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On the Relative Catchability of Snow Crab in the Newfoundland and Labrador Multispecies Trawl Surveys

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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TABLE OF CONTENTS

ABSTRACT

Comparative fishing occurred in the Newfoundland and Labrador Region from 2021 to 2023 to determine differences in catchability between outgoing survey vessels—Canadian Coast Guard Ship (CCGS) *Alfred Needler* and CCGS *Teleost*—using the standard Campelen 1800 trawl and the new vessels—CCGS *John Cabot* and CCGS *Capt Jacques Cartier*—fishing the modified Campelen trawl. Conversion factors were previously estimated for the CCGS *Alfred Needler* for fall in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Div.) 3KL based on comparative fishing from 2021 to 2022, however, limited spatial distribution of paired sets precluded estimation of conversion factors for the spring survey, or for Div. 3NO in the fall for this vessel. The CCGS *Alfred Needler* was decommissioned in February 2022. Subsequently, spring comparative fishing was undertaken between the CCGS *Teleost* and CCGS *John Cabot*, with a shadow survey in Div. 3LNO and a targeted program in subDiv. 3Ps. Additionally, further comparative fishing was required during the fall 2023 program to fill in identified data gaps from the fall 2021–22 program associated with shallow depths and representation of small Snow Crab (*Chionoecetes opilio*). Conversion factors are estimated for these programs and conclusions are presented from previous comparative fishing processes. Additional analyses are used here to support the extension of conversion factors across unsampled areas in some cases. These results should be considered alongside those presented in Newfoundland & Labrador Comparative Fishing Analysis - Part 1 (DFO 2024) and Newfoundland & Labrador Comparative Fishing Analysis - Part 2 (DFO 2025).

INTRODUCTION

Multispecies research vessel (RV) bottom trawl surveys have been conducted annually in the spring and fall in the Newfoundland and Labrador (NL) Region aboard the Canadian Coast Guard Ship (CCGS) *Teleost* (hereafter "Teleost"), and CCGS *Alfred Needler* (hereafter "Needler") or its sister ship the CCGS *Wilfred Templeman* (hereafter the "Templeman"; see Cadigan et al. 2006; Warren et al. 1997) since 1995 using a Campelen 1800 survey trawl. Data from these surveys are used to estimate the distribution and abundance of many fish and invertebrate species, to determine species life history characteristics, and to form the basis of many ecosystem indicators. The Needler and Teleost will no longer be used for these surveys after 2022 and 2023, respectively, and have been replaced by new Offshore Fishery Science Vessels (OFSVs), the CCGS *John Cabot* and CCGS *Capt Jacques Cartier* (hereafter the "Cabot", and "Cartier", respectively). Comparative fishing—direct side by side fishing comparison between the old and new vessels—occurred in the NL Region from 2021 to 2023. This is a standard approach to determining differences in catchability due to different survey protocols (change in vessel, gear, etc.), and was used to compare catchability between the outgoing vessels fishing the standard Campelen trawl and the new vessels fishing the modified Campelen trawl. The application of conversion factors is required to use the new vessels' data and resulting time series comparably with the previous vessels' series.

Conversion factors were previously estimated for the Needler for fall in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Div.) 3KL based on comparative fishing during 2021 and 2022 (DFO 2024). Sample size and spatial coverage of paired tows (see Silver et al. 2024; Wheeland et al. 2024) were insufficient to estimate standard conversion factors for the Needler survey time series in Div. 3LNOPs in the spring or in Div. 3NO in the fall. With the Needler decommissioned in February 2022 no additional comparative fishing was possible with this vessel. The Needler was the primary vessel for the Div. 3LNOPs spring survey time series since 2009, and was preceded by its sister ship the Templeman. The Needler and Templeman are assumed to have equivalent catchability in the NL trawl surveys.

There were several years where the Teleost was used for part or all of the spring survey when the Needler was unavailable. Therefore, comparative fishing was completed with the Teleost and Cabot during spring 2023 (DFO 2025) in subDiv. 3Ps and Div. 3LNO.

Analysis from the fall 2021–22 comparative fishing program (DFO 2024) found significant differences in catchability between vessels for Snow Crab (*Chionoecetes opilio*) between the Needler and Cabot in Div. 3KL, and between the Teleost and both Cabot and Cartier in Div. 2HJ3K + 3L deep (for Snow Crab > 40 mm carapace width [CW]).

The Teleost conversion estimated for Snow Crab in DFO (2024) was considered interim, as a data gap was identified for shallow depth sets which could disproportionately impact our ability to reliably estimate conversions for small crab that favour shallower depths. As a result, further comparative fishing was conducted in 2023. These data were included here, and Teleost fall conversion factors were estimated for the whole CW range of Snow Crab.

The first peer review process for NL conversion factors to the new OFSVs (DFO 2024) noted that conversion factors estimated within that process are intended to be applied to the vessel, season, and area for which they were derived, and that further application must be supported by additional analyses (e.g., consistency in environmental and biological conditions). Here we consider an extension of conversion factor application across space for Snow Crab. Where conversions could not be applied, we use a spatial-temporal model to test for a vessel effect on the scale of survey indices as used within the Snow Crab stock assessment.

METHODS

COMPARATIVE FISHING

Detailed methods from the fall 2021–22 comparative fishing program and analytical methods for conversion factor determination are outlined in Wheeland et al. (2024) and Trueman et al. (2025). Here we apply the same methods to data collected in the spring of 2023 between the Teleost and the Cabot in subDiv. 3Ps and Div. 3LNO, and update the fall Teleost and Cabot/Cartier results. A full list of completed sets by vessel pair, season, and NAFO Division are provided in Table 1.

Spring 2023

In the spring of 2023, paired survey tows were completed with the Cabot fishing the modified Campelen trawl and the Teleost fishing the standard Campelen trawl (Figure 1). Details on paired tows by Division are provided in Table 1. A shadow survey (Thiess et al. 2018) was planned at 80% of the standard survey allocation. Paired tows were completed at roughly 60% of the allocated sets in Div. 3LNO, as vessels switched between comparative and survey work throughout the season. Due to delays in vessel availability the shadow survey was not undertaken in subDiv. 3Ps; instead, a targeted program, focused on strata important to Atlantic Cod (*Gadus morhua;* Wheeland and Trueman 2024) and Snow Crab, was undertaken at the end of the survey season. Of note, this comparative work in subDiv. 3Ps occurred June 8–19, 2023, which is later than the usual survey time in this area (typically April through early May).

For development of the spring Snow Crab conversion factors, data from subDiv. 3Ps and Div. 3LNO were considered separately. This decision was made to ensure conversion factors were estimated under conditions for which they will be applied (i.e., in line with Snow Crab assessment boundaries). Additional analyses were completed with data combined across Div. 3LNOPs to examine consistency of model conclusions.

Fall 2023

In the fall of 2023, further comparative fishing was carried out between the Cabot and Teleost to fill data gaps identified during the first NL comparative fishing CSAS process (DFO 2024) (Figure 1). Targeted sets were completed in locations in Div. 3K that had previous high catches of small Snow Crab during recent RV trawl surveys and in strata < 250 m to address the gap in shallow water (Table 1). Additional pairs were completed in strata > 750 m to address deep water data gaps, however these were beyond the depth range of Snow Crab and are not included in results presented here.

Conversion Factor Estimation

In the analysis of comparative fishing data, the goal is to estimate the relative fishing efficiency by numbers and/or weights between a pair of vessel-gear combinations. A suite of 13 binomial (Table 2) and beta-binomial models (Table 3) with various assumptions for species size and station (i.e., set location) effects on the relative catch efficiency were fit to estimate size-disaggregated conversion factors for catch numbers by length (or CW for Snow Crab). Size (length or width) was included in the models as a fixed effect and applied as a smoothing effect, based on a general additive smooth function, for both model types. For the beta-binomial models, the same smooth construct was also applied to the overdispersion parameter. The station effect was included as a random effect on the intercept to accommodate different underlying densities of species across sets sampled and, in the more complicated models, it was included on the smoother to allow for a station and size interaction effect. However, accurately modelling this interaction requires a large amount of data and there were very few cases of the more complex models converging for species in the NL data set. A conversion factor is defined as the ratio of catchabilities between vessels A and B at size l (length for majority of species but CW for Snow Crab). Throughout the NL comparative fishing, size-disaggregated models were only fit if a species was present in a minimum of 25 paired tows for any given vessel/area combination.

Conversion factors are also estimated for catches aggregated across all sizes (size-aggregated models). The same model formulations as above are used for catch number conversions (i.e., abundance); however, the binomial and beta-binomial models are not appropriate for catch weight (biomass) since they are both using a discrete probability distribution. Instead, a model using a Tweedie distribution was implemented such that overdispersion in the catch weights could be properly accounted for along a continuous probability distribution.

The conversion factors are defined as an estimate of relative catch efficiency (ρ), or catch efficiency at size $\rho(l)$, with the conversion factor being the ratio of catchabilities between the old and new vessels. A ρ < 1 indicates the new vessel catches a greater amount, while a ρ > 1 indicates the new vessel catches less. If ρ = 1, conversion of catches between vessels is not required. For size-disaggregated models, when the 95% confidence interval (CI) of a ρ estimate overlapped with one across the conversion factor function this was considered not significant, and the adoption of a conversion factor is not recommended. When a size-based conversion is recommended, the conversion factor estimates from the 0.5 and 99.5 size percentiles were used as a constant below or above those percentiles, respectively, to account for a low sample size at these extreme sizes.

Full model formulations are detailed in Benoît et al. (2024), Trueman et al. (2025), and Yin and Benoît (2022).

VESSEL EFFECT TESTING FOR SUBDIV. 3PS INDICES

Data limitations precluded the estimation of conversion factors to the new vessels for the Needler (or its sister ship the Templeman) operating in subDiv. 3Ps in spring and previous data could not be assumed directly comparable to the new vessels.

To inform whether potential vessel differences have a significant impact on the estimation of indices derived for Snow Crab in this area in the context of stock assessment, various spatiotemporal models were applied to the unconverted survey data to determine whether there was a significant vessel effect (Table 4). This was done for density (standardized catches) of exploitable (> 94 mm CW) and pre-recruit (70–94 mm CW) Snow Crab.

The models were tested for their ability to converge. The 'sanity' function within the '*sdmTMB*' package (Anderson et al. 2024) was used to ensure that the maximum gradient log-likelihood with respect to all fixed effects was < 0.001, the Hessian was positive definite, and no random field marginal standard deviations were < 0.01 (Anderson et al. 2024). The best model was chosen following evaluation of the Akaike information criterion (AIC, Akaike 1973). Residuals of the best model and the conditional effects of the vessel term were examined.

EXTENSION OF CONVERSION FACTORS

Conversions between the new vessels and the Needler were not developed for Div. 3NO in the fall due to lack of paired tows in those Divisions for that season. To investigate if accepted conversions across Div. 3KL for the Needler (DFO 2024) could be extended into Div. 3NO, a qualitative examination of habitat characteristics for areas occupied by Snow Crab throughout Div. 3LNO was undertaken. This exercise calculated mean bottom temperatures and depths for all survey strata in Div. 3LNO and subsequently isolated a subset of 50 strata containing the highest ranking abundance of crab (defined here based on highest mean number per tow) in the fall trawl survey time series (1995–2020) in Div. 3LNO. This subset of ‘top strata’, inferred to represent primary habitat, was subsequently parsed into Div. 3L versus Div. 3NO and calculations of mean bottom temperature and depth were used to assess similarity in Snow Crab habitat characteristics across the two areas. The distribution of the highest 15 strata of the 50 top strata was also examined to determine if there was direct spatial connectivity between habitat areas extending through the divisional line separating Div. 3L from Div. 3NO.

