# **For Information:** Recap of the rationalisation of the FISS following the 2014-19 expansion series

(*From IM096 paper: IPHC-2020-IM096-07*)

**PREPARED BY: IPHC SECRETARIAT (R. WEBSTER; 1 DECEMBER 2020)**

## PURPOSE

To provide background on, and reviews the methods for the IPHC's Fishery-Independent Setline Survey (FISS) rationalisation following the 2014-19 expansion series, and proposes FISS designs for 2021-23 for endorsement.

## 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. Stock distribution estimates are based on the annual mean weight-per-unit effort (WPUE) for each IPHC Regulatory Area, computed as the average of WPUE of all Pacific halibut and for O32 (greater than or equal to 32" or 81.3cm in length) Pacific halibut caught at each station in an area. Mean numbers-per-unit-effort (NPUE) 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 National Marine Fishery Service (NMFS) 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. The latter included the following notable gaps in coverage:

- Regulatory Area 2A: Salish Sea and northern California

- Regulatory Area 2B: Salish Sea, coastal inlets and fjords, shallow waters east of Haida Gwaii
- Regulatory Area 3A: Cook Inlet, gaps inside and outside Prince William Sound
- Regulatory Area 3B: the waters around the Sanak and Shumagin Islands
- Regulatory Area 4A: western Aleutian region, waters shallower than 75 fathoms on Bering Sea shelf edge
- Regulatory Area 4B: eastern Aleutian region, Bowers Ridge and other waters in central region
- Regulatory Area 4CDE: northern Bering Sea shelf edge

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).

### *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:<br>• Station distribution<br>• Station count<br>• 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<br>Assist: assist others to collect data on a cost-recovery basis<br>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. The final design adopted by the IPHC at AM096 (IPHC-2020-AM096-R) combined the proposed subarea design in IPHC Regulatory Areas 2A, 4A and 4B, an enhanced randomized design in the core of the stock (IPHC Regulatory Areas 2B, 2C, 3A and 3B, with sample sizes in excess of those required to meet precision targets), and sampling all standard FISS stations in IPHC Regulatory Area 4CDE (Figure 1).

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 at the November Interim Meeting;
- Designs presented and potentially modified at the January/February Annual Meeting given Commissioner direction;
- 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.

## PROPOSED 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 2). 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 3-5). 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."*

## FISS DESIGN EVALUATION

### *Precision targets*

Prior to 2019, 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 was achieved in all areas beginning in 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).

In order to maintain the quality of the estimates used for the assessment, and for estimating stock distribution, we proposed that FISS designs should meet target CVs below 15% for O32 and all sizes WPUE for all IPHC Regulatory Areas. We also established precision targets of IPHC Biological Regions and a coastwide target (IPHC-2020-AM096-07), but achievement of the Regulatory Area targets is expected to ensure that targets for the larger units will also be met.

**Table 2.** Range of coefficients of variation for O32 and all sizes WPUE from 2011-19 by Regulatory Area.

| Reg Area | O32 WPUE (2011-19) | | | | All sizes WPUE (2011-19) | | | |
|---|---|---|---|---|---|---|---|---|
| | 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.

### *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, if stations are not selected randomly, sampling a subset of the full data frame in any area or region brings with it the potential for bias, due to trends in the unsurveyed portion of a management unit (Regulatory Area or Region) potentially differing from those in 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; see Appendix A) should be surveyed in order to reduce the likelihood of appreciable bias. For this, we proposed 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 reduce the chance of its percentage changing by more than 10% between successive surveys of the subarea, we minimize the potential for appreciable bias in the Regulatory Area or Region's indices as a whole.

To illustrate the process applied to each IPHC Regulatory Area, an example of IPHC Regulatory Area 4B, first presented at SRB014, is detailed in Appendix B.

*Analytical methods*

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

- Where a randomized design is not used, identify logistically feasible 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 observed data series augmented with 1 to 3 additional years of simulated data, where the design over those three years reflects the sampling priorities identified above.

Extending the modelling beyond three years was not considered worthwhile, as we expect further evaluation undertaken following collection of data during the one to three-year time period to substantially influence design choices for subsequent years. In this manner, projected designs can be evaluated and then efficiently updated to reflect observed data as they become available.

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 sufficiently informative for design development.

**SAMPLING DESIGN OPTIONS**

The historical sampling, combined with FISS expansions from 2014-2019, established a full sampling design of 1890 stations from California to the Bering Sea shelf edge on a 10 nmi grid from depths of 10 – 400 ftm (Figure 1). Future annual FISS designs will comprise a selection of stations from this frame. Sample design options include the following:

- Full sampling of the 1890 station design (Figure 1).
- Completely randomized sampling of stations within each IPHC Regulatory Area (example in Figure 6).
- Randomized cluster sampling (example in Figure 7), in which clusters of stations are selected that comprise (where possible) 3-4 stations to make an operationally efficient fishing day.
- Subarea sampling, in which IPHC Regulatory Areas are divided into non-overlapping subareas (see Appendix A), and all stations within a selection of these are sampled to allow for more efficient vessel activity on each sampling trip.

The latter two options above are examples that meet primary (statistical) sampling objectives, but also include a consideration of logistics and cost. For designs such as those in Figures 6 and 7, the randomization ensures that resulting estimates (e.g. WPUE, NPUE indices) are unbiased. Designs based on sampling subareas require an evaluation of the potential for bias, as discussed above.

From a scientific perspective, more information is always better; however, sampling the full grid (Figure 1) is unnecessary as the precision target for the index can be maintained with substantial subsampling. While a fully randomized subsampling design (or a randomized cluster subsampling design) with sufficient sample size will still meet scientific needs, in several IPHC Regulatory Areas where Pacific halibut are concentrated in a subset of the available habitat, such a design can be inefficient. For this reason, we considered the subarea design, in which effort is focused in most years on habitat with highest density (which generally contributes most to the overall variance), while sampling other habitat with sufficient frequency to maintain low bias.

*'Core' areas vs ends of the stock distribution*

In considering potential FISS designs, it is helpful to make a distinction between the 'core' IPHC Regulatory Areas 2B, 2B, 3A and 3B, and the areas at the southern and northern ends of the stock's North America range, IPHC Regulatory Areas 2A, 4A, 4B and 4CDE. The former has generally high density throughout, while the latter have relatively high density limited to distinct subareas within each IPHC Regulatory Area. In other words, Pacific halibut distribution tends to become more heterogeneous ('patchy') toward the ends of the species range in the IPHC Convention Area. These areas are also much more logistically challenging to sample and generally produce lower catch rates. For these end areas, a fully randomised design would be inefficient, both logistically and statistically, as it would require effort where little is needed for estimation with low variance, while the frequently narrow bathymetric habitat area would result in a sparse randomised design with high vessel running time between selected stations. Provided the sampling rate is sufficient, a randomised design is generally more practical in the core areas, and it also avoids concerns about bias that could arise from a subarea design that omits subareas with relatively high density.

## 2020-22 Design Proposals and Evaluation

For AM096, the IPHC Secretariat put forward two alternative design proposals, one based on a subarea design in all IPHC Regulatory Areas, and the other on a randomised design in the four core areas, and a subarea design elsewhere (IPHC-2020-AM096-07). The full design and randomised cluster design were also presented, but received little discussion during the meeting.

IPHC Regulatory Area 4CDE was given special attention by staff, with each proposal including sampling of the full 10 nmi grid along the Regulatory Area 4CDE shelf edge in 2020-22 (last fished in 2016). While it may be possible to reduce FISS sampling and still meet precision/bias targets, we noted 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 would help greatly in achieving these goals. The need to sample these stations in 2021-22 was to have been re-evaluated following the results of the 2020 FISS.

*Subarea design*

Each of the IPHC Regulatory Areas at the ends of the stock was divided into 3-4 subareas for future sampling, based on a combination of recent Pacific halibut density and geography (Appendix A). Prior to developing a final proposal, several options for each of these IPHC Regulatory Areas were evaluated to help plan which subareas could be sampled in each year while maintaining CVs within targets (Appendix A). For the core areas, rotating sampling of IPHC FISS charter regions was considered to allow for less than 100% sampling effort while still maintaining a logistically efficient design.

The proposed subarea designs for 2020-22 are shown in Figures 8-10.

*Compromise design*

The proposed compromise design featured random sampling of stations within each of the core areas, and the subarea design elsewhere. The sampling rate in the core areas was chosen to produce an annual sampling design with approximately 1000 stations, representing a modest reduction of recent years' sample sizes and while still meeting precision targets.

The proposed compromise designs for 2020-22 are shown in Figures 11-13.

All designs were evaluated to ensure that they were projected to meet precision targets for 2020-22, using simulated data to augment the observed time series as described above. Subarea designs in IPHC Regulatory Areas 2A, and 4B were evaluated prior to IM094 based on space-time modelling output from 2018, while evaluation of designs in other IPHC Regulatory Areas was completed prior to AM096. Table 3 shows projected CVs for the proposed compromise design based on fitting models to the FISS data augmented with simulated data for 2020-22. No evaluation was undertaken for IPHC Regulatory Area 4CDE as the full design was proposed in all years.

**Table 3.** Projected CVs for 2020-22 for the compromise design. Target CV is 15% in all IPHC Regulatory Areas.

| | **Projected CV (%)** | | |
|---|---|---|---|
| **Regulatory Area** | **2020** | **2021** | **2022** |
| 2A | 13.0 | 13.0 | 14.2 |
| 2B | 6.2 | 6.0 | 6.4 |
| 2C | 6.4 | 6.3 | 6.7 |
| 3A | 4.8 | 4.9 | 5.1 |
| 3B | 8.2 | 8.2 | 8.5 |
| 4A | 9.6 | 9.3 | 9.7 |
| 4B | 8.7 | 8.7 | 14.2 |

### CONSIDERATION OF COST

Both the subarea and compromise design incorporate some consideration of cost by using a logistically efficient design in at least some IPHC Regulatory Areas. The purpose of factoring in cost was to provide a statistically efficient and logistically feasible design for consideration by the Commission. During the Interim and Annual Meetings and subsequent discussions, cost, logistics and tertiary considerations (Table 1) are also factored in developing the final design for implementation in the current year. In particular, the FISS is funded by sales of captured fish and is intended to have long-term revenue neutrality, meaning that any design must also be evaluated in terms of the following factors:

- Expected catch of Pacific halibut;
- Expected Pacific halibut sale price;
- Charter vessel costs, including relative costs per skate and per station;
- Bait costs;
- IPHC Secretariat administrative costs.

Balancing these factors may result in modifications to the design such as increasing sampling effort in high-density regions and decreasing effort in low density regions. At present, with stocks near historic lows and extremely low prices for fish sales, the current funding model may require that some low-density habitat be omitted from the design entirely (as occurred in 2020). This will have implications for data quality (see below), particularly if such reductions in effort relative to proposed designs continue over multiple years.

