Space-time modelling of survey data and FISS designs for 2021-23

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PURPOSE

To provide results of the space-time modelling of fishery-independent survey data for Pacific halibut in 2020, and to present IPHC FISS designs for 2021-23.

BACKGROUND

The IPHC's Fishery-Independent Setline Survey (FISS) provides data used to compute indices of Pacific halibut density for use in monitoring stock trends, estimating stock distribution, and as an important input in the stock assessment. Space-time modelling is used to estimate the time series of mean weight-per-unit effort (WPUE) for each IPHC Regulatory Area, both O32 (greater than or equal to 32" or 81.3cm in length) and all sizes of Pacific halibut. WPUE indices are used to estimate the distribution of the stock among IPHC Regulatory Areas and Biological Regions. Mean numbers-per-unit-effort (NPUE) are also estimated from space-time modelling, and is used to index the trend in Pacific halibut density for use in the stock assessment models.

FISS history 1993-2010

The IPHC has undertaken FISS activity since the 1960s. However, methods were not standardized to a degree (e.g. the bait and gear used) that allows for simple combined analyses until 1993. From 1993 to 1997, the annual design was a modification of a design developed and implemented in the 1960s, and involved fishing triangular clusters of stations, with clusters located on a grid (IPHC 2012). Coverage was limited in most years, and was generally restricted to IPHC Regulatory Areas 2B through 3B. The modern FISS design, based on a grid with 10 nmi (18.5 km) spacing, was introduced in 1998, and over the subsequent two years was expanded to include annual coverage in all IPHC Regulatory Areas within the depth ranges of 20-275 fathoms (37-503 m) in the Gulf of Alaska and Aleutian Islands, and 75-275 fathoms (137-503 m) in the Bering Sea (IPHC 2012). Annually-fished stations were added around islands in the Bering Sea in 2006, and in the same year, a less dense grid of paired stations was fished in shallower waters of the southeastern Bering Sea, providing data for a calibration with data from the annual NOAA-Fisheries trawl survey (Webster et al. 2020).

FISS expansions 2011-19

Examination of commercial logbook data and information from other sources, it became clear by 2010 that the FISS design had gaps in coverage of Pacific halibut habitat that had the potential to lead to bias in estimates derived from its data. These gaps included deep and shallow waters outside the FISS depth range (0-20 fathoms and 275-400 fathoms), and unsurveyed regions within the 20-275 fathom depth range within each IPHC Regulatory Area.

This led the IPHC Secretariat to propose expanding the FISS to provide coverage within the unsurveyed habitat with United States and Canadian waters. In 2011 a pilot expansion was undertaken in IPHC Regulatory Area 2A, with stations on the 10 nmi grid added to deep (275-400 fathoms) and shallow (10-20 fathoms) waters, the Salish Sea, and other, smaller gaps in coverage. (The 10 fathom limit in shallow waters was due to logistical difficulties in fishing longline gear in shallower waters.) A second expansion in IPHC Regulatory Area 2A was completed in 2013, with a pilot California survey between latitudes of 40-42°N.

The full expansion program began in 2014 and continued through 2019, with the goal of sampling the entire FISS design of 1,890 stations in the shortest time logistically possible. Each year included FISS expansions in one or two IPHC Regulatory Areas:

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

The FISS expansion program has allowed us to build a consistent and complete picture of Pacific halibut density throughout its range in Convention waters. Sampling the full FISS design has reduced bias as noted above, and, in conjunction with space-time modelling of survey data (see below), has improved precision. This has also allowed the Commission to, for the first time, fully quantify the uncertainty associated with estimates based on partial sampling of the species range. It has also provided us with a complete set of observations over the full FISS design (Figure 1) from which an optimal subset of stations can be selected when devising annual FISS designs. Note that in the Bering Sea, the full FISS design does not provide complete spatial coverage, and FISS data are augmented with calibrated data from National Marine Fisheries Service (NMFS) and Alaska Department of Fish and Game (ADFG) trawl surveys (stations can vary by year – 2019 designs are shown in Figure 1).

