IPHC Fishery-Independent Setline Survey (FISS) and commercial data modelling

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Part 1: 2022-24 FISS design evaluation

PURPOSE

To review the 2022-24 FISS designs presented at SRB018 and endorsed by the Scientific Review Board (SRB) at that meeting.

BACKGROUND

At SRB018, Secretariat staff presented proposed FISS designs for 2022-24 together with an evaluation of those designs (Webster 2021). Based on the evaluation, it is expected that the proposed designs would lead to estimated indices of density that would meet bias and precision criteria. In their report (IPHC-2021-SRB018-R, paragraph 16) the SRB stated:

> *The SRB **ENDORSED** the final 2022 FISS design as presented in Fig. 2, and provisionally **ENDORSED** the 2023-24 designs (Figs. 3 and 4), recognizing that these will be reviewed again at subsequent SRB meetings.*

PROPOSED DESIGNS FOR 2022-24

The designs proposed for 2022-24 (Figures 1.1 to 1.3) use efficient subarea sampling in IPHC Regulatory Areas 2A, 4A and 4B, and incorporate a randomized subsampling of FISS stations 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 1000 stations in an average year. This was also used to generate the designs originally proposed for 2020 (but modified as a result of the impact of COVID19 and cost considerations), and for those proposed and approved for 2021. In 2020, designs for 2022-23 were also approved subject to revision. We are proposing one change from that 2022 design, bringing forward by one year (from 2023 to 2022) the sampling of the central and western subareas of IPHC Regulatory Area 4B to reduce the risk of bias in estimates from that area. Thus, we propose that:

- In 2022 the lower-density western and central subareas of IPHC Regulatory Area 4B in sampled, followed by the higher-density eastern subarea in 2023-24
- The higher-density western subarea of IPHC Regulatory Area 4A be sampled in all three years, with the medium-density northern shelf edge subarea added in 2023 only
- The highest-density waters of IPHC Regulatory 2A in northern Washington and central/southern Oregon are proposed for sampling in each year of the 2022-24 period
- The near-zero density waters of the Salish Sea in IPHC Regulatory 2B are not proposed for sampling in 2022-24

Following this three-year period, it is expected that the remaining subareas will be included during the subsequent 3-5 years. These include the southeastern subarea of IPHC Regulatory 4A, and lower-density waters of IPHC Regulatory 2A (see below).

The design proposals again include full sampling of the standard FISS grid in IPHC Regulatory Area 4CDE. The Pacific halibut distribution in this area continues to be of particular interest, as it is a highly dynamic region with an apparently northward-shifting distribution of Pacific halibut, and increasing uncertainty regarding connectivity with populations adjacent to and within Russian waters.

RECOMMENDATION

That the Scientific Review Board:

1) **RECOMMEND** that the Commission note the SRB endorsement of the proposed 2022 design (Figure 1.1) and provisional endorsement of the proposed 2023-24 designs (Figures 1.2 and 1.3).

References

IPHC 2021. Report of the 18th Session of the IPHC Scientific Review Board (SRB) IPHC-2021-SRB18-R.

Webster, R. A. 2021. 2022-24 FISS design evaluation. IPHC-2021-SRB018-05 Rev_1.

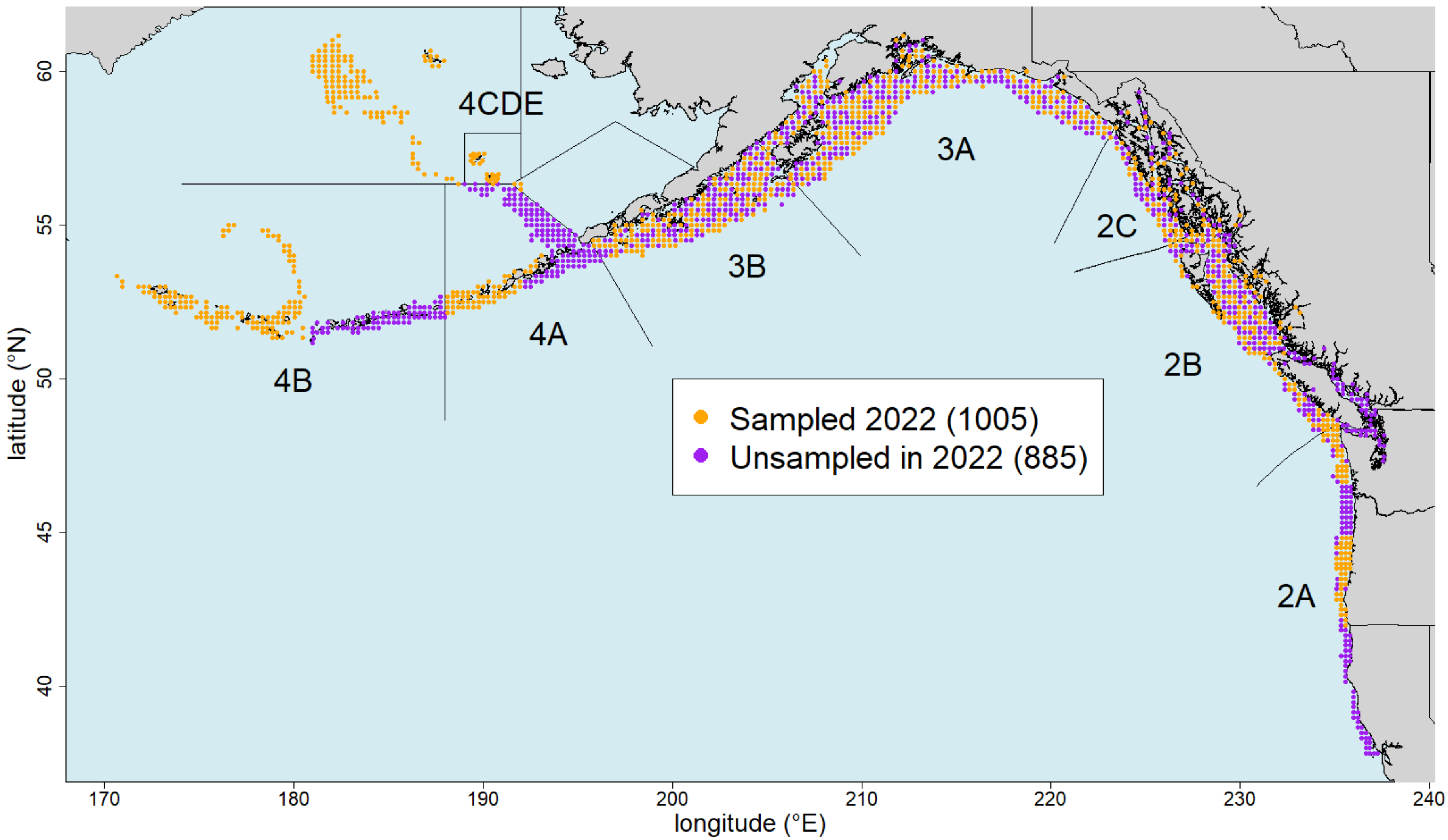

Figure 1.1. Proposed minimum FISS design in 2022 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

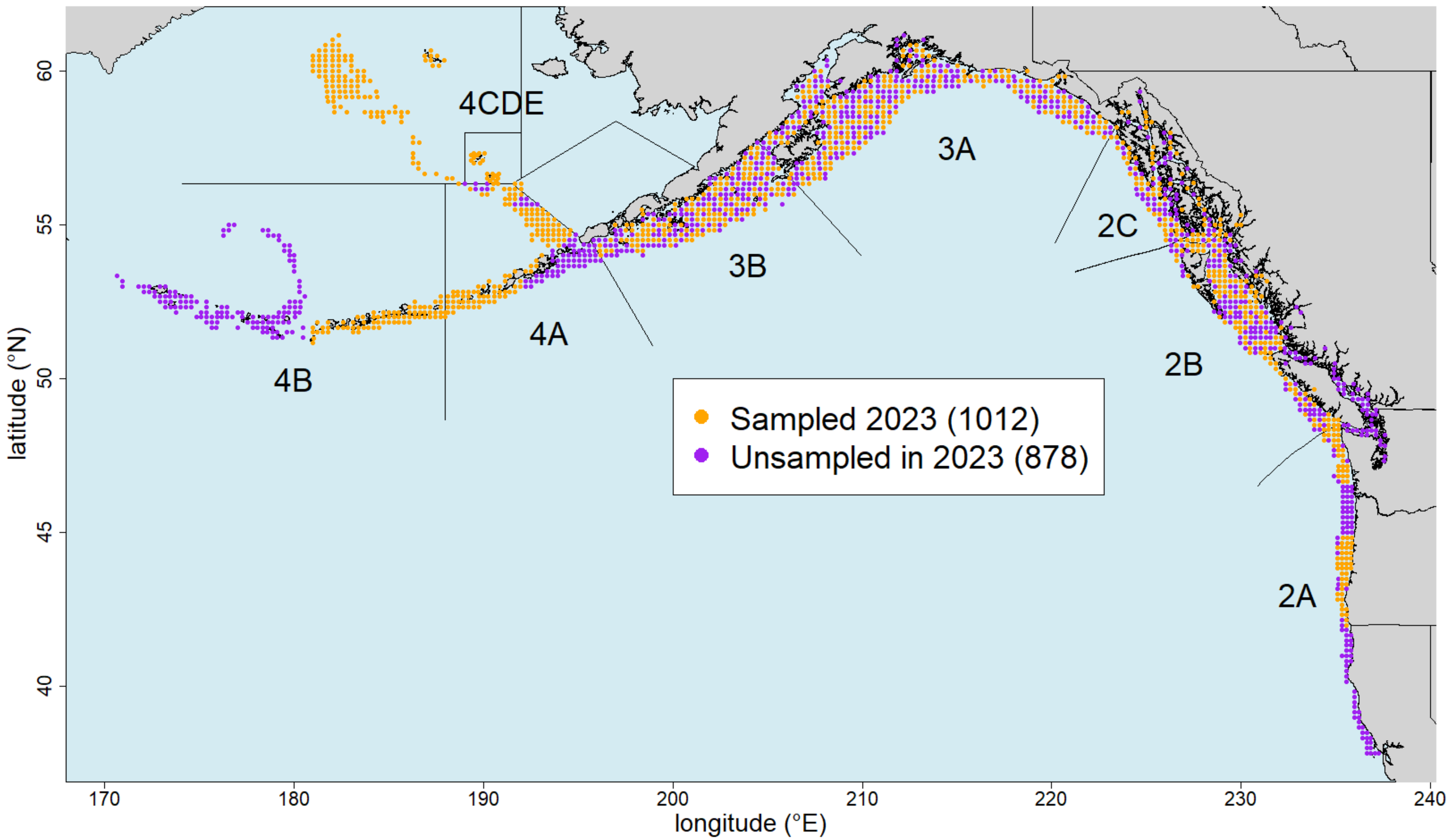

Figure 1.2. Proposed minimum FISS design in 2023 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

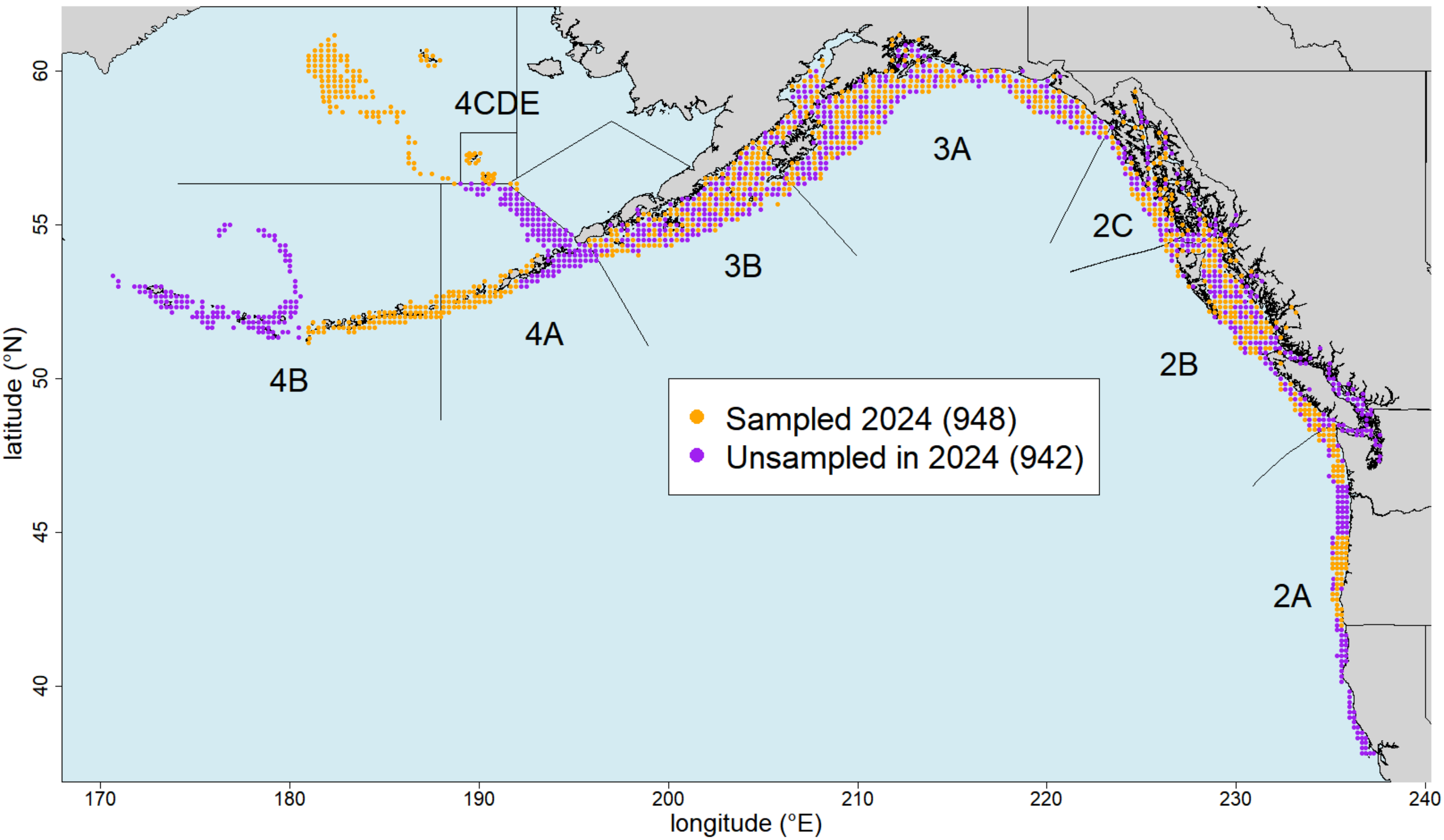

Figure 1.3. Proposed minimum FISS design in 2024 (orange circles) based on randomized sampling in 2B-3B, and a subarea design elsewhere. Purple circles are optional for meeting data quality criteria.

Part 2: Modelling of IPHC length-weight data

PURPOSE

To present results of fitting models to IPHC length-weight data from FISS and commercial sampling, and make recommendations of revised length-net weight relationships for applications to non-IPHC data sources.

BACKGROUND/INTRODUCTION

Historical length-weight curve

The IPHC's standard length to net weight relationship was used in all commission work to convert length to net weight of halibut until 2015, when individual weights were added to standard commercial data collections. More recently, the IPHC's Fishery Independent Setline Survey (FISS) began collecting individual weights in 2017, and made such collections comprehensive in 2019. The parameters of this relationship were estimated in 1926 based on a relatively small sample of Pacific halibut (454 fish) collected off Masset in IPHC Regulatory Area 2B. Using 1989 data, Clark (1992) re-estimated the relationship's parameters and found good agreement with the earlier curve, and no changes to the historical IPHC relationship were made. While it was recognized that such a calculated relationship will not be consistently accurate when computing total or mean weights from small numbers of Pacific halibut, it was assumed that predictions should be accurate when data come from larger samples of fish (Clark 1992). However, when Courcelles (2012) estimated the relationship from data collected in 2011, she found significant differences between her estimated curve and that derived from the 1989 data, although inference was limited to a relatively small part of Area 3A and to the time of the FISS. Reports from staff working on the FISS, along with other anecdotal reports, suggested that the historical length-net weight relationship has been overestimating the weight of Pacific halibut on average in recent years.

Adjustments and conversion factors

Various adjustment and conversion factors have been used to account for Pacific halibut measured at different stages of processing following capture (Table 2.1).

Table 2.1 Definitions of types of weight measures used by the IPHC and multipliers used to convert to net weight.

Weight	Definition	Multiplier to convert to net weight	Notes
Round	Head-on, not gutted, no ice and slime	0.75	
Gross (vessel weight)	Head-on, gutted, with ice and slime	0.8624	Assumes 10% head weight and 2% shrinkage, or 12% head, and 2% ice and slime
Dressed (vessel weight)	Head-on, gutted, no ice and slime	0.88	Assumes 10% head weight and 2% shrinkage, or 12% head only
Gross (dock weight)	Head-on, gutted, with ice and slime	0.882 or 0.88	Assumes 10% head weight and 2% ice and slime; deductions either additive (10+2=12% in 2A and 2B) or multiplicative (1-0.9*0.98=0.118 or 11.8% in Alaska)
Dressed (dock weight)	Head-on, no ice and slime (washed)	0.9	Assumes 10% head weight
Net	Head-off, gutted, no ice and slime (washed)	1	

The historical relationship between fork length and net weight includes adjustments for the weight of the head, and of ice and slime (I/S): gross landed weight (gutted, with head, ice and slime) was assumed to include a proportion of 0.12 head weight and 0.02 ice and slime, which combine to give a multiplier of 0.8624 to convert gross to net weight. Clark (1992) noted that subsequent studies showed the head weighed less than 0.12 of gross weight, but that the adjustment factor worked well anyway, possibly because of additional shrinkage of fish after being weighed at sea (as they were in the 1926 study in which the relationship was estimated). In practice, combined deductions of 0.12 in Areas 2A and 2B, and 0.118 in Alaska, were applied to commercial landings to convert from gross to net weight. These both include the 0.02 deduction for ice and slime assumed in the IPHC length-net weight relationship, but use 0.1 as the proportion for the head. This head deduction has been required as part of IPHC regulations since 2008 (Leaman and Gilroy 2008, Gilroy et al. 2008). The way the two deductions are combined differs among areas. In Areas 2A and 2B, these deductions are simply added (0.1+0.02=0.12), while in Alaska, the corresponding multipliers (1 minus the deduction) are multiplied, leading to a multiplier of 0.882, and a deduction of 0.118.

Estimating and comparing length-net weight curves

The commercial sampling program and the FISS weight sampling provide us with two independent data sources to use in re-estimating length-net weight relationships. For estimating the relationship between fork length and net weight, only head-on fish (with the same standard head and I/S deductions assumed in the standard IPHC relationship, 0.10 and 0.02 respectively) are used to ensure a consistent comparison due to the high spatial variability in the proportion of the weight removed when cutting heads (see below). Function parameters are estimated by fitting linear models (on the log scale) using least squares. Let *L* be the fork length of a halibut in centimetres, and *W* be its net weight in pounds. The standard IPHC length-net weight relationship is

$$W = 6.921 \times 10^{-6} L^{3.24} \quad (1)$$

More generally, the relationship between length and weight is assumed to have the following form

$$W = \alpha L^{\beta}$$

While this can be fitted as a non-linear model, it is somewhat easier to linearise the equation by taking logs of both sides, giving

$$\log(W) = a + \beta \log(L)$$

where $a = \log(\alpha)$. For the standard IPHC model, *a* = −11.88, or -12.57 if weights in kg are used as we do in the analyses below. Now suppose we have *N* halibut in our sample, and each is indexed by *i*, *i* = 1, …, *N*. Then the model we fit is

$$\log(W_i) = a + \beta \log(L_i) + \varepsilon_i \quad (2)$$

where $\varepsilon_i \sim N(0, \sigma^2)$.

For both FISS and commercial data, several observations appeared to be extreme outliers. Such outliers were likely the result of errors (e.g., incorrect conversion to or from metric or imperial units), and to avoid the most extreme values influencing the estimated relationships, observations with measured weight more than twice or less than half the value predicted by the historical length-weight curve were excluded from the statistical analyses. These amounted to just 21 out of over 62,000 commercial samples from 2015-20, and 22 out of over 83,000 FISS samples from 2019-20.

Commercial catch sampling

In 2015, collection of weight data by IPHC staff began on randomly sampled fish in commercial landings. Sample weights were measured in all ports except Dutch Harbor and St Paul, which were added the following year. In 2017, weighing of fish was expanded to include all Pacific halibut selected for biological sampling (length measurement, fin clip for genetic analysis, and otolith collection). The addition of recording fish weights to commercial sampling was motivated by a desire for more accurate estimation of commercial landings, validation of adjustments for head weights and the weight of ice and slime, and validation or revision of the IPHC historical length-net weight relationship. Sample sizes by year and IPHC Regulatory Area are given in Table 2.2.

Table 2.2. Sample sizes of weighed commercial Pacific halibut by year and IPHC Regulatory Area.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
2015	32	801	1431	1538	1133	798	192	147
2016	303	1943	1673	1470	1492	1574	1466	1270
2017	1118	1376	1367	1453	1381	997	1816	1632
2018	2253	1421	1612	1676	808	925	1307	1494
2019	1731	1076	1573	1751	1751	1322	968	960
2020	1318	1694	1717	1608	1606	937	1264	905

Head weight

Head weight was estimated from a subset of Pacific halibut that were weighed twice, before and after the head was cut in the plant. Data showed that head cuts were highly variable (Webster and Erikson 2017), and the proportion of the fish removed varied greatly among ports and plants. Because the head cut was so variable, the IPHC regulations were changed in 2018 (?) to require all catch to be offloaded and weighed with the head on to ensure consistent treatment of fish across ports and plants, and accurate accounting for the mortality in stock assessment and management analyses. Following the regulation change, commercial sampling for head weight was discontinued, and the 10% deduction for head is applied to all offloaded Pacific halibut as a standard part of the conversion to net weight. (With the requirement to land fish head on, the accuracy of that 10% adjustment became moot – it is simply part of the IPHC definition of net weight.)