### IMPLICATIONS OF 2020 FISS ON ESTIMATION IN SUBSEQUENT YEARS

The reduced FISS in 2020 has some implications for data quality, not only in the current year, but in subsequent years. IPHC Regulatory Areas 2A, 4A, 4B and 4CDE will have no FISS sampling in 2020, and WPUE and NPUE indices estimated from the space-time modelling is unlikely to meet precision targets. Information for 2020 for these areas comes only from covariate relationships in the space-time model and from prior years' data through the modelled temporal correlation. Not only will the estimates for 2020 be imprecise relative to prior years, but the lack of data on stock trends from 2019 to 2020 means that there is the potential for bias in the estimates. The impact of the reduced FISS design will propagate into subsequent years' estimates. For example, the 2021 estimates will be less precise than they would have been if data had been collected in 2020. However, if the proposed 2021 design is implemented, we expect this to bring the FISS back on track to meet data quality targets in coming years. The high sampling effort in 2020 in IPHC Regulatory Areas 2B, 2C and 3A means that estimates from these areas should meet data quality targets this year. The reduced sampling in IPHC Regulatory Area 3B should be sufficient for precision targets to be met, given that CVs have been well within the 15% target in recent years in this area. There is a chance for some modest bias with the more variable western portion of IPHC Regulatory Area 3B being unsampled, but with some information on stock trend from the eastern region, this is of less concern than the bias potential in areas with no 2020 sampling.

## RECOMMENDATION

That the Commission **NOTE** paper IPHC-2020-SS09-03 that provides background on, and reviews the methods for the IPHC's Fishery-Independent Setline Survey (FISS) rationalisation following the 2014-19 expansion series, and proposes FISS designs for 2021-23 for endorsement.

## REFERENCES

IPHC 2020. Report of the 16th Session of the IPHC Scientific Review Board (SRB) IPHC-2020-SRB016-R. 19 p.

IPHC 2020. Report of the 17th Session of the IPHC Scientific Review Board (SRB) IPHC-2020-SRB017-R. 21 p.

IPHC 2020. Report of the 96th Session of the IPHC Annual Meeting (AM096) IPHC-2020-AM096-R. 51 p.

IPHC 2020. IPHC Circular 2020-013: Intersessional Decision (22-29 May 2020). 2 p.

IPHC 2012. (Soderlund E, Randolph D, and Dykstra C) IPHC setline charters 1963 through 2003 IPHC-2012-TR058. 264p.

Webster RA 2016. Space-time modelling of setline survey data using INLA. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2015: 552-568.

Webster RA 2017. Results of space-time modelling of survey WPUE and NPUE data. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2016: 241-257.

Webster R 2019a. Methods for spatial survey modelling – Program of work for 2019. IPHC-2020-SRB014-05 Rev_1. 6 p.

Webster R 2019b. Space-time modelling of IPHC Fishery-Independent Setline Survey (FISS) data. IPHC-2020-IM095-07 Rev_1. 19 p.

Webster R 2019c. Space-time modelling of IPHC Fishery-Independent Setline Survey (FISS) data. IPHC-2020-AM096-07. 32 p.

Webster RA, Soderlund E, Dykstra CL, and Stewart IJ (in press). 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

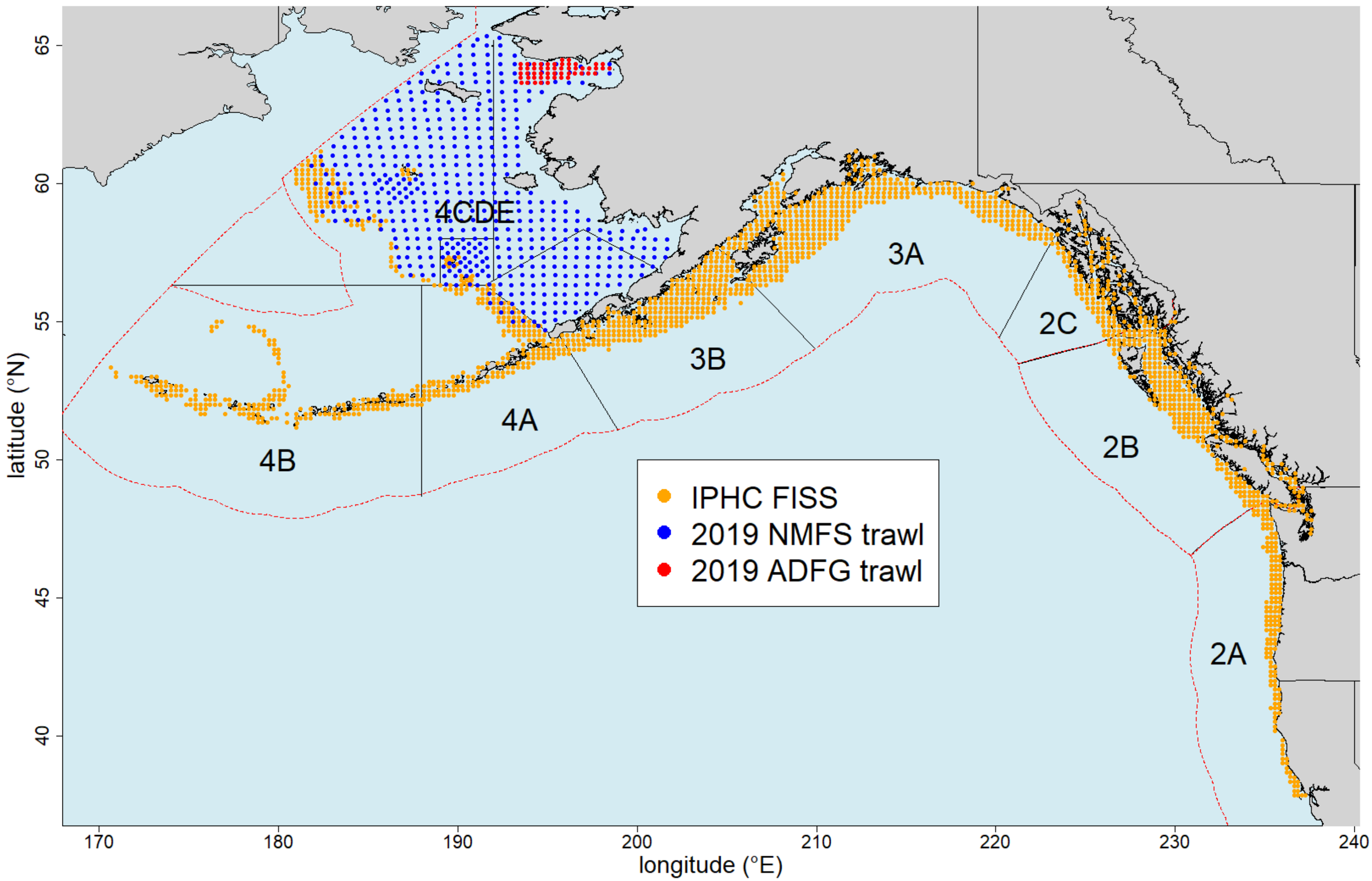


**Figure 1.** Map of the full 1890 station FISS design, with orange circles representing stations available for inclusion in annual sampling designs, and other colours representing trawl stations from 2019 NMFS and ADFG surveys used to provide complementary data for Bering Sea modelling.

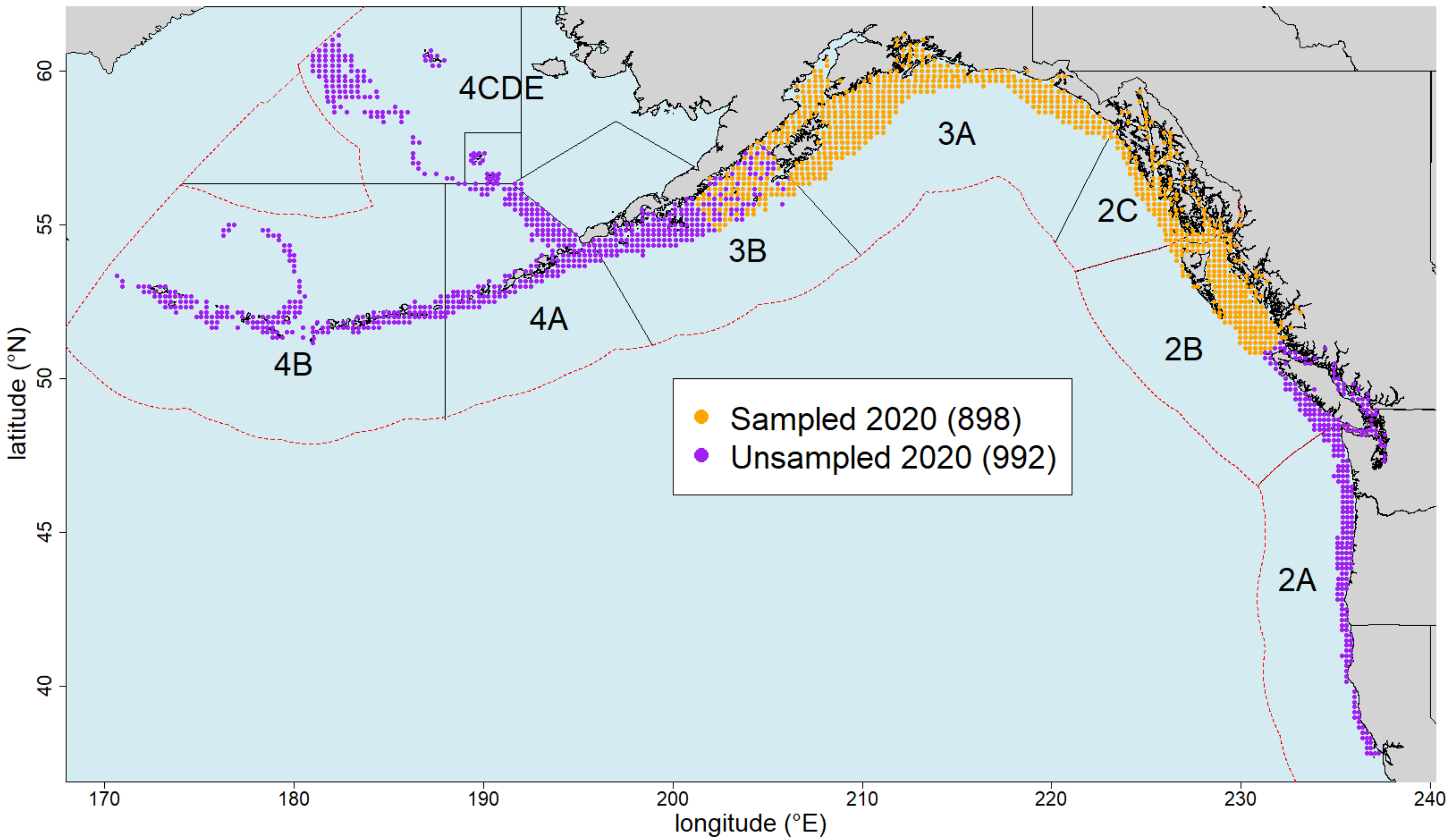


**Figure 2.** Map of the implemented 2020 FISS design, with orange circles representing those stations to be fished in 2020, and purple circles representing stations to be next fished in subsequent years.