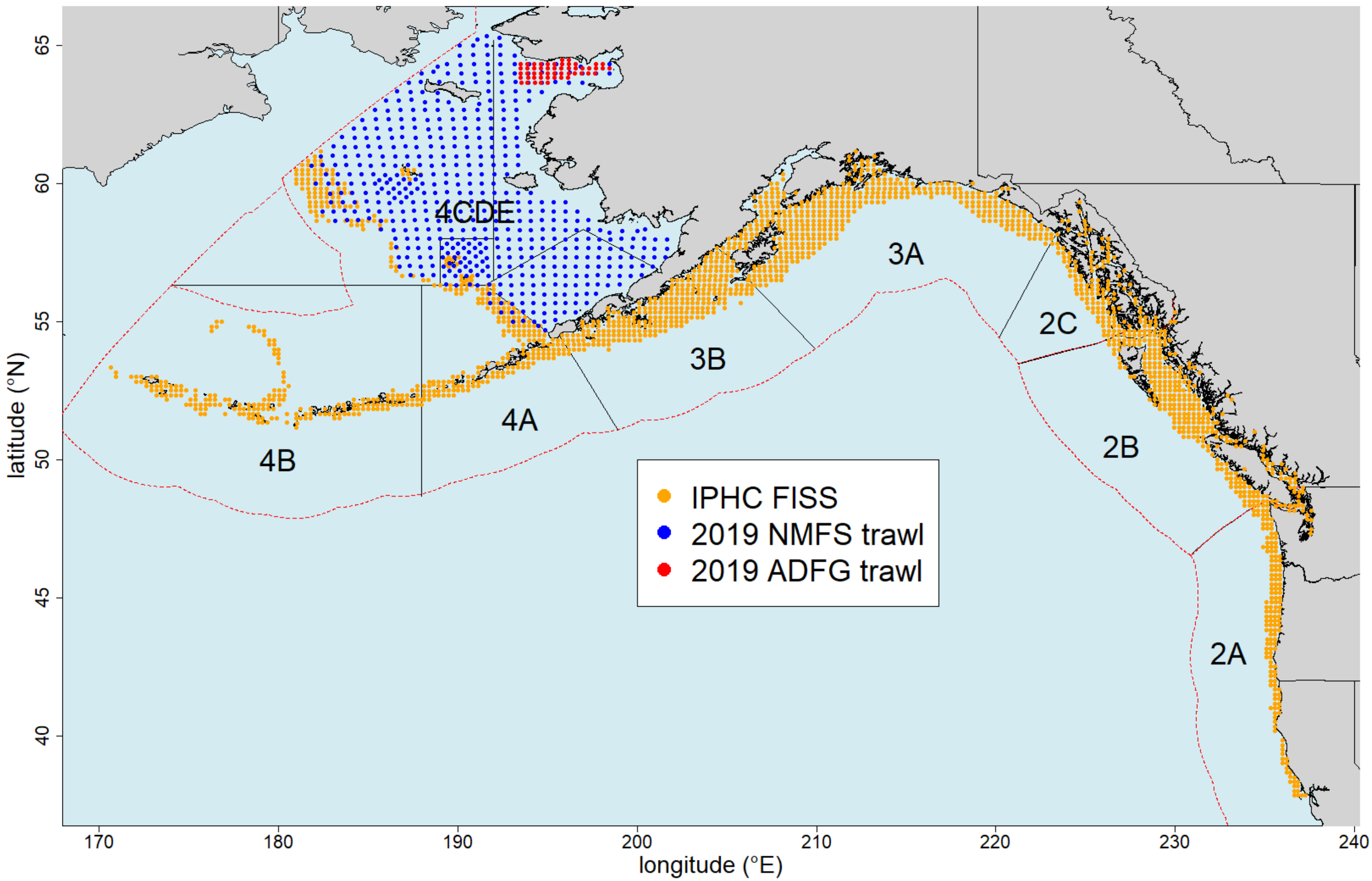

Figure 1. Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs, and other colours representing trawl stations from 2019 NOAA-Fisheries and ADFG surveys used to provide complementary data for Bering Sea modelling.

Space-time modelling

In 2016, a space-time modelling approach was introduced to estimate time series of weight and numbers-per-unit-effort (WPUE and NPUE), and to estimate the stock distribution of Pacific halibut among IPHC Regulatory Areas. This represented an improvement over the largely empirical approach used previously, as it made use of additional information within the survey data regarding the degree of spatial and temporal of Pacific halibut density, along with information from covariates such as depth (see Webster 2016, 2017). It also allowed a more complete of accounting of uncertainty, for example, prior to the use of space-time modelling, uncertainty due to unsurveyed regions in each year was ignored in the estimation. The IPHC's Scientific Review Board (SRB) has provided supportive reviews of the space-time modelling approach (e.g. IPHC-2018-SRB013-R), and the methods were recently published in a peer-review journal (Webster et al. 2020).

FISS design objectives

The primary purpose of the annual FISS is to sample Pacific halibut to provide data for the stock assessment and estimates of stock distribution for use in the development of an IPHC management procedure. The priority of a rationalised FISS is therefore to maintain or enhance data quality (precision and bias) by establishing baseline sampling requirements in terms of station count, station distribution and skates per station. Potential considerations that could add to or modify the design are logistics and cost (secondary design layer), and FISS removals (impact on the stock), data collection assistance for other agencies, and IPHC policies (tertiary design layer). These priorities are outlined in Table 1.

Table 1. Prioritization of FISS objectives and corresponding design layers.

Priority	Objective	Design Layer
Primary	Sample Pacific halibut for stock assessment and stock distribution estimation	Minimum sampling requirements in terms of: • Station distribution • Station count • Skates per station
Secondary	Long term revenue neutrality	Logistics and cost: operational feasibility and cost/revenue neutrality
Tertiary	Minimize removals, and assist others where feasible on a cost-recovery basis.	Removals: minimize impact on the stock while meeting primary priority Assist: assist others to collect data on a cost-recovery basis IPHC policies: ad-hoc decisions of the Commission regarding the FISS design

Review process

At the 96th Session of the IPHC Annual Meeting (AM096) in February 2020, alternative designs were presented to IPHC Commissioners that had been evaluated based on scientific criteria (IPHC-2020-AM096-07), in particular, meeting specific precision targets (coefficients of variation, CVs, below 15%) for WPUE and NPUE indices, and ensuring low probability of large bias in estimators of those indices. These evaluation methods had been previously reviewed by the SRB at SRB014 (IPHC-2019-SRB014-05 Rev_1) with application to IPHC Regulatory Areas 4B and (in presentation) 2A, and introduced to Commissioners at IM095 (IPHC-2019-IM095-07 Rev_1). While development of the proposed designs focused on the Primary Objective of the FISS (Table 1), logistics and cost (Secondary Objective) were also considered in developing proposals based on annual sampling of subareas of each IPHC Regulatory Area on a rotating basis.

Following the completion of the coastwide FISS expansion efforts, 2019/2020 was the first year fully rationalised designs could be proposed. It is expected that the design proposal and review process going forward will be as follows:

- The Secretariat present design proposals to SRB for three subsequent years at the June meeting;
- First review of design proposals by Commissioners will occur at the September work meeting, revised if necessary based on June SRB input;
- Presentation of proposed designs for approval at the November Interim Meeting;
- Ad-Hoc modifications possible at Annual Meeting (due to unforeseen issues arising);
- Adopted AM design for current year modified for cost and logistical reasons prior to summer implementation in FISS (February-April).

Consultation with industry and stakeholders occurs throughout the FISS planning process, and particularly in finalizing design details as part of the FISS charter bid process, when stations can be added to provide for improved logistical efficiency. We also note the opportunities for stakeholder input during public meetings (Interim and Annual Meetings) and through the IPHC's Research Advisory Board.

Results of space-time modelling in 2020

Revisions to the data inputs for space-time modelling of survey data included the use of a smoother curve for calibrating NMFS trawl survey data with IPHC FISS data in the Bering Sea, and the inclusion of snap-gear data in IPHC Regulatory Area 2B modelling. The former was a result of recommendations from reviewers of Webster et al. (2020), in which we presented methods for space-time modelling of Bering Sea survey data.

Figures 2 and 3 show time series estimates of O32 WPUE (most comparable to fishery catch-rates) and all sizes NPUE over the 1993-2020 period included in the 2020 space-time modelling. Overall there was an estimated increase of 6% in the coastwide O32 WPUE index, due largely to a 16% increase in Region 3, offset by a 7% decrease in Region 2 (Figure 2). Coastwide all sizes NPUE was stable, with just a 1% estimated decrease (Figure 3). Estimated 1993-20 time series by IPHC Regulatory Area are in Appendix A.