Ice and slime

It was hoped that commercial sampling would yield estimates of the weight of ice and slime through the comparison of fish weight twice, before and after washing. Plant operations have not allowed for the collecting of such data, and therefore it has not been possible to validate the assumed 2% adjustment for ice and slime. In the absence of any updated information, that adjustment remains in use. The Commission considers this adjustment to be applicable only in the absence of any water used to remove ice from the unloaded fish prior to weighing. The 'plug' ice in the body cavity is assumed to be removed and not part of the 2% deduction for all fish.

Length-net weight curves

We estimated the length-net weight curve for each IPHC Regulatory Area and for each year from 2016-20, allowing us to assess variation in estimated curves over time and space, as well as make comparisons between estimated curves and the historical length-net weight relationship. Variation in space over the five-year period (Figures 2.1 to 2.5) was generally much greater than variation in time within each IPHC Regulatory Area (Figures 2.6 to 2.13). IPHC Regulatory Areas 2A and 4CDE showed much greater temporal variation in estimated curves (Figures 2.6 and 2.13) than other areas: timing and distribution of sampling is less consistent in these Regulatory Areas than elsewhere, which makes inference on changes in the relationship more difficult over short periods. Estimated curves for Regulatory Areas 2B (Figure 2.7) and 3B (Figure 2.10) are close to the historical curve in all years, while those for Regulatory Areas 2C, 3A, 4A and 4B and consistently below the historical curve, with the degree of difference varying among areas.

FISS sampling

Wide-scale weighing of Pacific halibut on the IPHC FISS commenced in 2019 and continued through 2020. In 2019, the intention was to record dressed weight of all legal-sized (O32) fish using motion-compensated scales, with the exception of some larger fish, that were weighed dockside. Due to technical issues, fish on some trips were unable to be weighed. Sample sizes by year and area are given in Table 2.3.

Table 2.3. Sample sizes of weighed FISS Pacific halibut by year and IPHC Regulatory Area.

Year	2A	2B	2C	3A	3B	4A	4B	4CDE
2019	786	3889	10898	15460	4530	3758	495	1545
2020	0	8103	6392	24815	2642	0	0	0

A random subsample of sublegal (U32) fish had dressed weight recorded (those selected for otolith collection), along with round weight, in order to estimate the relationship between round and dressed weight for use in predicting weight of fish not selected for otolith sampling (and therefore with no dressed weight). Predictions of net weight from round weight (coastwide data) and from length (by IPHC Regulatory Area) were compared to determine which variable was the most accurate predictor of net weight. The approach we took was to model the relationship between the ratio of dressed to round weight and round weight, after applying the normalizing arcsin-square root transformation. Thus for the *i*th fish, the model was

$$\sin^{-1}\left(\sqrt{\frac{w_{dressed,i}}{w_{round,i}}}\right) = b_0 + b_1 w_{round,i} + \eta_i$$

where $\eta_i \sim N\left(0,\tau^2\right)$. The parameter estimates (for weights in kg) were $\widehat{b}_0$= 1.215 (SE=0.003) and $\widehat{b}_1$= -0.007619 (SE=0.000610). Thus, we estimate that as round weight increases, the corresponding dressed weight is a decreasing fraction of round weight, ranging from 88% for fish at 0.5 kg to 84% for 8 kg fish (the approximate weight range of fish in the data).

The estimated relationship with round weight was found to produce more accurate predictions (Figure 2.14), with much less variability from true net weight (scaled from dressed weight as per Table 2.1) and no constraint forced on maximum predicted weight by a strict relationship with length. This led to the recommendation that round weights of U32 Pacific halibut continue to be measured during the FISS, but that measurement of dressed weight for a subsample of such fish can be discontinued. From 2020 onwards, dressed weight (and hence net weight) is being predicted for each U32 fish from the relationship estimated from the 2019 data.

There was general consistency across years for each of the four IPHC Regulatory Area sampled in both 2019 and 2020 (Figures 2.15-2.18) in estimated length-net weight relationships, although differences for Regulatory Areas 2C and 3B (the latter having greatly reduced sampling in 2020) were somewhat larger than Regulatory Areas 2B and 3A. As with length-net weight relationships estimated from commercial sampling data, spatial variation in the estimated relationships among areas was much greater than temporal variation within areas (Figures 2.19-2.20).

Estimating shrinkage

As noted above, there is the assumption of 2% shrinkage when converting weights made on board a vessel to net weight. A subsample of Pacific halibut from FISS sampling was weighed both on the vessels and later at the dock during the 2016 and 2017 FISS seasons, providing data with which to estimate the shrinkage rate of fish. The data file recording at sea and dockside weights for the same individuals includes measurements on 562 fish, although 12 only have a single weight recorded. At sea weights were recorded as round weights, while dockside weights were of head-on and washed fish (i.e., dockside dressed, Table 2.1). To estimate shrinkage, round weights must first be converted into at-sea dressed weights, requiring multiplication of round weights by 0.85 (0.75/0.88 from Table 2.1). Without data to validate this assumed multiplier directly, we are in the problematic position of trying to estimate shrinkage based on values that may themselves be in error due to inaccuracy of the multiplier. While we were able to estimate a relationship between round weight and dressed weight for U32 fish above, the fish weighed twice are O32 fish, and therefore the estimated relationship may not apply. Given the assumed 0.85 multiplier, the average % shrinkage across all 550 fish with both weights is 1.9% (SE=0.2%), and is therefore consistent with a shrinkage multiplier of 2% as assumed in Table 2.1. Future FISS sampling should include a selection of O32 Pacific halibut weighed twice, before and after gutting, to validate the conversion from round weight to dressed at sea.

Commercial and FISS length-weight comparisons

The estimated length-net weight curves above can be used to predict net weight for Pacific halibut with missing direct measurements from both commercial and FISS sampling. With two independent sources of IPHC length-weight data since 2019, thought must be given to how (or whether) to combine the two sources for estimating length-weight curves for use outside of the IPHC when direct weight measurement is not available, i.e., for other survey data (e.g., NMFS and DFO surveys), commercial observer data, and data from recreational catch sampling. While the FISS data are typically collected in a spatially comprehensive manner within each IPHC Regulatory Area, they are temporally restricted to the May-September summer period. Conversely, commercial samples are collected throughout the fishing season, but may more geographically limited due to the concentration of fishing effort in the most productive habitat within each area. In this section we assess the likely importance of any differences in estimated length-net weight curves that may be a result of such sampling differences when it comes to calculating statistics such as mean weight of sampled fish.

For 2019 and 2020 data, we fitted two length-net weight models to the combined commercial and FISS data for each IPHC Regulatory Area:

Model 1: Assume length-net weight relationships are the same for both data sources

Model 2: Allows parameters for length-net weight relationships to differ between the data sources

Table 2.4. Estimated model parameters (with standard errors) for Models 1 and 2 fitted to combined FISS and commercial data (with weight in kg), by IPHC Regulatory Area and year. Note that the historical length-net weight relationship has intercept of -12.57 and slope of 3.24.

Reg Area	Year	Model 1		Model 2			
		Intercept (SE)	Slope (SE)	FISS		Commercial	
				Intercept (SE)	Slope (SE)	Intercept (SE)	Slope (SE)
2A	2019	-13.51 (0.08)	3.42 (0.02)	-13.16 (0.11)	3.35 (0.02)	-13.43 (0.10)	3.40 (0.02)
2B	2019	-12.40 (0.03)	3.18 (0.01)	-12.40 (0.04)	3.18 (0.01)	-12.79 (0.09)	3.26 (0.02)
	2020	-12.69 (0.03)	3.24 (0.01)	-12.72 (0.03)	3.24 (0.01)	-12.57 (0.08)	3.21 (0.02)
2C	2019	-12.44 (0.02)	3.18 (0.00)	-12.46 (0.02)	3.19 (0.00)	-12.20 (0.07)	3.13 (0.01)
	2020	-12.56 (0.03)	3.21 (0.01)	-12.63 (0.03)	3.23 (0.01)	-12.33 (0.07)	3.16 (0.02)
3A	2019	-12.25 (0.02)	3.14 (0.00)	-12.26 (0.02)	3.14 (0.00)	-12.34 (0.07)	3.15 (0.02)
	2020	-12.15 (0.02)	3.11 (0.00)	-12.14 (0.02)	3.11 (0.00)	-12.38 (0.07)	3.16 (0.02)
3B	2019	-12.78 (0.03)	3.26 (0.01)	-12.75 (0.03)	3.26 (0.01)	-13.05 (0.07)	3.32 (0.02)
	2020	-12.59 (0.03)	3.21 (0.01)	-12.51 (0.04)	3.20 (0.01)	-13.16 (0.07)	3.34 (0.02)
4A	2019	-12.00 (0.03)	3.09 (0.01)	-12.07 (0.03)	3.11 (0.01)	-12.56 (0.08)	3.21 (0.02)
4B	2019	-12.13 (0.08)	3.10 (0.02)	-11.80 (0.10)	3.04 (0.02)	-12.72 (0.10)	3.23 (0.02)
4CDE	2019	-12.07 (0.04)	3.11 (0.01)	-12.04 (0.05)	3.10 (0.01)	-12.51 (0.08)	3.20 (0.02)

Model parameter estimates are given in Table 2.4. We compared the actual observed mean net weight of fish mean to net weights predicted from each model for each source (FISS and commercial), and to that predicted by the historical relationship. Only fish included in the modelling were used in the comparison, i.e., only data from fish with directly measured weights were included (some extreme outlying data were excluded). Results of the comparisons of mean net weights are presented in Table 2.5. Figures comparing the FISS and commercial data and estimated length-net weight curves for Model 2 are shown in Figures 2.21-2.32.

As might be expected, Model 2 produced estimated mean net weights closest to the observed values, with differences all within 1% (Table 2.5). In cases where estimated length-net weight curves differed between FISS and commercial data to some degree, this model accounts for such differences. Model 1, while less accurate in estimating observed mean net weights than Model 2, still performed well in almost all cases, with differences of less than 2% except for the FISS mean in IPHC Regulatory Area 2A, the commercial mean in IPHC Regulatory 3A, and the FISS mean in IPHC Regulatory Area 4B, all in 2019. We note that those three cases are ones in which there were differences between the FISS and commercial length-net weight curves when estimated separately (Figures 2.21, 2.24 and 2.27), but where one data source had much larger sample sizes and so had greater influence on the estimates of a single length-net weight curve in Model 1: for IPHC Regulatory Area 2A, 69% of the data came from commercial samples; for 3A in 2019, 90% of the data came from FISS samples; and for 4B, 66% of the data came from commercial samples.

Discussion

Analysis of the IPHC length-weight data has made it clear that currently there is a positive bias in weights predicted from the historical length-net weight relationship in most IPHC Regulatory

Areas, especially (in absolute terms) for the largest Pacific halibut. that the IPHC recommends that this bias can best be eliminated by weighing individual fish directly. In the absence of sampling capability, the bias can be reduced through the use of relationships estimated from more contemporary IPHC FISS and commercial data. For IPHC data where there is no reliable direct weight measurement, the weight of a fish can be predicted from the length-net weight relationship estimated for its IPHC Regulatory Area and year of capture, and for its data source (commercial or FISS sampling). This change has already been made to the prediction of net weight for fish captured on the FISS with missing weight measurements.

For predicting weights for Pacific halibut sampled from non-IPHC data sources, Model 1 is of more practical use than Model 2, as it would not require a choice of which IPHC source was most likely to resemble the data source of interest (recreational, observer, etc). By combining data from the more temporally comprehensive commercial samples with data from the spatially extensive FISS, the resulting length-net weight represents an average that can be applied to a wide range of data sources.

Spatial differences in estimated length-net weight curves imply that area-specific curves should be used. On the other hand, the relative temporal stability of these curves suggests that curves could be estimated from multiple years' data, and only revised periodically. Following the 2021 FISS, three consecutive years of data from both IPHC sources will be available for core areas (2B, 2C, 3A and 3B), and two years (2019 and 2021) for other areas, providing a combined data set for estimation of curves for application to non-IPHC length data in 2021.

In fitting Model 1, we simply combined the data without weighting the two data sources, so each fish, no matter its source, was given equal weight. This resulted in instances where the estimated length-net weight equation was more influenced by data from one source than the other, typically the FISS in the core areas, and sometimes the commercial samples elsewhere. Generally, this did not matter much, as the two sources produced consistent estimated relationships most of the time (Figures 2.21 to 2.32). It may be desirable, however, to weight the data sources equally (i.e., down-weight data from the source with the larger sample size relative to the other source) to produce a relationship that better represents an average of the FISS and commercial data relationships, and thus one that is as widely applicable as possible for each IPHC Regulatory Area.

Therefore, the IPHC intends to produce a revised length-net weight relationship based on Model 1 (combined fitting) and including all data from 2019-2021. This relationship should be used in place of the historical relationships for the calculation of all non-IPHC mortality estimates where individual weights cannot be collected for 2021 and until further notice. The Secretariat anticipates re-evaluating the relationship as additional years of data are collected and updating it accordingly.

Finally, we note that there remain two components to the estimation of weight from length that are not directly estimable from recent FISS and commercial sample data: the conversion from round to net weight (or round to dress weight), and the adjustment factors for ice and slime (conversion from unwashed to wash). The former only has data available for U32 fish, while there are no data available to estimate the latter. We recommend that future FISS sampling include a random sample of O32 fish weighed twice, before and after dressing, and that renewed efforts should be made to weigh a sample of fish twice dockside, before and after washing.

RECOMMENDATIONS

That the Scientific Review Board:

1) **NOTE** paper IPHC-2021-SRB019-05.2 that presents methods for revised the length-net weight relationships from FISS and commercial sampling data
2) **RECOMMEND** that the IPHC provide a revised length-net weight relationship for each IPHC Regulatory Area based on modelling of combined FISS and commercial sample data to be used for the calculation of all non-IPHC mortality estimates where individual weights cannot be collected, for 2021 and until further notice.

References

Clark, W. G. 1992. Validation of the IPHC length-weight relationship for halibut. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 1991: 113–116.

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Table 2.5. Comparison of mean observed Pacific halibut net weight with mean nets weights predicted from Models 1 and 2 (see text) and the historical length-net weight relationship. Intensity of shading indicates magnitude of departures from observed mean, either negative (blue) or positive (orange/brown).

Reg Area	Calculation method	2019				2020			
		FISS		Commercial		FISS		Commercial	
		Mean (kg)	diff from Observed	Mean (kg)	diff from Observed	Mean (kg)	diff from Observed	Mean (kg)	diff from Observed
2A	Observed	9.9		7.6					
	Model 1	9.6	−3.1%	7.7	+1.1%				
	Model 2	9.9	−0.3%	7.6	−0.4%				
	Historical	9.9	−0.8%	8.0	+4.9%				
2B	Observed	9.4		11.0		10.7		11.0	
	Model 1	9.3	−1.4%	11.1	+1.3%	10.6	−0.7%	11.1	+1.0%
	Model 2	9.4	−0.7%	10.9	−0.3%	10.7	−0.3%	10.9	−0.5%
	Historical	9.5	+0.8%	11.4	+3.6%	11.0	+2.3%	11.4	+4.0%
2C	Observed	10.8		13.5		11.4		14.3	
	Model 1	10.8	−0.5%	13.5	−0.3%	11.3	−0.9%	14.4	+0.8%
	Model 2	10.8	−0.5%	13.5	−0.5%	11.3	−0.5%	14.3	−0.4%
	Historical	11.3	+4.3%	14.2	+4.9%	11.5	+0.5%	14.7	+2.4%
3A	Observed	8.5		8.7		8.6		9.1	
	Model 1	8.5	−0.7%	8.9	+2.1%	8.6	−0.6%	9.2	+1.0%
	Model 2	8.5	−0.4%	8.7	−0.5%	8.6	−0.5%	9.0	−0.5%
	Historical	8.9	+3.8%	9.3	+6.8%	9.1	+5.5%	9.7	+7.4%
3B	Observed	8.4		9.1		6.4		9.0	
	Model 1	8.3	−1.1%	9.2	+0.9%	6.3	−0.9%	9.0	−0.1%
	Model 2	8.3	−0.5%	9.1	−0.3%	6.3	−0.5%	8.9	−0.3%
	Historical	8.3	−1.0%	9.3	+1.0%	6.5	+2.1%	9.2	+3.3%
4A	Observed	6.0		9.9					
	Model 1	5.9	−1.4%	10.0	+1.0%				
	Model 2	5.9	−0.4%	9.3	−0.5%				
	Historical	5.9	−0.6%	10.3	+4.2%				
4B	Observed	8.7		9.0					
	Model 1	8.3	−3.7%	9.0	+0.7%				
	Model 2	8.6	−1.0%	9.0	−0.3%				
	Historical	9.2	+3.9%	9.9	+10.7%				
4CDE	Observed	6.9		11.0					
	Model 1	6.8	−1.2%	11.0	−0.0%				
	Model 2	6.9	−0.6%	11.0	−0.4%				
	Historical	6.8	−1.7%	11.2	+1.1%				

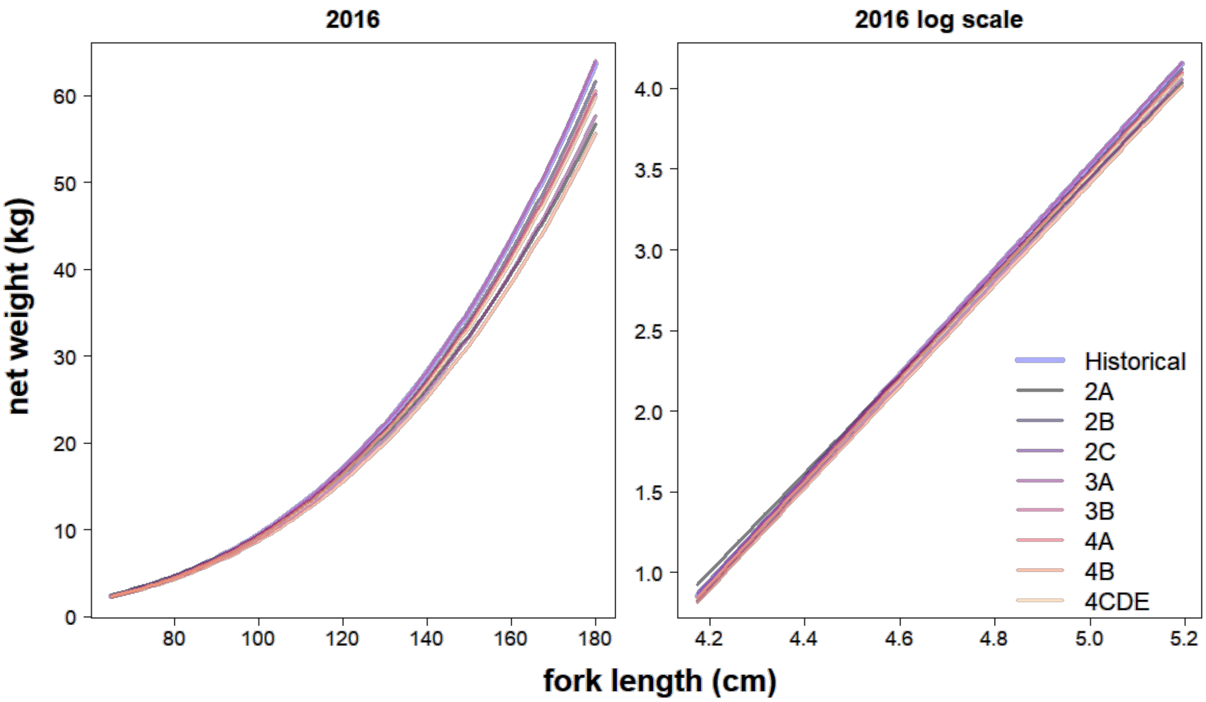

Figure 2.1 Comparison of estimated length-net weight curves from commercial data by IPHC Regulatory Area for 2016.