RESULTS

CONVERSION FACTORS: SPRING TELEOST

During the spring 2023 Teleost comparative fishing program, Snow Crab were caught in 85 sets across Div. 3LNOPs (37 in 3Ps, 48 in 3LNO), with a CW range of 5–139 mm (Figure 2).

Sets in subDiv. 3Ps covered a smaller area than the typical survey due to the targeted nature of the sampling and had a truncation of depth (< 250 m) and temperature range covered relative to the range of conditions Snow Crab are typically caught in during this survey (Figure 3, Figure 4). However, this area was specifically selected to target Snow Crab, with strata sampled covering areas considered most important for this species in subDiv. 3Ps during the RV survey. Data are therefore considered representative for conversion estimates for this species. Sets in Div. 3LNO covered conditions considered to be representative of the standard survey (e.g., depth, temperature, see Figure 5) for Snow Crab in this area.

For both areas, the best model selected was one with no size effect and a station effect included on the intercept (Table 2); though for subDiv. 3Ps, an overdispersion parameter was also included. In both cases the 95% CIs for the best models selected overlapped with one (i.e., equal catch efficiency between vessels) and thus no conversion is required between the Teleost and Cabot for Snow Crab in spring for subDiv. 3Ps (Figure 6) or Div. 3LNO (Figure 7). The residuals (Figure 8, Figure 9) and station effect distributions (Figure 10, Figure 11) for both models indicate a good fit to the data. This conclusion remains consistent when analysis is completed for all NAFO Divisions combined (Figure 12) and for size-aggregated analysis for subDiv 3Ps (Figure 13) and Div. 3LNO (Figure 14).

CONVERSION FACTORS: FALL TELEOST

An interim conversion had been previously accepted for Snow Crab at a truncated CW range of 40–138 mm, but further analyses were recommended following additional sampling (DFO 2024). With the inclusion of the fall 2023 data, 22 additional sets with Snow Crab were added, bringing the total fall sets with Snow Crab to 148, with a CW range of 6–138 mm represented throughout the sets (Figure 15).

Of the suite of models assessed, two models were in close contention for best model fit (Table 5); one with no size effect (Figure 16) and the other with a significant size effect (Figure 17). Given the consistency in residual fits (Figure 18, Figure 19) and station effect distribution (Figure 20, Figure 21), the final model selected had no size effect and a constant conversion factor of 0.69 ± 0.06 (Figure 16). This conclusion replaces the interim result previously reported in DFO (2024). Analyses of the abundance and biomass data agree with this conclusion, with both biomass and abundance having a significant conversion (Figure 22).

Residuals estimated for Div. 2H in the adopted model were notably different from the other areas; however, this is the result of a very small sample size in this area in conjunction with a single large catch of Snow Crab 10–30 mm CW on one vessel and is not considered to reflect overall model performance.

VESSEL EFFECT TESTING FOR SUBDIV. 3PS INDICES

The inclusion of survey vessel and/or calendar day did not improve the models' performances. Therefore both were excluded from the final model. The conditional effects of *post-hoc* models that included vessel as a covariate further illustrated there were no significant differences evident (Figure 23, Figure 24). The final model selected was:

$$Density = s(scaled\ depth) + 0 + as.factor(Year) \qquad \text{(Eq. 1)},$$

where $Density$ is the standardized biomass (kg/km^2) of Snow Crab (either exploitable or pre-recruits) in a standard trawl survey set during spring DFO RV trawl surveys, $scaled\ depth$ is the average depth (m) during each trawl scaled so that (set depth - mean(depth)/sd(depth)), and $Year$ is the year of the survey, represented as a factor. Depth was scaled to include a spatial-varying coefficient. Anisotropy was included with separate Matérn ranges estimated for the spatial and spatiotemporal random fields. A Tweedie distribution with log link was used, and there were no patterns upon examination of residuals (Figure 25, Figure 26).

Based on these results, vessel (unconverted Needler and Teleost) was determined to have no significant effect on indices of exploitable and pre-recruit Snow Crab in subDiv. 3Ps. Therefore the conversion factors developed for the Teleost to the new vessel time series can be applied to the Needler time series without impacting interpretation of these indices as used within the stock assessment.

EXTENSION OF CONVERSION FACTORS

The distributions of bottom temperature and depth across the 'top strata' for Snow Crab in Div. 3L versus Div. 3LNO showed tight conformity in means and variance for both metrics across Divisions (Figure 27). Coupled with a demonstration of direct spatial connectivity between the most abundant strata in Div. 3LN, where previous tagging studies have shown direct exchanges across Divisions (Mullowney et al. 2020), the population of Snow Crab in Div. 3LN was inferred to be a homogenous unit occupying like habitat and therefore conversions from the Needler Div. 3KL in fall are considered applicable to Div. 3NO.

DISCUSSION

Results for conversion factor analysis of Snow Crab are not consistent across vessel, season, or NAFO Division. This was expected given the vast area sampled, differences in habitat (e.g., slope, substrate) and ecosystem characteristics across the survey area (e.g., Pepin et al. 2014), known differences in vessel power and trawl performance between the Teleost and Needler (Trueman et al. 2025), and seasonal effects on catchability of Snow Crab (Mullowney et al. 2021). Application of a conversion factor outside of the area/vessel/season for which it was estimated is associated with a degree of unquantifiable uncertainty. It should only be done following consideration of factors that may impact relative catchability, distribution and habitat characteristics (e.g., depth, temperature) relative to location of paired tows, size distribution and behaviour of the stock or species in question, and other relevant biological characteristics.

For fall, a significant conversion was found for both the Teleost and Needler (Table 6). Sampling for the Needler conversion was primarily in Div. 3K, with accepted application across Div. 3KL (DFO 2024). Given consistency in habitat occupied by Snow Crab (e.g., depth, temperature, Figure 27) and size distribution (Pantin et al. 2024), conversion factors estimated for Snow Crab in Div. 3KL in fall for the Needler are considered appropriate for application across the entire fall survey area. Offshore tagging work has shown direct connectivity between Div. 3L and 3N, highlighting the ability of Snow Crab to travel large distances in short periods of time along the Div. 3LN slope edge (Mullowney et al. 2020) and leading to an inference of a homogenous biological population of crab occupying similar habitats across NAFO Division lines.

Though it was not possible to estimate a conversion factor for the Needler spring time series, conversion factors were estimated for the years the Teleost completed the spring survey when the Needler was unavailable. No significant difference in relative catchability was found between the Teleost and new vessels in subDiv. 3Ps or Div. 3LNO (i.e., ρ did not differ significantly from one).

Data limitations precluded the estimation of conversion factors for the Needler series in subDiv. 3Ps in spring. Here, a spatiotemporal model was used to examine the significance of possible vessel effects in the estimation of indices of exploitable and pre-recruit Snow Crab densities. These analyses indicated no significant vessel effect, suggesting that at the scale of these standardized catch rates, the vessel change did not have a measurable effect. We note that there are currently limited sets with the new vessels and there has been recent incomplete survey coverage (Rideout et al. 2022; Wheeland et al. 2023). These factors may impact our ability to separate vessel and year effects and it is recommended that similar analyses be completed when additional data have been collected in subDiv. 3Ps with the Cabot and/or Cartier (e.g., in 2–3 years) to check for consistency of results regarding vessel effects.

The meeting did not examine potential effects on small Snow Crab < 70 mm CW, and further work on this is recommended as size effects on relative catchability were detected for the Needler in the fall survey in Div. 3KL.

CONCLUSIONS

Conversion factors for Snow Crab are outlined in Table 6 and Table 7 for the new OFSVs. With the application of the appropriate conversion factor, when available, survey data from the Cabot and Cartier fishing the modified Campelen trawl can be used in the direct continuation of the previous time series.

Direct comparison of the relative catchability between the Needler/Templeman and the Cabot/Cartier for spring Div. 3LNOPs is not possible. Analyses have indicated that the vessel effect of the Needler in subDiv. 3Ps is not significant in the estimation of indices of exploitable and pre-recruit biomass used in the assessment of this stock. However, given limited data collected to date with the Cabot/Cartier, further monitoring as additional data are collected with the new vessels is recommended.

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TABLES

Table 1. Summary of successful paired sets per vessel pair, year, season, and NAFO Division. Vessels are CCGS Alfred Needler *(AN), CCGS* John Cabot *(CAB), CCGS* Capt Jacques Cartier *(CAR), and CCGS* Teleost *(TEL).*

Vessel Pair	Year	Season	NAFO Div.	No. Paired Tows
TEL:CAR	2021	Fall	2H	14
TEL:CAR	2021	Fall	2J	18
TEL:CAR	2021	Fall	3K	8
TEL:CAR	2021	Fall	**Total**	**40**
AN:CAB	2022	Spring	3N	12
AN:CAB	2022	Spring	3P	25
AN:CAB	2022	Spring	**Total**	**37**
AN:CAB	2022	Fall	3K	71
AN:CAB	2022	Fall	3L	2
AN:CAB	2022	Fall	3N	17
AN:CAB	2022	Fall	3O	10
AN:CAB	2022	Fall	**Total**	**100**
TEL:CAR	2022	Fall	2H	20
TEL:CAR	2022	Fall	2J	38
TEL:CAR	2022	Fall	3K	82
TEL:CAR	2022	Fall	**Total**	**140**
TEL:CAB	2022	Fall	2J	5
TEL:CAB	2022	Fall	3K	8
TEL:CAB	2022	Fall	3L	4
TEL:CAB	2022	Fall	**Total**	**17**
TEL:CAB	2023	Spring	3L	32
TEL:CAB	2023	Spring	3N	35
TEL:CAB	2023	Spring	3O	23
TEL:CAB	2023	Spring	3Ps	51
TEL:CAB	2023	Spring	**Total**	**141**
TEL:CAB	2023	Fall	2J	28
TEL:CAB	2023	Fall	3L	14
TEL:CAB	2023	Fall	3K	22
TEL:CAB	2023	Fall	**Total**	**64**

Table 2. A set of binomial models with various assumptions for the size effect and station effect in the relative catch efficiency. A smoothing size effect can be considered and the station effect can be added to the intercept without interaction with the size effect, or added to both the intercept and smoother to allow for interaction between the two effects.

Model	$log(\rho)$	Size Effect	Station Effect
$BI0$	β_0	constant	not considered
$BI1$	$\beta_0 + \delta_{0,i}$	constant	intercept
$BI2$	$\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b}$	smoothing	not considered
$BI3$	$\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b} + \delta_{0,i}$	smoothing	intercept
$BI4$	$\mathbf{X}_f^T (\boldsymbol{\beta}_f + \boldsymbol{\delta}_i) + \mathbf{X}_r^T (\mathbf{b} + \boldsymbol{\epsilon}_i)$	smoothing	intercept, smoother

Table 3. A set of beta-binomial models with various assumptions for the size effect and station effect in the relative catch efficiency, and the size effect on the variance parameter. A smoothing size effect can be considered in both the conversion factor and the variance parameter. A possible station effect can be added to the intercept without interaction with the size effect, or added to both the intercept and the smoother to allow for interaction between the two effects.