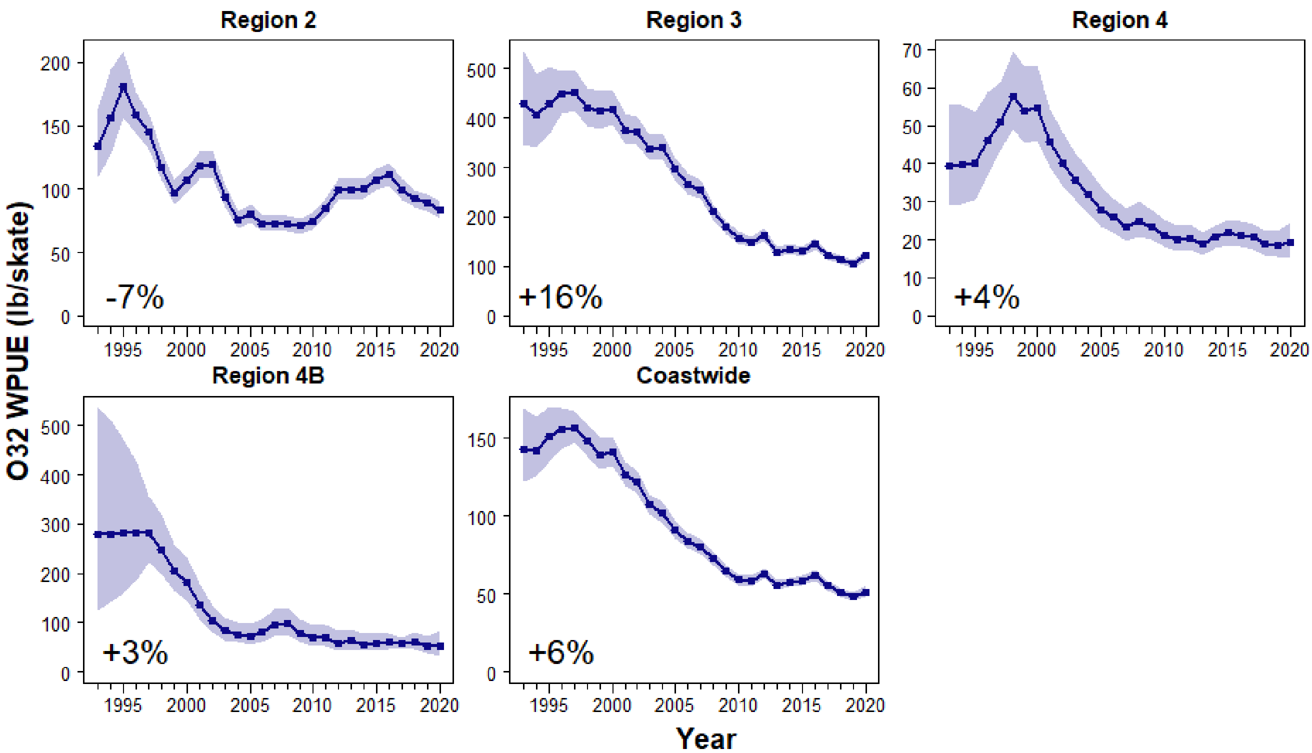

Figure 2. Space-time model output for O32 WPUE for 1993-2020 for Biological Regions. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean O32 WPUE from 2019 to 2020.

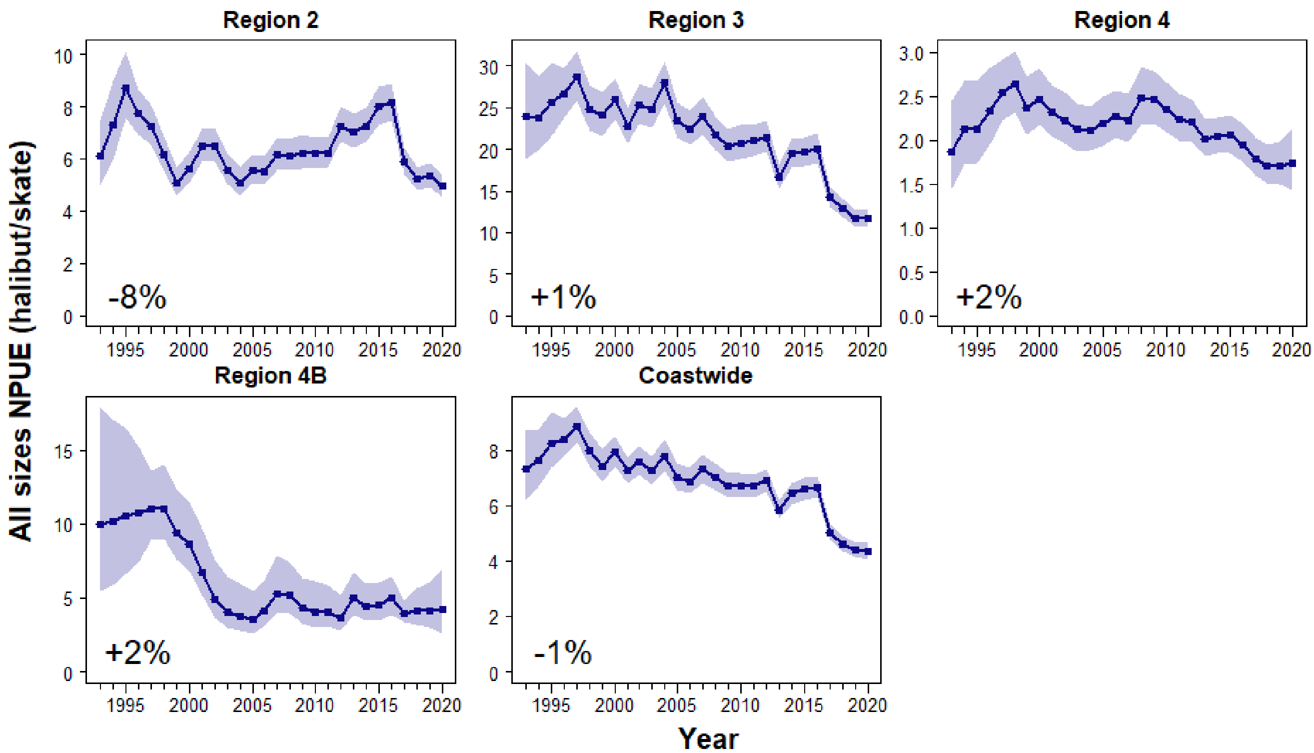

Figure 3. Space-time model output for all sizes NPUE for 1993-2020 for Biological Regions. Filled circles denote the posterior means of all sizes NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean all sizes NPUE from 2019 to 2020.