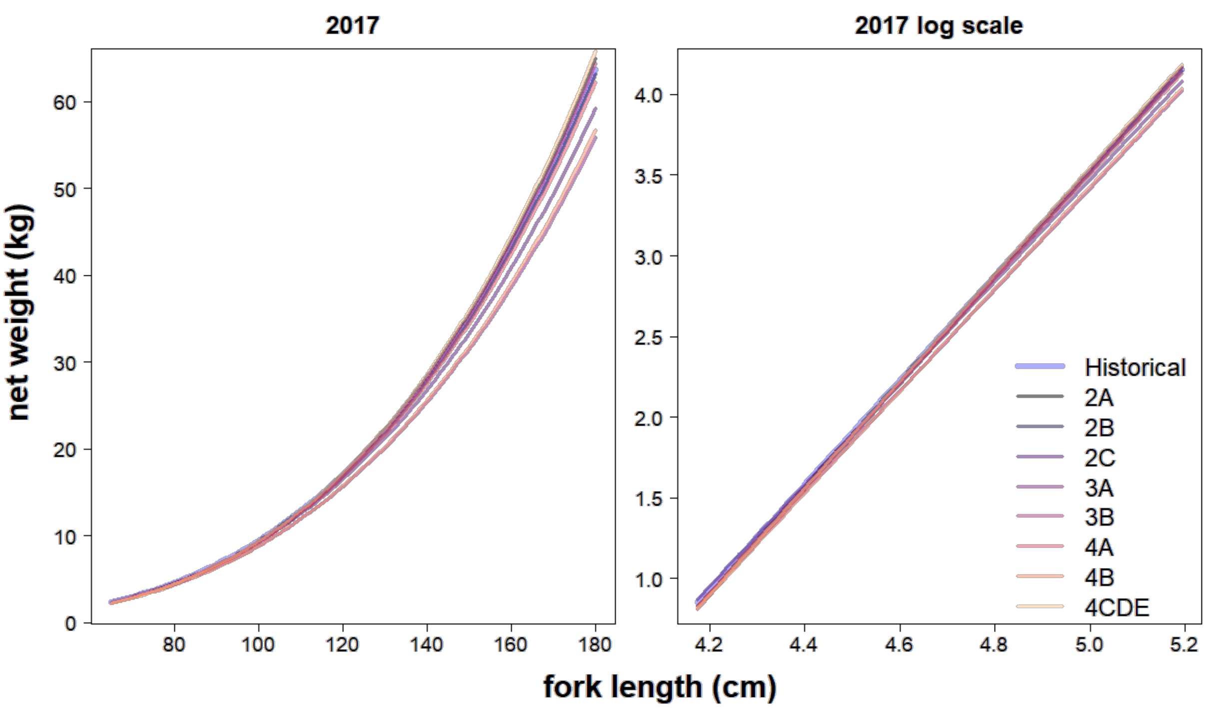

Figure 2.2 Comparison of estimated length-net weight curves from commercial data by IPHC Regulatory Area for 2017.

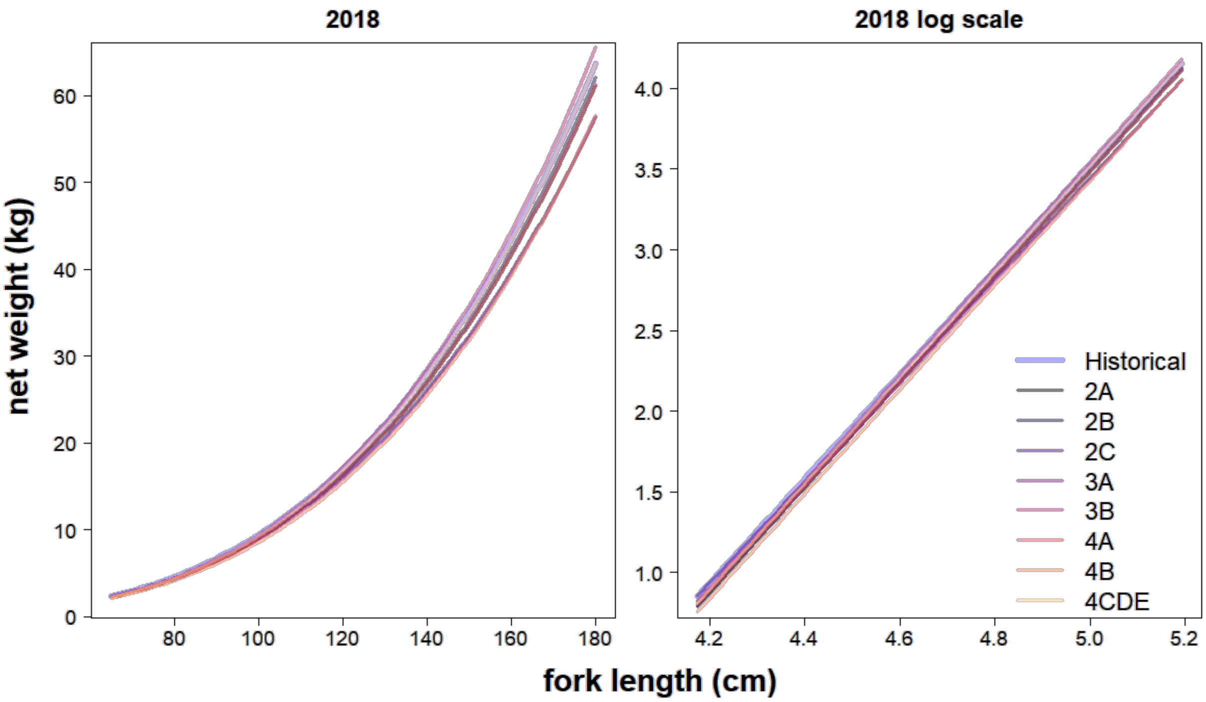

Figure 2.3 Comparison of estimated length-net weight curves from commercial data by IPHC Regulatory Area for 2018.

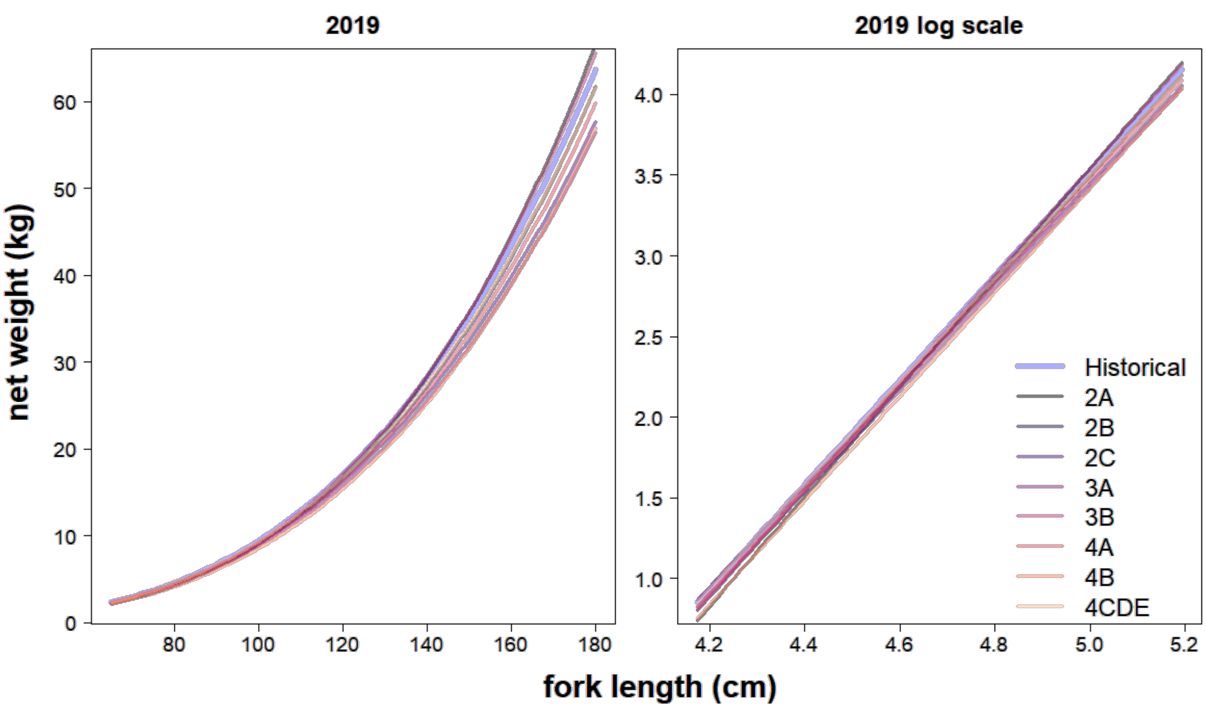

Figure 2.4 Comparison of estimated length-net weight curves from commercial data by IPHC Regulatory Area for 2019.

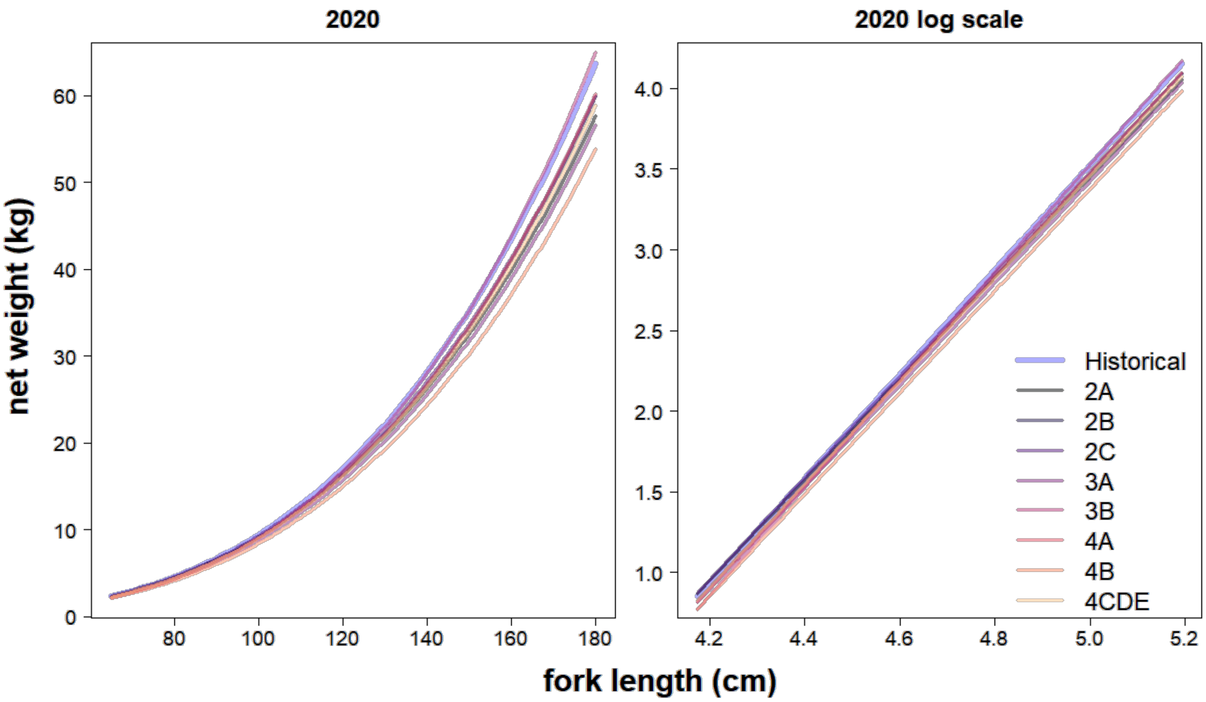

Figure 2.5 Comparison of estimated length-net weight curves from commercial data by IPHC Regulatory Area for 2020.

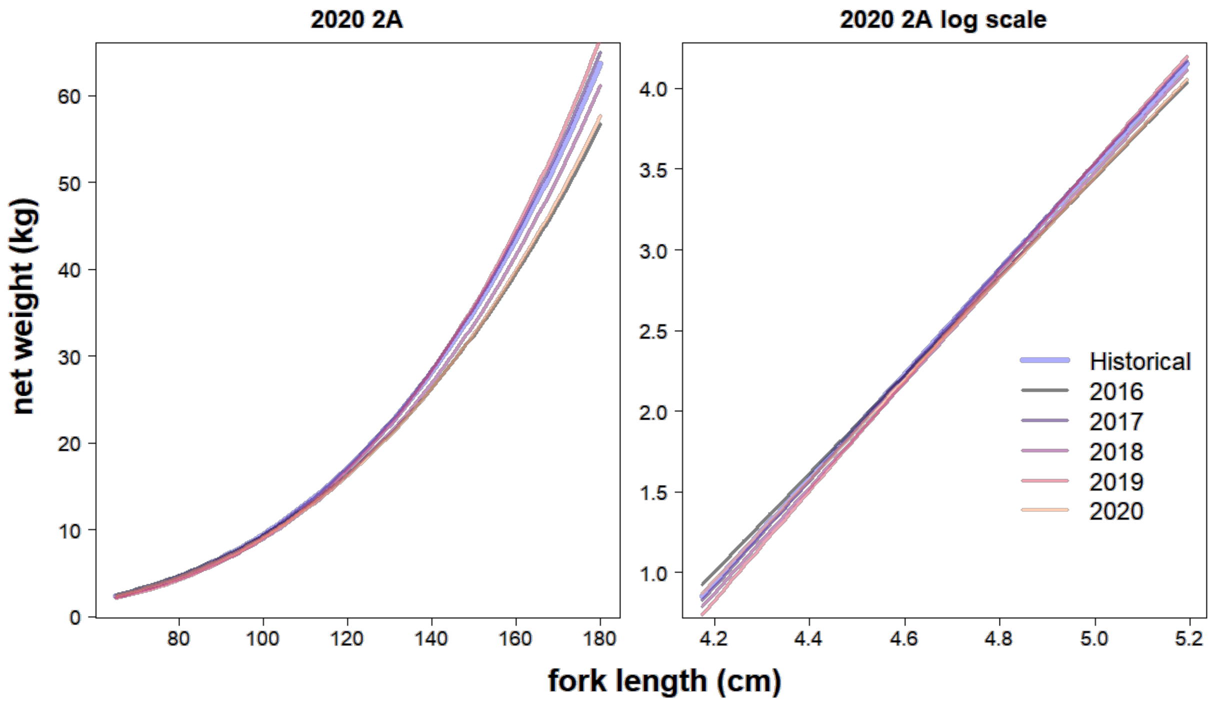

Figure 2.6 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 2A.

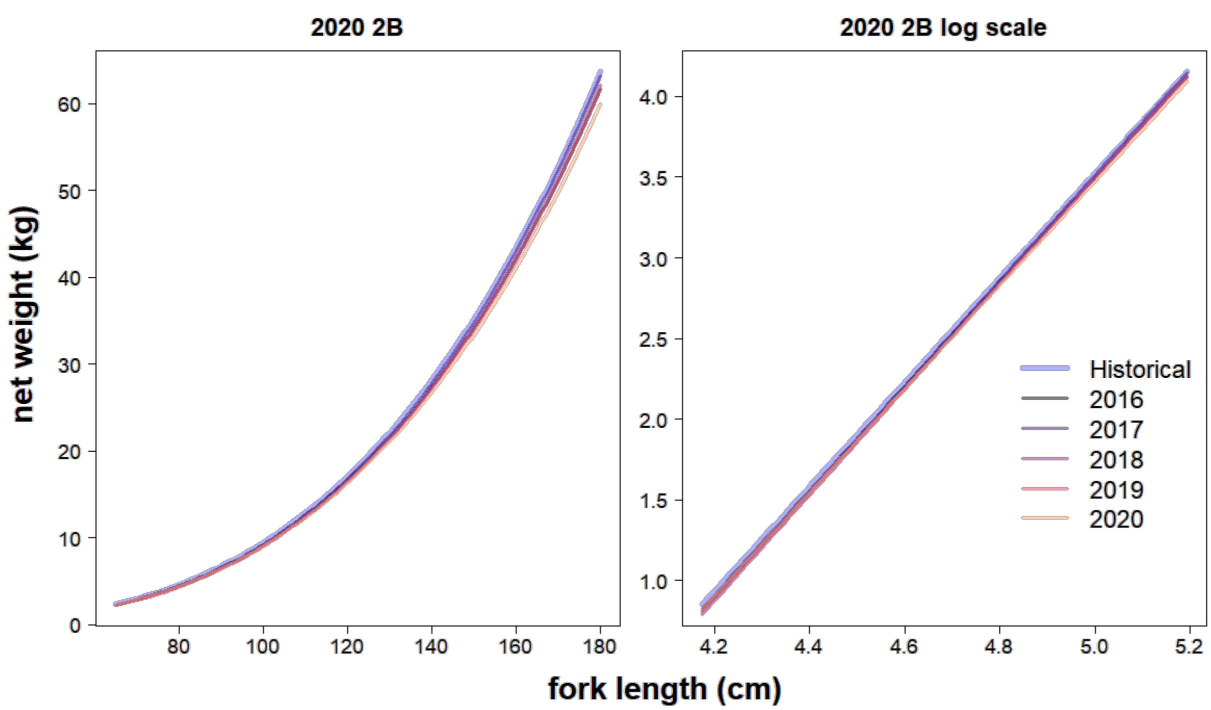

Figure 2.7 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 2B.

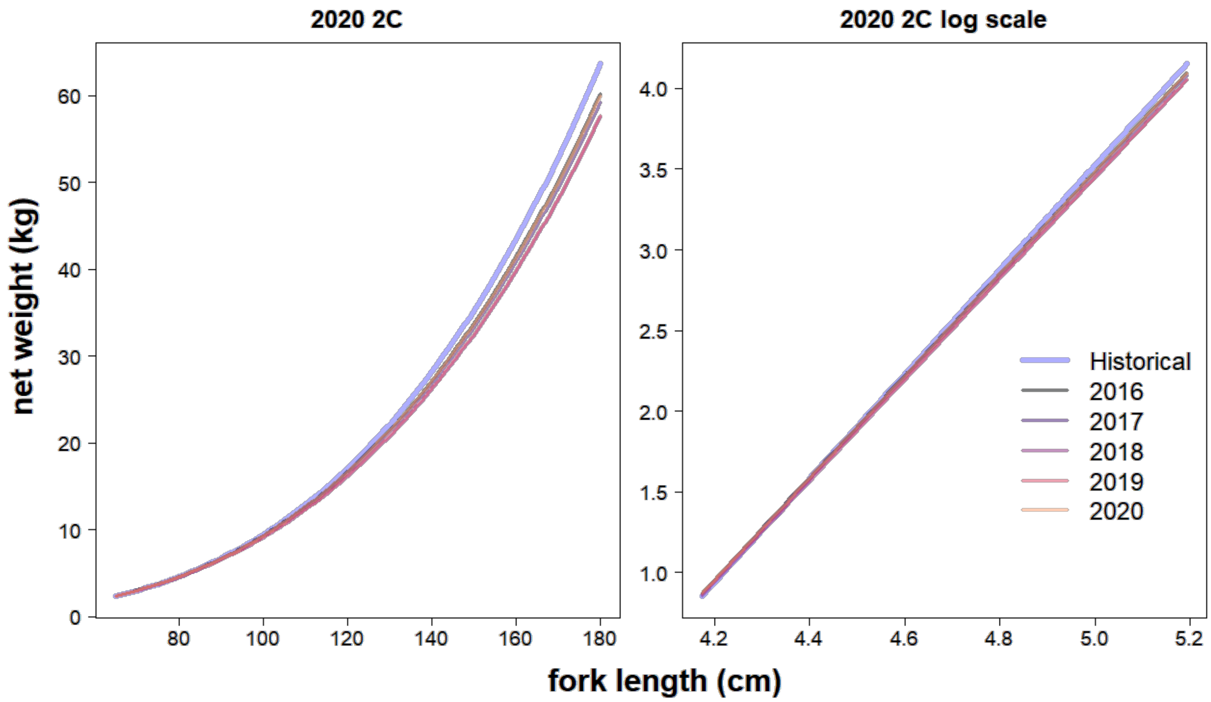

Figure 2.8 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 2C.

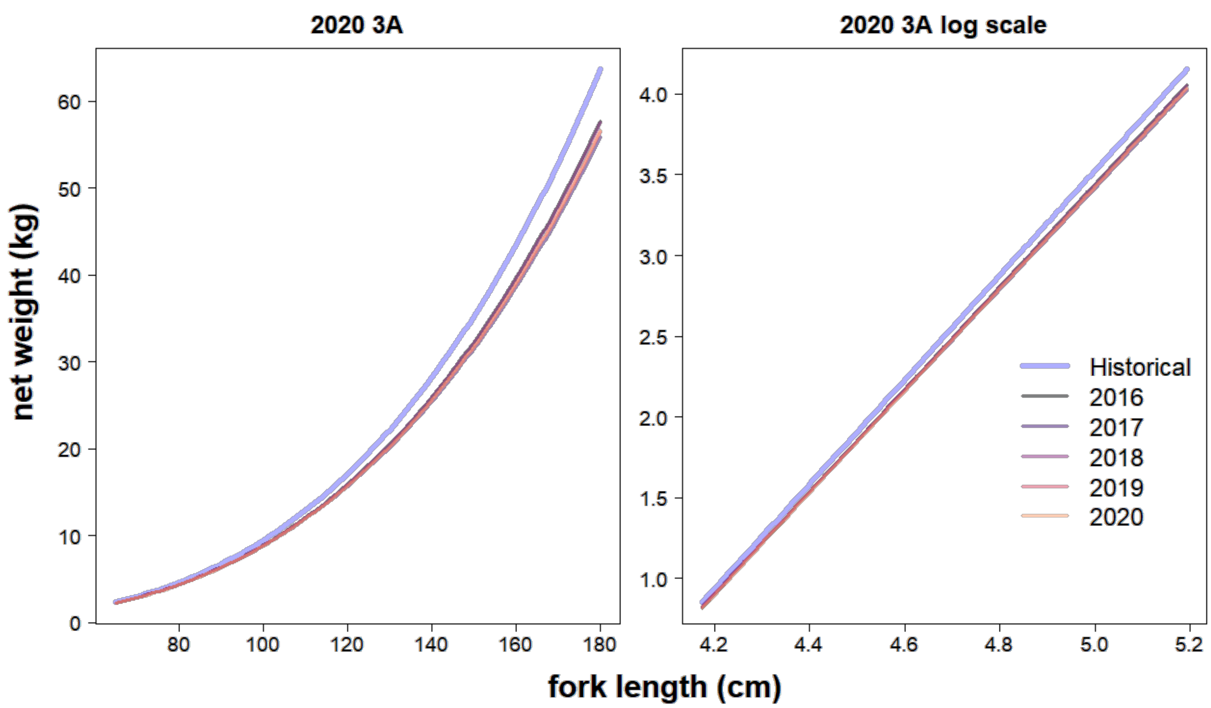

Figure 2.9 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 3A.