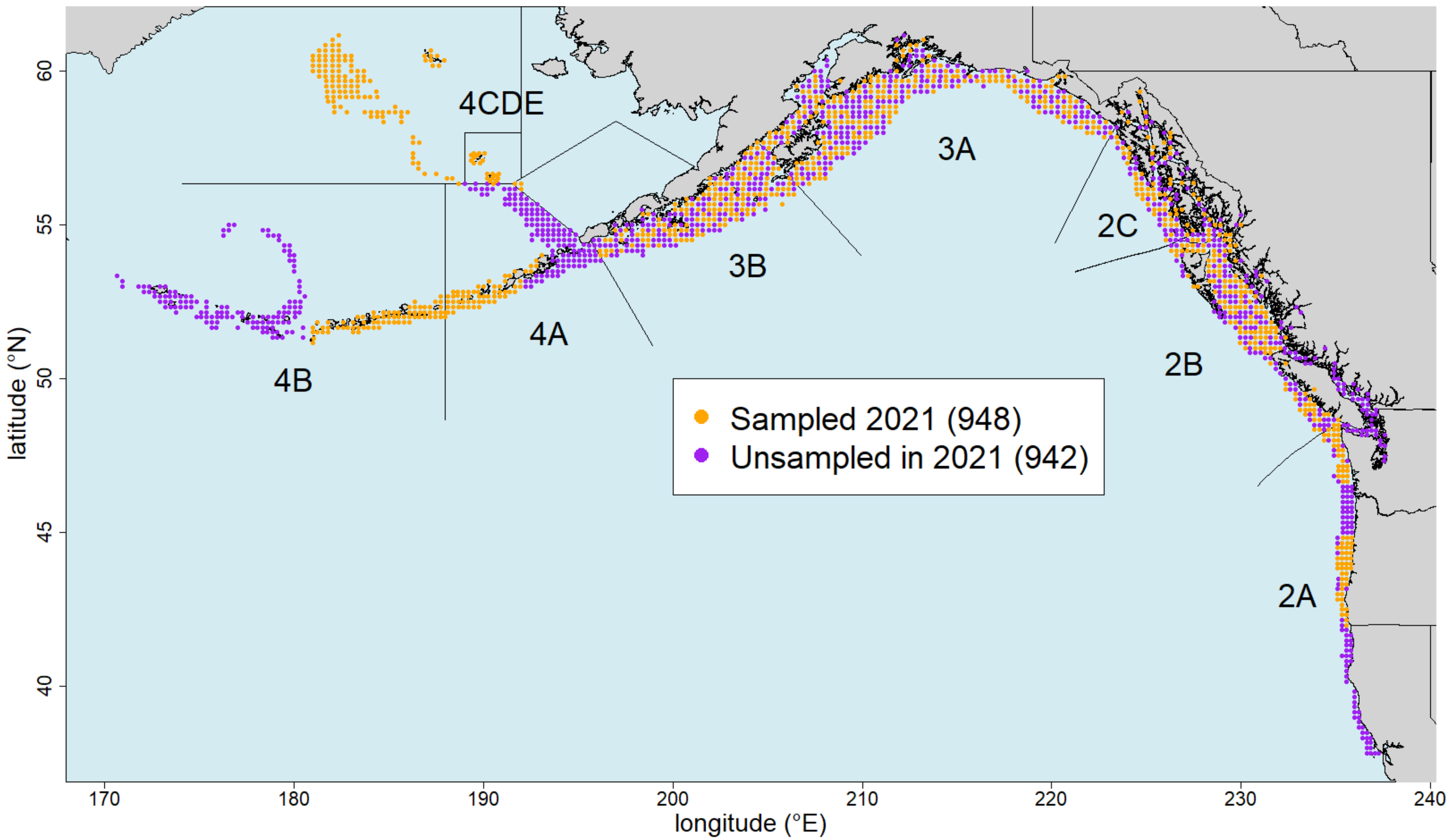


**Figure 3.** Proposed minimum FISS design in 2021 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

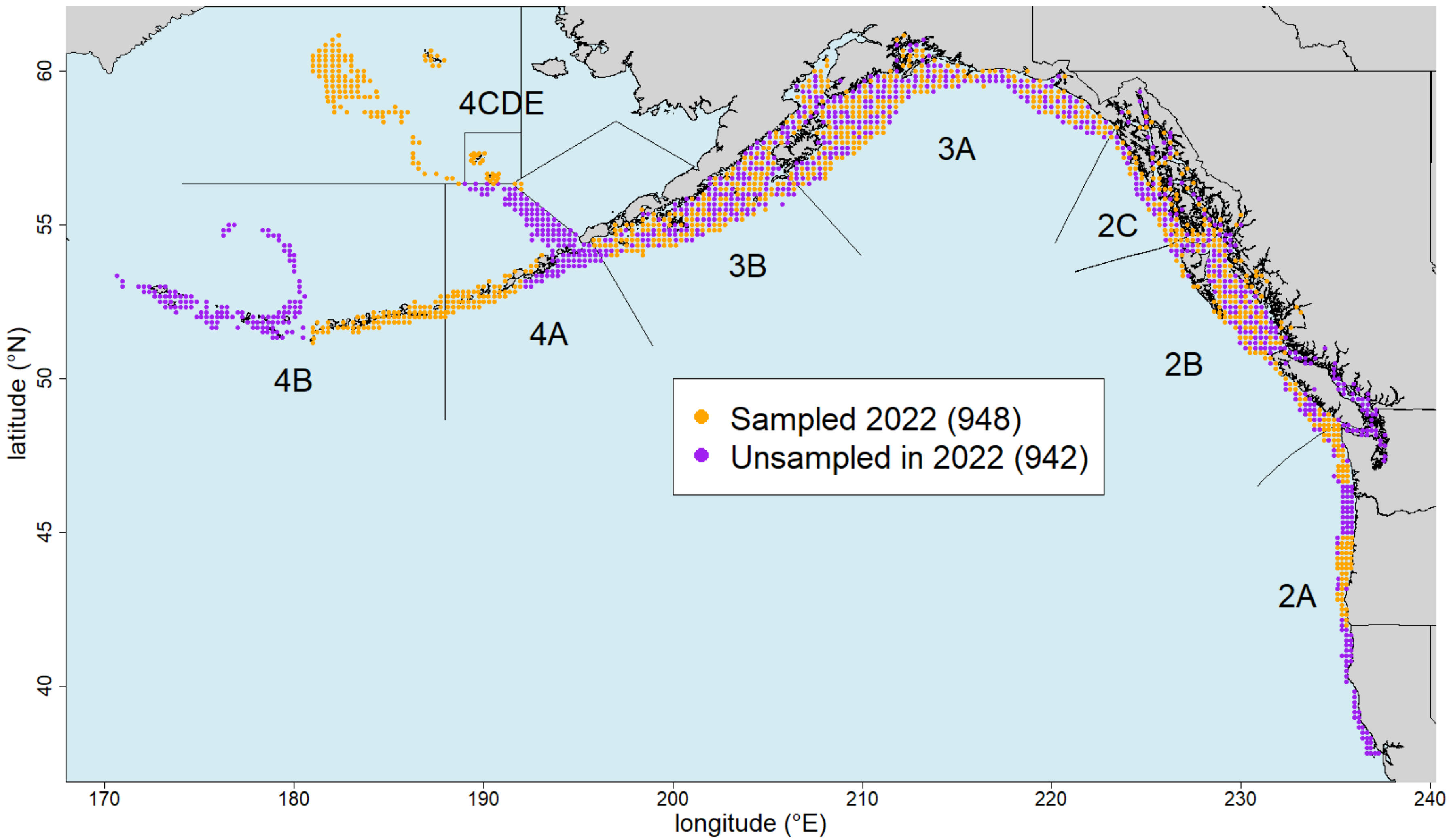


**Figure 4.** Proposed minimum FISS design in 2022 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

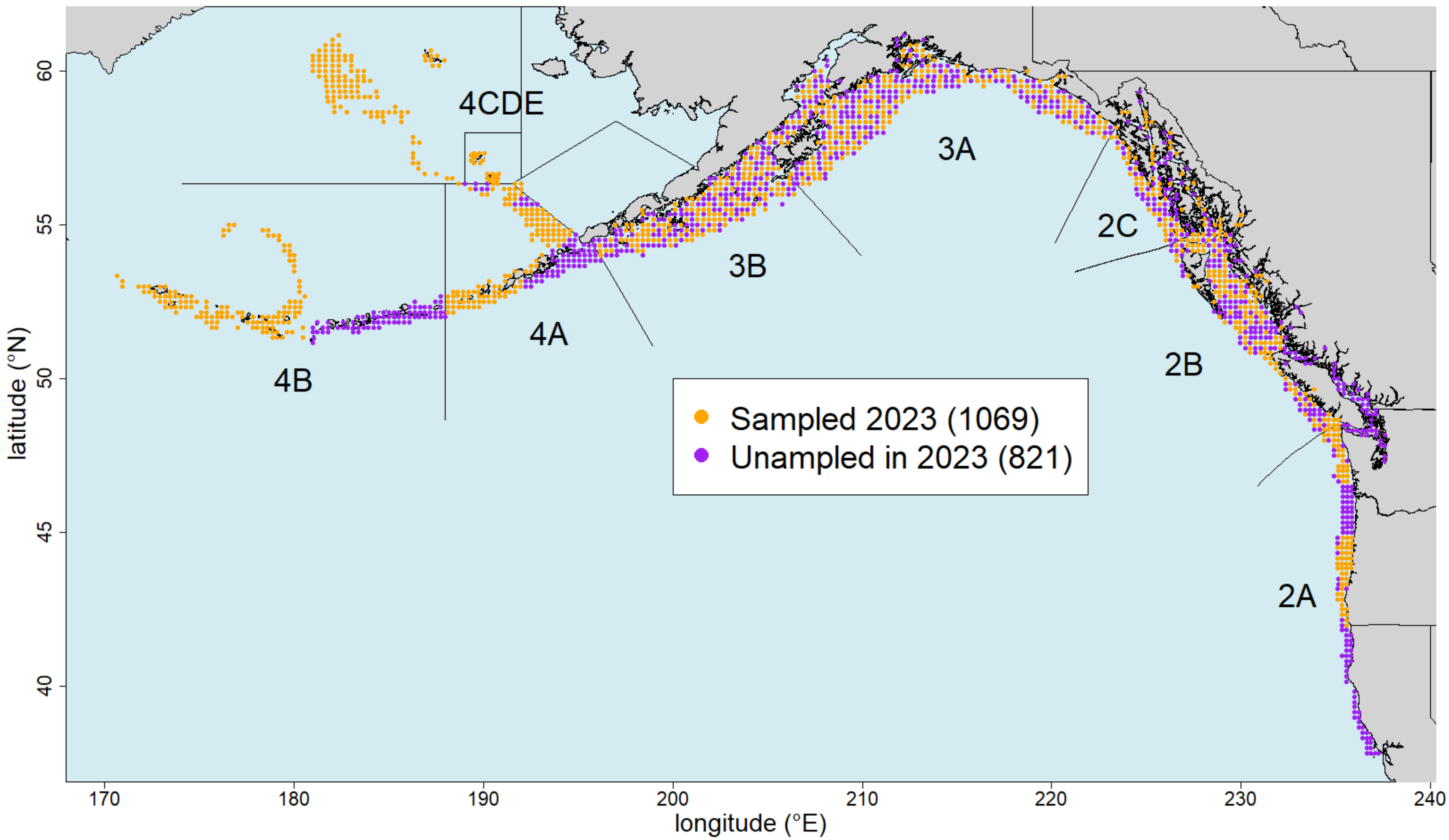


**Figure 5.** Proposed minimum FISS design in 2023 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

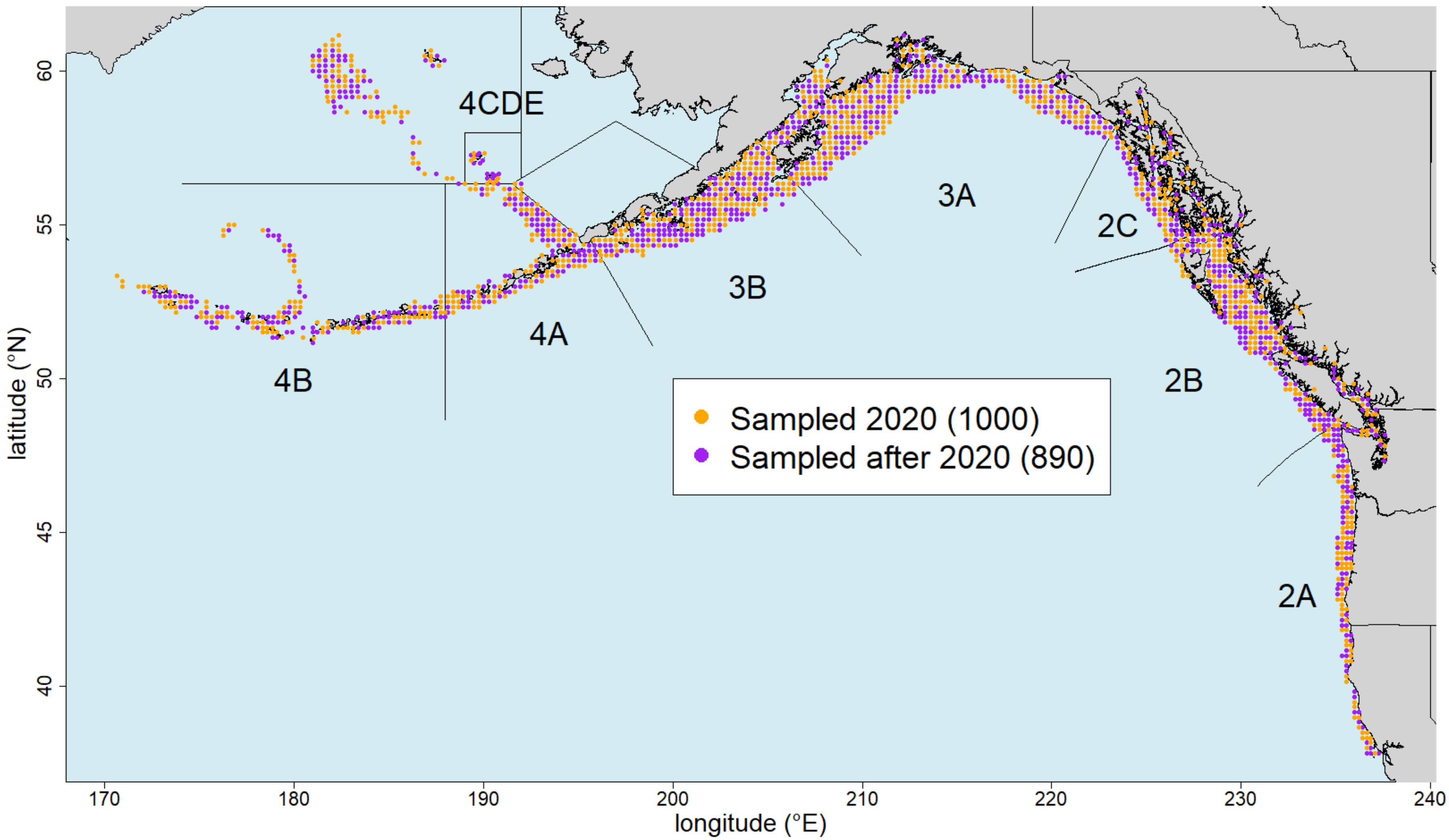