In Regulatory Area 2B, 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. Parameter estimates of gear type differences all implied that snap gear catch rates were lower on average (Table 2), with estimated catch rate ratios of 0.72 to 0.83 for the three indices modelled in 2020 (i.e. we estimate snap gear had 72% to 83% of the catch of fixed gear, depending on the index). Posterior 95% credible intervals were all wide, and included the value 1, i.e. no difference in catch rate, meaning that no clear conclusions regarding the relative effectiveness of the two gear types can be drawn from this project on its own. However, the results are generally consistent with those of the much larger gear comparison study in 2019, which estimated a ratio of 0.86 for all three indices. Additional modelling will be used to combine the data from both studies and from future studies to be conducted elsewhere, which will lead to more precise overall estimates of the ratio of catch rates across all IPHC Regulatory Areas.

Table 2. 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 the St James charter region in Regulatory Area 2B in 2020.

Variable	**Ratio of snap to fixed catch rate**	
	Posterior mean	**95% credible interval**
O32 WPUE	0.83	0.63 – 1.10
All sizes WPUE	0.79	0.60 – 1.03
All sizes NPUE	0.72	0.60 – 1.17

PROPOSED FISS DESIGNS FOR 2021-23

Due to budgetary constraints and the impact of COVID-19, neither the proposed nor adopted AM096 designs described below were implemented in 2020. Instead, a design with sampling only within the core areas was undertaken for the 2020 FISS (IPHC-2020-CR-013; Figure 4). Because of this, our proposal for 2021-23 is to shift the 2020-22 Secretariat-preferred compromise proposal presented at AM096 (see below) to instead be implemented in 2021-23 (Figures 5-7). This design uses efficient subarea sampling in IPHC Regulatory Areas 2A, 4A and 4B, but incorporates a randomized design in IPHC Regulatory Areas 2B, 2C, 3A and 3B (except for the near-zero catch rate inside waters around Vancouver Island), with a sampling rate chosen to keep the sample size close to 1,000 stations in an average year. Outside the core areas, the subarea design allows for logistically efficient sampling, and therefore accounts for the Secondary Objective discussed above (Table 1). It is likely that this design represents the maximum effort that can be deployed outside the core areas in coming years, while still meeting the Secondary Objective. These designs were reviewed by the SRB at SRB016 (IPHC-2020-SRB016-R), and SRB017 (IPHC-2020-SRB017-R). In the report of the latter meeting, the SRB stated the following:

> *"The SRB RECOMMENDED that the Commission endorse the final 2021 FISS design as proposed by IPHC Secretariat, and provided at Appendix IVa."; and*
>
> *"The SRB provisionally ENDORSED the 2022 and 2023 FISS design proposals provided at Appendix IVb and IVc, recognizing that these will be reviewed again at subsequent SRB meetings."*

The Commission reviewed the designs at IM096 (IPHC-2020-IM096-R) and the subsequent Special Session SS09 (IPHC-2020-SS09-R). At the latter meeting, the Commission recommended that the IPHC Secretariat proceed with an "optimised" version of the design in Figure 5 for 2021, in which stations are added to core IPHC Regulatory Areas and skates per station are increased in those areas to optimise the 2021 FISS design for revenue (Figure 8).

> IPHC-2020-ID016 (para. 8) *The Commission **RECOMMENDED** that the IPHC Secretariat proceed with an 'optimised' version of the 'minimum 2021 FISS design', involving adding an additional ~398 stations within the areas covered by the 'minimum 2021 FISS design' and where feasible, adding additional skates on each station (Fig. 2). The Commission reserved the right to make ad-hoc adjustments to the 2021 FISS at the 97th Session of*

the IPHC Annual Meeting (AM097), based on updated information to be provided by the IPHC Secretariat on IPHC Regulatory Areas 4B and 2A.

RECOMMENDATION

That the Commission **NOTE** paper IPHC-2021-AM097-07 that provides results of space-time modelling of survey data in 2020 and presents FISS designs for 2021-23.