Model	$log(\rho)$	$log(\phi)$	Size Effects	Station Effect
$BB0$	β_0	γ_0	constant/constant	not considered
$BB1$	$\beta_0 + \delta_{0,i}$	γ_0	constant/constant	intercept
$BB2$	$\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b}$	γ_0	smoothing/constant	not considered
$BB3$	$\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b}$	$\mathbf{X}_f^T \boldsymbol{\gamma} + \mathbf{X}_r^T \mathbf{g}$	smoothing/smoothing	not considered
$BB4$	$\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b} + \delta_{0,i}$	γ_0	smoothing/constant	intercept
$BB5$	$\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b} + \delta_{0,i}$	$\mathbf{X}_f^T \boldsymbol{\gamma} + \mathbf{X}_r^T \mathbf{g}$	smoothing/smoothing	intercept
$BB6$	$\mathbf{X}_f^T (\boldsymbol{\beta}_f + \boldsymbol{\delta}_i) + \mathbf{X}_r^T (\mathbf{b} + \boldsymbol{\epsilon}_i)$	γ_0	smoothing/constant	intercept, smoother
$BB7$	$\mathbf{X}_f^T (\boldsymbol{\beta}_f + \boldsymbol{\delta}_i) + \mathbf{X}_r^T (\mathbf{b} + \boldsymbol{\epsilon}_i)$	$\mathbf{X}_f^T \boldsymbol{\gamma} + \mathbf{X}_r^T \mathbf{g}$	smoothing/smoothing	intercept, smoother

Table 4. A set of spatiotemporal models applied to unconverted Snow Crab survey data in determination of a vessel effect and associated Aikaike Information Criterion (AIC) values.

Model	**AIC**
$\text{Density}_{\text{exp}} = \text{s(depth)} + 0 + \text{fYear} + \text{fVessel} + \text{fSurvey} + \text{s(Day)}$	Did not pass sanity check
$\text{Density}_{\text{exp}} = \text{s(depth)} + 0 + \text{fYear} + \text{fVessel} + \text{fSurvey}$	10640.17
$\text{Density}_{\text{exp}} = \text{s(depth)} + 0 + \text{fYear} + \text{fVessel}$	10639.36
$\text{Density}_{\text{exp}} = \text{s(depth)} + 0 + \text{fYear}$	**10633.72**
$\text{Density}_{\text{exp}} = \text{s(depth)} + 0 + \text{fVessel}$	10693.08

Table 5. Relative evidence for size-disaggregated binomial and beta-binomial models for the CCGS Teleost *(TEL) and CCGS* John Cabot/Capt Jacques Cartier*, and CCGS* Alfred Needler *(AN) and CCGS* John Cabot *comparative fishing analysis based on the Aikaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) and delta (Δ) values compared to lowest AIC/BIC per analysis grouping. The data grouping column indicates the season, NAFO Divisions, and vessel pairing applicable per row. Note that AIC/BIC comparison should only be considered per row, and not between rows as input data is different for each data grouping. Entries with '-' indicate models that did not converge. BI4 and BB6 did not converge for any analysis and are not included in the table.*

Data Grouping	Value	BI0	BI1	BI2	BI3	BB0	BB1	BB2	BB3	BB4	BB5
Fall 2HJ3KL (TEL)	AIC	6085	5386	6010	5370	5845	5363	5817	5788	5349	5344
Fall 2HJ3KL (TEL)	BIC	6092	5402	6034	5401	5861	5387	5848	5836	5389	5399
Fall 2HJ3KL (TEL)	ΔAIC	741	43	667	26	502	20	473	445	6	0
Fall 2HJ3KL (TEL)	ΔBIC	706	15	647	14	474	0	462	449	2	12
Fall 3KL (AN)	AIC	4626	4460	4590	4440	4548	4428	4515	4498	4408	4387
Fall 3KL (AN)	BIC	4633	4474	4611	4469	4562	4450	4543	4541	4444	4437
Fall 3KL (AN)	ΔAIC	239	73	203	53	161	41	128	111	21	0
Fall 3KL (AN)	ΔBIC	196	37	174	32	125	12	106	104	6	0
Spring 3LNO (TEL)	AIC	1558	1306	1536	1296	1458	1304	1442	1414	1292	-
Spring 3LNO (TEL)	BIC	1565	1319	1556	1323	1471	1324	1469	1455	1326	-
Spring 3LNO (TEL)	ΔAIC	266	14	244	4	166	12	150	122	0	-
Spring 3LNO (TEL)	ΔBIC	245	0	237	4	152	5	150	136	6	-
Spring 3Ps (TEL)	AIC	1281	1147	1244	1144	1144	1112	1146	-	1115	1119
Spring 3Ps (TEL)	BIC	1287	1160	1264	1170	1156	1131	1172	-	1147	1163
Spring 3Ps (TEL)	ΔAIC	169	35	132	32	32	0	34	-	3	7
Spring 3Ps (TEL)	ΔBIC	156	29	132	38	25	0	41	-	15	32

Table 6. Summary of comparative fishing conversion factor analysis results for CCGS Alfred Needler *(AN), CCGS* John Cabot *(CAB), CCGS* Capt Jacques Cartier *(CAR), CCGS* Teleost *(TEL), and CCGS* Capt Jacques Cartier *and CCGS* John Cabot*, collectively (CAX).*

Vessel Pair	Season	NAFO Divisions	ρ (biomass)	ρ (abundance)	Conclusion
AN:CAB	Spring	3LNOPs	n/a	n/a	Insufficient data to determine conversion factor.
TEL:CAB	Spring	3Ps	1	1	No conversion factor required (ρ = 1).
TEL:CAB	Spring	3LNO	1	1	No conversion factor required (ρ = 1)
TEL:CAX	Fall	2HJ3KL	Derive from converted abundance.	0.69 ± 0.06	Constant conversion across size. Apply to abundance, calculate biomass from converted abundance.
AN:CAB	Fall	3KL	Apply size-based conversion on abundance.	Table 7	Size-based conversion factor. This factor is applicable across the fall survey area for this vessel given consistency in Snow Crab habitat.
AN:CAB	Fall	3NO	n/a	n/a	Insufficient data to determine conversion specific to this area. Apply conversion factor estimated from 3KL paired tows.

Table 7. Size-based conversion (± standard error [SE]) for CCGS Alfred Needler and CCGS John Cabot, for Snow Crab. Carapace width (mm) range displayed is for the 0.5 and 99.5 percentile range, and conversions below 11 mm should be applied at 0.52 ± 0.06 and above 126 mm at 1.02 ± 0.10.

Carapace Width (mm)	Conversion	SE
11	0.52	0.06
12	0.52	0.06
13	0.53	0.06
14	0.53	0.06
15	0.53	0.06
16	0.53	0.06
17	0.54	0.06
18	0.54	0.06
19	0.54	0.06
20	0.55	0.06
21	0.55	0.06
22	0.55	0.06
23	0.56	0.06
24	0.56	0.06
25	0.56	0.05
26	0.57	0.05
27	0.57	0.05
28	0.57	0.05
29	0.58	0.05
30	0.58	0.05
31	0.58	0.05
32	0.59	0.05
33	0.59	0.05
34	0.59	0.05
35	0.60	0.05
36	0.60	0.05
37	0.61	0.05
38	0.61	0.05
39	0.61	0.05
40	0.62	0.05
41	0.62	0.05
42	0.62	0.05
43	0.63	0.05
44	0.63	0.05
45	0.63	0.05
46	0.64	0.05
47	0.64	0.05
48	0.65	0.05
49	0.65	0.05
50	0.65	0.05
51	0.66	0.05
52	0.66	0.05
53	0.67	0.05
54	0.67	0.05
55	0.67	0.05
56	0.68	0.05
57	0.68	0.05
58	0.69	0.05
59	0.69	0.05
60	0.69	0.05
61	0.70	0.05
62	0.70	0.05
63	0.71	0.05
64	0.71	0.05
65	0.71	0.05
66	0.72	0.05
67	0.72	0.05
68	0.73	0.05
69	0.73	0.05
70	0.74	0.05
71	0.74	0.06

Carapace Width (mm)	Conversion	SE
72	0.74	0.06
73	0.75	0.06
74	0.75	0.06
75	0.76	0.06
76	0.76	0.06
77	0.77	0.06
78	0.77	0.06
79	0.78	0.06
80	0.78	0.06
81	0.79	0.06
82	0.79	0.06
83	0.79	0.06
84	0.80	0.06
85	0.80	0.06
86	0.81	0.06
87	0.81	0.06
88	0.82	0.06
89	0.82	0.06
90	0.83	0.06
91	0.83	0.06
92	0.84	0.07
93	0.84	0.07
94	0.85	0.07
95	0.85	0.07
96	0.86	0.07
97	0.86	0.07
98	0.87	0.07
99	0.87	0.07
100	0.88	0.07
101	0.88	0.07
102	0.89	0.07
103	0.89	0.08
104	0.90	0.08
105	0.90	0.08
106	0.91	0.08
107	0.92	0.08
108	0.92	0.08
109	0.93	0.08
110	0.93	0.08
111	0.94	0.08
112	0.94	0.08
113	0.95	0.09
114	0.95	0.09
115	0.96	0.09
116	0.97	0.09
117	0.97	0.09
118	0.98	0.09
119	0.98	0.09
120	0.99	0.10
121	0.99	0.10
122	1.00	0.10
123	1.01	0.10
124	1.01	0.10
125	1.02	0.10
126	1.02	0.10

FIGURES

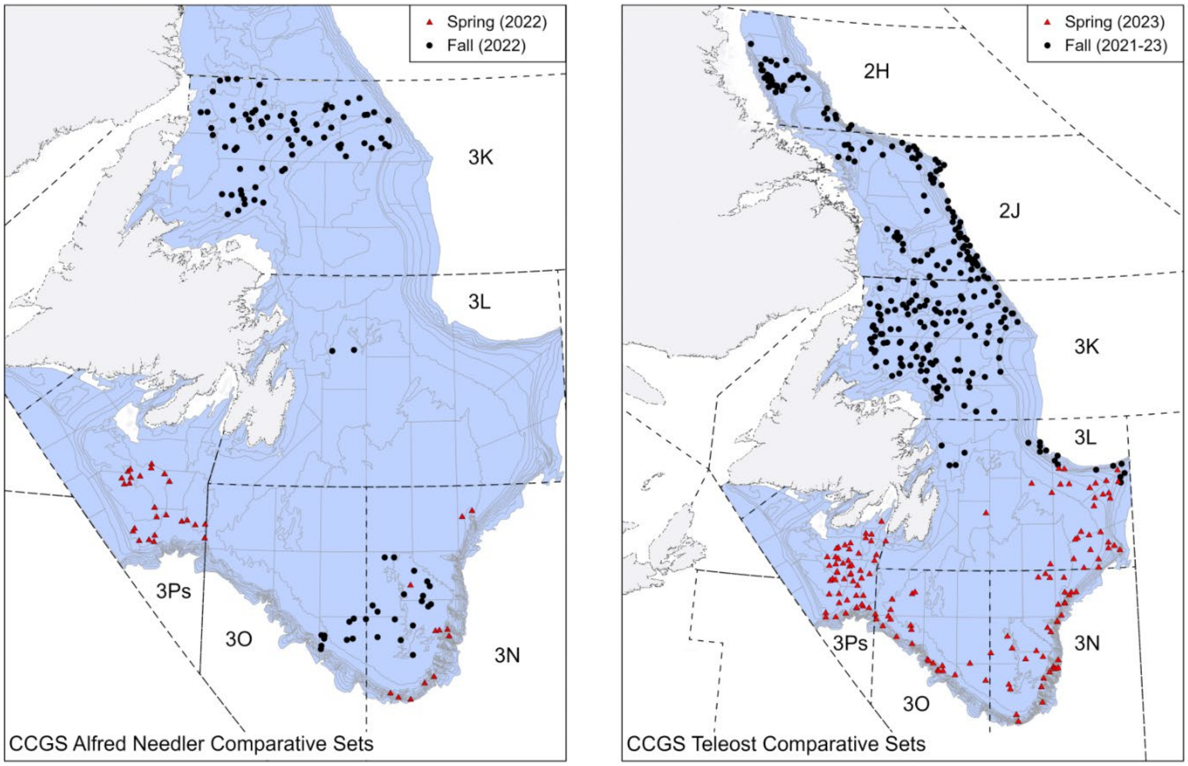


Figure 1. Newfoundland and Labrador multispecies survey areas (blue). Annually there is a spring survey (NAFO Div. 3LNOPs) and fall survey (NAFO Div. 2HJ3KLNO). Points indicate the location of paired tows for each vessel.