**Figure 6.** Map of a potential 1000 station FISS design, with completely randomized station selection within each IPHC Regulatory Area. Orange circles represent stations selected for sampling, while purple circles represent stations to be sampled in subsequent years.

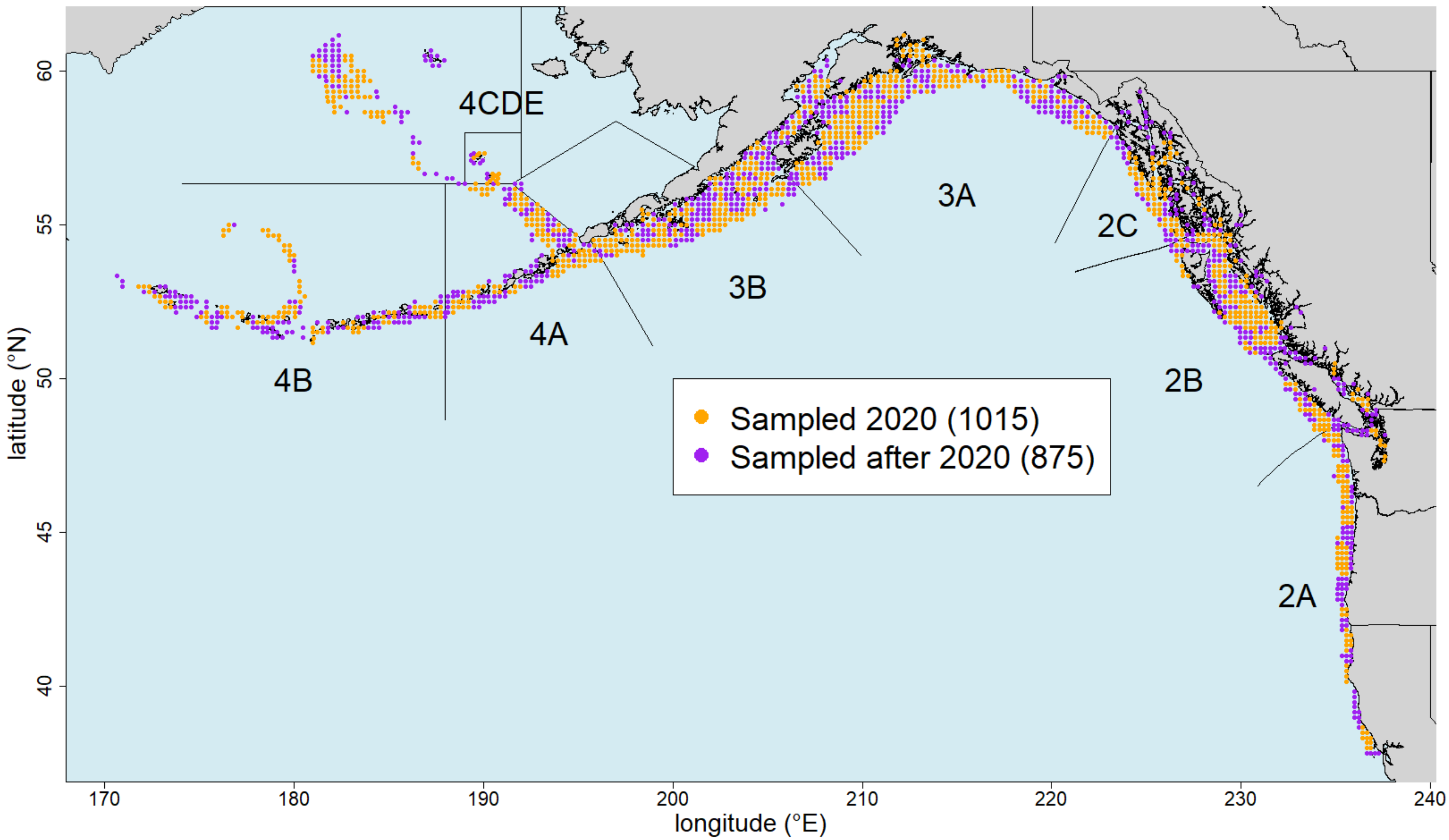


**Figure 7.** Map of a potential approximately 1000 station FISS design, with randomized selection of clusters of 3-4 stations within each IPHC Regulatory Area. Orange circles represent stations selected for sampling, while purple circles represent stations to be sampled in subsequent years.