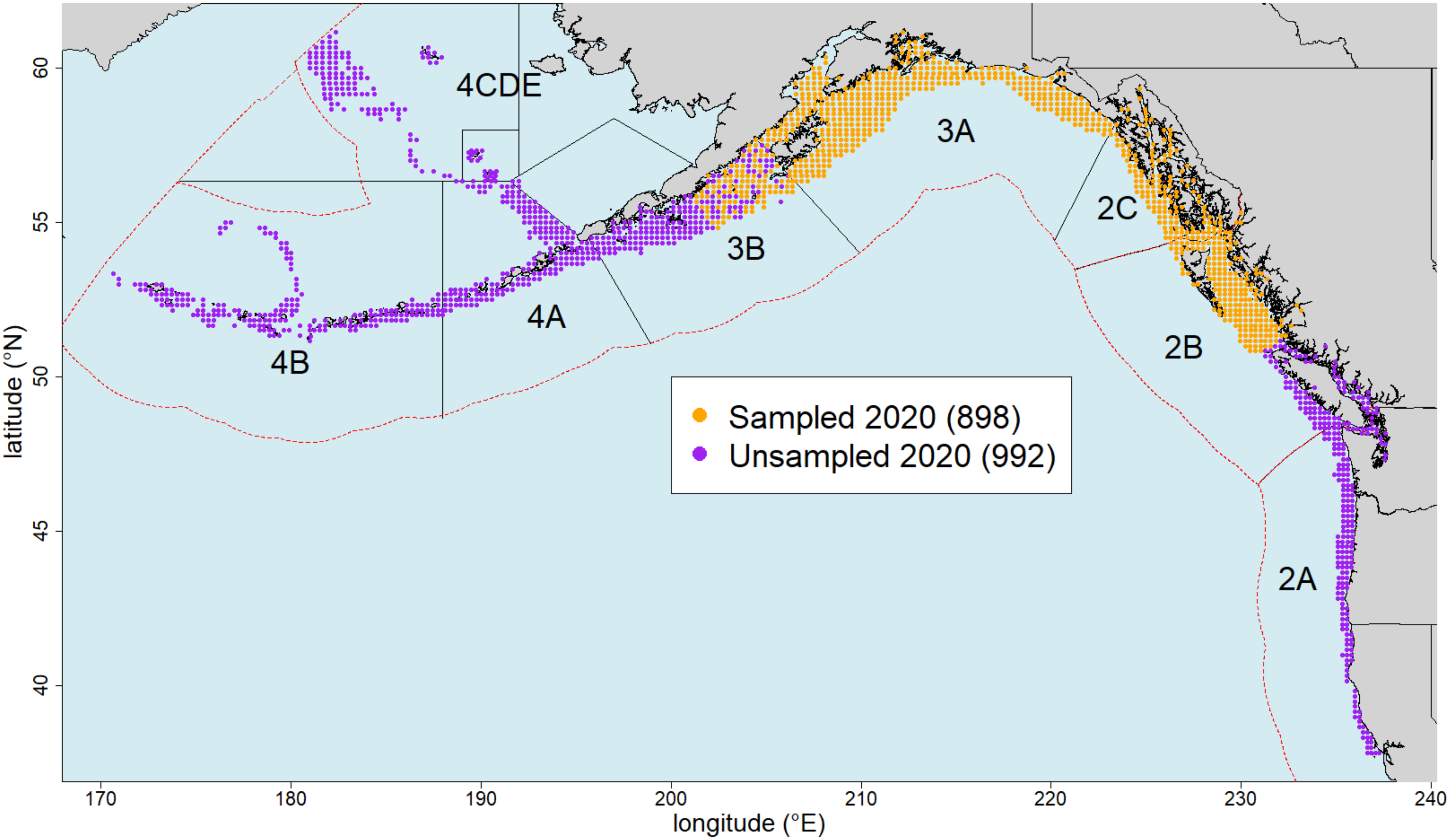

Figure 4. Map of the implemented 2020 FISS design, with orange circles representing those stations to be fished in 2020, and purple circles representing stations to be next fished in subsequent years.

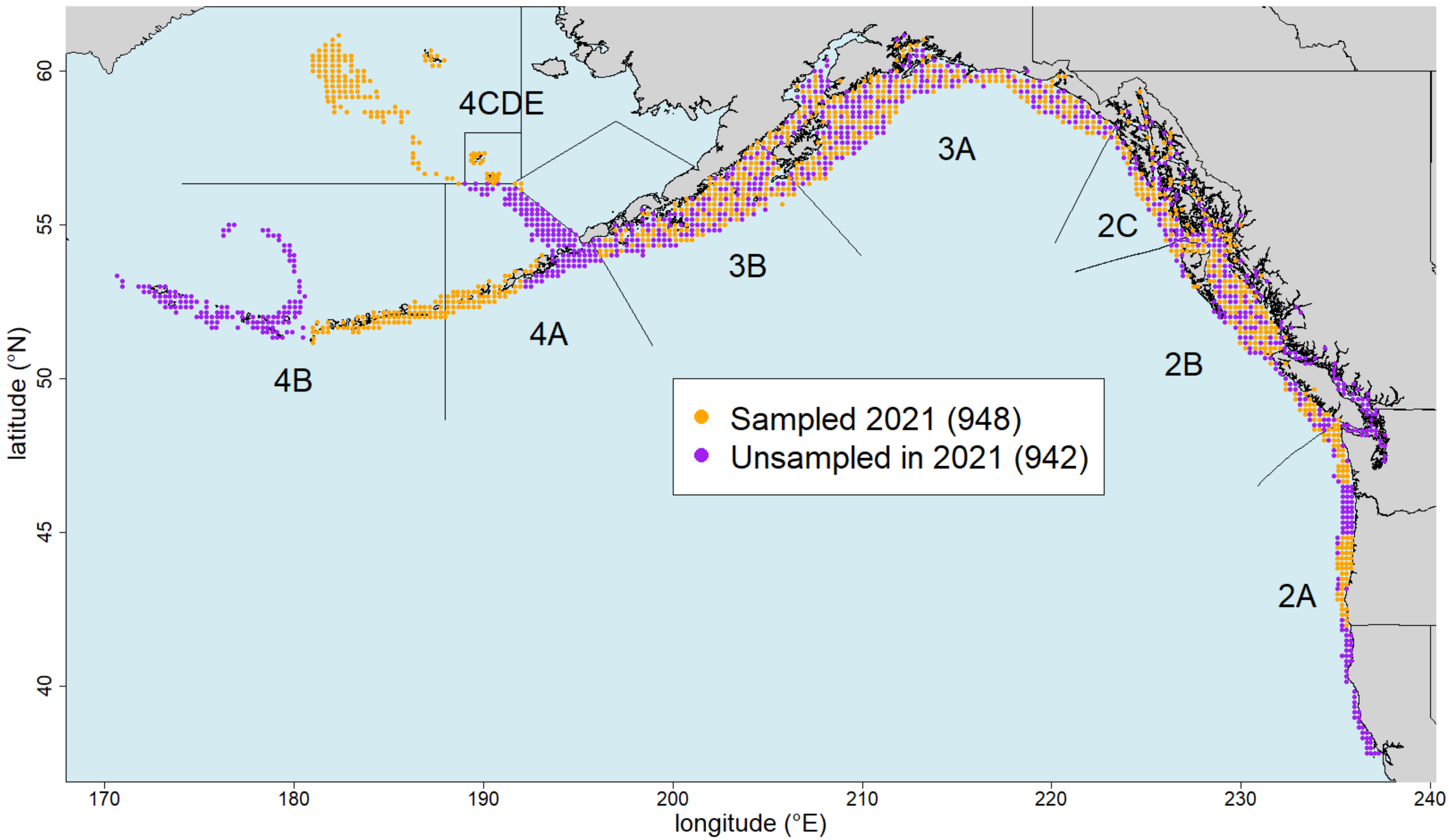

Figure 5. Proposed '*minimum 2021 FISS design*' (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