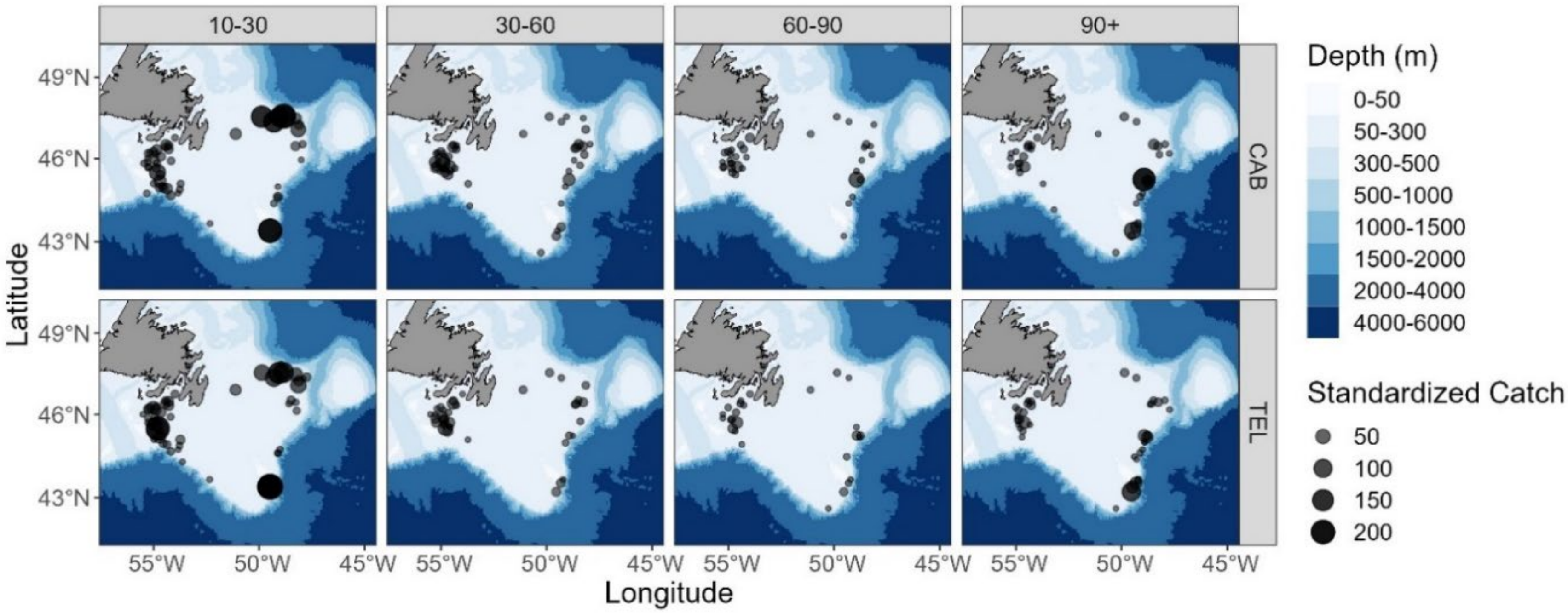


Figure 2. A map of Snow Crab catches for spring 2023 comparative fishing by CW group (width in mm specified in top panel) by the CCGS John Cabot *(top) and the CCGS* Teleost *(bottom) in comparative fishing sets, where circle size is proportional to catch weight (kg).*

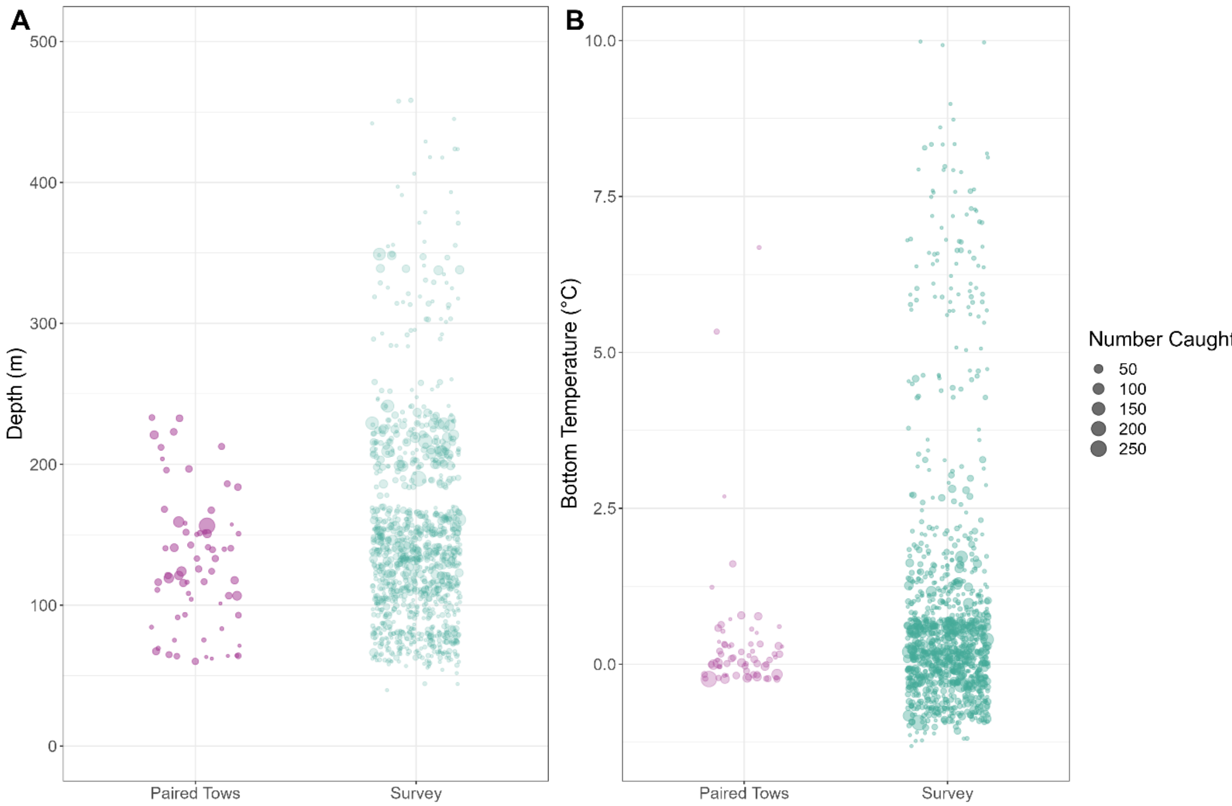


Figure 3. Comparison of depth (m) and bottom temperature (°C) range for catch of Snow Crab during the spring 2023 comparative fishing program (paired tows with the CCGS Teleost *and CCGS* John Cabot*), and during the typical spring survey of subDiv. 3Ps, sampled by the CCGS* Teleost *for 2011 onwards (survey), where circle size is proportional to catch number.*

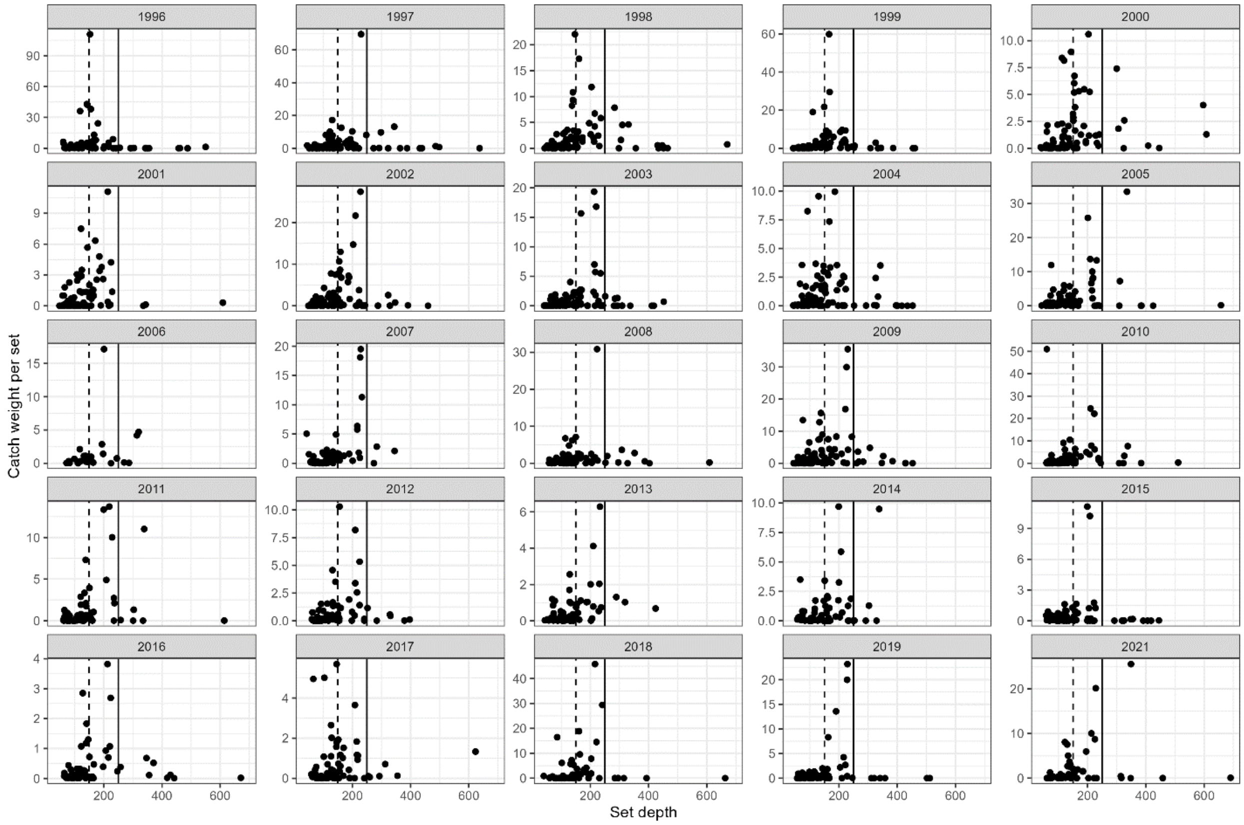


Figure 4. Catches of Snow Crab by depth in the DFO-NL spring trawl survey in subDiv. 3Ps from 1996–2021. Vertical lines show general depth range of paired sets in subDiv 3Ps completed with the CCGS Alfred Needler *(150 m, dashed line) and CCGS* Teleost *(250 m, solid line).*