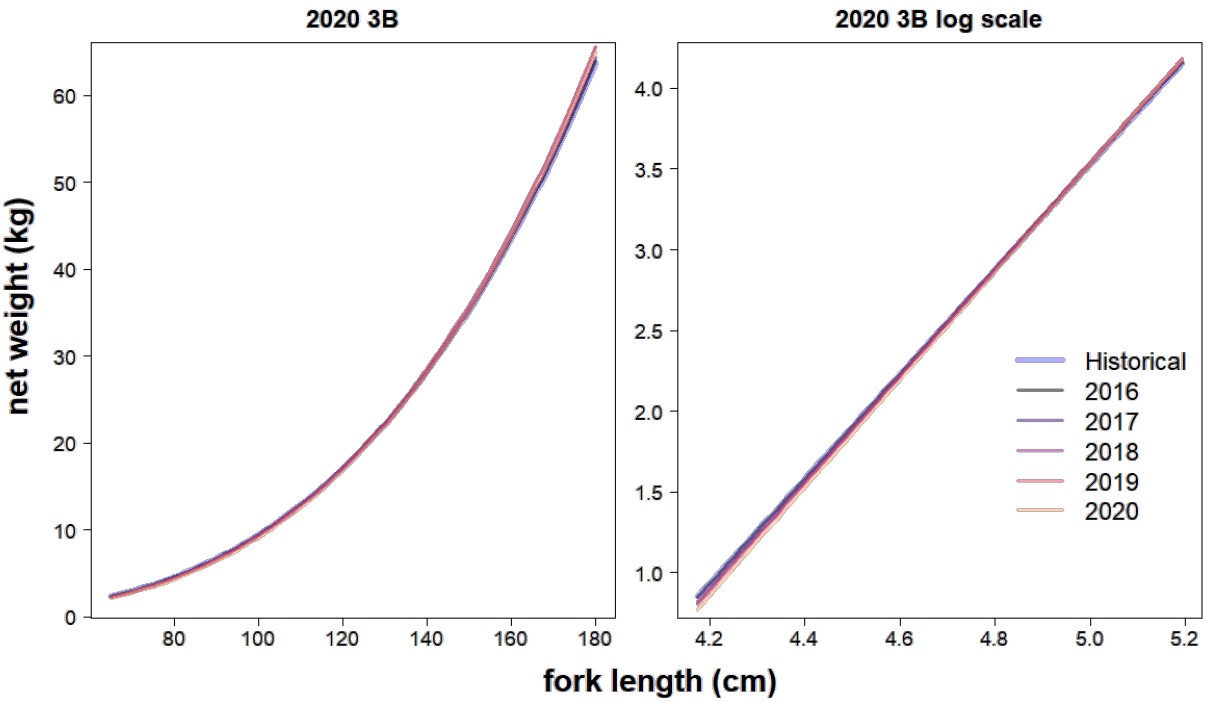

Figure 2.10 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 3B.

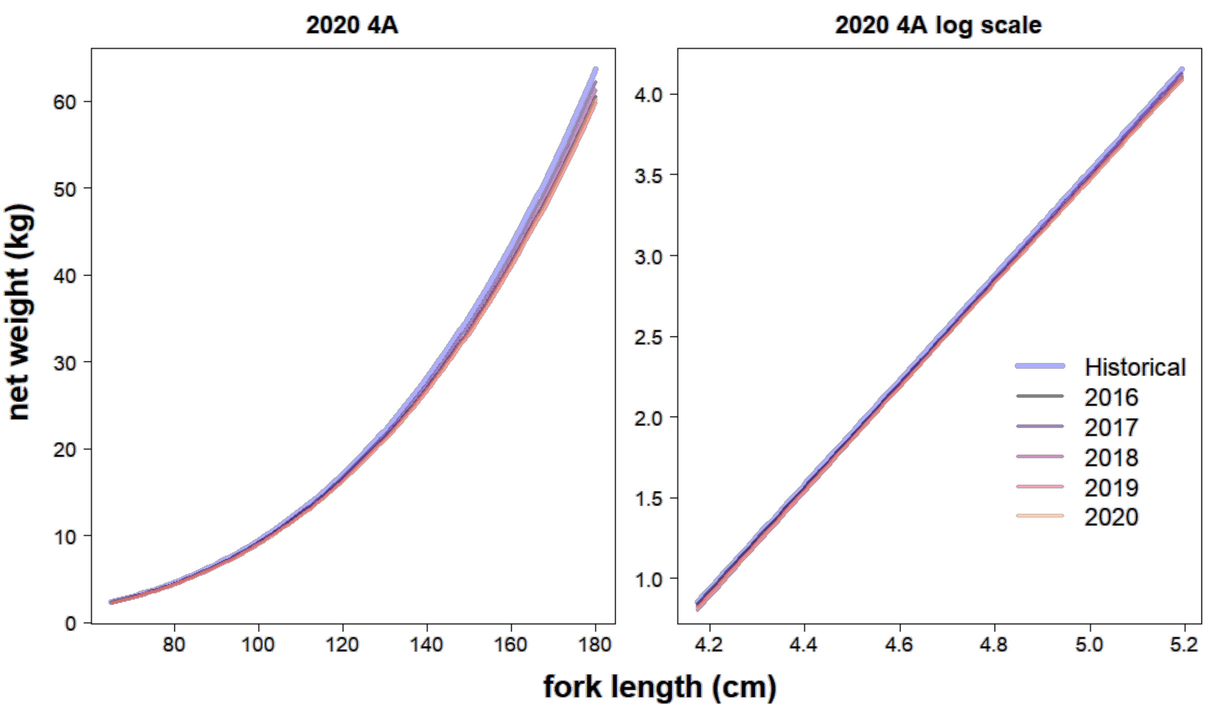

Figure 2.11 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 4A.

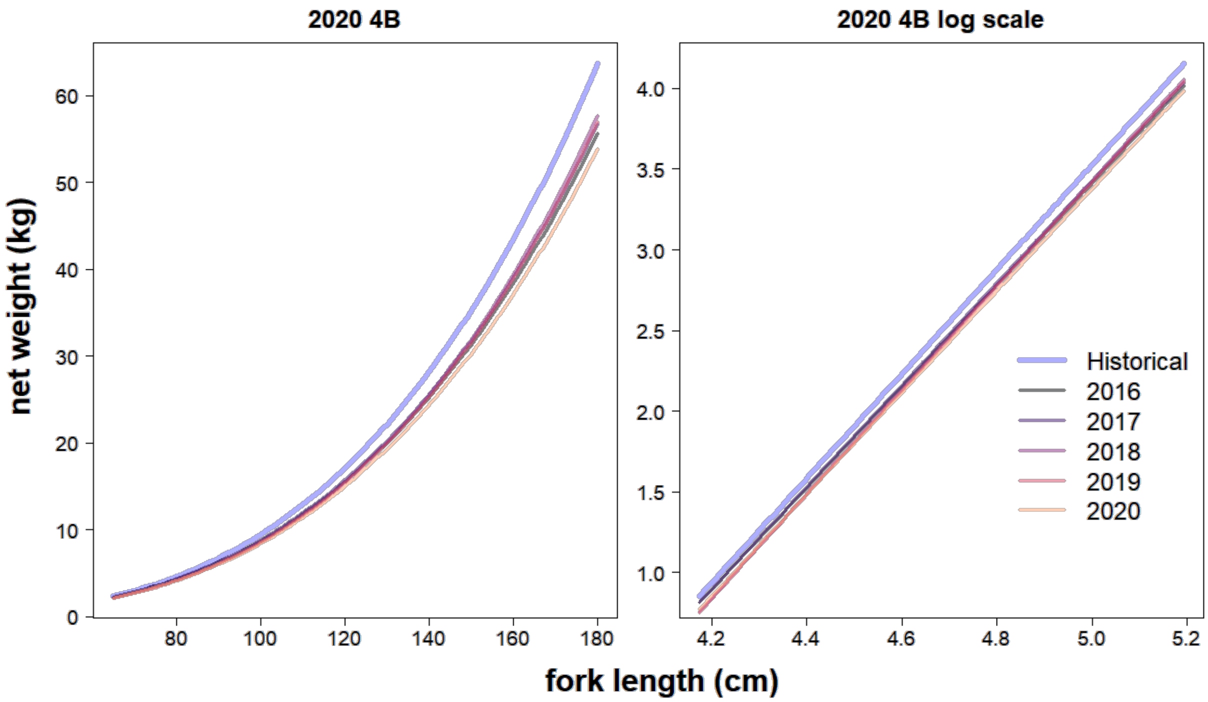

Figure 2.12 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 4B.

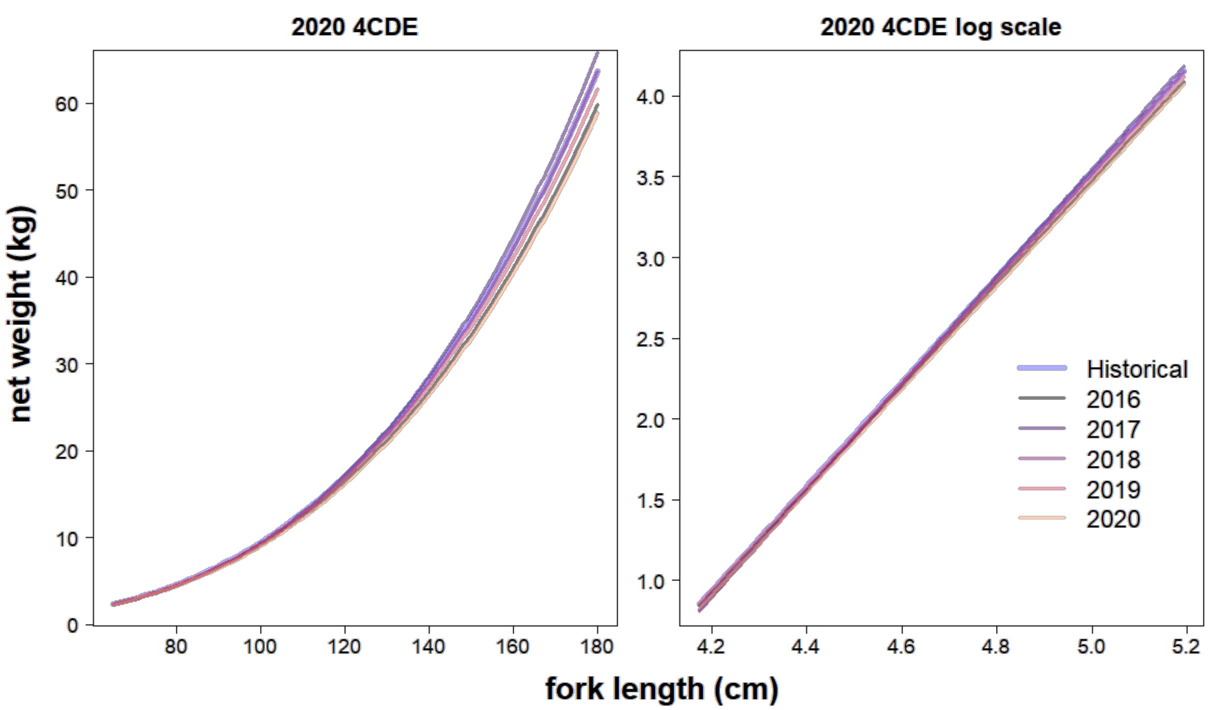

Figure 2.13 Comparison of estimated length-net weight curves from commercial data by year for IPHC Regulatory Area 4CDE.

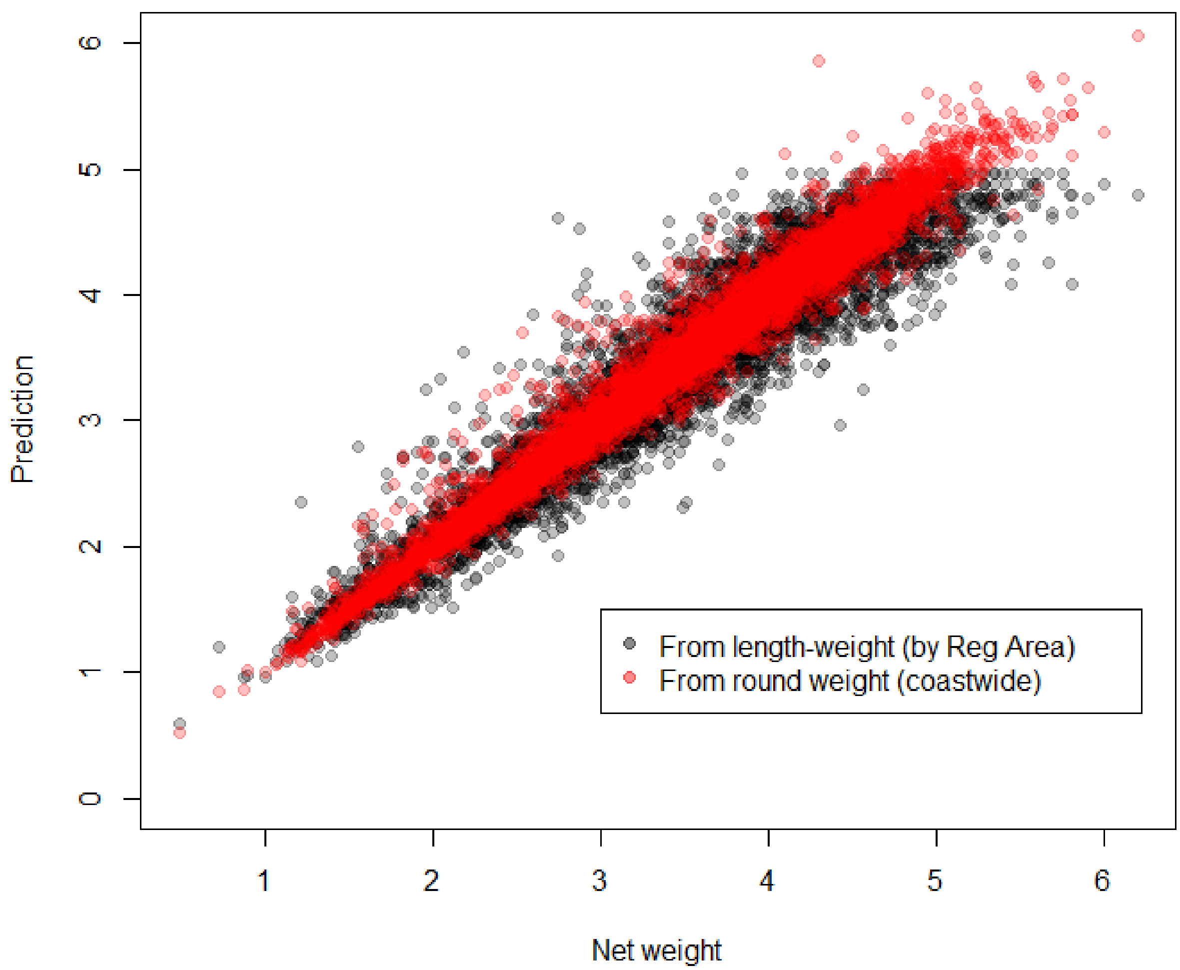

Figure 2.14 Model prediction of net weight from estimated length-net weight relationship (by IPHC Regulatory Area) and estimated coastwide relationship between net weight and round weight.

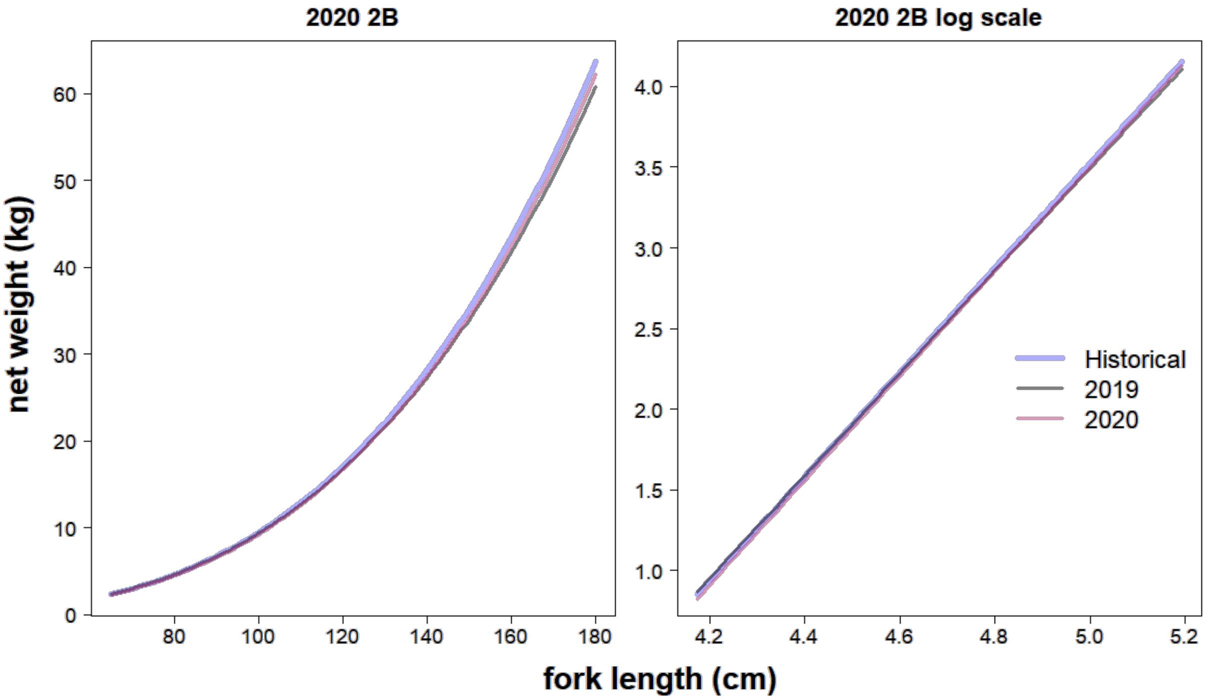

Figure 2.15 Comparison of estimated length-net weight curves from FISS data by year for IPHC Regulatory Area 2B.

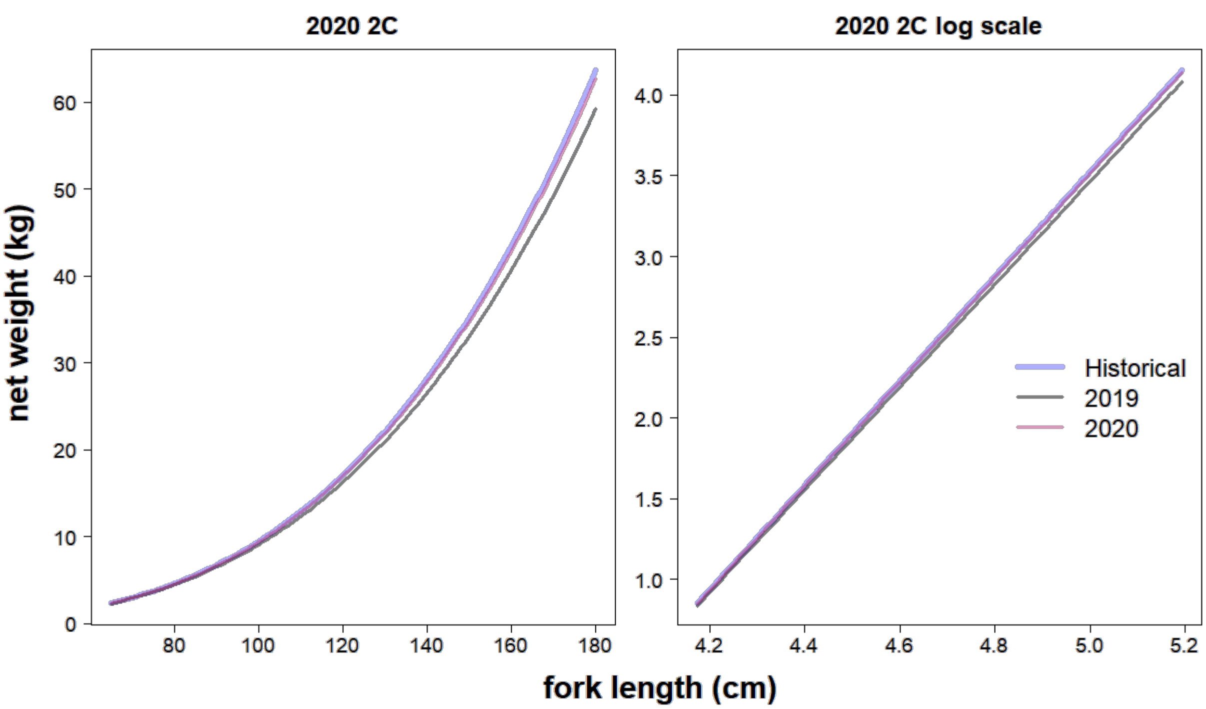

Figure 2.16 Comparison of estimated length-net weight curves from FISS data by year for IPHC Regulatory Area 2C.