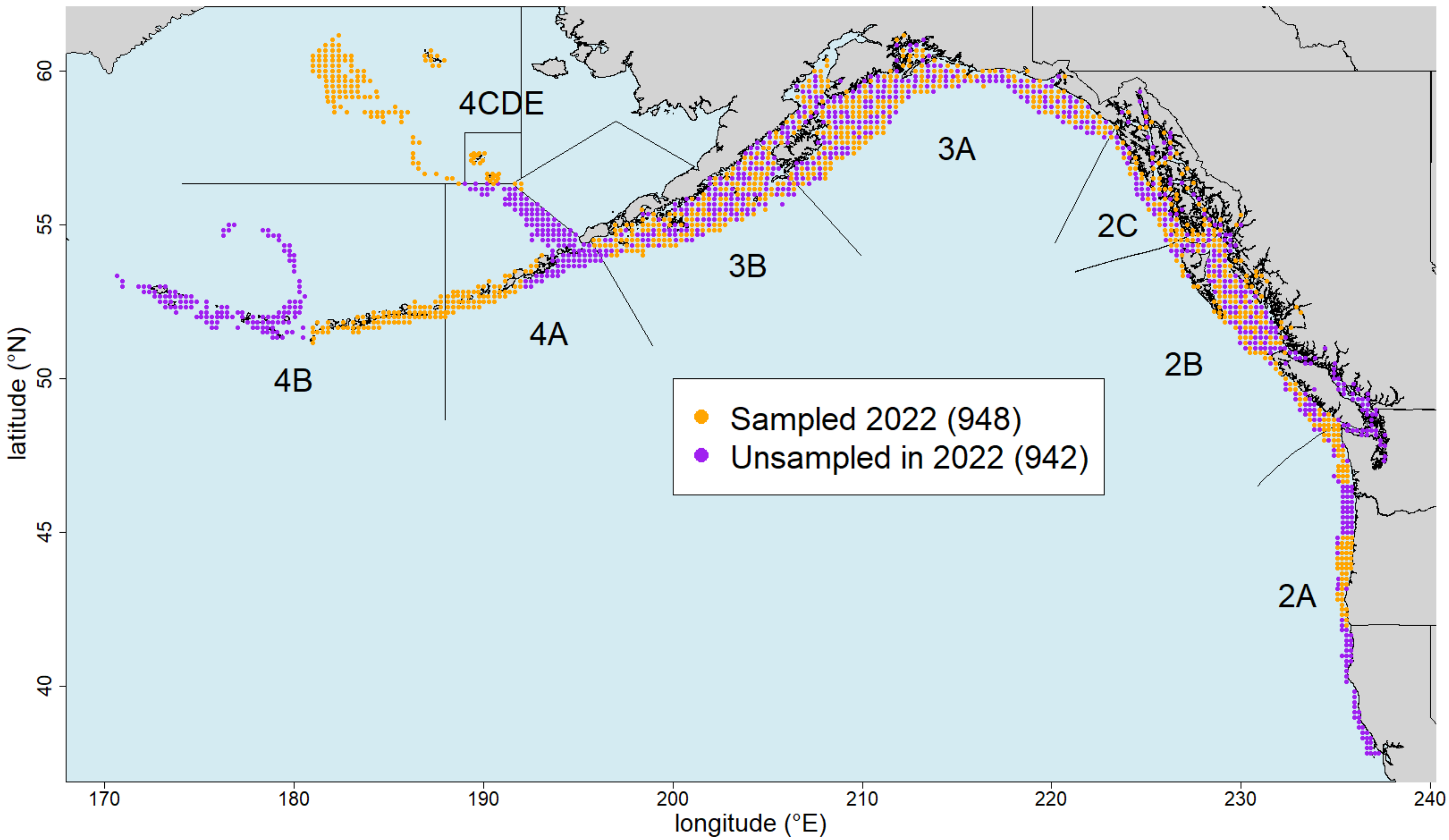

Figure 6. Proposed '*minimum 2022 FISS design*' (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

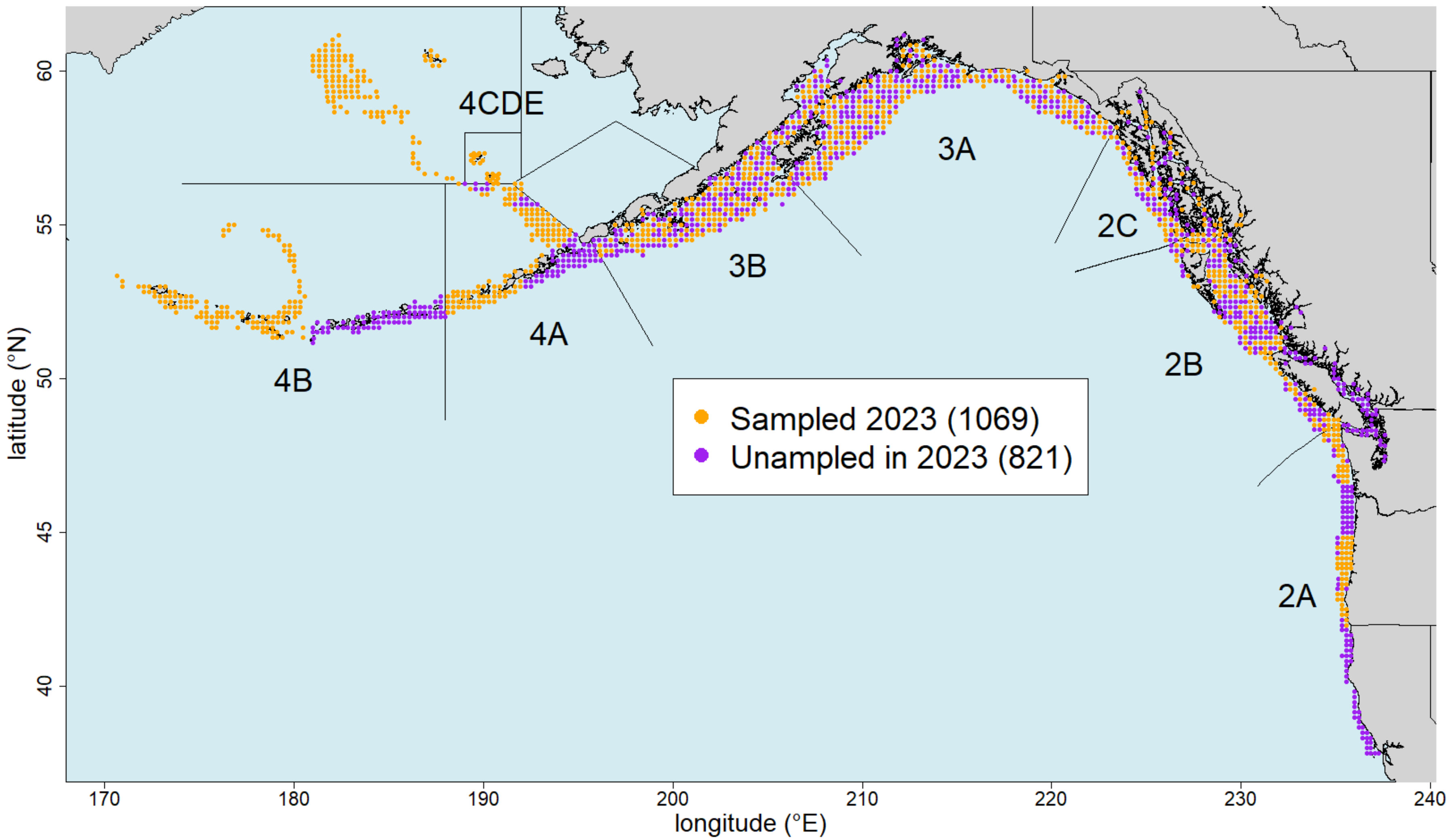

Figure 7. Proposed *'minimum 2023 FISS design'* (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