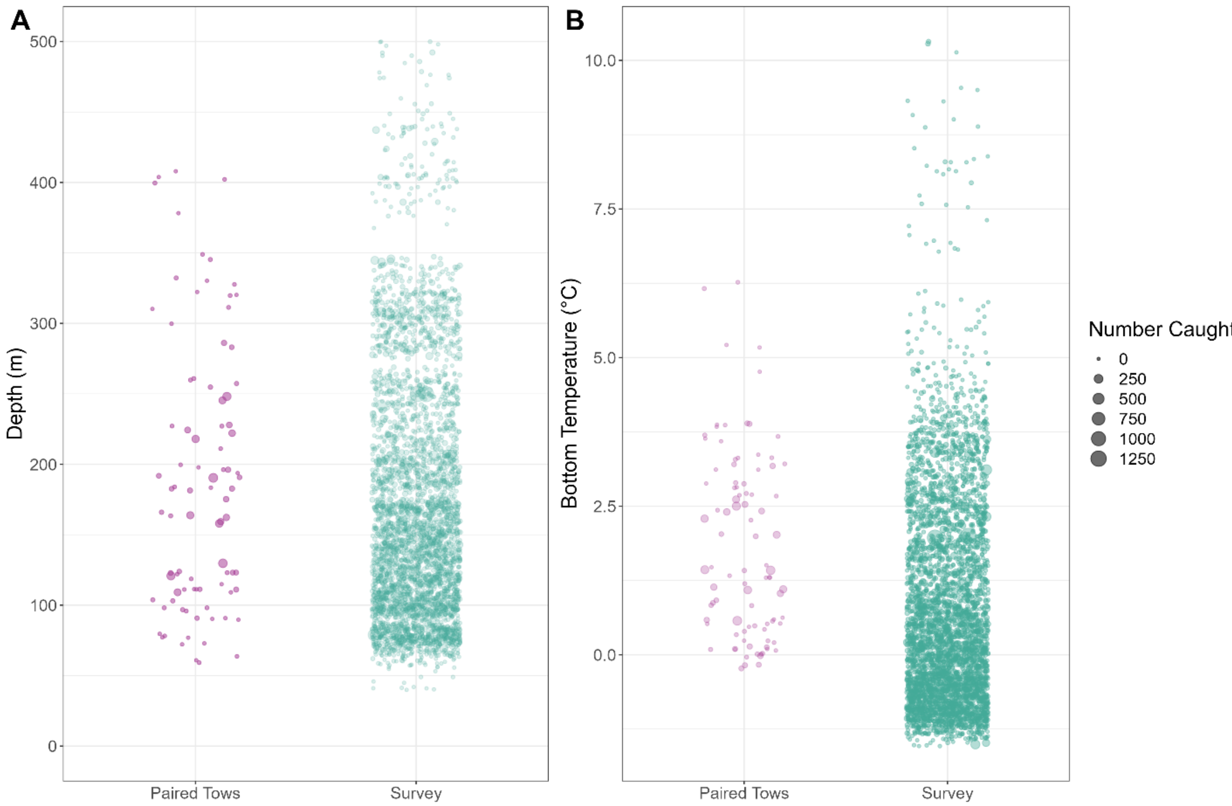


Figure 5. Comparison of depth (m) and bottom temperature (°C) range for catch of Snow Crab during the spring 2023 comparative fishing program (paired tows with the CCGS Teleost *and CCGS* John Cabot*), and during the typical spring survey Div. 3LNO, sampled by the CCGS* Teleost *for 2011 onwards (survey), where circle size is proportional to catch number.*

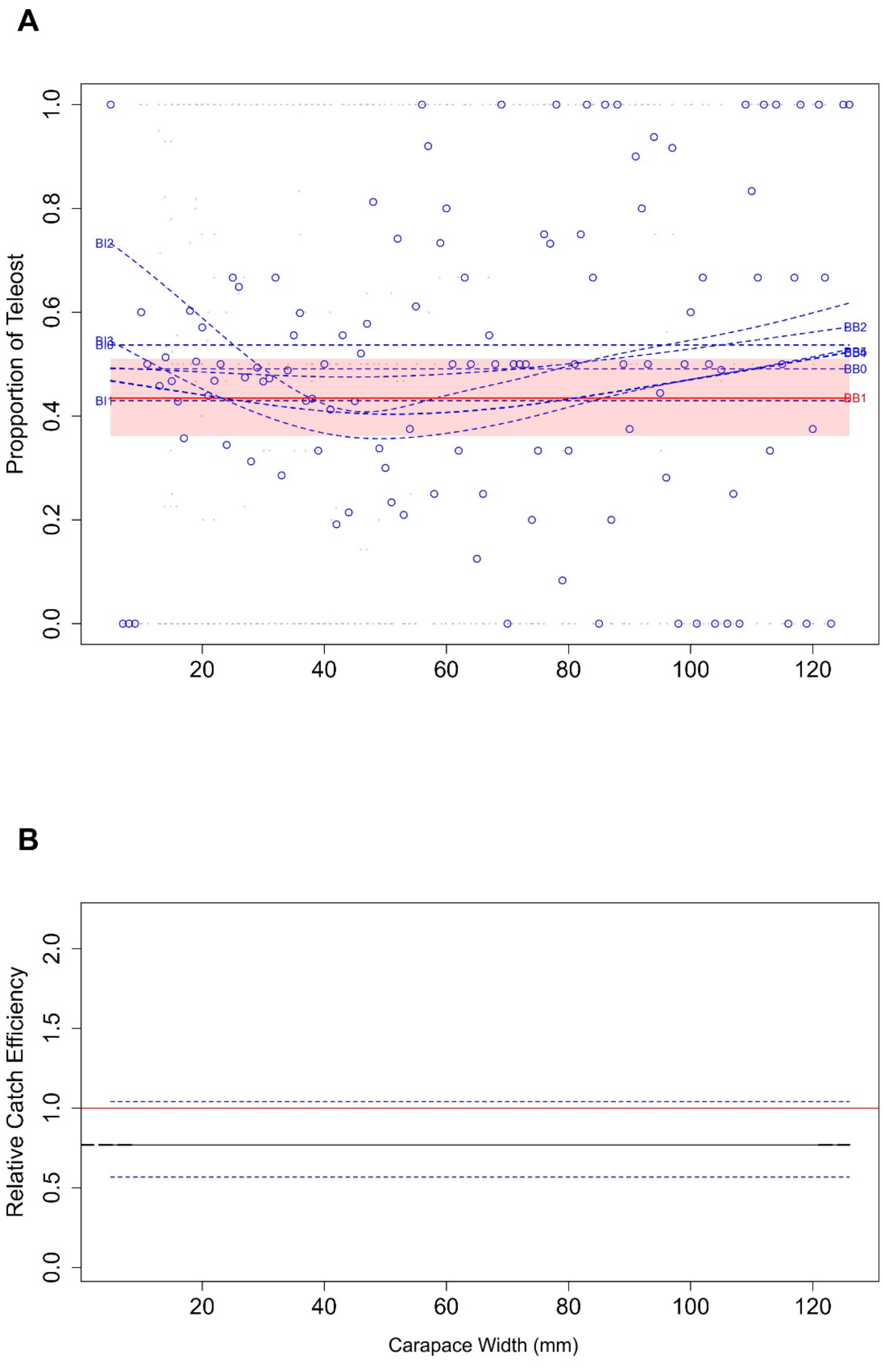
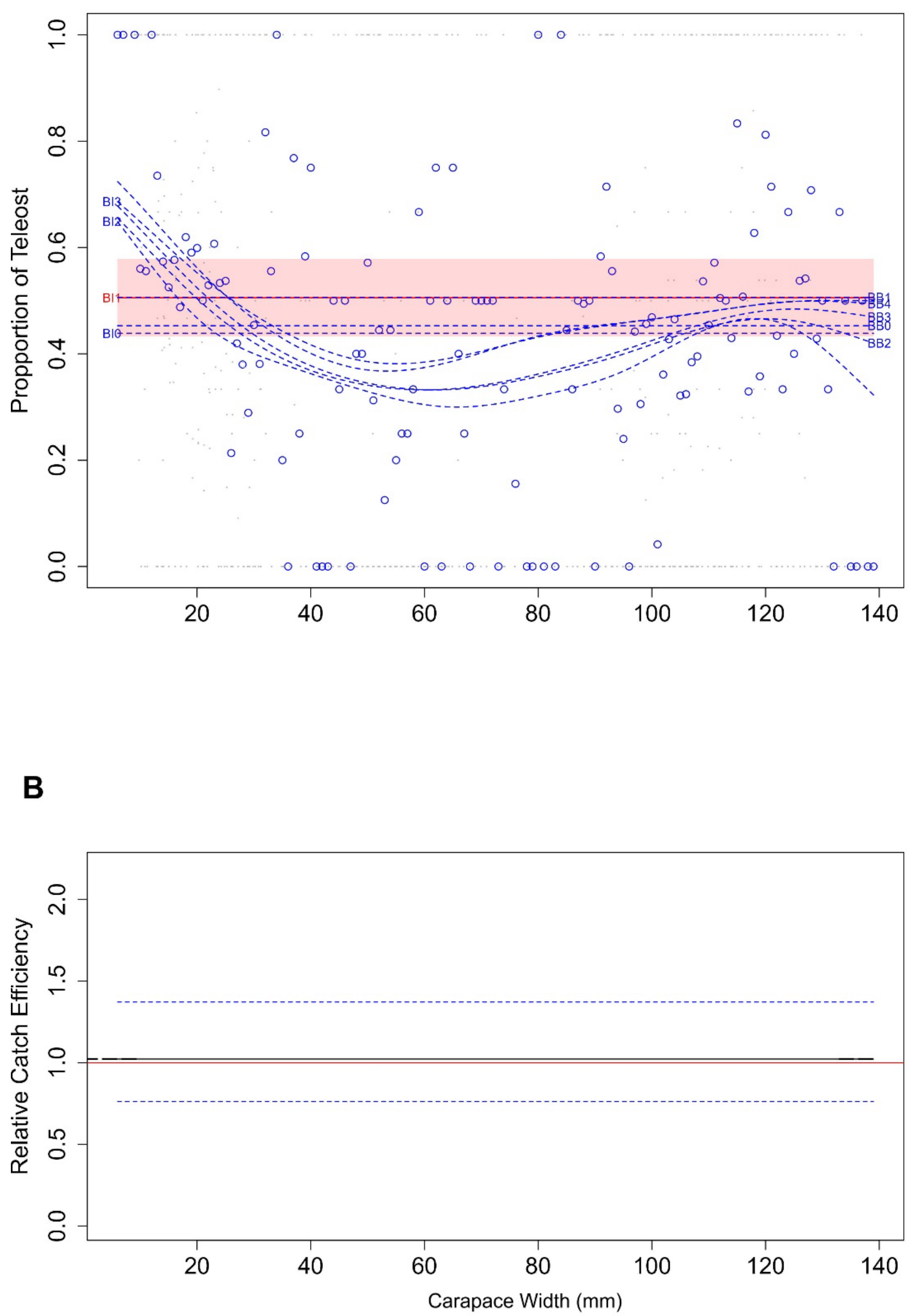