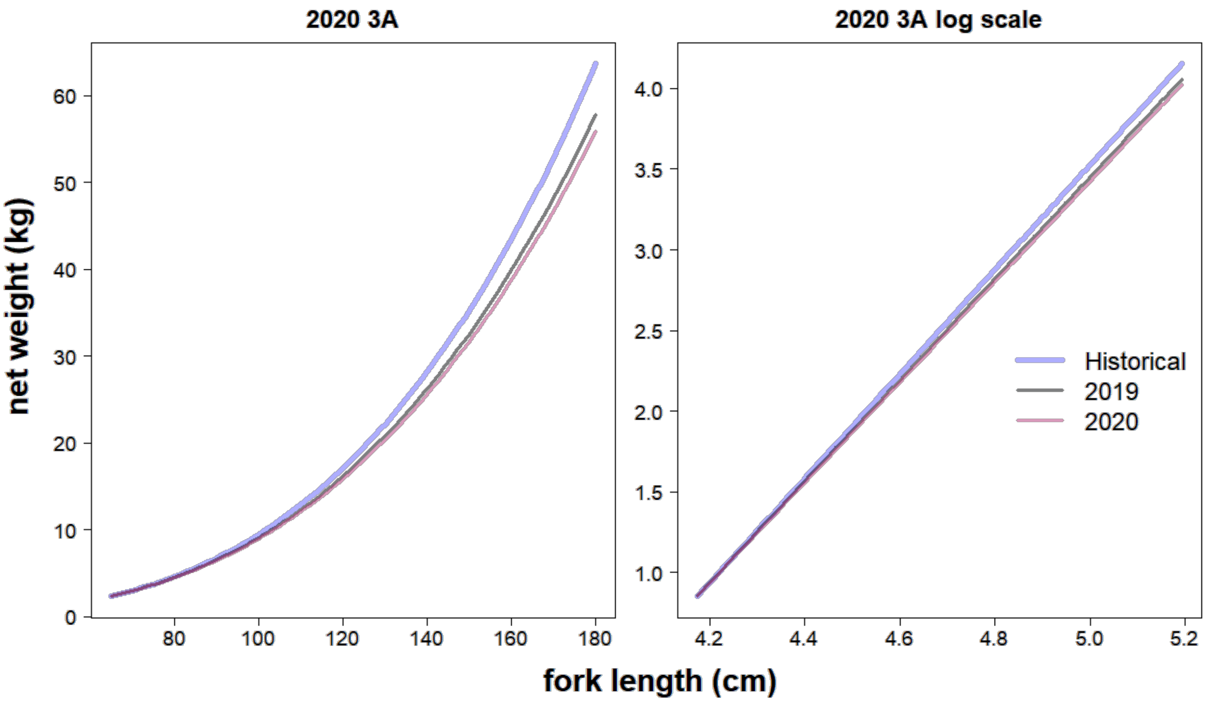

Figure 2.17 Comparison of estimated length-net weight curves from FISS data by year for IPHC Regulatory Area 3A.

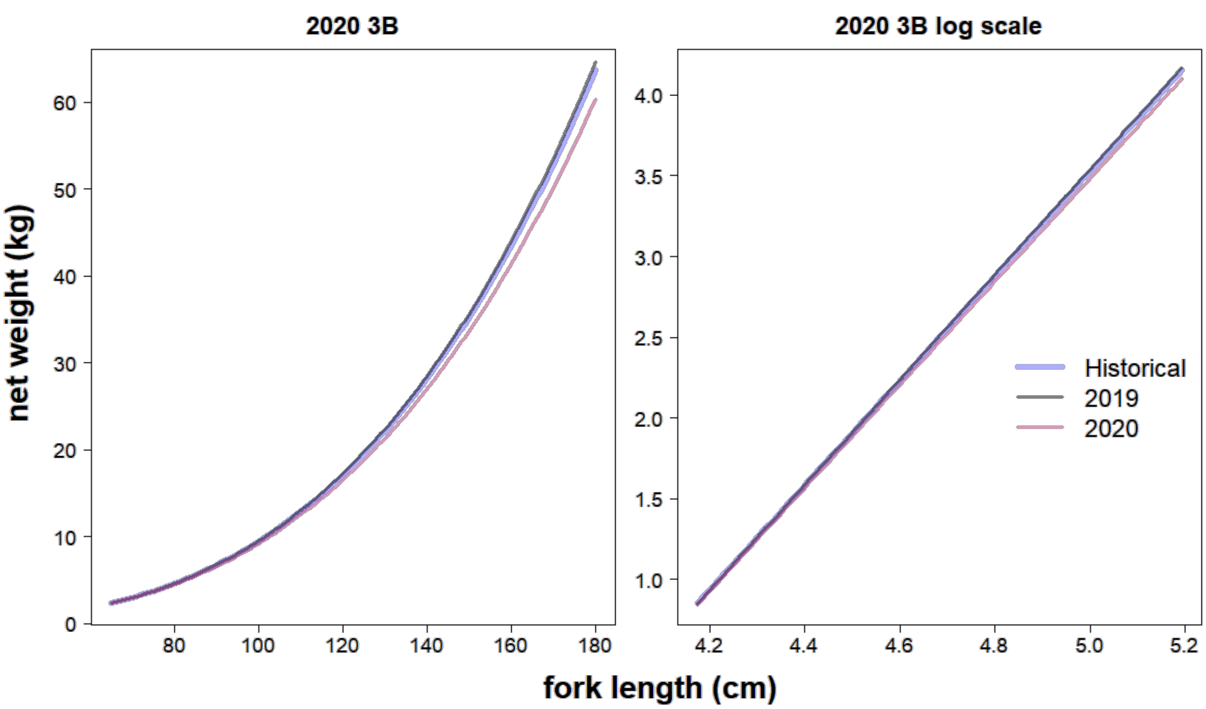

Figure 2.18 Comparison of estimated length-net weight curves from FISS data by year for IPHC Regulatory Area 3B.

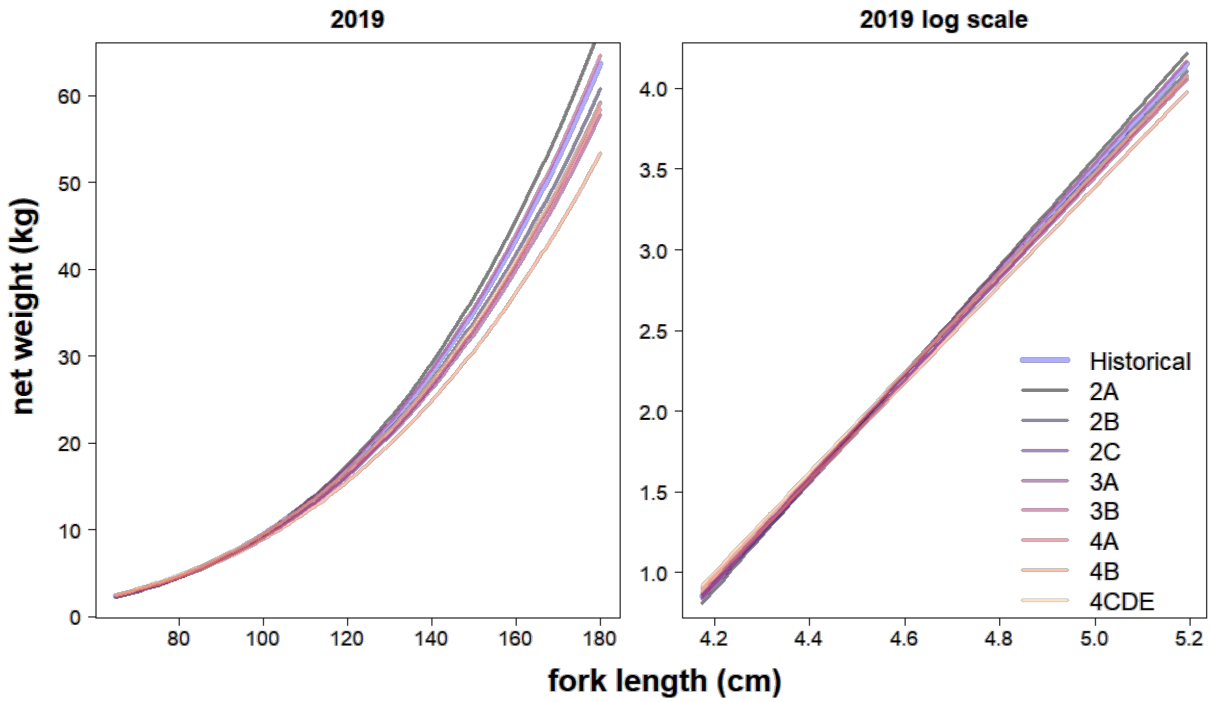

Figure 2.19 Comparison of estimated length-net weight curves from FISS data by IPHC Regulatory for 2019.

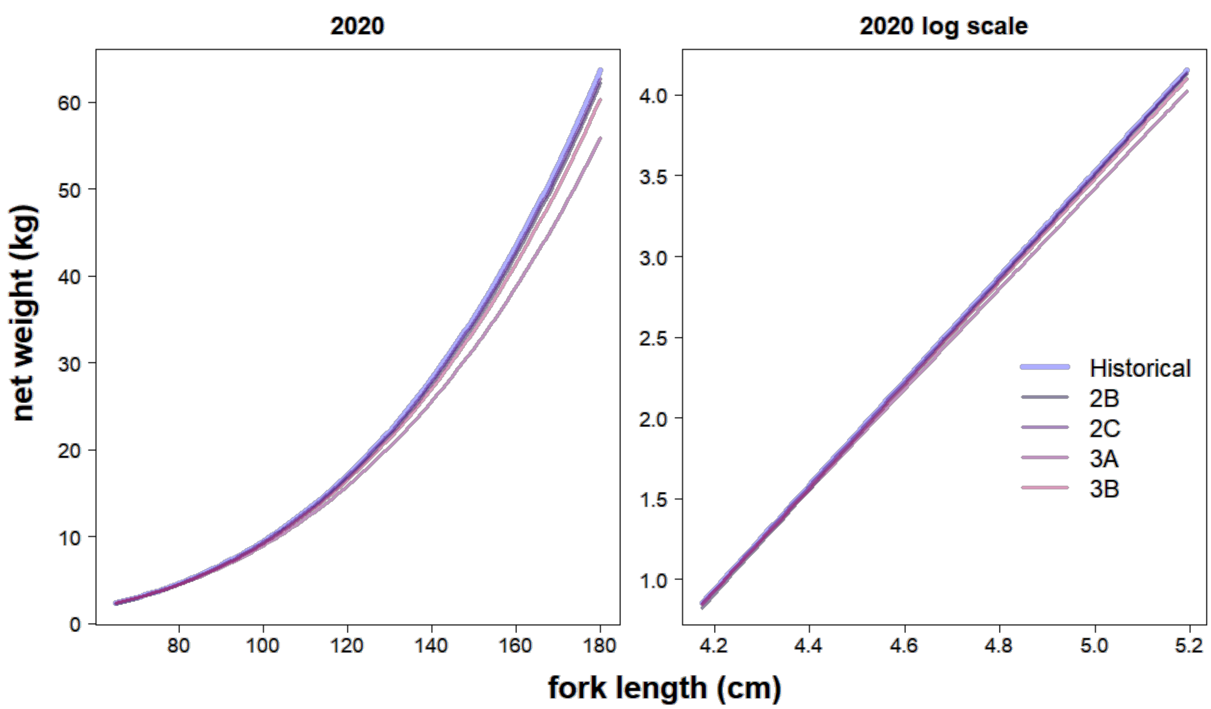

Figure 2.20 Comparison of estimated length-net weight curves from FISS data by IPHC Regulatory for 2020.

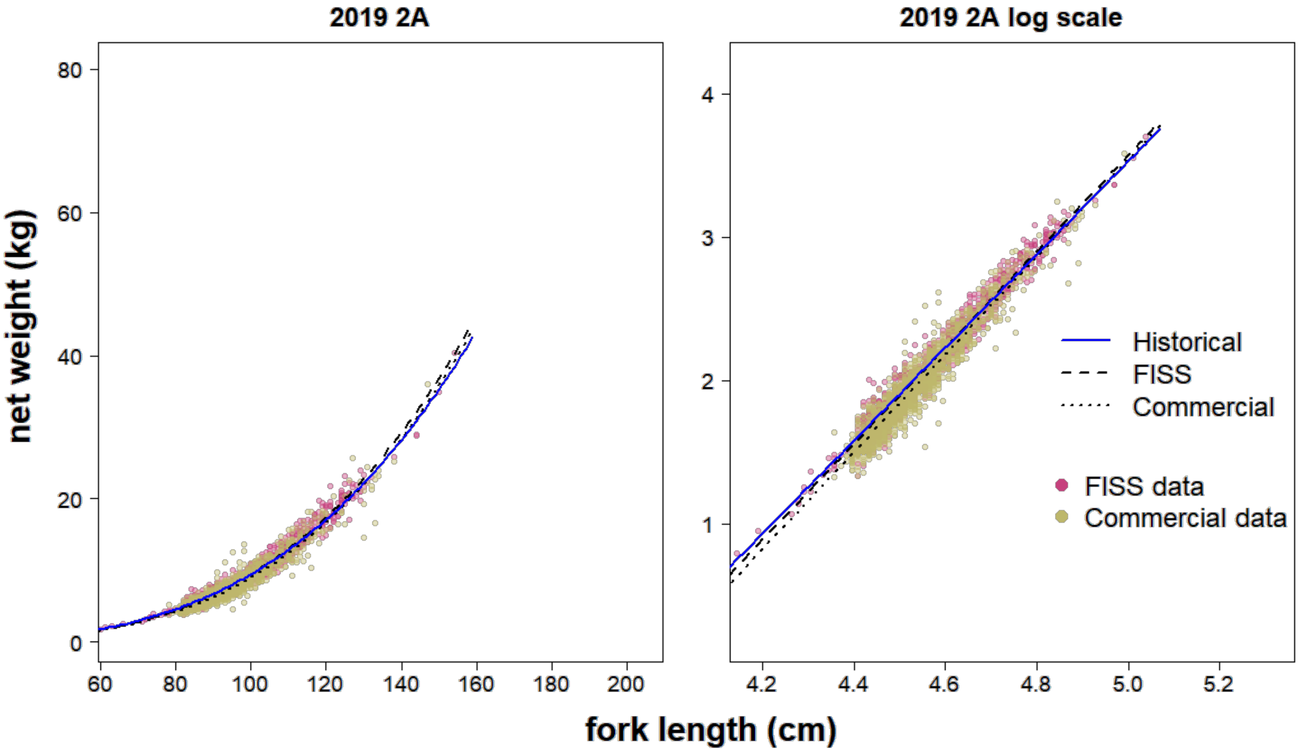

Figure 2.21 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 2A in 2019.

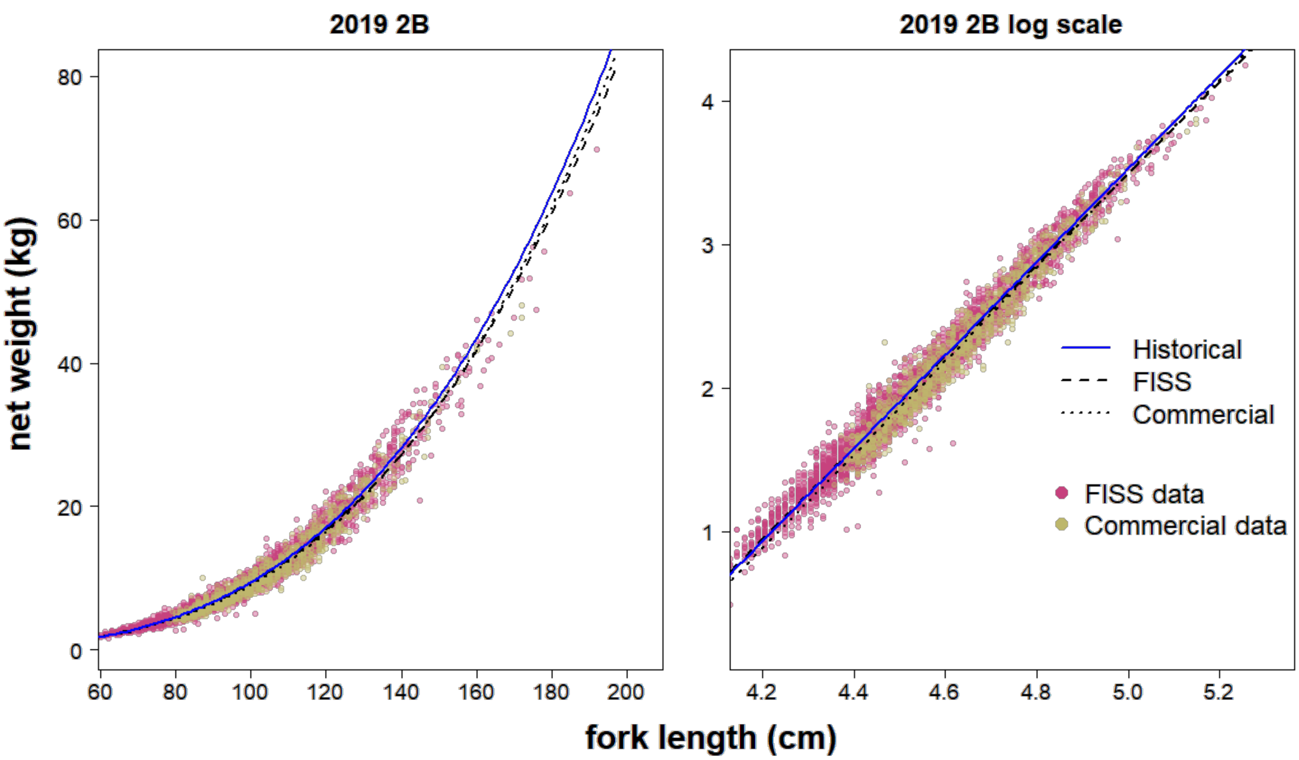

Figure 2.22 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 2B in 2019.

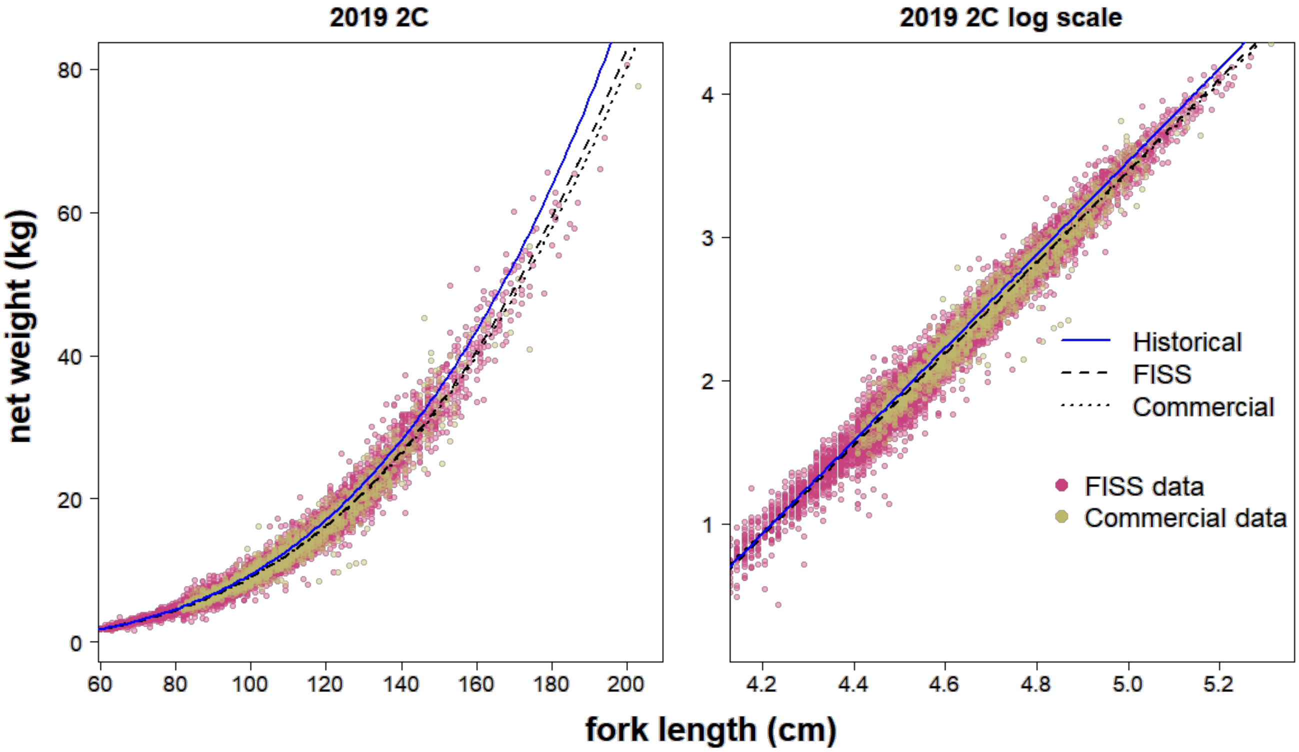

Figure 2.23 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 2C in 2019.