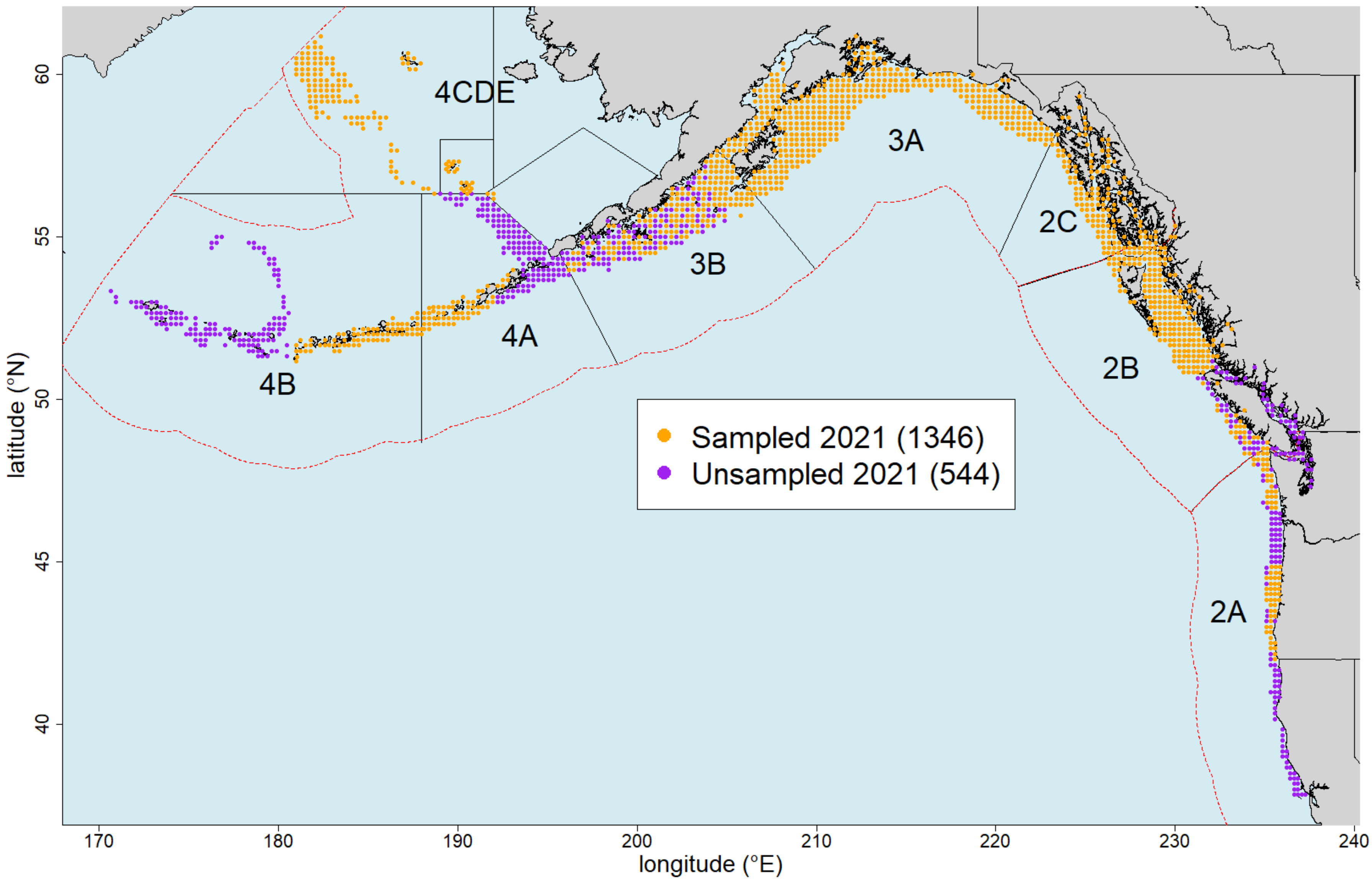

Figure 8. '*Optimised minimum 2021 FISS design*' (orange circles). Stations represented by purple circles are not planned for sampling in 2021.

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Webster R. A., Soderlund E., Dykstra C. L., and Stewart I. J. (2020). Monitoring change in a dynamic environment: spatio-temporal modelling of calibrated data from different types of fisheries surveys of Pacific halibut. Can. J. Fish. Aquat. Sci. 1421-1432.