Figure 6. Snow Crab conversion factor between the CCGS Teleost *and CCGS* John Cabot *for spring subDiv. 3Ps. (A) Estimated size-specific catch proportion functions, $logit(p_{Ai}(l))$, for each converged model, with the selected model plotted using a red solid line along with its approximate 95% CI (shaded area), as well as the size class-specific mean empirical proportion of total catch in a pair made by the CCGS* Teleost *(blue dots). (B) Estimated relative catch efficiency (conversion factor) function from the best model (black line) with 95% CI (dashed blue lines). The horizontal red line indicates equivalent efficiency between vessels.*

A



B

Figure 7. Snow Crab conversion factor between the CCGS Teleost *and CCGS* John Cabot *for spring Div. 3LNO. (A) Estimated size-specific catch proportion functions, $logit(p_{Ai}(l))$, for each converged model, with the selected model plotted using a red solid line along with its approximate 95% CI (shaded area), as well as the size class-specific mean empirical proportion of total catch in a pair made by the CCGS* Teleost *(blue dots). (B) Estimated relative catch efficiency (conversion factor) function from the best model (black line) with 95% CI (dashed blue lines). The horizontal red line indicates equivalent efficiency between vessels.*

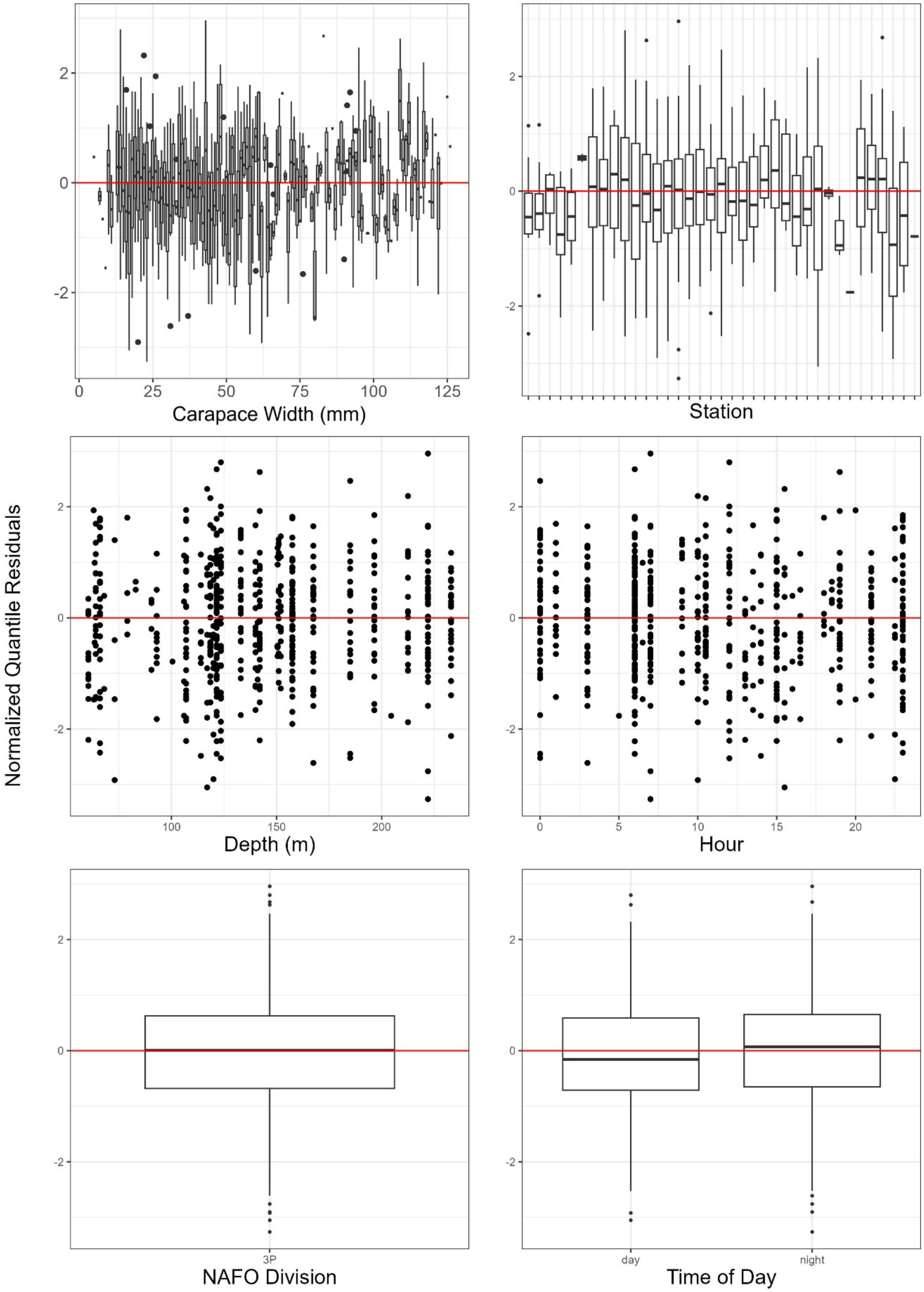


Figure 8. Normalized quantile residuals as a function of CW, station, depth, hour, NAFO Division, and diel period for Snow Crab, best model selected for size-disaggregated conversion factor analysis for the CCGS Teleost *and CCGS* John Cabot *for spring subDiv. 3Ps.*

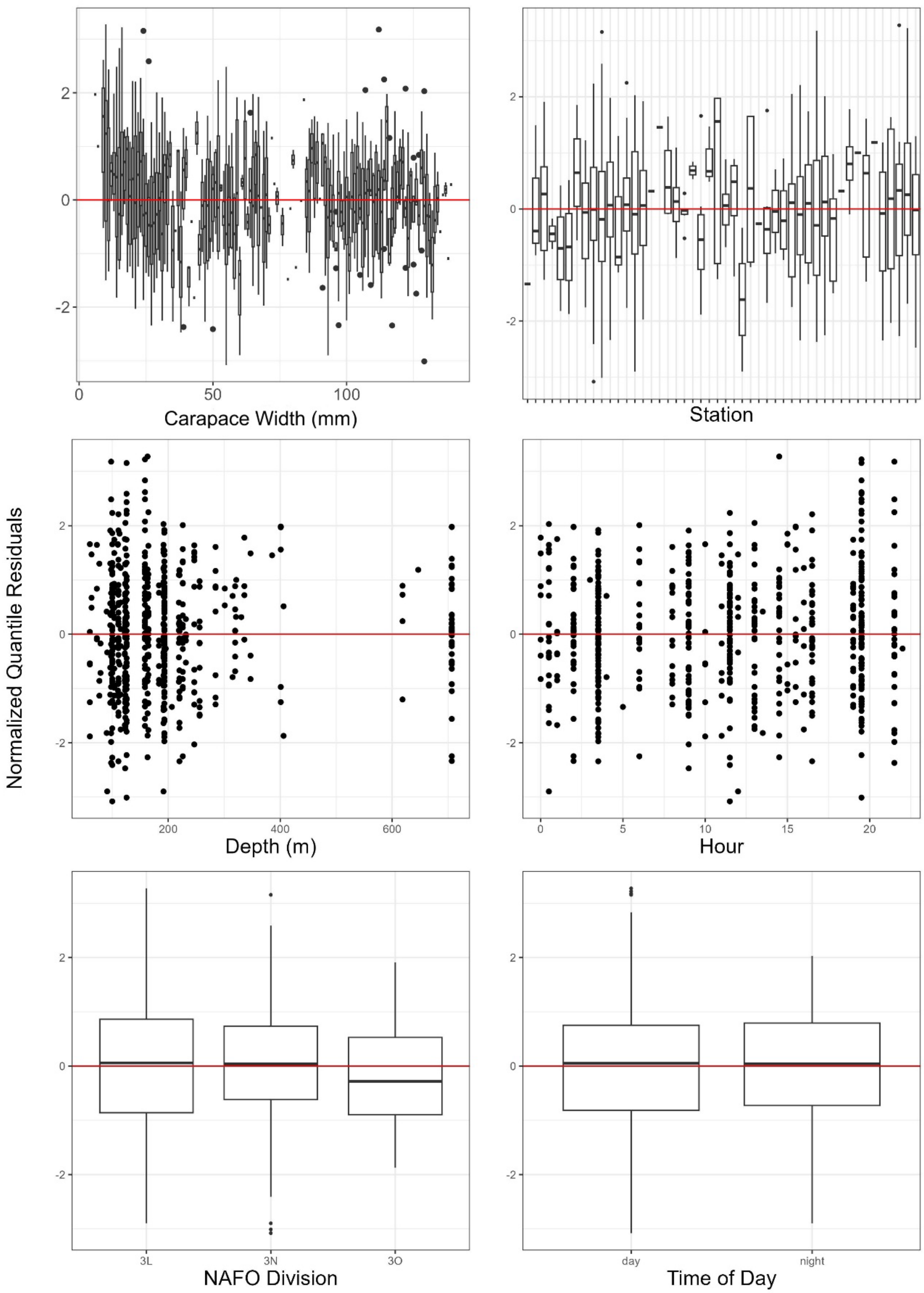


Figure 9. Normalized quantile residuals as a function of CW, station, depth, hour, NAFO Division, and diel period for Snow Crab, best model selected for size-disaggregated conversion factor analysis for the CCGS Teleost*, and CCGS* John Cabot *for spring Div. 3LNO.*