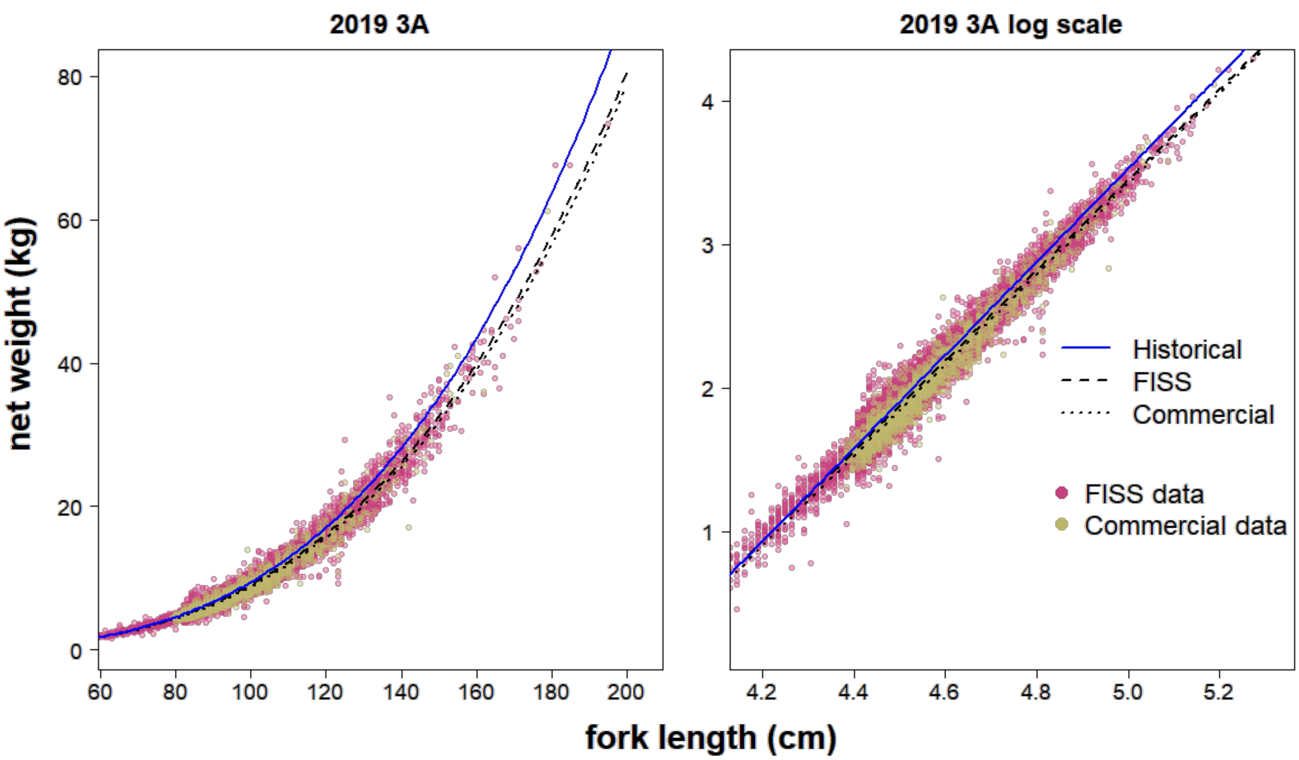

Figure 2.24 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 3A in 2019.

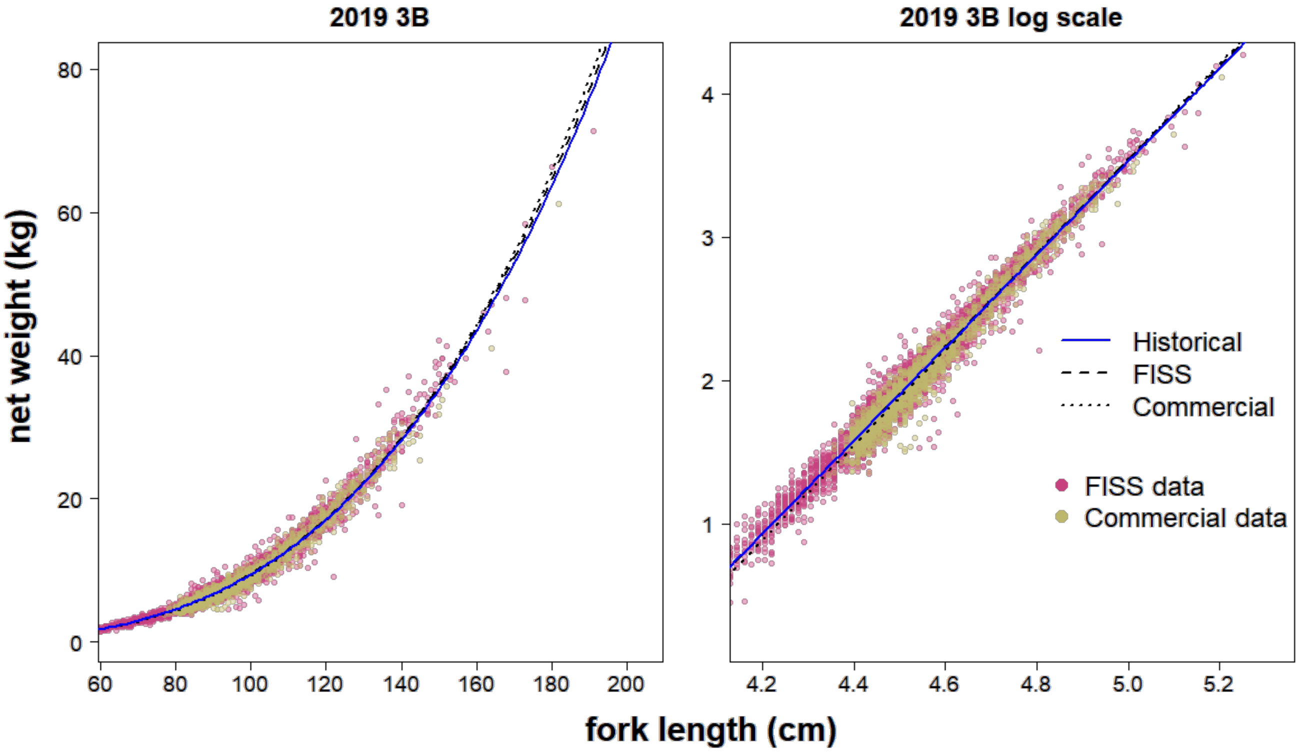

Figure 2.25 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 3B in 2019.

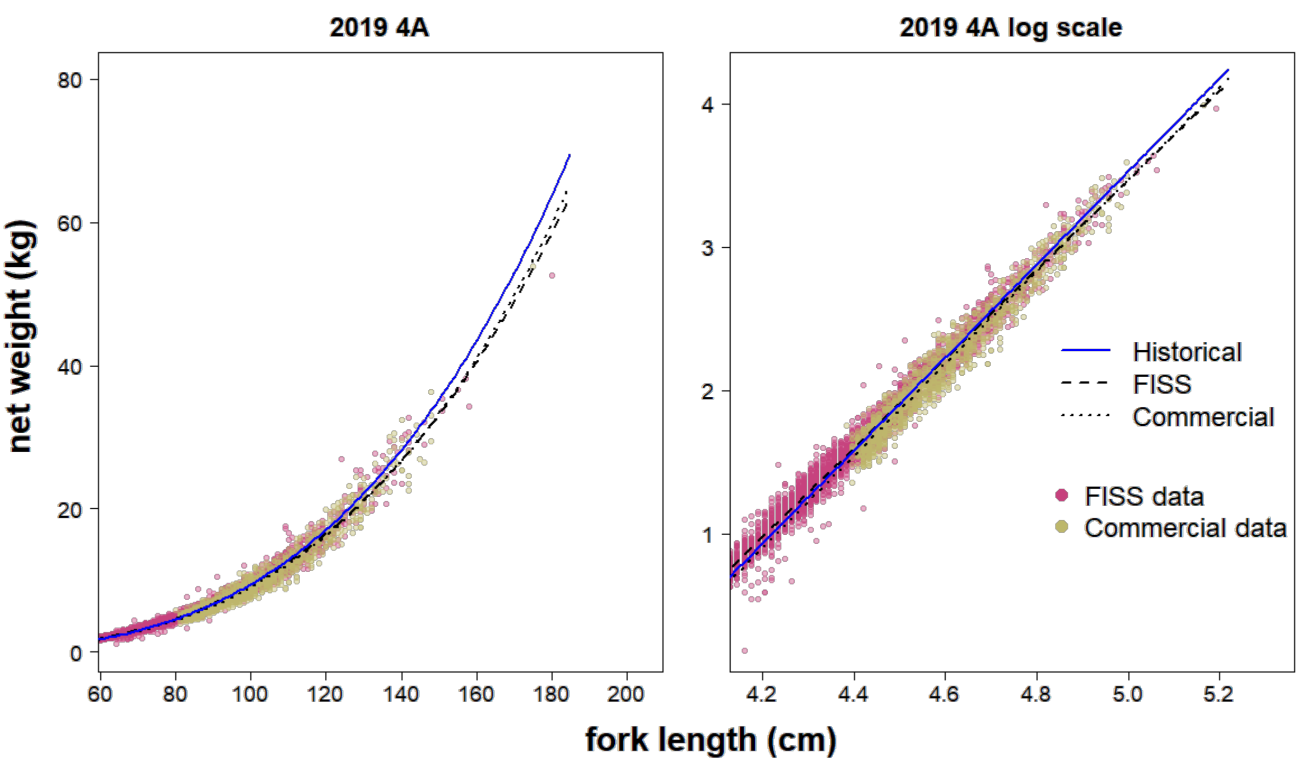

Figure 2.26 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 4A in 2019.

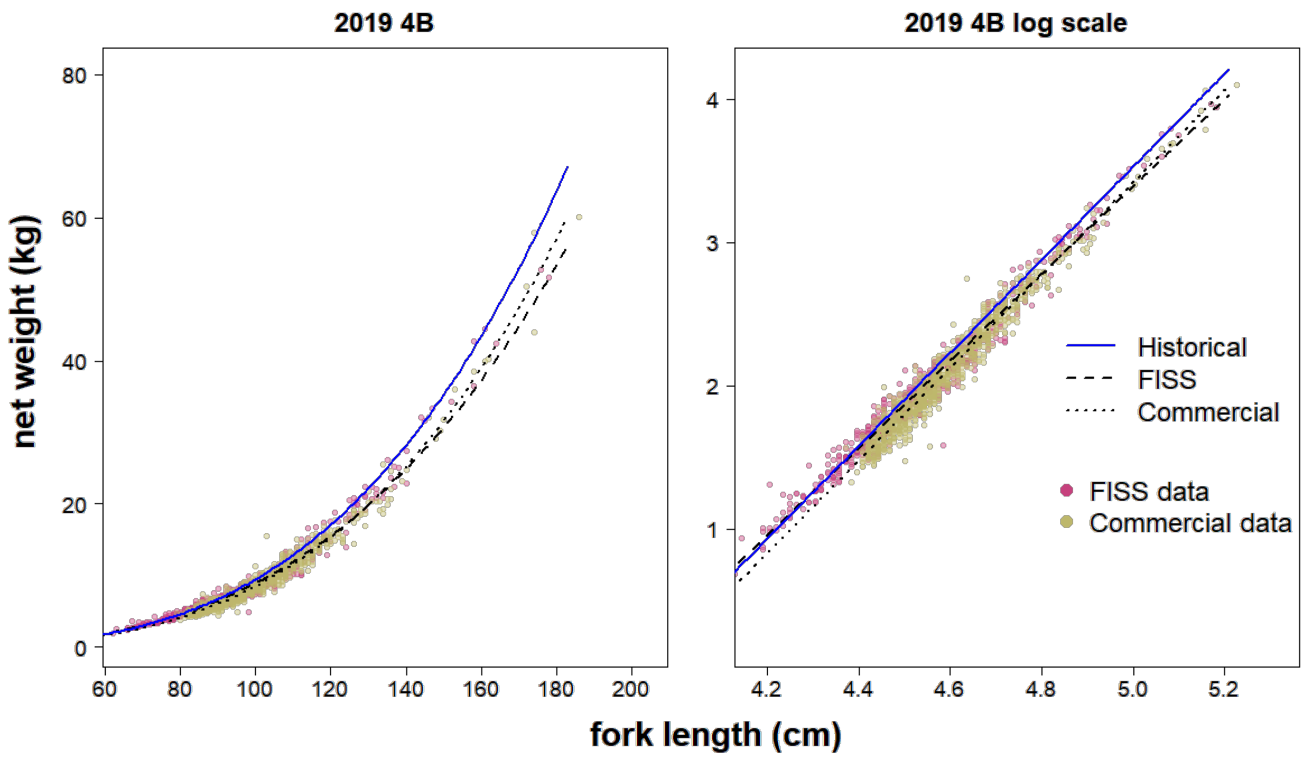

Figure 2.27 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 4B in 2019.

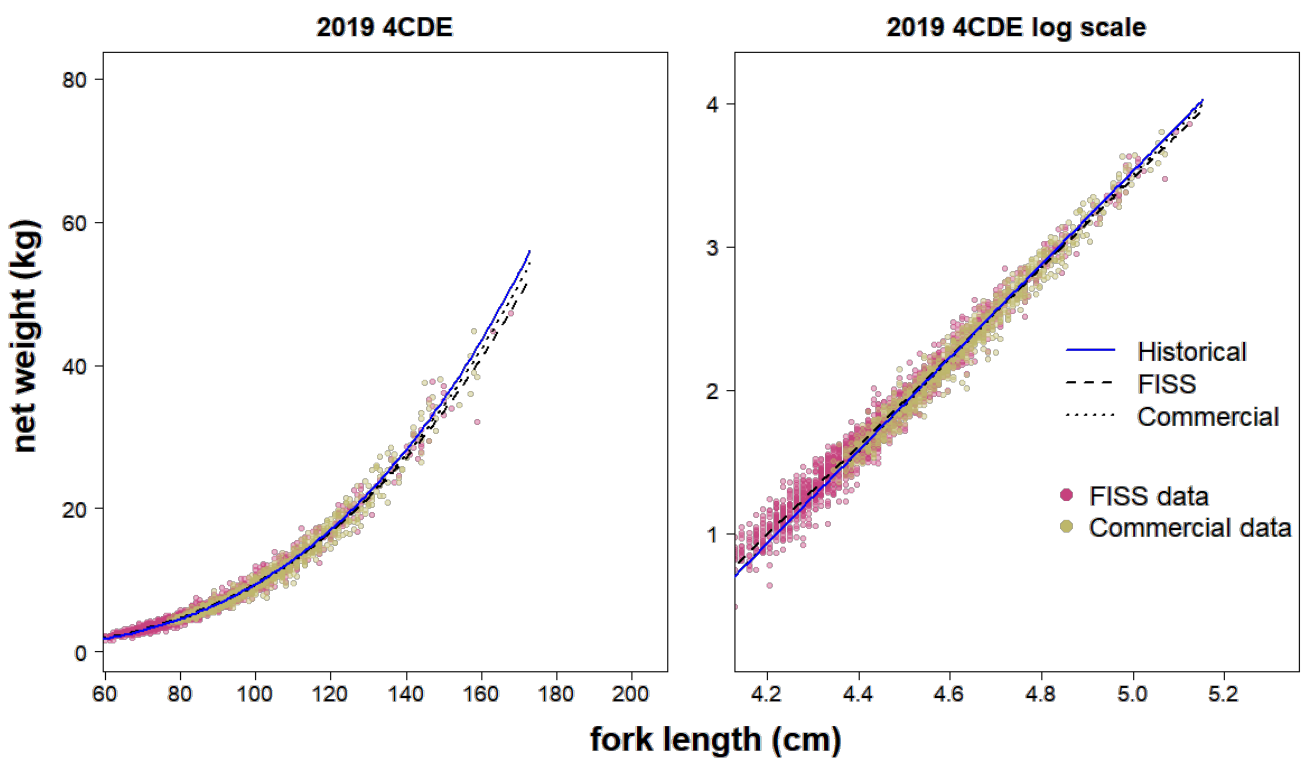

Figure 2.28 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 4CDE in 2019.

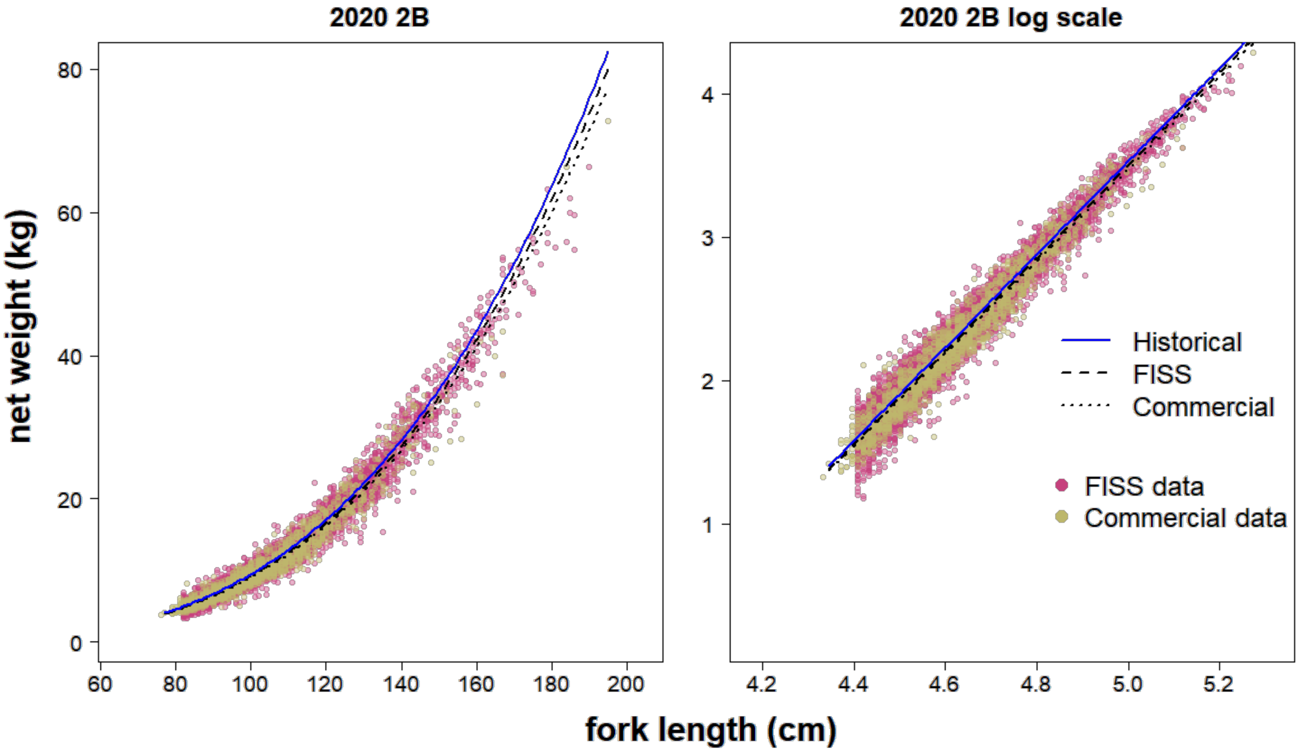

Figure 2.29 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 2B in 2020.

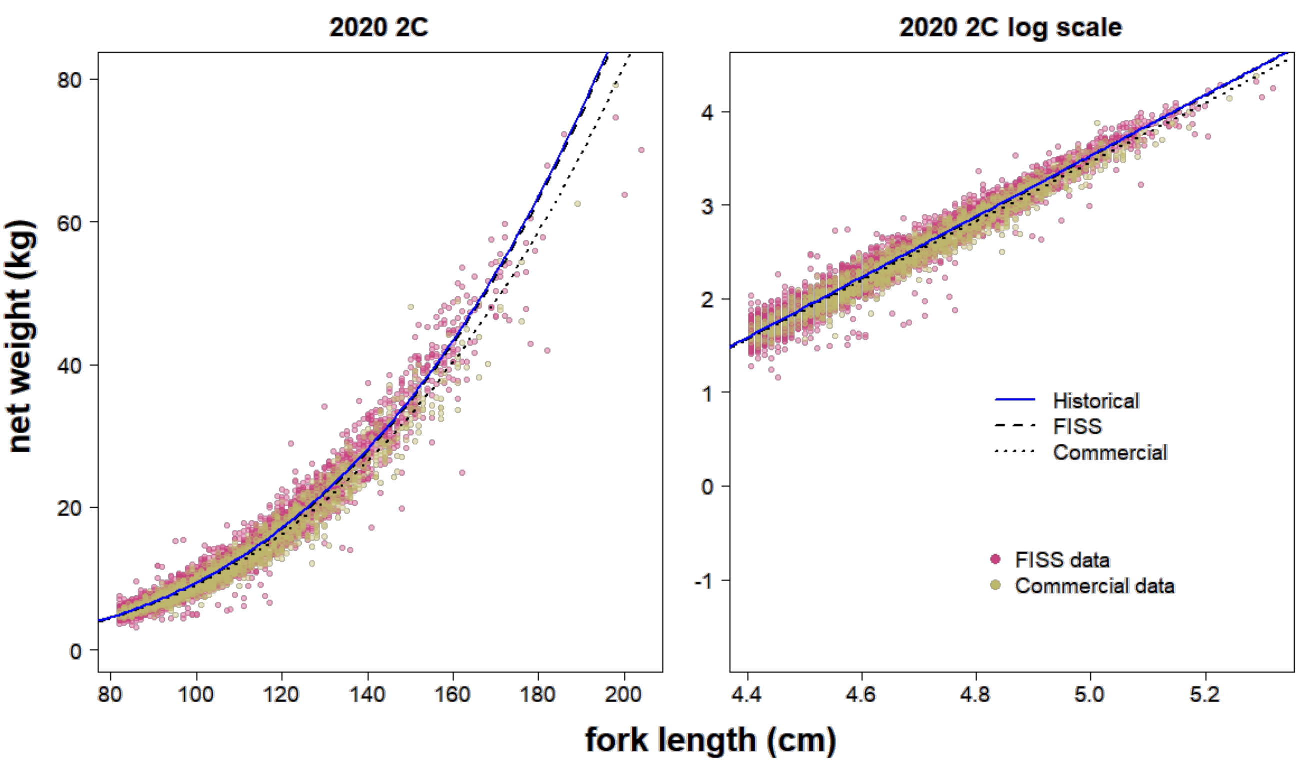

Figure 2.30 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 2C in 2020.