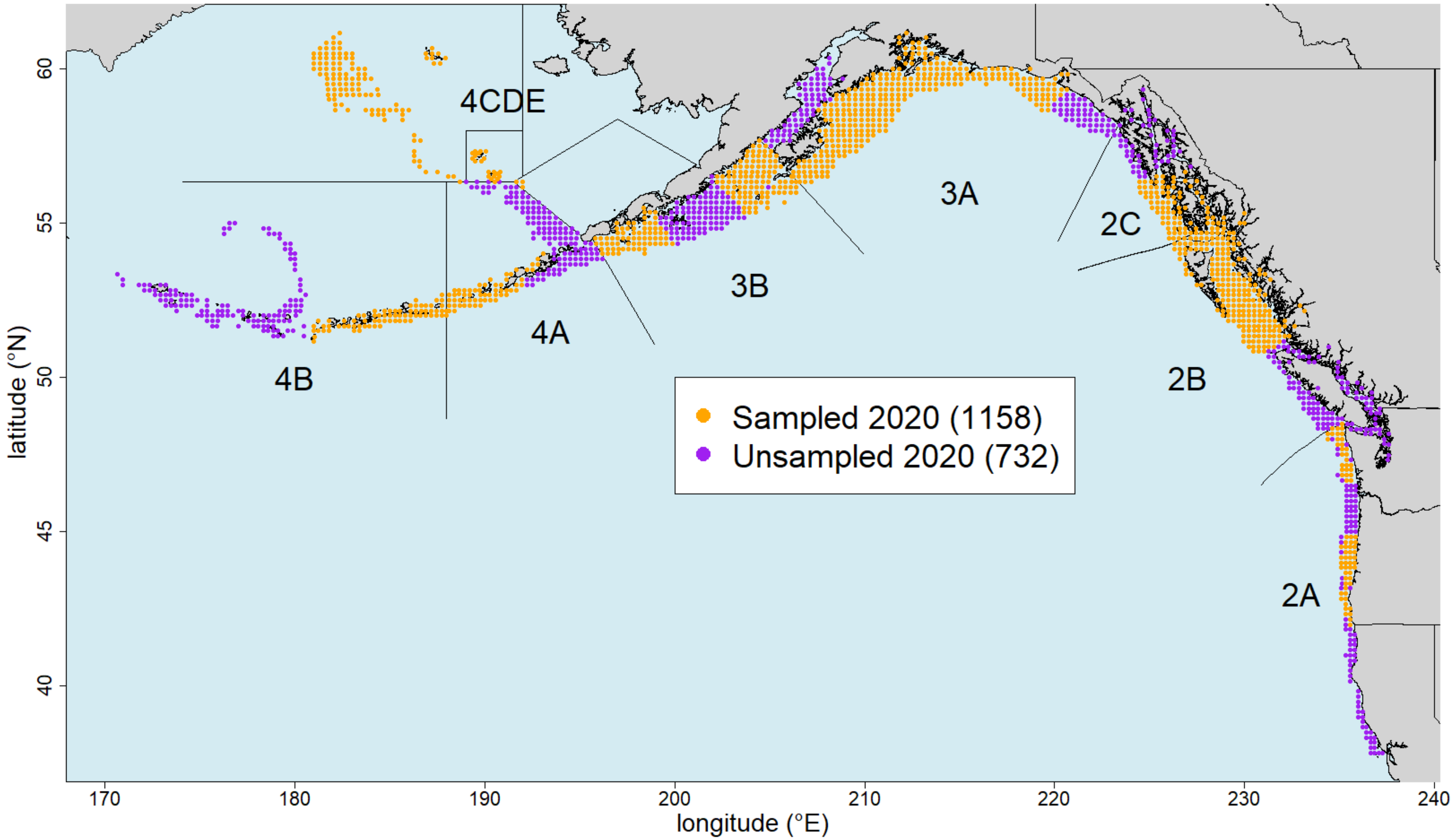


**Figure 8.** Minimum FISS design for 2020 (orange circles) proposed at AM096 based on subareas. Purple circles are optional for meeting data quality criteria.

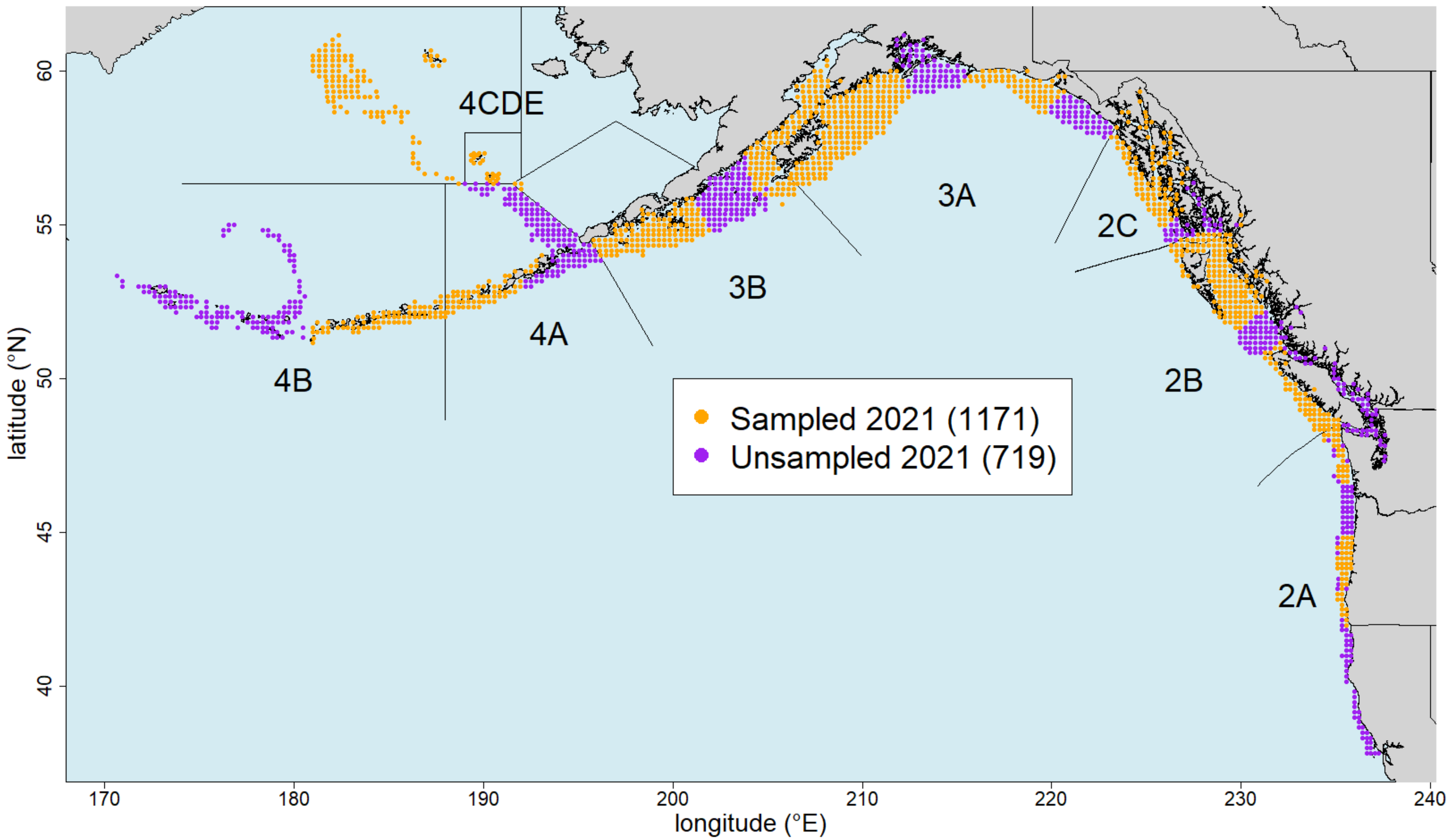


**Figure 9.** Minimum FISS design for 2021 (orange circles) proposed at AM096 based on subareas. Purple circles are optional for meeting data quality criteria.

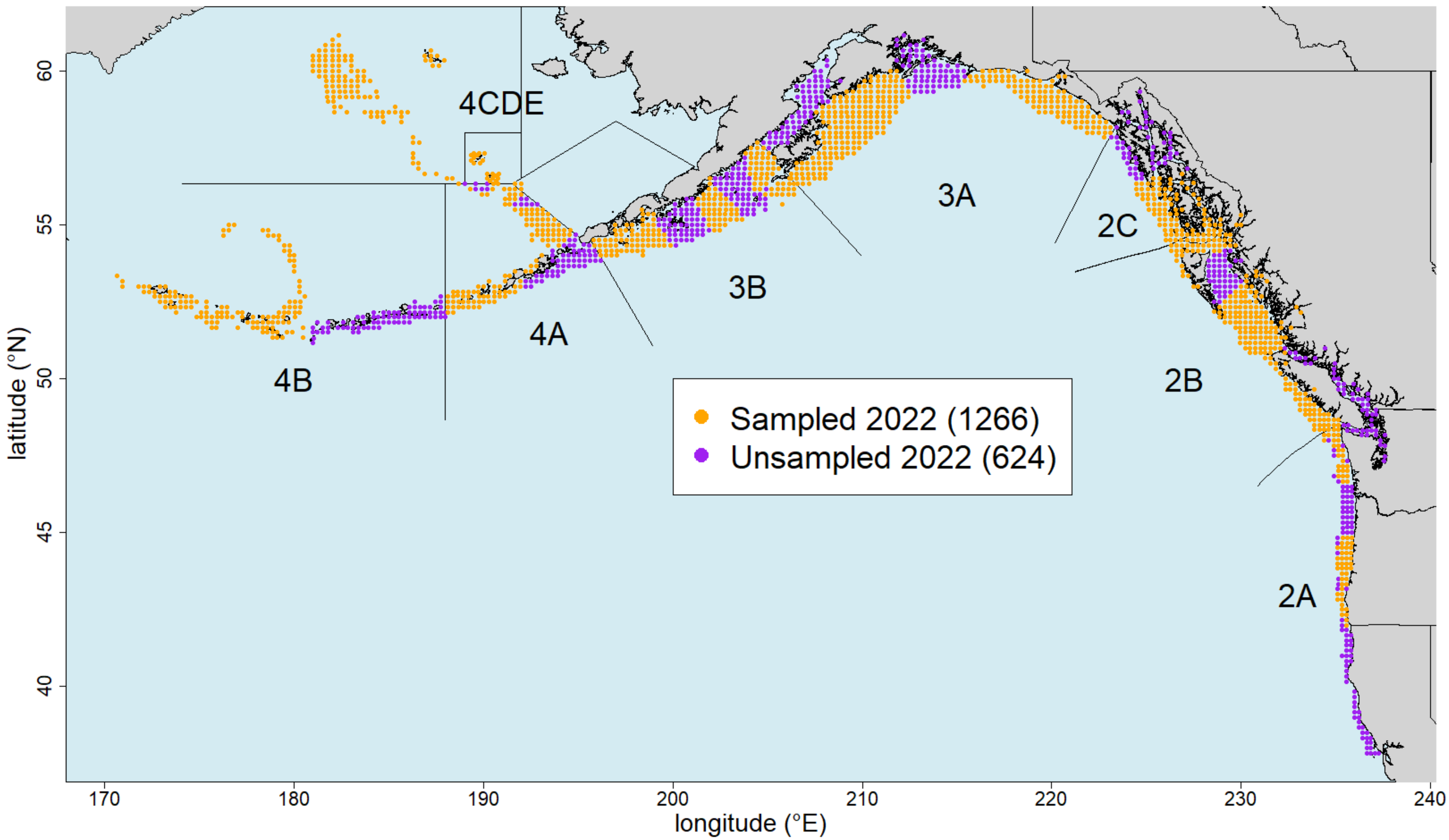


**Figure 10.** Minimum FISS design for 2022 (orange circles) proposed at AM096 based on subareas. Purple circles are optional for meeting data quality criteria.