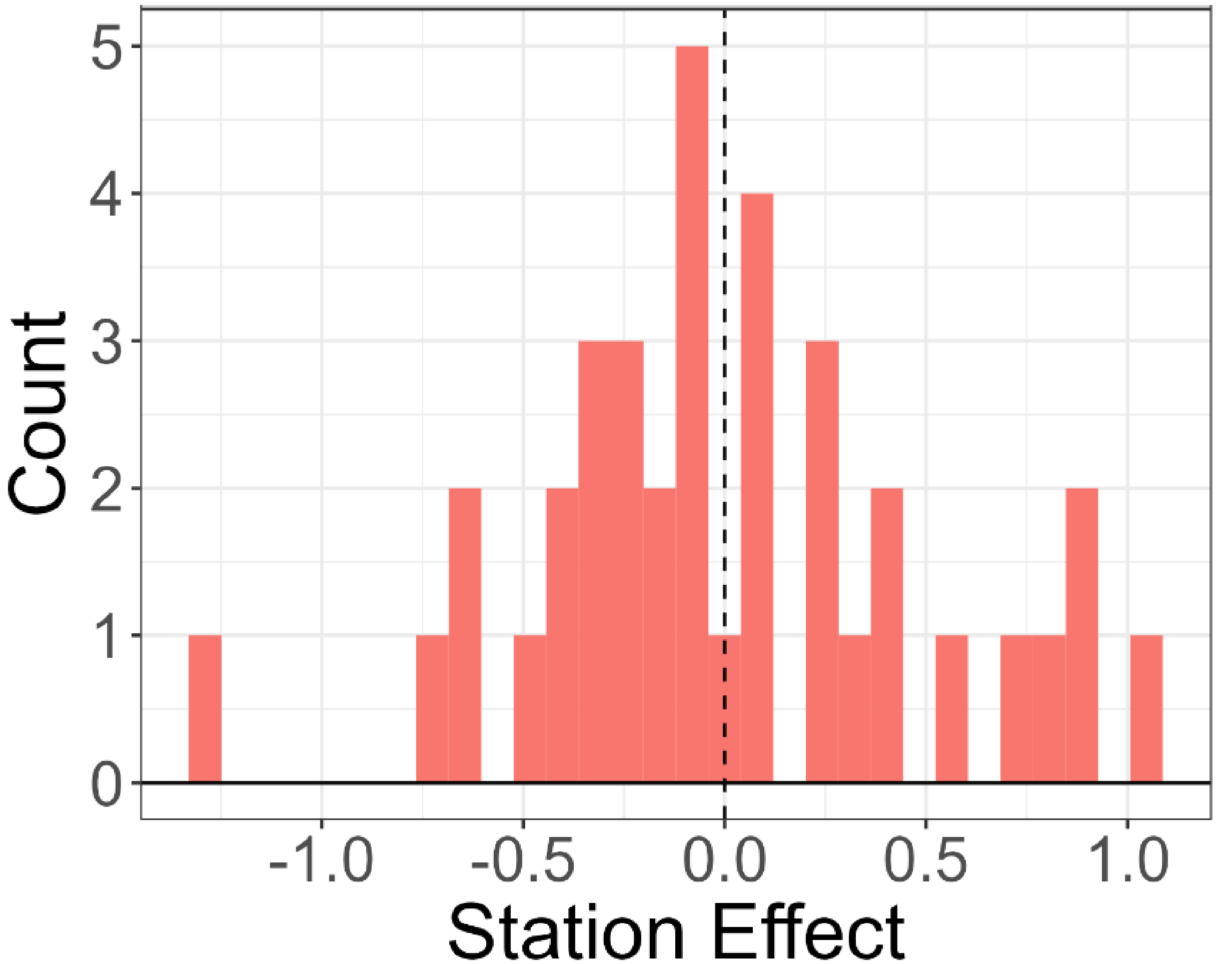


Figure 10. Histogram of station effect for best model selected for Snow Crab conversion factor analysis of CCGS Teleost *and CCGS* John Cabot *in spring subDiv. 3Ps.*

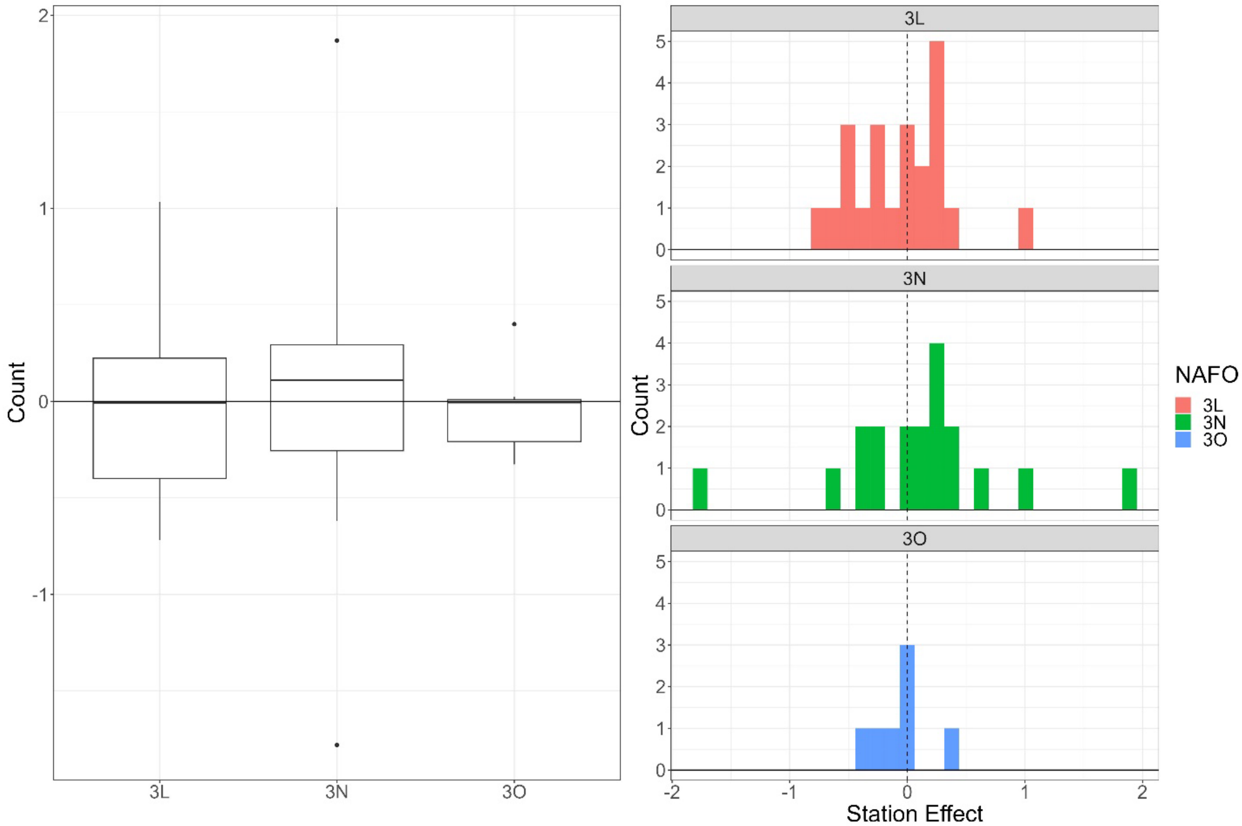


Figure 11. Boxplot (left) and histogram (right) of station effect by NAFO Division for best model selected for Snow Crab conversion factor analysis of CCGS Teleost *and CCGS* John Cabot *in spring Div. 3LNO.*

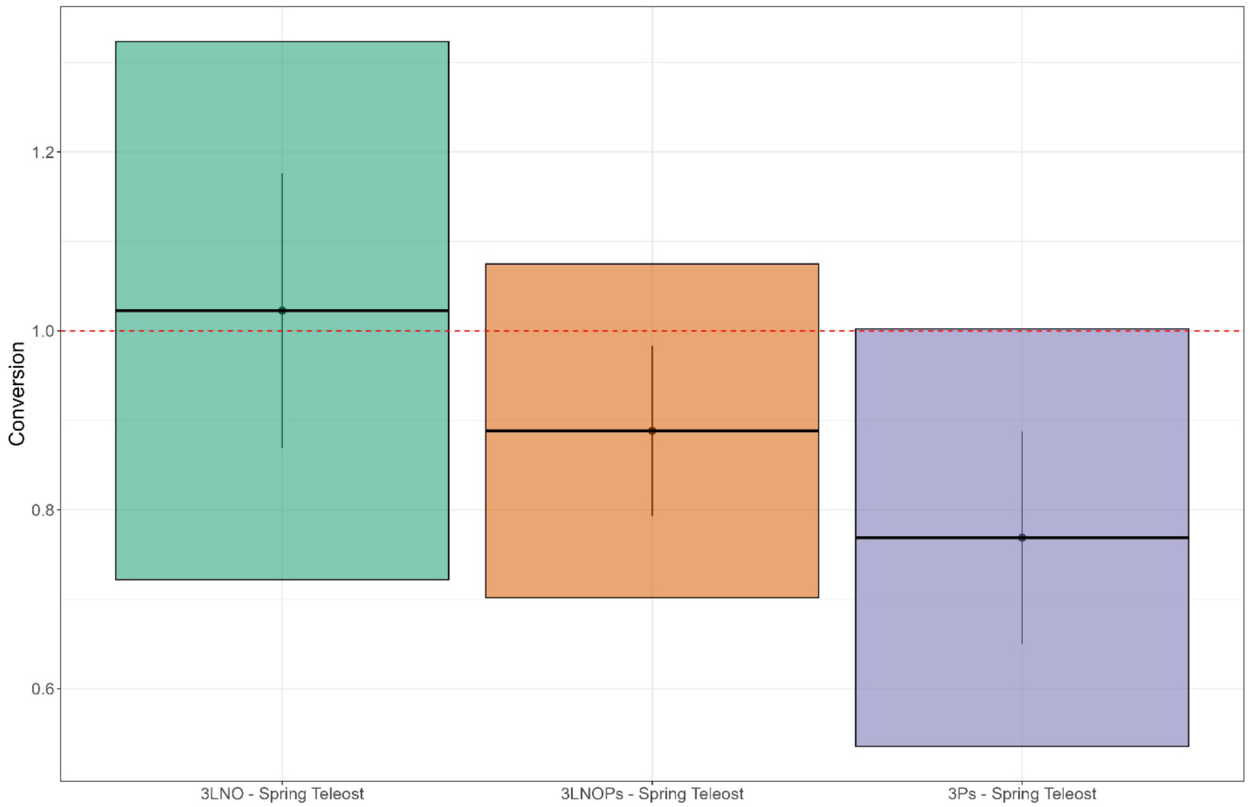


Figure 12. Comparison of estimated conversion factors for Snow Crab across comparative fishing areas in spring. From left to right, CCGS Teleost *and CCGS* John Cabot *for Div. 3LNO, Div. 3LNOPs, and subDiv. 3Ps. Points and thick centre lines show the estimated conversion factor (ρ), with bars showing the standard error and boxes representing the 95% CIs. The red dashed line shows the value for equal catch efficiency.*