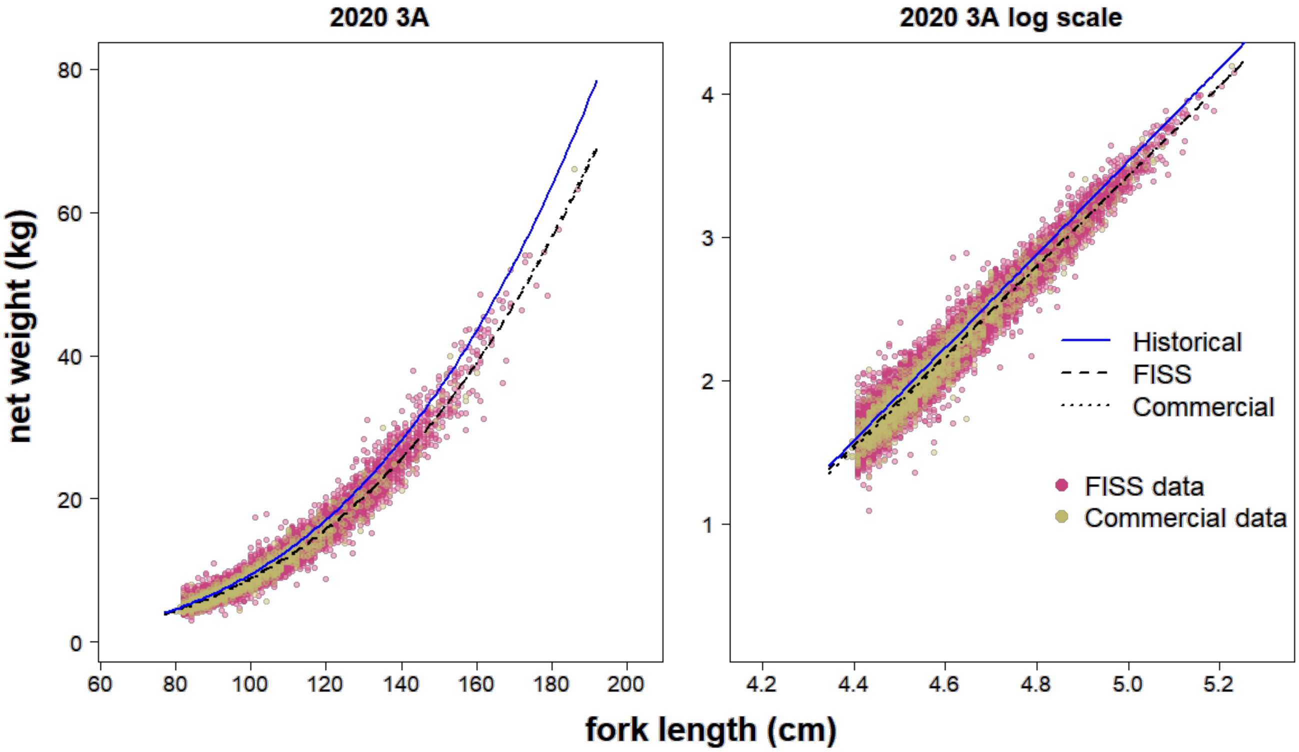

Figure 2.31 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 3A in 2020.

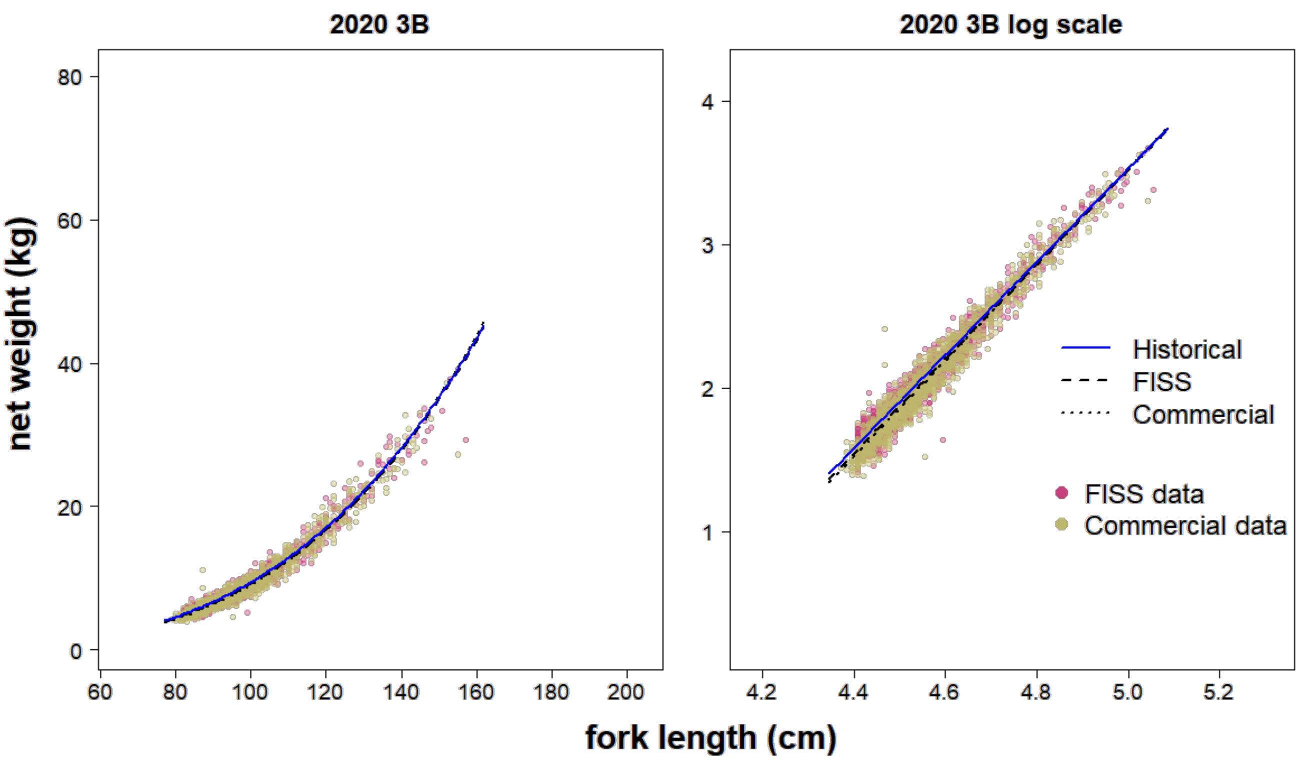

Figure 2.32 Comparison of estimated length-net weight curves from FISS and commercial data for IPHC Regulatory Area 3B in 2020.

Part 3: Review of IPHC hook competition standardization

PURPOSE

To provide a review of the IPHC approach to standardizing WPUE and NPUE for competition for baits on the Fishery-Independent Setline Survey (FISS). A short discussion of IPHC experiments with hook timers is also provided.

BACKGROUND/INTRODUCTION

In 2007, the IPHC transitioned from IPHC Regulatory Area-specific stock assessments to a coastwide stock assessment. At the same time, the IPHC began using the O32 WPUE index (including all fish over 32 inches, 81 cm, in length; this corresponds to the current directed commercial fishery minimum size limit for landings) from the FISS to estimate the distribution of the stock among IPHC Regulatory Areas. In order to address concerns that such an index can be affected by catchability differences among areas, Secretariat staff devised adjustments intended to standardise the index for at least some contributors to catchability differences. The most important of these, and one of only two standardisations still applied (along with an adjustment for FISS timing), is the hook competition standardisation. Originally devised as an average adjustment applied at the IPHC Regulatory Area level, with the introduction of the space-time model for estimating WPUE and NPUE indices, this was updated to a station-specific adjustment in 2016, as supported by the SRB (IPHC-2016-SRB09-R).

STANDARDIZATION FOR HOOK COMPETITION

Gear saturation is the process by which catch rates decrease disproportionately to abundance as the sampling gear becomes fully occupied. Although it may be present for many types of sampling gear, for longline gear, as deployed by the IPHC, gear saturation may be considered via competition for the finite number of hooks deployed. The IPHC method for standardisation for hook competition was developed by Clark (2008), and was based on the number of baits removed on FISS sets, B_i, by predator species *i*. The Baranov catch equation was used to model the B_i, the number of baits removed by predator *i* after a time period, *T*:

$$B_i = B_0 \frac{F_i}{Z}\left(1 - e^{-ZT}\right)$$

Here F_i is the instantaneous rate of bait removal by predator *i*, B_0 is the initial number of baited hooks, and *Z* is the sum of the instantaneous rates applied by all bait takers. It follows that the expected catch (*C*) of halibut (*h*), which is one of the bait predators, is given by

$$C_h = B_0 \frac{F_h}{Z}\left(1 - e^{-ZT}\right) \quad (1)$$

For the FISS sets, soak time is assumed to be of sufficient length that catches of all species are unaffected by the exact value of *T*. For simplicity, we therefore set *T*=1 in the above equations. It is further assumed that empty hooks are due to bait taking by species other than halibut, and, therefore, halibut do not escape once captured. In these equations, $\left(1 - e^{-Z}\right)$ (with *T*=1) is the expected fraction of baits removed by all takers during the active period. An estimate of *Z* is therefore given by $\log(B_0/B_1)$, where B_1 is the number of baits remaining when the gear is hauled.

The IPHC approach to standardising for hook competition is to treat F_h as the standardised index for Pacific halibut at a given station, which is estimated by rearranging (1) and substituting in the estimate of Z:

$$F_h = \frac{C_h}{B_0} \log\left(\frac{B_0}{B_1}\right) \frac{B_0}{B_0 - B_1} \tag{2}$$

With C_h/B_0 representing catch per unit effort, the remaining part of the right-hand side of (2) is the hook competition adjustment factor. We note that the IPHC approach has the same mathematical derivation as the method developed contemporaneously by Etienne et al. (2013).

In practice, we substitute WPUE or NPUE for C_h/B_0 in (2), for which effort is measured by the number of effective skates, rather than the count of baits set. As the adjustment factor has a lower bound of 1, the result of the standardisation would be to increase average WPUE or NPUE, with larger positive adjustments made when fewer baits are returned. To maintain the indices on a scale familiar to stakeholders, all adjustment factors are divided by the same scalar, based on the coastwide mean adjustment factor for 1998. Importantly, this approach implicitly accounts for changes in predator density, not only among stations within a sampling year, but also across years, such that a long-term change in the level of competition would be accounted for.

Pacific halibut represents the most common species captured, and therefore the largest contribution to the hook competition correction. However, non-target species (commonly dogfish, Pacific cod and others depending on the geographical area) are frequently encountered in abundance at some FISS stations every year. Missing baits are attributed to hook competition, except where they are lost during setting, in which case they are recorded as such, and the baits deployed adjusted accordingly. Aggregating by area and year, generally 5-40% of baited hooks are returned with baits, with lowest rates of return in IPHC Regulatory Area 2A (typically less than 10%) and highest in IPHC Regulatory Area 4B (20-40% each year).

To avoid the adjustment going to infinity as the number of baits returned goes to zero, a small amount (B_0/100, for our 100-hook skates) is added to both the B_0 and B_1 when computing Z. Note also that when zero Pacific halibut are captured, the multiplicative adjustment leaves the value of WPUE or NPUE unchanged at zero.

As an example, Figures 3.1-3.3 demonstrate the effect of the standardisation on O32 WPUE from IPHC Regulatory Area 2B in 2018. This was a year in which dogfish captures were higher than normal in parts of the area, leading to lower bait returns and negatively impacting the observed survey catch of Pacific halibut. Figure 3.1 shows the hook competition adjustment factors for each station, while Figures 3.2 and 3.3 respectively plot O32 WPUE by station before and after application of the hook competition standardisation (i.e., before and after multiplication by the factors in Figure 3.1).

IPHC HOOK TIMER STUDIES

Historical work on hook timers (Kaimmer 2011, Parma et al. 1995) was intended to produce data on the rate of bait capture by Pacific halibut and competing species. However, the timers in use in those studies were not tripped most of the time, and it appears they were not sensitive to the capture of smaller fish or to smaller fish taking the bait without being captured (Parma et al. 1995).

The IPHC is currently collaborating on a study of standard and modified circle hooks that will use hook timers to record the capture time of different species. Modern hook timers are expected to be more sensitive than those used in historical studies, and it is therefore hoped that this study will yield data that will help inform the calculation of the hook competition standardisation.

RECOMMENDATION

That the Scientific Review Board:

1) **NOTE** paper IPHC-2021-SRB019-05.3 that presents an overview of the IPHC standardization for hook competition on FISS sets.

References

Clark, W.G. 2008. Effect of hook competition on survey CPUE. Int. Pac. Halibut Comm. Report of Research and Assessment Activities 2007: 211-215.

Etienne M. P., Obradovich S. Yamanaka L. and McAllister M. 2013. Extracting abundance indices from longline surveys: method to account for hook competition and unbaited hooks. Preprint arXiv:1005.0892v3

IPHC 2016. Report of the 9th Session of the IPHC Scientific Review Board (SRB) IPHC-2016-SRB09-R. 5 p.

Kaimmer, S. M. 2011. Special setline experiments 1985-1994 objectives, data formats, and collections. IPHC Technical Report 53.

Parma, A. M., Kaimmer, S. M. and Sullivan, P. J. 1995. A progress report on the use of hook timers and underwater observations to assess the effect of bait competition on CPUE. Int. Pac. Halibut Comm. Report of Research and Assessment Activities 1994: 211-221.

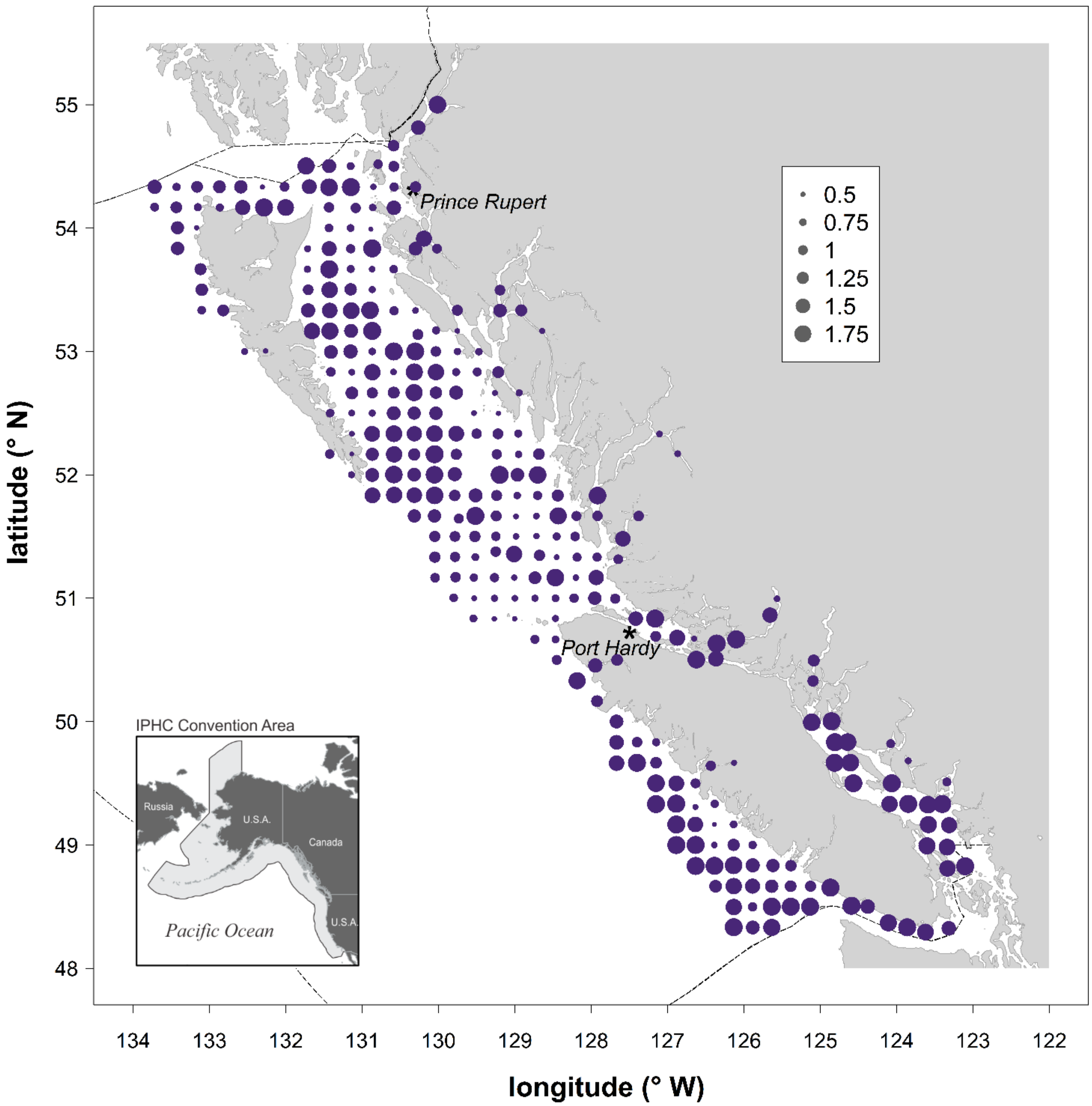

Figure 3.1. Hook competition adjustment factors for each station in IPHC Regulatory Area 2B in 2018. Larger circles are due to greater competition for baits (fewer baits returned), while smaller circles are a result of lower levels of competition.

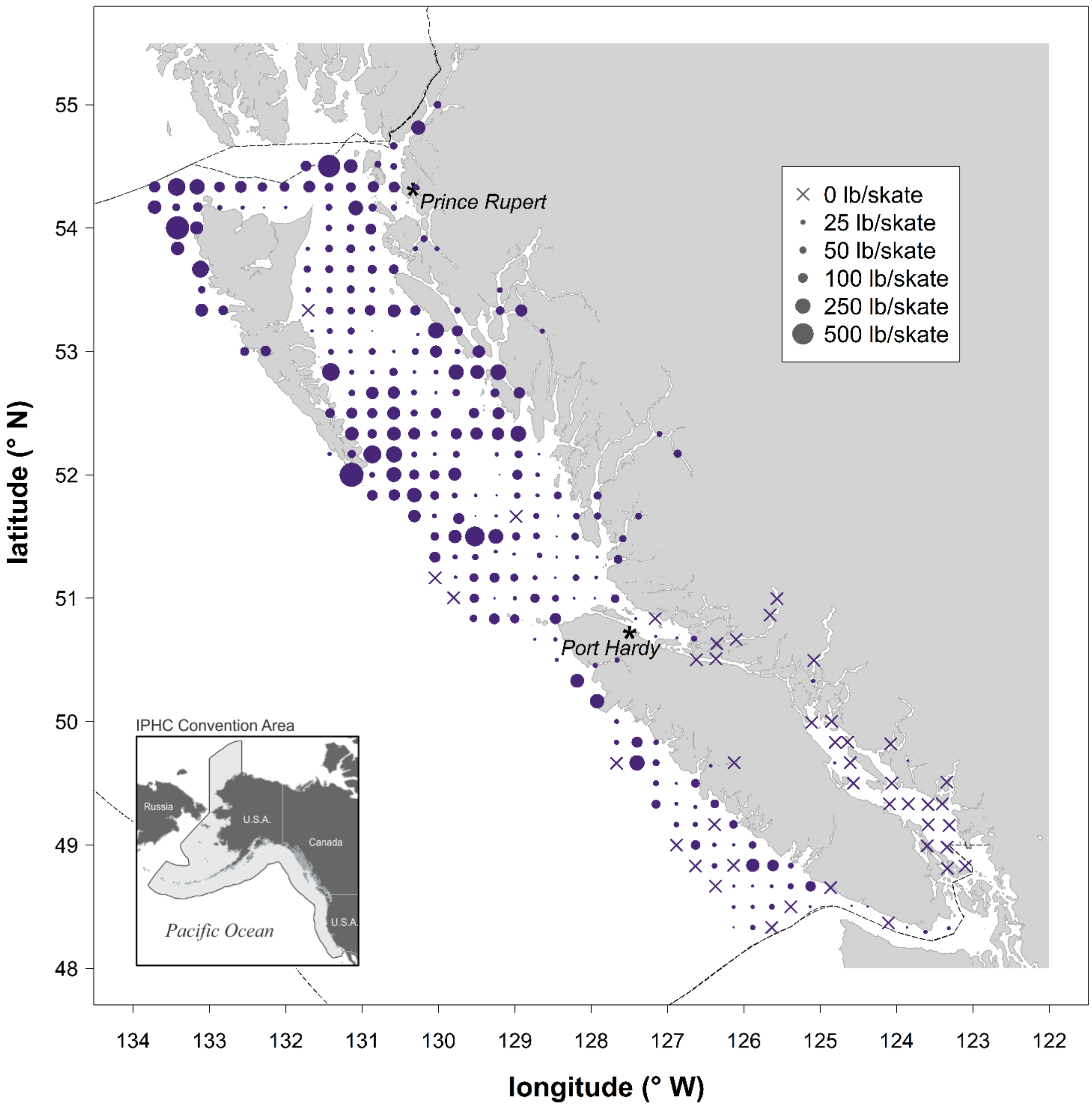

Figure 3.2. Raw O32 WPUE (lb/skate) for each station in IPHC Regulatory Area 2B in 2018.

