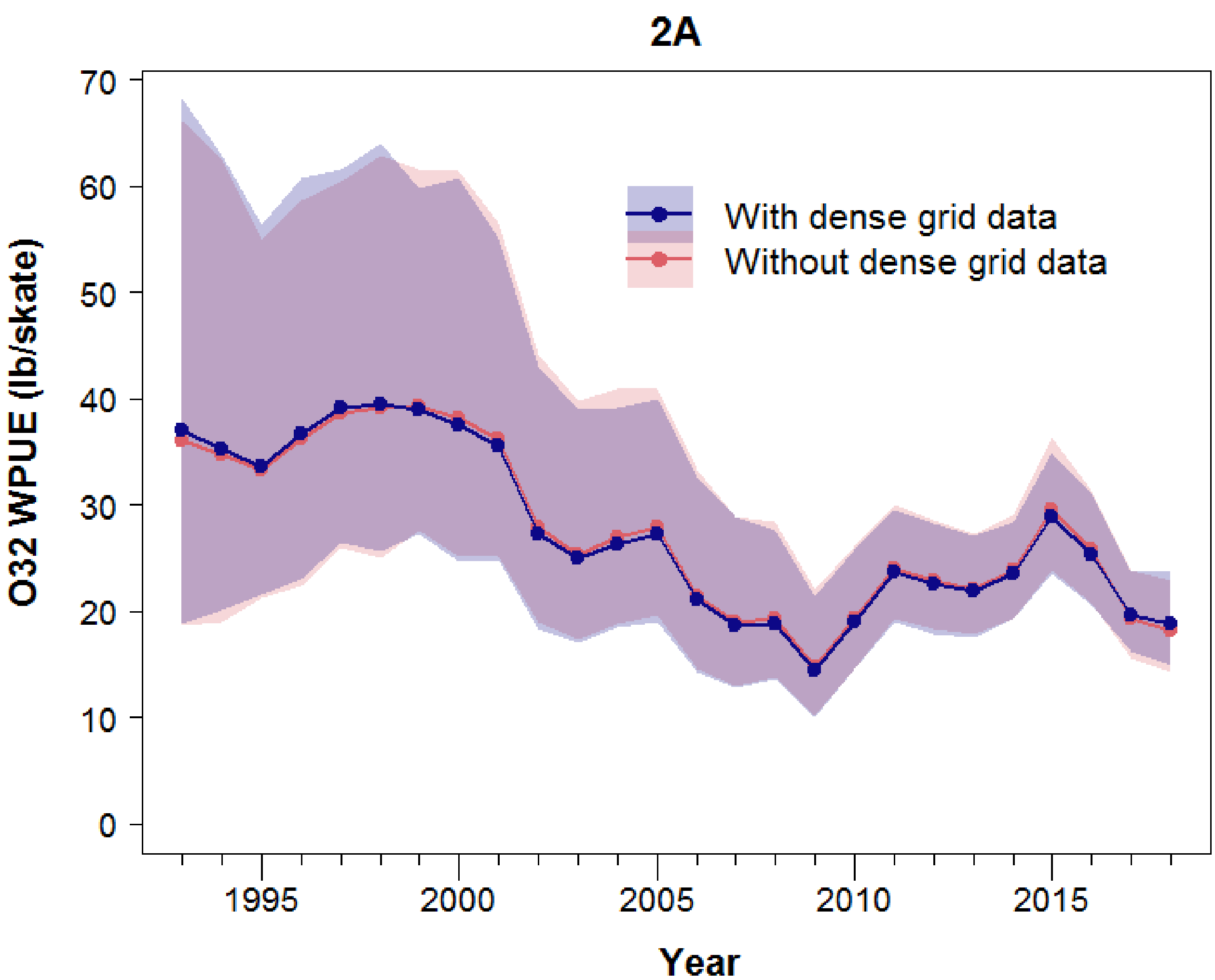

Figure B.5. Time series of posterior means of average O32 WPUE in IPHC Regulatory Area 2A from space-time modelling undertaken in 2018, comparing results from models including and excluding data from the ad hoc dense grid expansion off the north Washington coast. The shaded regions show 95% posterior credible intervals.