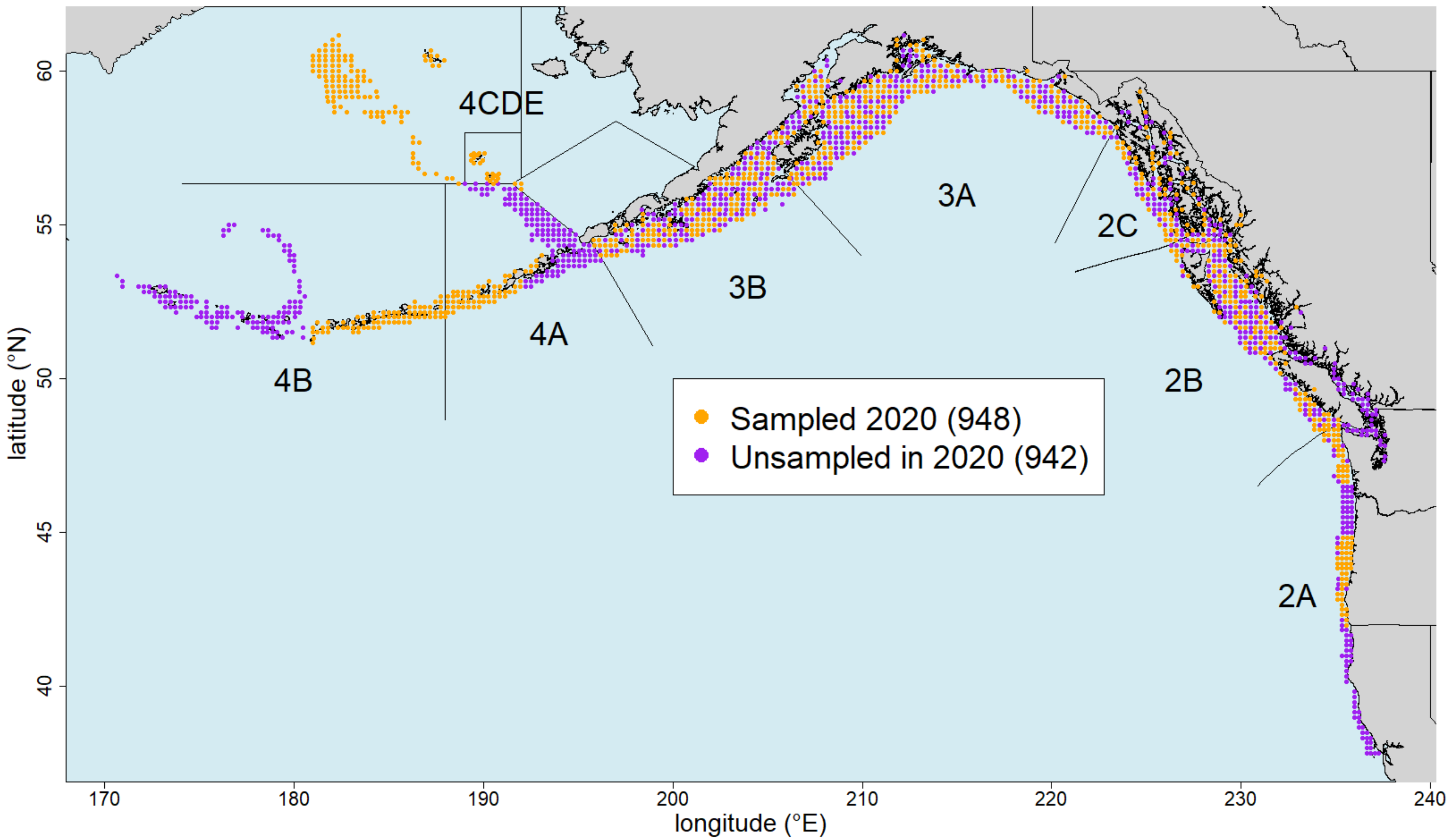


**Figure 11.** Minimum FISS design for 2020 (orange circles) proposed at AM096 based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

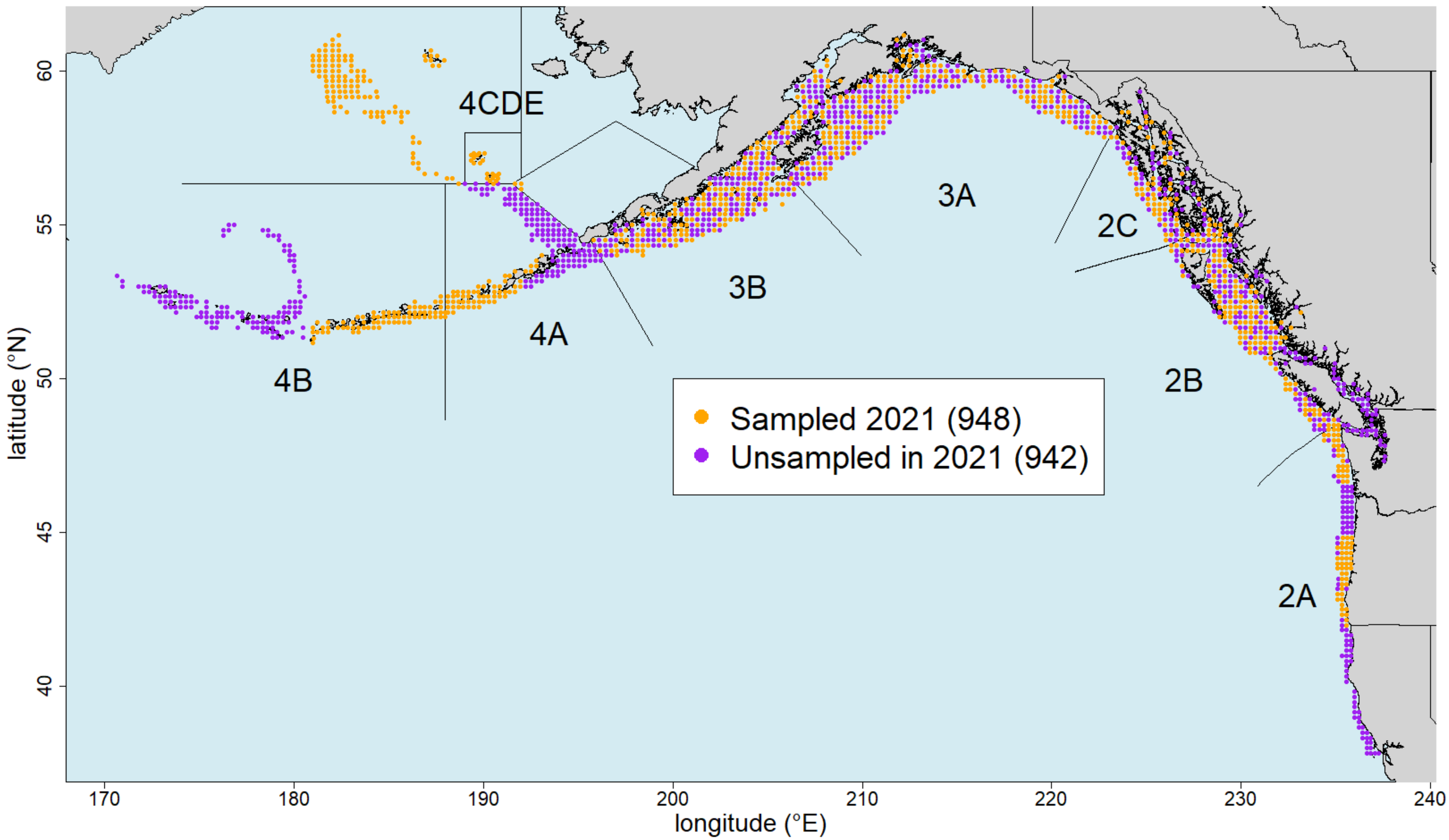


**Figure 12.** Minimum FISS design for 2021 (orange circles) proposed at AM096 based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