APPENDIX A
Space-time modelling results by IPHC Regulatory Area

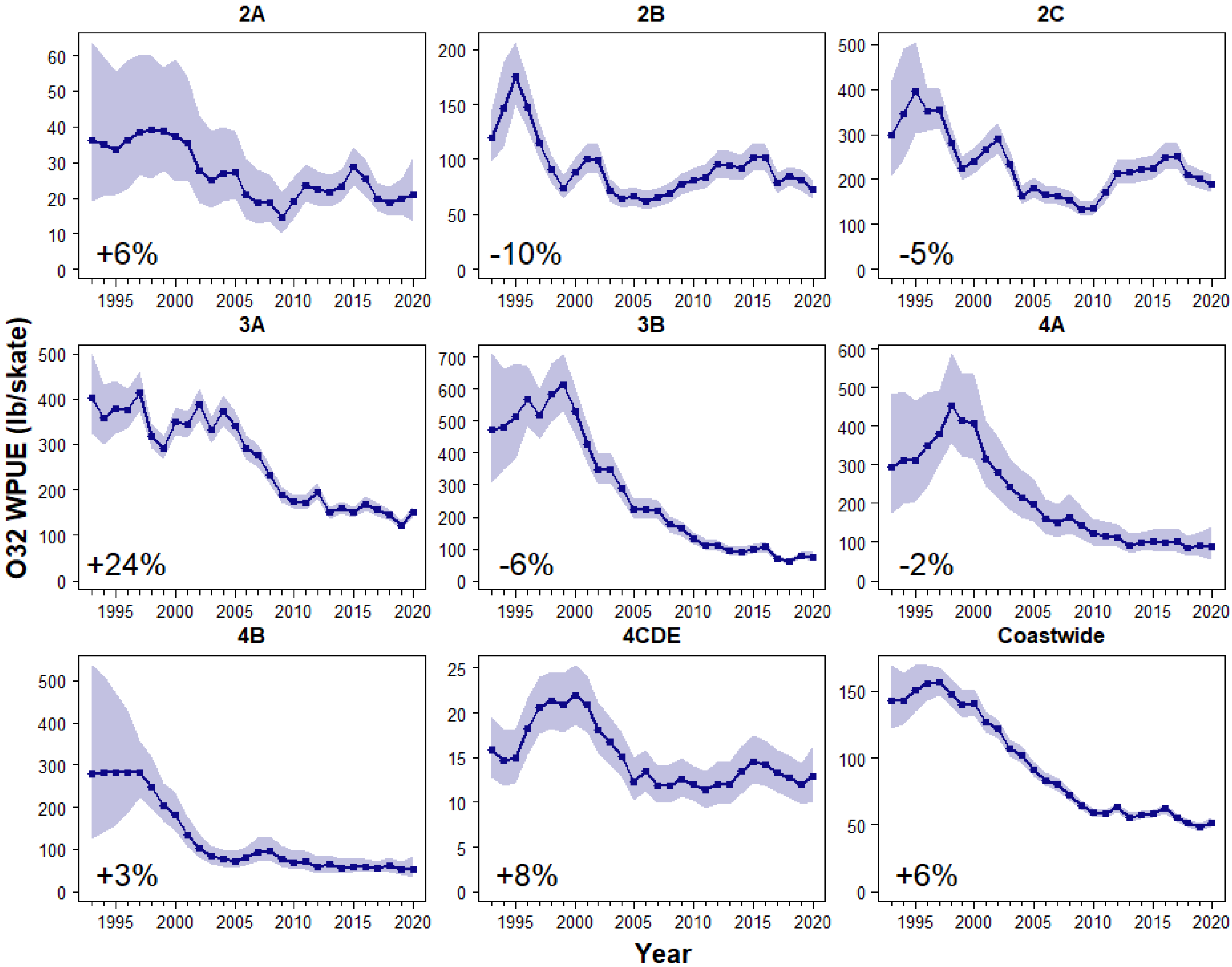

Figure A.1. Space-time model output for O32 WPUE for 1993-2020. Filled circles denote the posterior means of O32 WPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean O32 WPUE from 2019 to 2020.

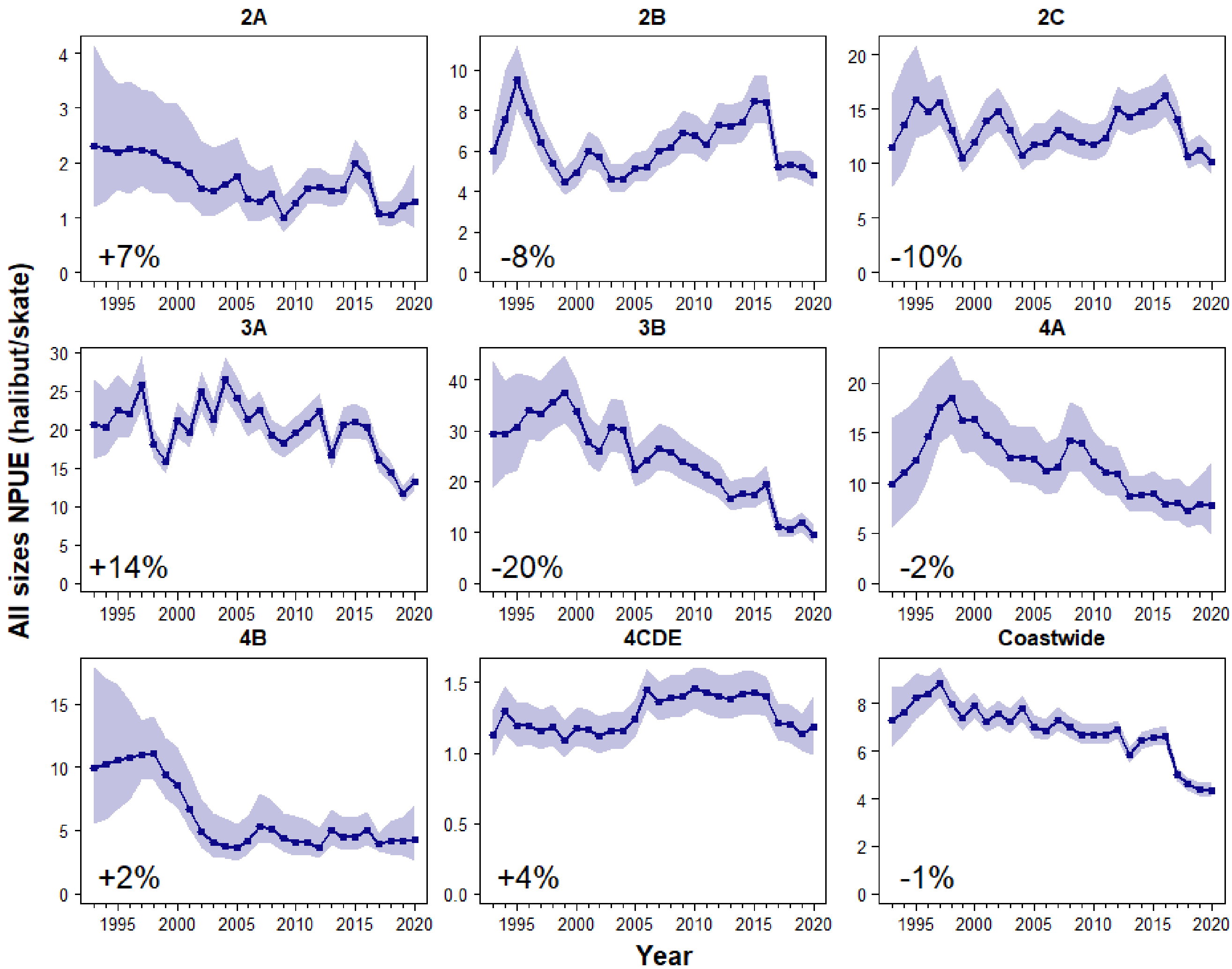

Figure A.2. Space-time model output for all sizes NPUE for 1993-2020. Filled circles denote the posterior means of all sizes NPUE for each year. Shaded regions show posterior 95% credible intervals, which provide a measure of uncertainty: the wider the shaded interval, the greater the uncertainty in the estimate. Numeric values in the lower left-hand corners are estimates of the change in mean total NPUE from 2019 to 2020.