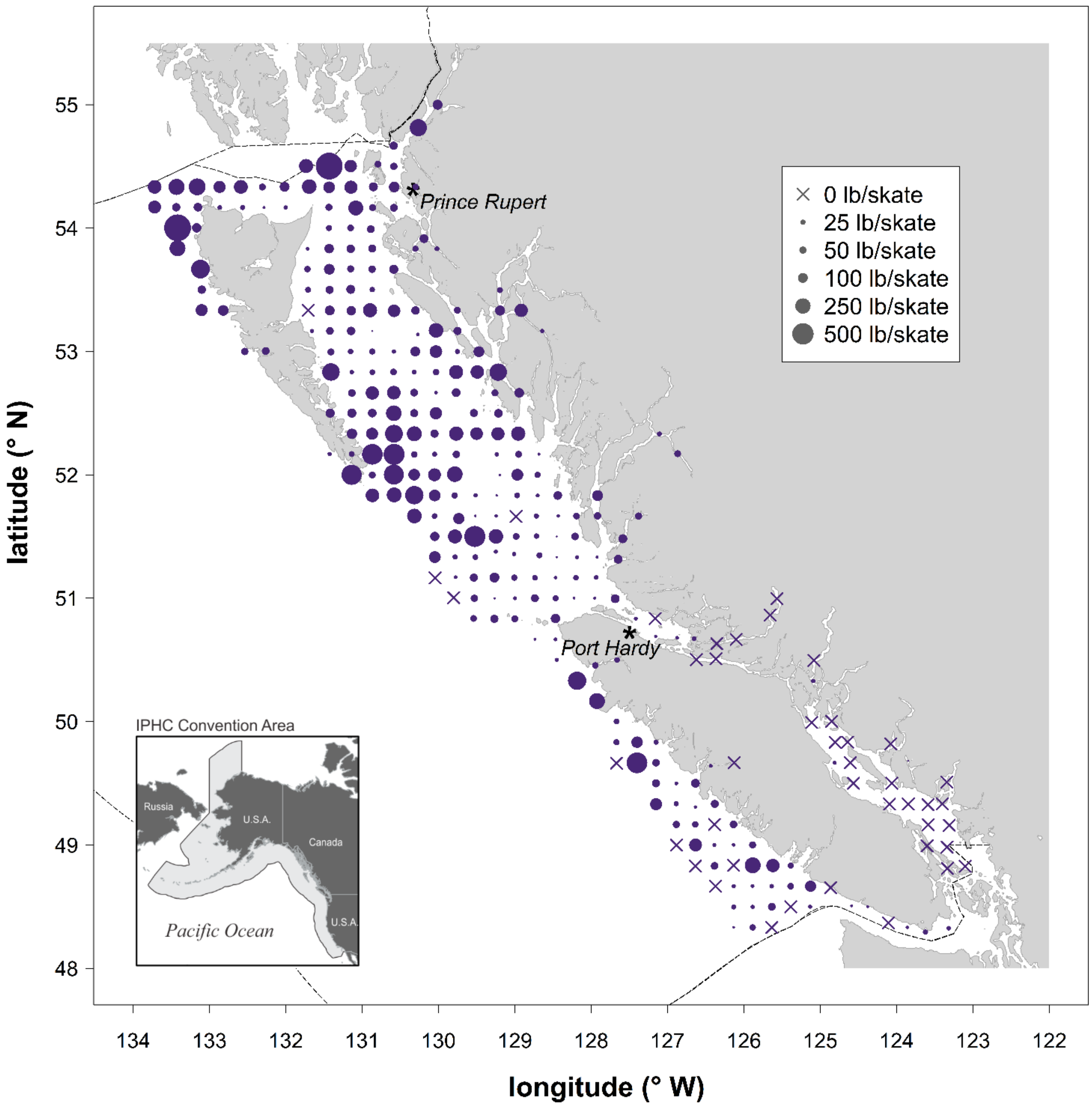

Figure 3.3. O32 WPUE (lb/skate) for each station standardized for hook competition in IPHC Regulatory Area 2B in 2018.

Part 4: Accounting for the effects of whale depredation on the FISS

PURPOSE

To describe a simple approach for accounting for the effects of whale depredation on FISS catch rates within the space-time model.

BACKGROUND/INTRODUCTION

The presence of sperm whales and orcas during the fishing and hauling of FISS sets can lead to such sets being designated as ineffective for the use in analyses due to the potential impact on recorded catch rates Pacific halibut of depredation by these marine mammals (IPHC-2021-VSM01, page 18). The criteria for ineffectiveness, which were tightened in 2019, are as follows:

- Sperm whales: a sperm whale is spotted within 3 nmi of the boat while hauling gear
- Orcas: a set has more than 1 lips-only Pacific halibut or a set has other observations of orca feeding on Pacific halibut

These criteria were designed to minimize the potential for including biased data in the annual indices. Sperm whales have been found to depredate cryptically on the gear at large distances from the vessel, while orcas generally leave clear evidence of depredation or are observed in the act. Coastwide, relatively few sets are designated as ineffective due to sperm whale and orca depredation each year: from 2010-2020, 1.4-3.0% of all sets fished included sperm whales or orcas as a reason for ineffectiveness. However, the impacts can be greater for a given area and year. For example, IPHC Regulatory Area 3A has had up to 6% of sets affected by whales (mainly sperm whales), while IPHC Regulatory Area 4A is the area most affected by orca encounters, with over 10% of sets affected in some years. In the latter case, the FISS expansion year of 2014 has 12% of sets designated as ineffective with sperm whales or orcas given as a reason. Given that several of those sets have only been fished once prior to 2021, the effect of the loss of data on estimates of density indices may be disproportionate.

We propose a simple solution to allow data from sets affected by whale depredation to be included in the estimation of WPUE and NPUE (weight and numbers per unit effort) indices of density: include binary (0=no whale; 1=whale) covariates in the space-time model for sets with whale depredation ineffectiveness codes. By estimating a parameter for the difference between affected and unaffected sets, we can make use of valuable data that would otherwise be excluded from analysis, while basing index estimation only on prediction at a zero value of the covariate (i.e., no whale effects for the standardized indices).

IPHC REGULATORY AREA 4A

As noted above, IPHC Regulatory Area 4A is the area with the greatest proportion of sets affected by whale interactions, almost all of which are interactions with orcas (139 orca sets from 1993-2020 and three sperm whale sets). We refitted the space-time model (see IPHC-2021-SRB018-05 Rev_1, Appendix B for details) to the O32 WPUE 1993-2020 data series, including sets with ineffectiveness codes for either orca or sperm whale interactions but omitting whale-affected sets that also included another ineffectiveness reason (e.g., both orcas and gear issues). As few sets with zero catch were ineffective due to whale interactions, we included the whale covariate in the non-zero model component (noting also that additional modelling showed no evidence of an effect on the probability of zero WPUE, supporting this choice).

The value of the coefficient transforms to 0.51 (95% CI: 0.43 – 0.60) on the original scale, i.e., O32 WPUE on whale-affected sets is estimated to be 51% of that on unaffected sets on average. Figure 4.1 compares the estimated O32 WPUE time series calculated from predictions at all FISS stations in IPHC Regulatory Area 4A for a model that excludes all whale-affected sets ("Excluded") and the model fitted here, that includes those sets but adjusts for the effect of whales by predicting with the whale covariate set to 0 ("Included (adjusted)"). The means of both time series are very close across all years, but we see an improvement in precision (narrower 95% CIs) when the whale-affected sets are included.

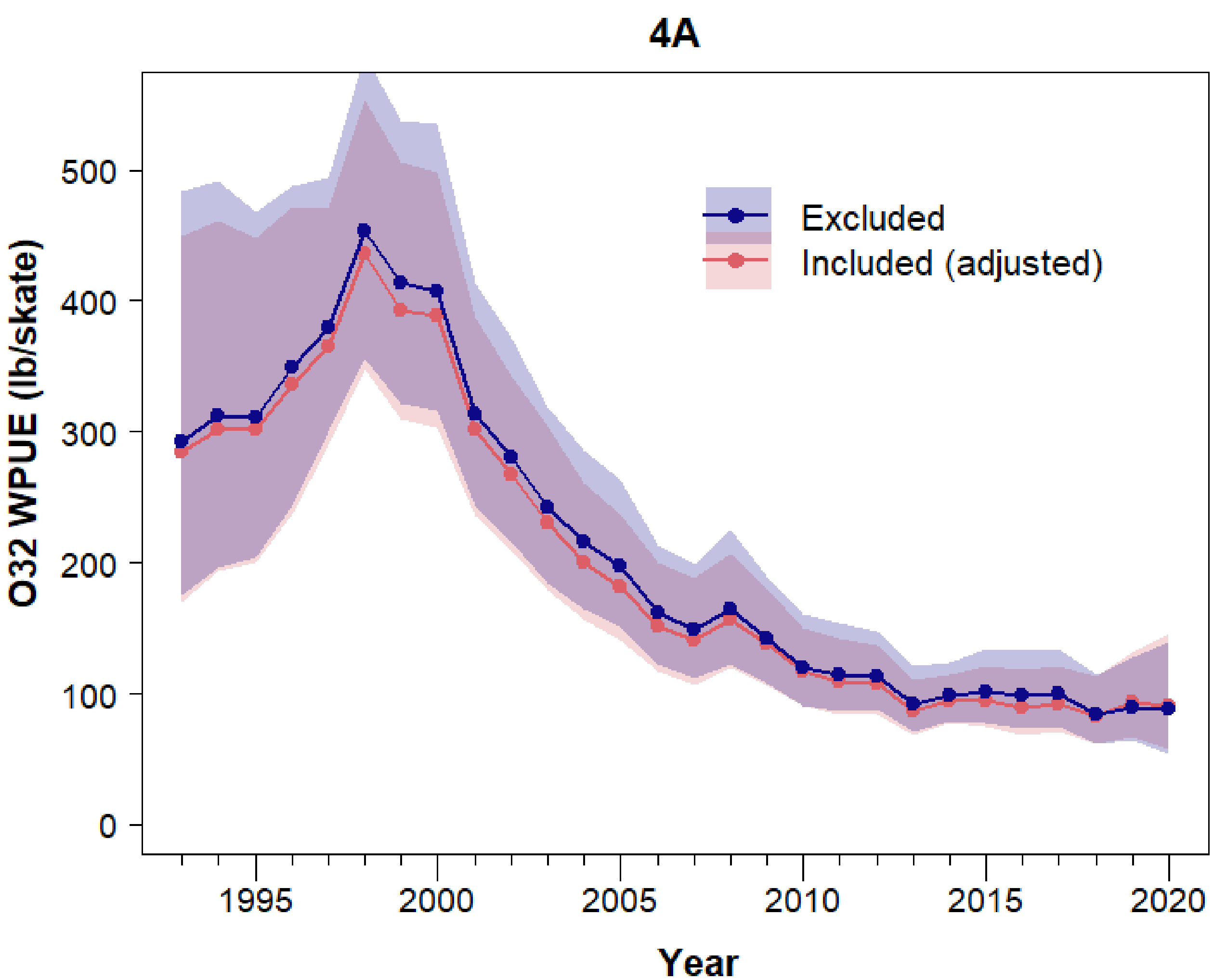

Figure 4.1. Comparison of the estimated O32 WPUE time series from the space time model calculated from predictions at all FISS station locations in IPHC Regulatory Area 4A for a model that excludes all whale-affected sets ("Excluded", blue line) and a model that includes those sets but adjusts for the effect of whales by predicting with the whale covariate set to 0 ("Included (adjusted)", red line). Shaded regions represent 95% posterior credible intervals.

Figure 4.2 compares the time series from the new model ("Included (adjusted)" – note the colour change from Figure 4.1) with the time series estimated the last time most of the whale-affected sets were included as "effective" sets ("Included (effective)"), prior to the tightening of the FISS ineffectiveness criteria for whales in 2019. The time series is consistently lower when these sets are included, a result of the lower average WPUE for these sets. This supports the tightening of the ineffectiveness criteria in 2019, as their inclusion without any adjustment leads to a likely negative bias in the time series.

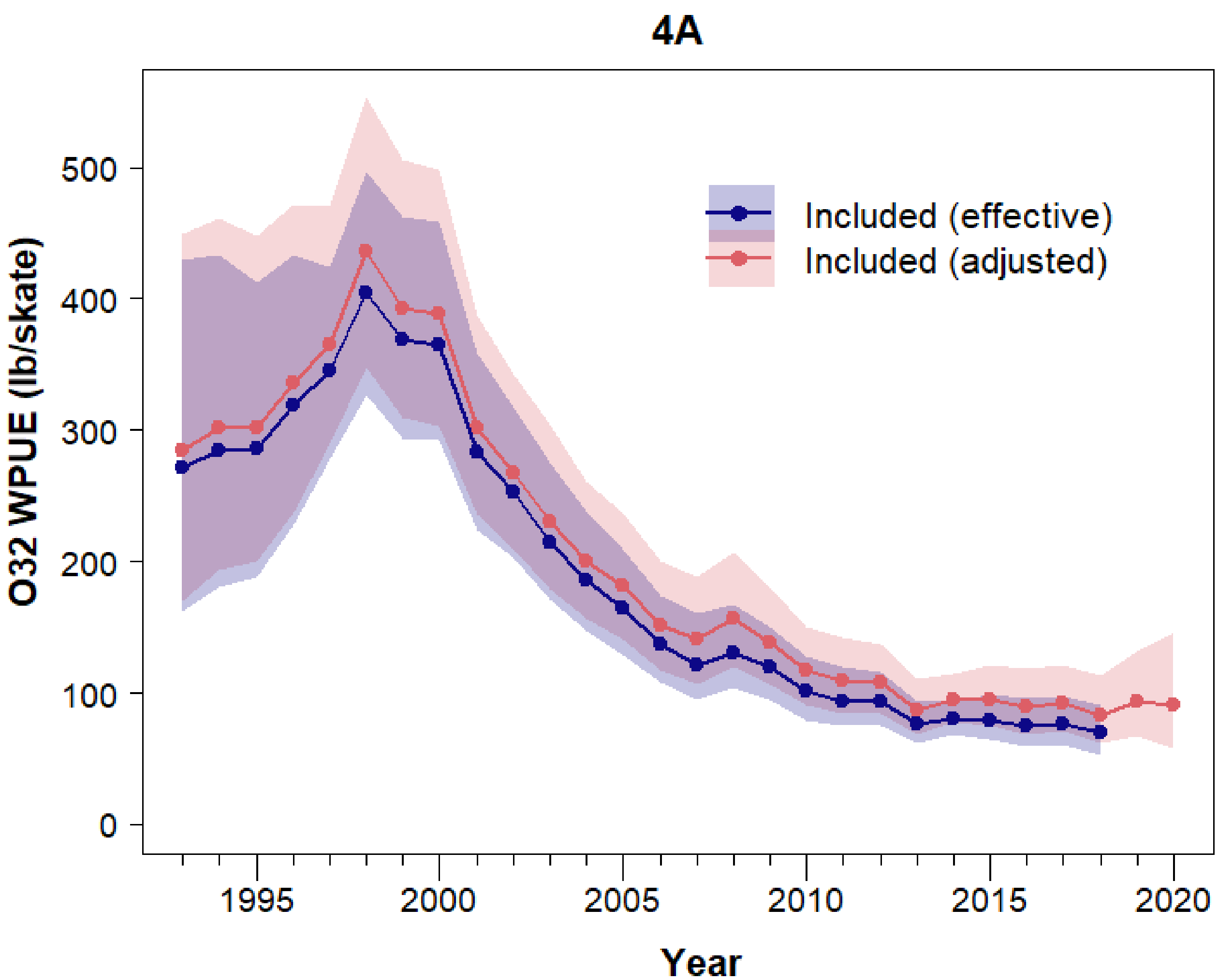

Figure 4.2. Comparison of the estimated O32 WPUE time series from the space time model calculated from predictions at all FISS station locations in IPHC Regulatory Area 4A for a model that included most whale-affected sets ("Included (effective)", blue line) without adjustment, and a model that also includes those sets but adjusts for the effect of whales by predicting with the whale covariate set to 0 ("Included (adjusted)", red line). Shaded regions represent 95% posterior credible intervals.

IPHC REGULATORY AREA 3A

Both sperm whales and orcas interact with FISS sets in IPHC Regulatory Area 3A, but with 116 sets affected by sperm whales over the 1993-2020 period vs 29 orca sets (and 18 with both), the former species provides a large majority of recorded whale interactions. For this area, we fitted a model with binary covariates for each species in the non-zero component of the model. We also fitted a model that included a species interaction effect, but found no evidence for such an interaction. The model estimates a much smaller effect of whale interactions than in IPHC Regulatory Area 4A, with orca-affected estimated to have 84% (68-104%) of the O32 WPUE of unaffected sets, and sperm whale-affected sets having 86% (75-99%) of the O32 WPUE of unaffected sets. With a smaller proportion of affected sets in this area, and with a lower estimated effect of whale interactions, the effect on WPUE of including these sets in the modelling is negligible (Figure 4.3).

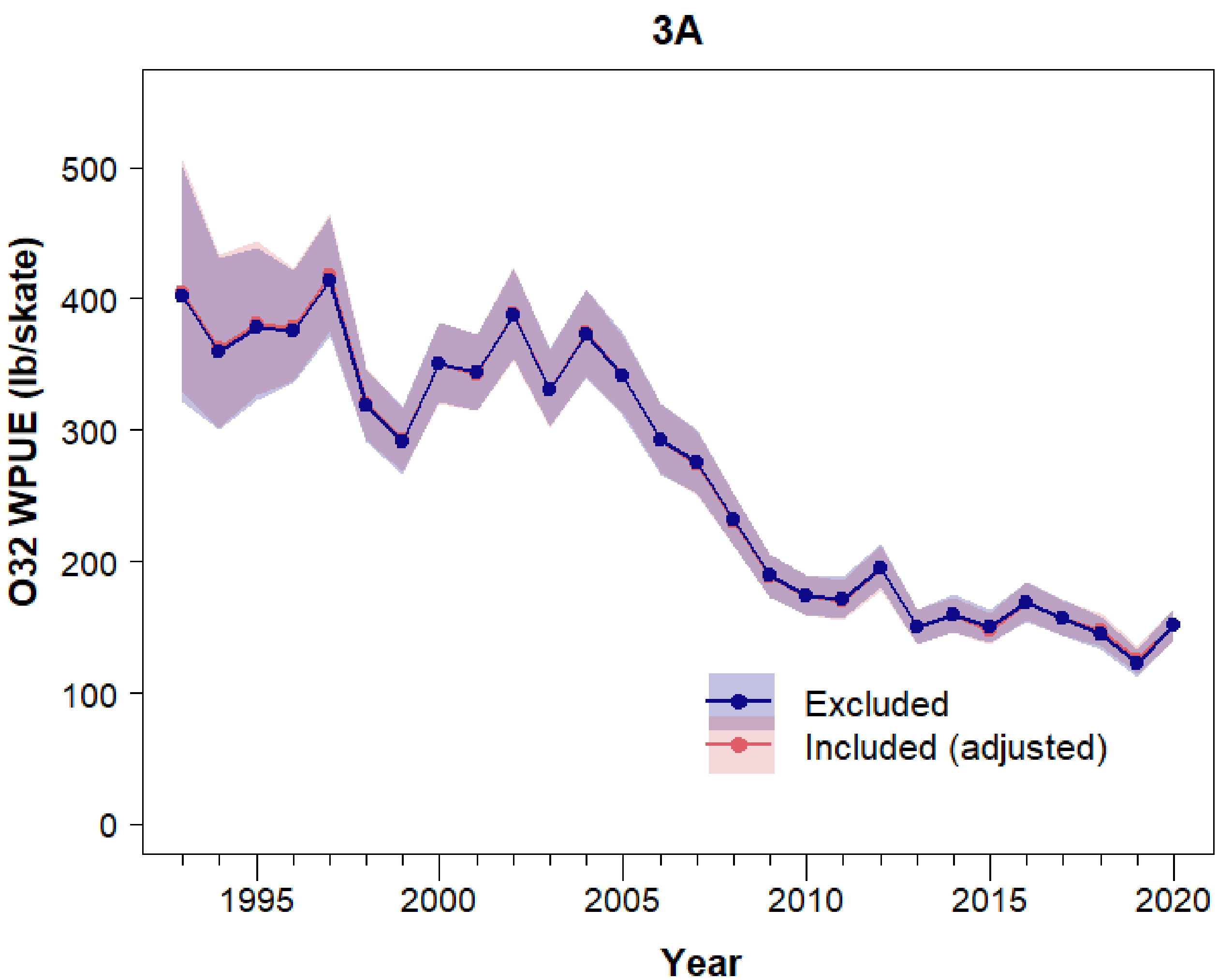

Figure 4.3. Comparison of the estimated O32 WPUE time series from the space time model calculated from predictions at all FISS station locations in IPHC Regulatory Area 3A for a model that excludes all whale-affected sets ("Excluded", blue line) and a model that includes those sets but adjusts for the effect of whales by predicting with the whale covariate set to 0 ("Included (adjusted)", red line). Shaded regions represent 95% posterior credible intervals.

Discussion

Our examples show that including sets deemed ineffective due to whale interactions in the space-time model while accounting for whale effects on catch rates can lead to improved precision in estimates of the WPUE time series when whale effects are strong and those sets are a relatively high proportion of all sets (IPHC Regulatory 4A), but have little to no effect on estimates when whale impacts are weaker and affected sets are a smaller proportion of all sets (IPHC Regulatory Area 3A). Our results also support the strengthening of ineffectiveness criteria related to whale depredation in 2019. The similarity of the two times series in Figure 4.1, in particular, implies that the space-time model has been producing accurate predictions at stations where data were previously missing because of sets that were considered ineffective due to potential whale depredation.

We propose that in order to maximise the information used to produce estimates of density indices from the space-time model, beginning in 2021, data from “ineffective” sperm whale and orca-affected sets be included in the modelling with appropriate covariates to account for difference in catch rates between affected and unaffected sets. In IPHC Regulatory Areas where such interactions are rare, precise estimation of whale covariate parameters will not be possible, and we can simply continue to omit such sets from the analyses with little loss of information.

RECOMMENDATIONS

That the Scientific Review Board:

1) **NOTE** paper IPHC-2021-SRB019-05.4 that presents an approach to accounting for the effects of whale interactions on FISS catch rates through the space-time modelling.
2) **RECOMMEND** that the Secretariat should apply such an approach going forwards.

References

IPHC 2021. International Pacific Halibut Commission Fishery-Independent Setline Survey Sampling Manual (2021). IPHC-2021-VSM01.

Webster, R. A. 2021. 2022-24 FISS design evaluation. IPHC-2021-SRB018-05 Rev_1.