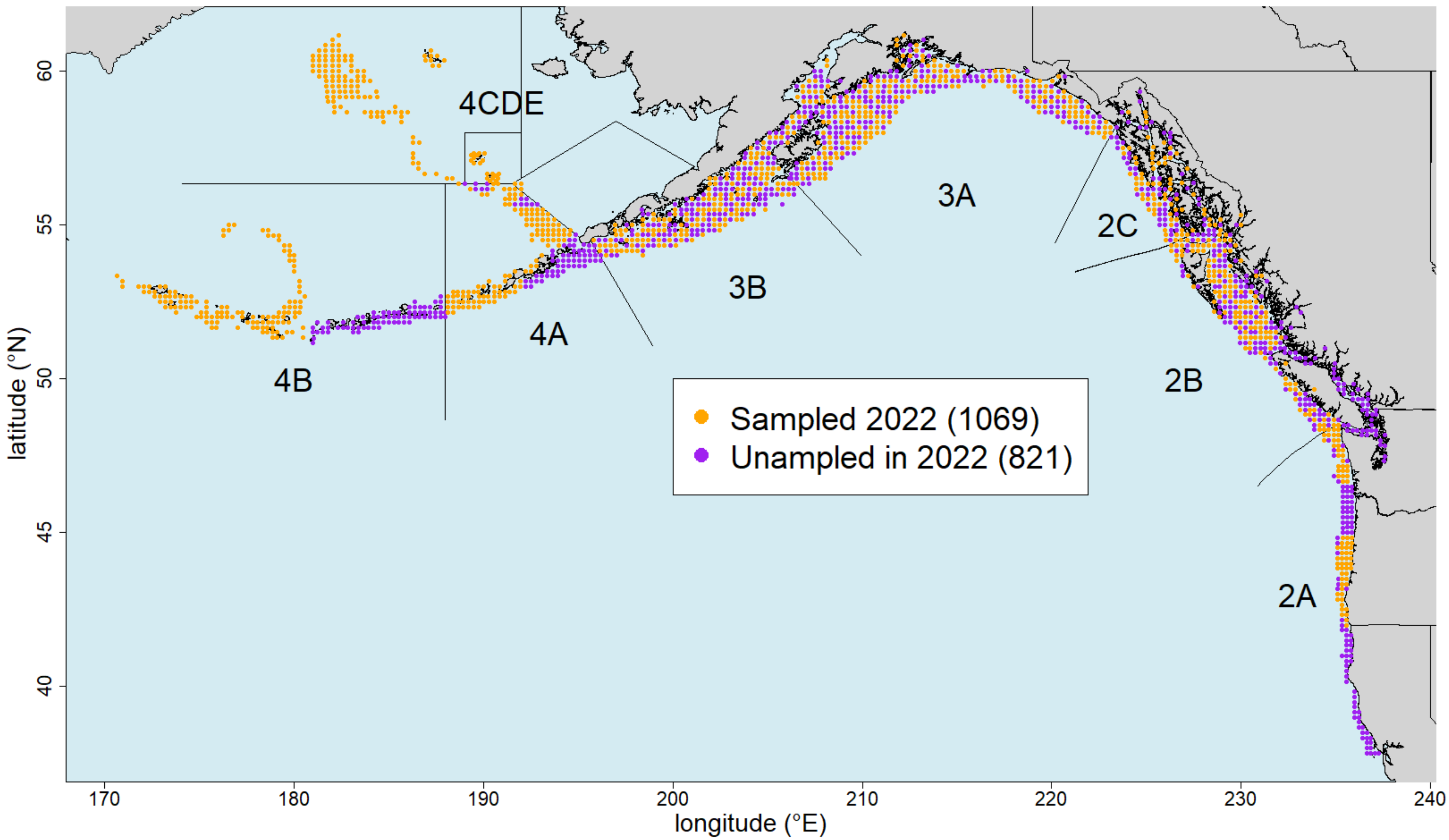


**Figure 13.** Minimum FISS design for 2022 (orange circles) proposed at AM096 based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

# Appendix A

## Subareas within IPHC Regulatory Areas

*IPHC Regulatory Area 4B*

Regulatory Area 4B is a relatively small area, can be divided into fairly distinct subareas based on the 2017 FISS expansion results (Figure A.1):

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 A.2) 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 should succeed in maintaining target CVs, while reducing net cost. However, additional analysis of the historical WPUE time series shows 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 (see Appendix B). 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:

- 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.

Fitting space-time models to the augmented data sets showed that fishing only Subarea 3 from 2020-22 is expected to be sufficient to reduce and then maintain CVs to below 15%. Fishing Subarea 1 and 2 in 2022 should also meet the precision target, and would be the preferred minimum design in that year in order to ensure that bias remained low.

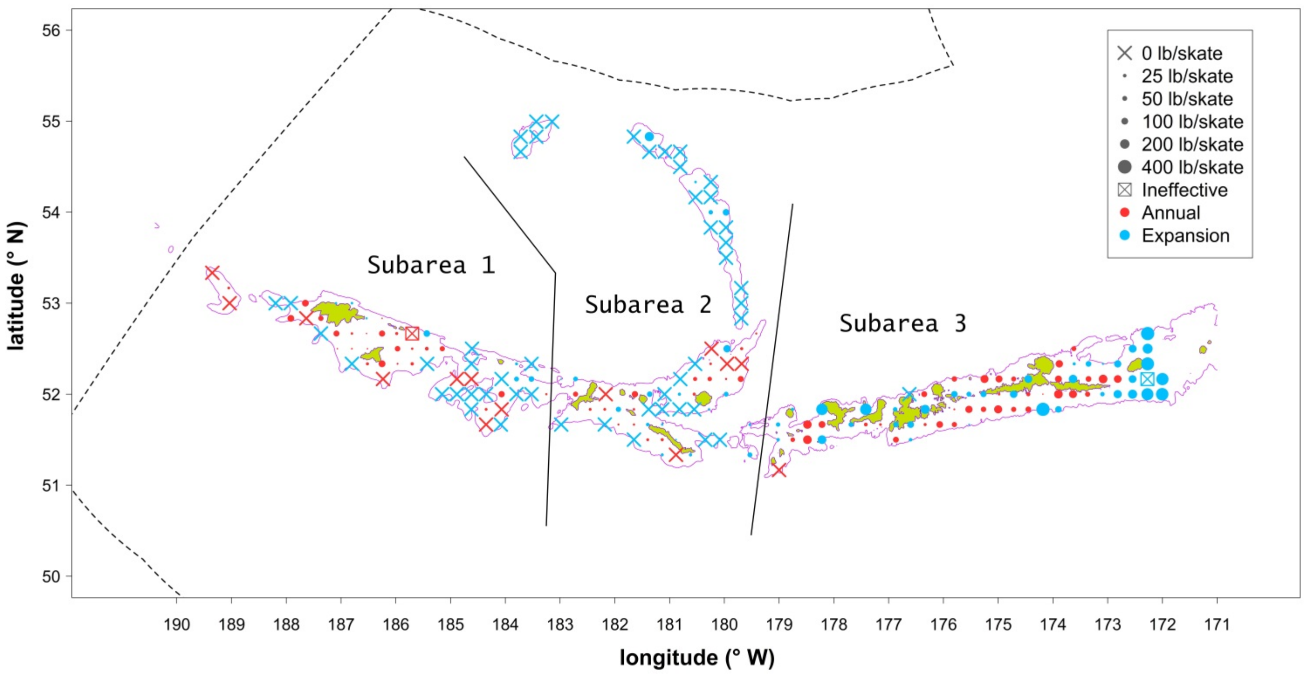


**Figure A.1.** Map of the 2017 FISS expansion design in IPHC Regulatory Area 4B showing the subareas used in the analysis.

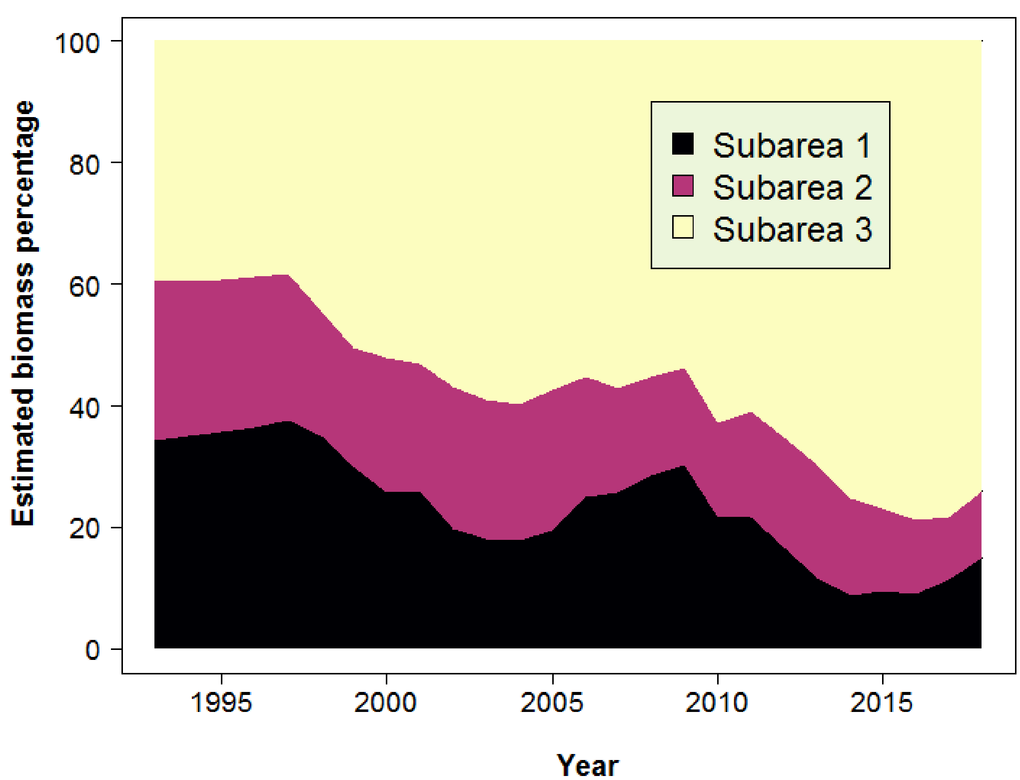


**Figure A.2.** Estimated IPHC Regulatory Area 4B biomass % by subarea and year.

*IPHC Regulatory Area 4A*

Like Regulatory Area 4B, we have divided Regulatory Area 4A into geographic subareas (Figure A.3) for use in devising an efficient FISS design. Subarea 1 is a high density subarea, which in recent years has had 65-85% of the biomass, and has been historically variable in terms of its proportion of the biomass (Figure A.4). Subarea 2 is a low-density area with a very stable proportion of the Regulatory Area 4A biomass, while Subarea 3 has had more variable biomass. (The smallest subarea, Subarea 4, is covered by the annual NMFS trawl survey, and we are not proposing to sample it as part of the annual survey.)

Based on this information, the following designs were evaluated for 2020-22:

- 2020: Only Subarea 1 fished (59 stations)
- 2021: Only Subarea 1 fished (59 stations)
- 2022a: Only Subarea 3 fished (63 stations)
- 2022b: Subareas 2 and 3 fished (114 stations)
- 2022c: Subareas 1 and 3 fished (122 stations)

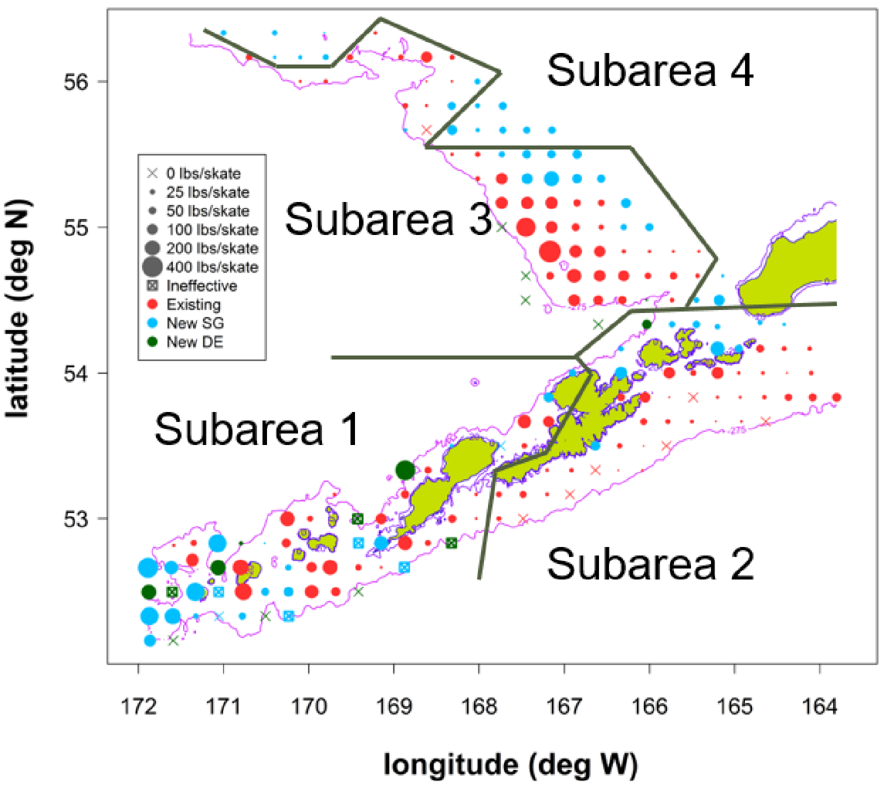


**Figure A.3.** Map of the 2014 FISS expansion design in IPHC Regulatory Area 4A showing the subareas used in the analysis.

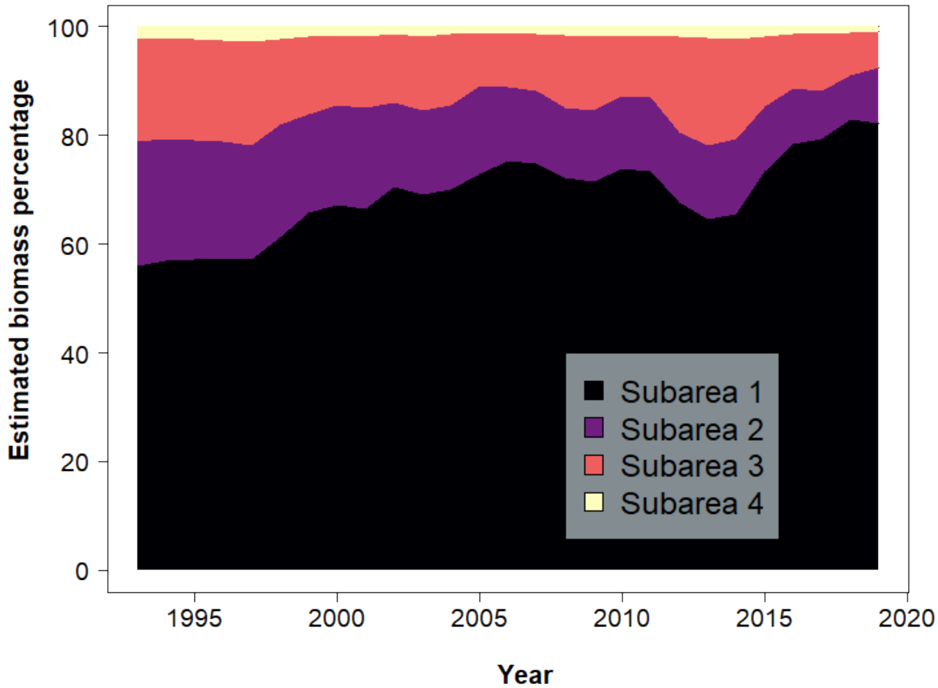


**Figure A.4.** Estimated Regulatory Area 4A biomass % by subarea and year.

Sampling only Subarea 1 in Regulatory Area 4A was sufficient to meet precision targets in 2020-21. For 2022, designs that omitted Subarea 1 were not expected to meet precision targets, and the minimum proposed design for 2022 is to fish Subareas 1 and 3.

*IPHC Regulatory Area 2A*

In IPHC Regulatory Area 2A, we again proposed subareas based on density and geography, but these subareas were not contiguous due to the existence of two distinct higher density regions, one off the north Washington coast, and the other of the central Oregon coast (Figure A.5). Thus, we created Subarea 1 to include both of these higher density regions, while Subarea 2 includes the moderate density zone between them, as well as the northern part of California. Subarea 3 includes the remaining low density regions in the Salish Sea, California, and the stations in deep and shallow waters throughout the Regulatory Area. The proportion of biomass in each subarea does not change greatly over periods less than five years (Figure A.6), and this relative stability should allow us to reduce sampling frequency in lower density subareas while maintaining precision targets.

For the 2020-22 period, we evaluated a sampling design in which only Subarea 1 was sampled. This 72-station design was sufficient to maintain CVs for mean WPUE below the 15% target in all years, while having low expected bias due to the stability of the biomass distribution among subareas.

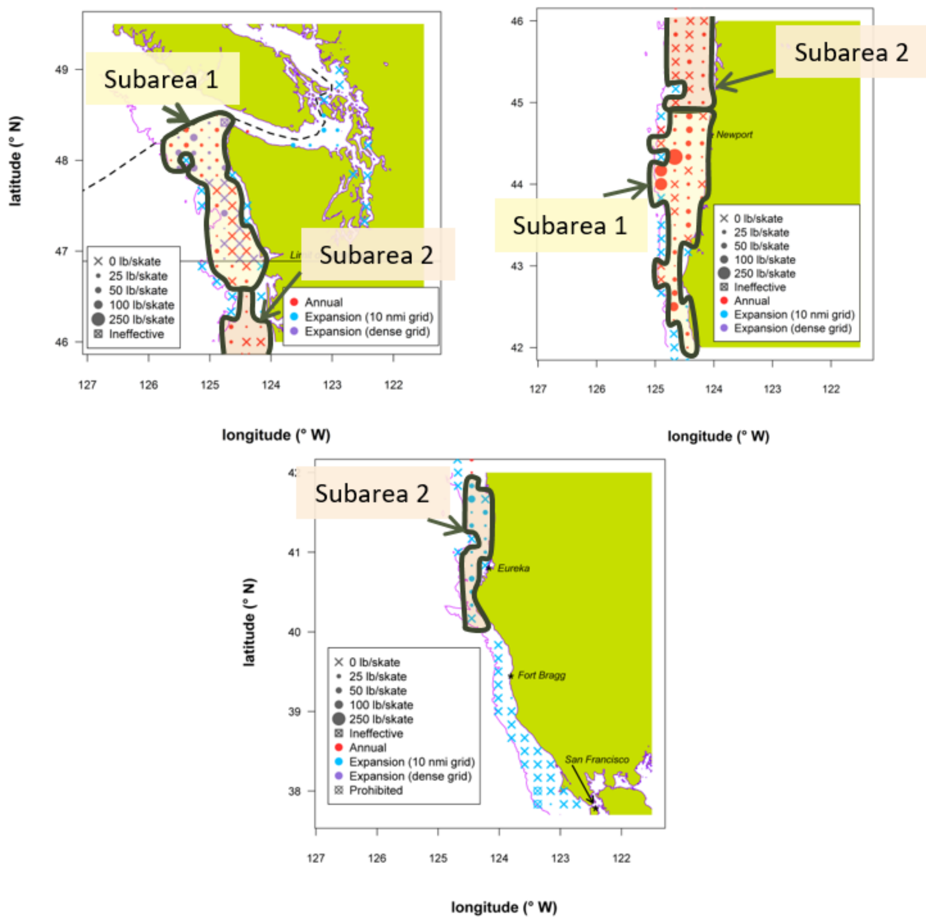


**Figure A.5.** Map of the 2017 FISS expansion design in IPHC Regulatory Area 2A showing the subareas used in the analysis. Subarea 3 is unlabeled but is comprised of the stations outside of Subareas 1 and 2.

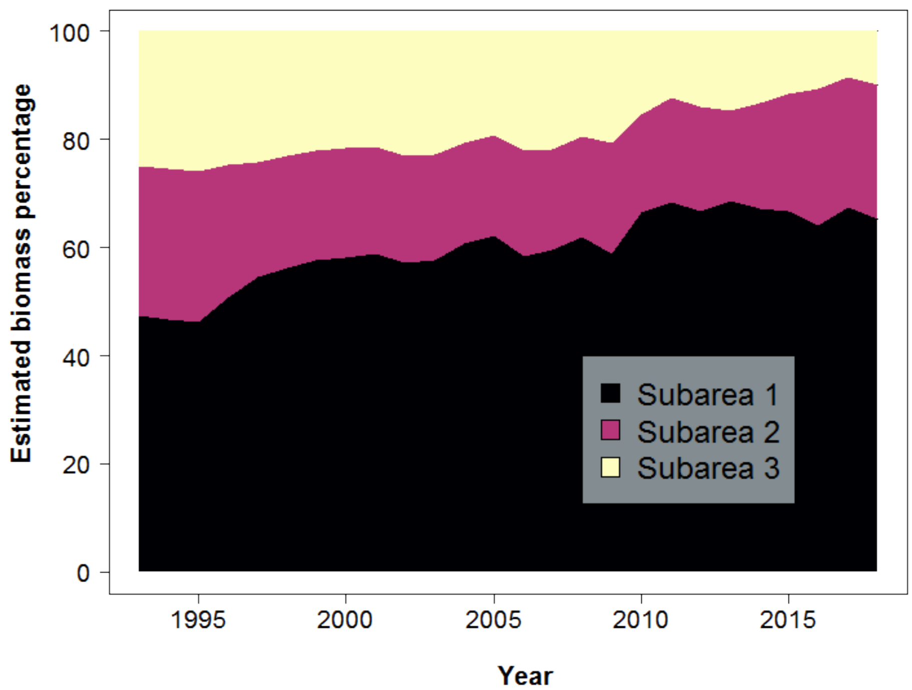


**Figure A.6.** Estimated IPHC Regulatory Area 2A biomass % by subarea and year.

## Appendix B

### Example of managing bias when subareas are employed: IPHC Regulatory Area 4B

The division of IPHC Regulatory 4B into subareas was described in Appendix A. Along with Figure A.1, showing trends in biomass proportions within IPHC Regulatory Area 4B, we also considered Table B.1 when determining the frequency with which each subarea should be sampled in order to maintain low bias. This table, derived from the data in Figure A.1, shows how many years until at least a 10% absolute change in estimated biomass proportion is recorded by year and subarea.

Subarea 1 often sees changes of at least 10% over a 3-4 year period. For example, the value “4” in 1996 in Table B.1 for Subarea 1 means that a 10% absolute change in this subarea’s biomass proportion from the 1996 estimate was first observed four years later, in 2000. Likewise, a change of at least 10% from the 1997 estimate also first observed in 2000, and so on. Table cells with dashes (from 2012 onwards for Subarea 1) mean that a change of at least 10% has yet to be observed.

We interpret the data in Table B.1 to mean that Subareas 1 and 3 should be sampled every 3-4 years to maintain low bias, while Subarea 2 can be sampled less frequently (with the caveat discussed in Appendix A).

Similar tables were referenced when determining sampling priorities for subareas within other IPHC Regulatory Areas for subarea-based designs.

**Table B.1** For each year, the number of years until at least a 10% absolute change in estimated biomass share 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 | – | 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 | – | – | – | – | – | – | – |
| 2 | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 3 | 6 | 6 | 4 | 3 | 4 | 3 | 3 | – | – | – | – | – | – |