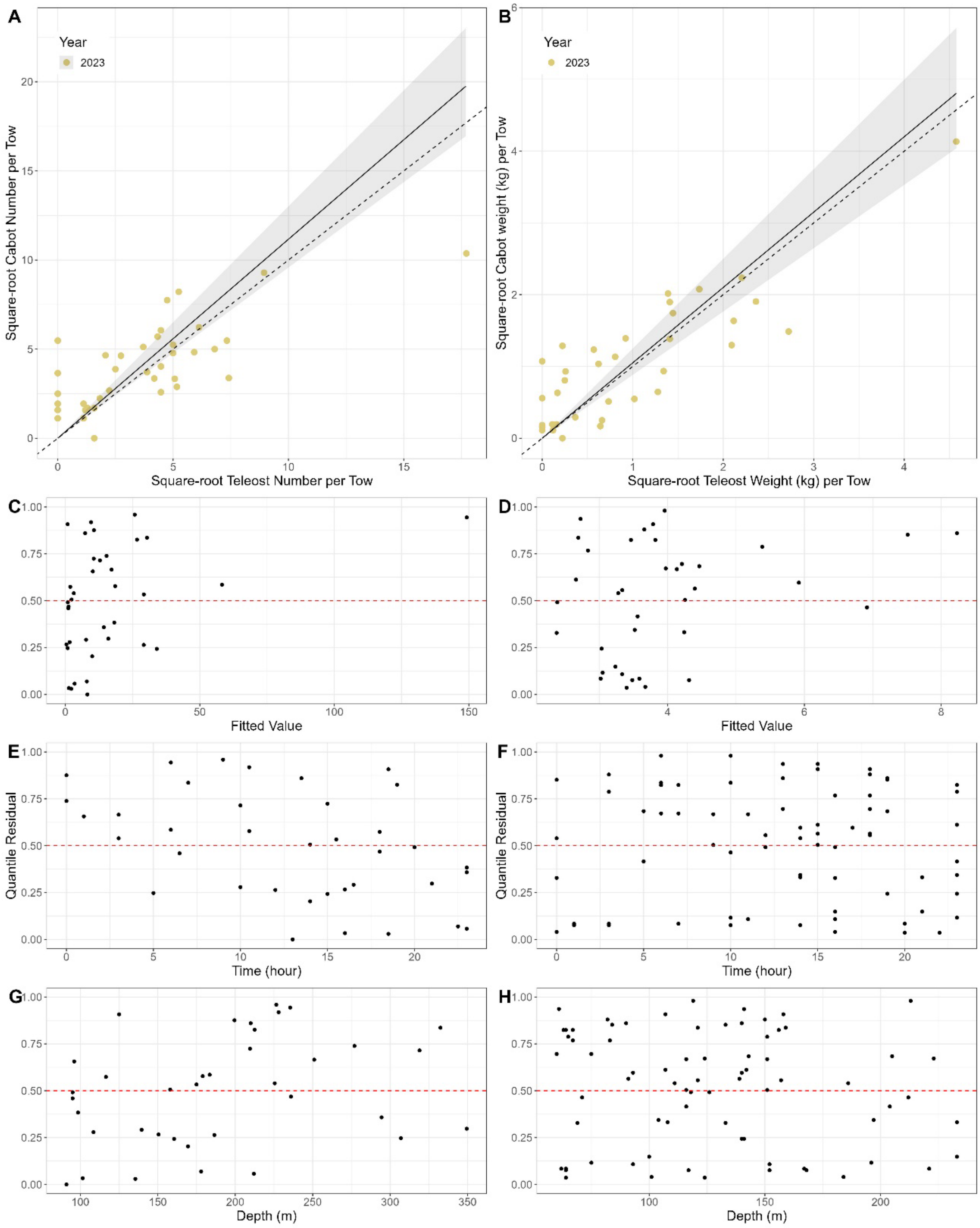


Figure 13. Results of size-aggregated analysis for the CCGS Teleost *and CCGS* John Cabot *for catch of Snow Crab, spring subDiv. 3Ps. (A) Biplot of the square-root of CCGS* John Cabot *catch numbers against the square-root of CCGS* Teleost *catch numbers, where the solid black line and shaded interval show the estimated conversion and approximate 95% CIs from the best size-aggregated model. (B) same as in (A), except for catch weights. Quantile residuals from the analysis of catch numbers and weights are plotted, respectively, as a function of the following conditions within the paired sets: fitted values (C, D), time (E, F), and depth (G, H).*

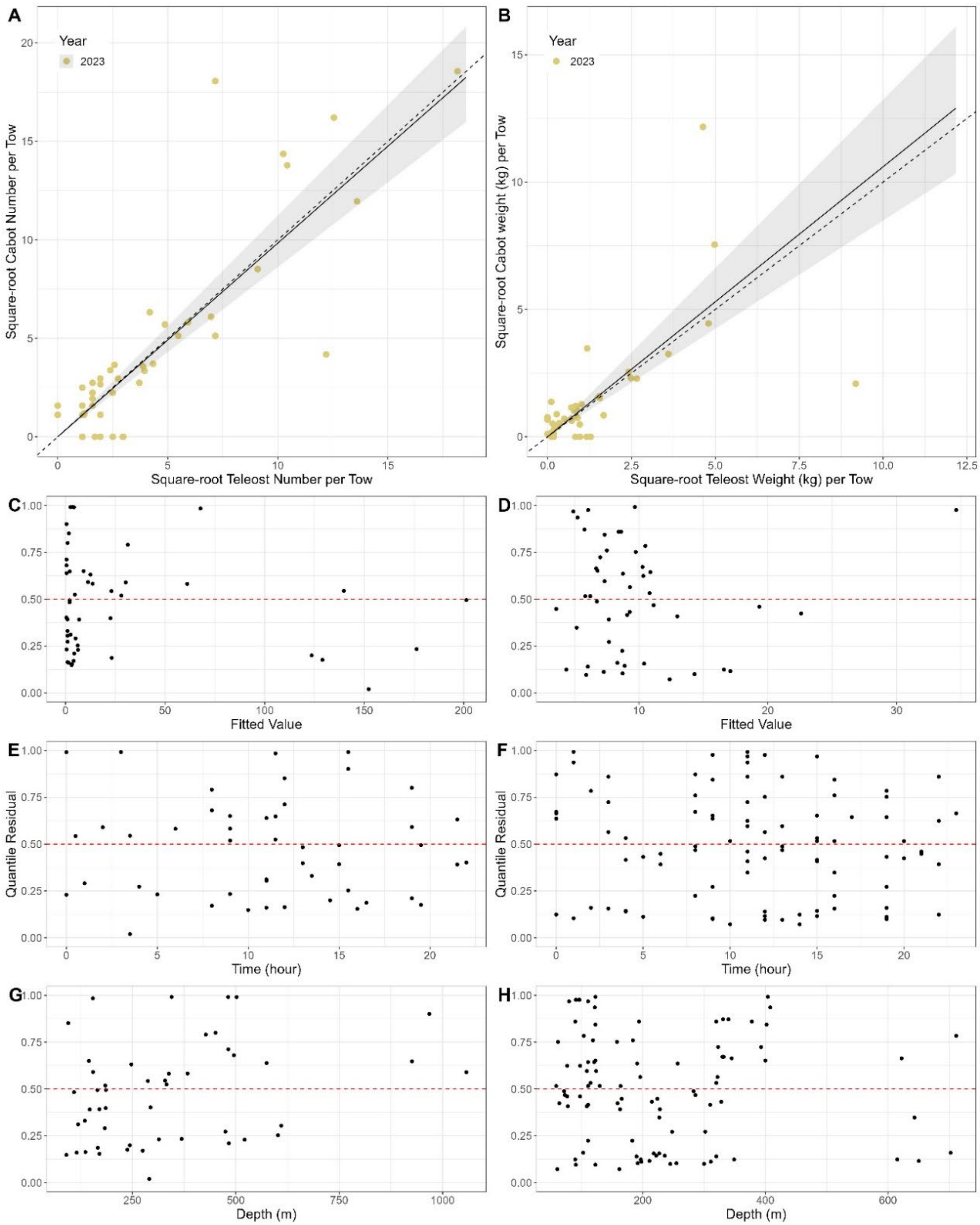


Figure 14. Results of size-aggregated analysis for the CCGS Teleost *and CCGS* John Cabot *for catch of Snow Crab, spring, Div. 3LNO. (A) Biplot of the square-root of CCGS* John Cabot *catch numbers against the square-root of CCGS* Teleost *catch numbers, where the solid black line and shaded interval show the estimated conversion and approximate 95% CIs respectively, from the best size-aggregated model. (B) same as in (A), except for catch weights. Quantile residuals from the analysis of catch numbers, weights are plotted as a function of the following conditions within the paired sets: fitted values (C, D), time (E, F) and, depth (G, H).*

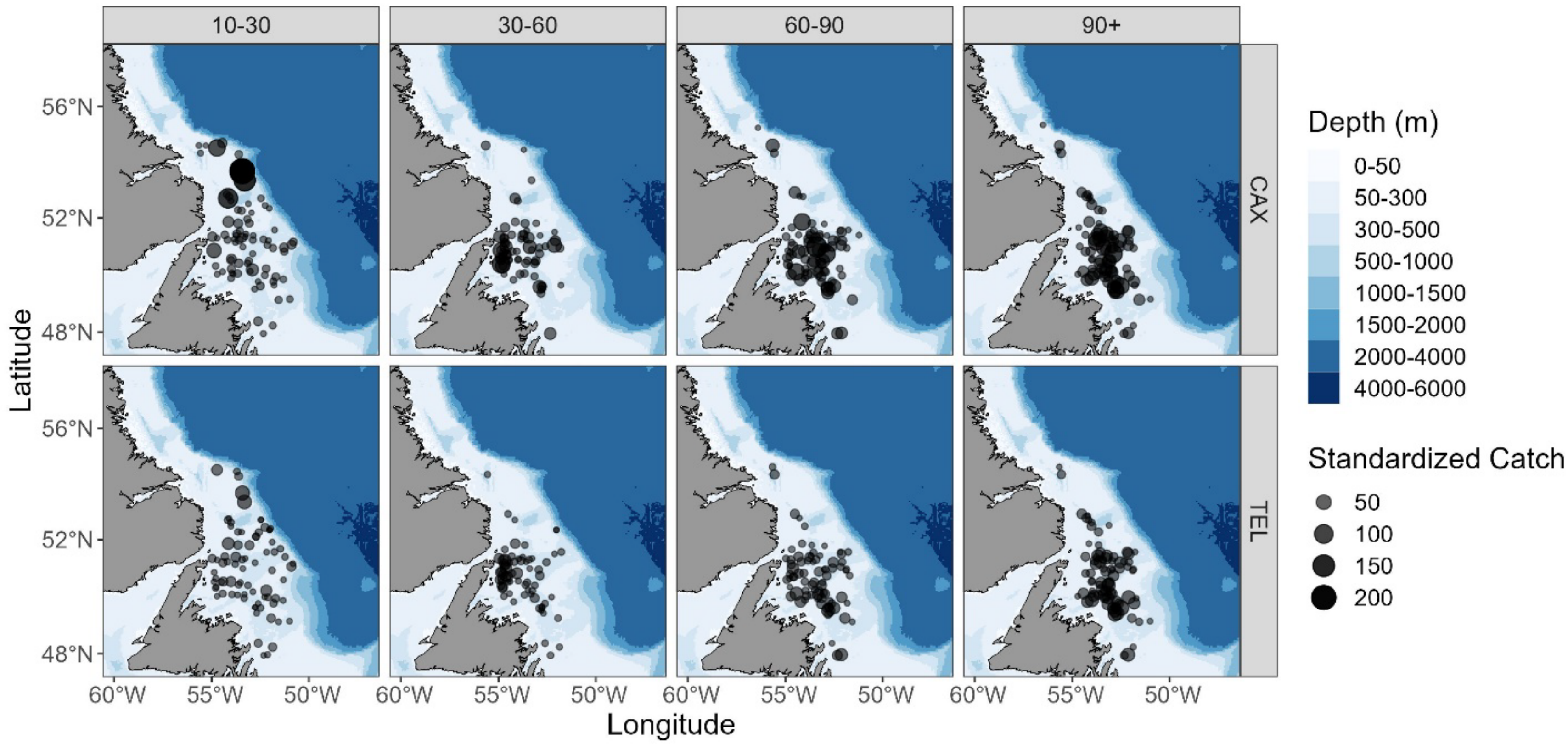


Figure 15. A map of Snow Crab catches for fall 2021–23 comparative fishing by CW group (width in mm specified in top panel) by the CCGS Capt Jacques Cartier/John Cabot *(top) and the CCGS* Teleost *(bottom) in comparative fishing sets, where circle size is proportional catch weight (kg).*

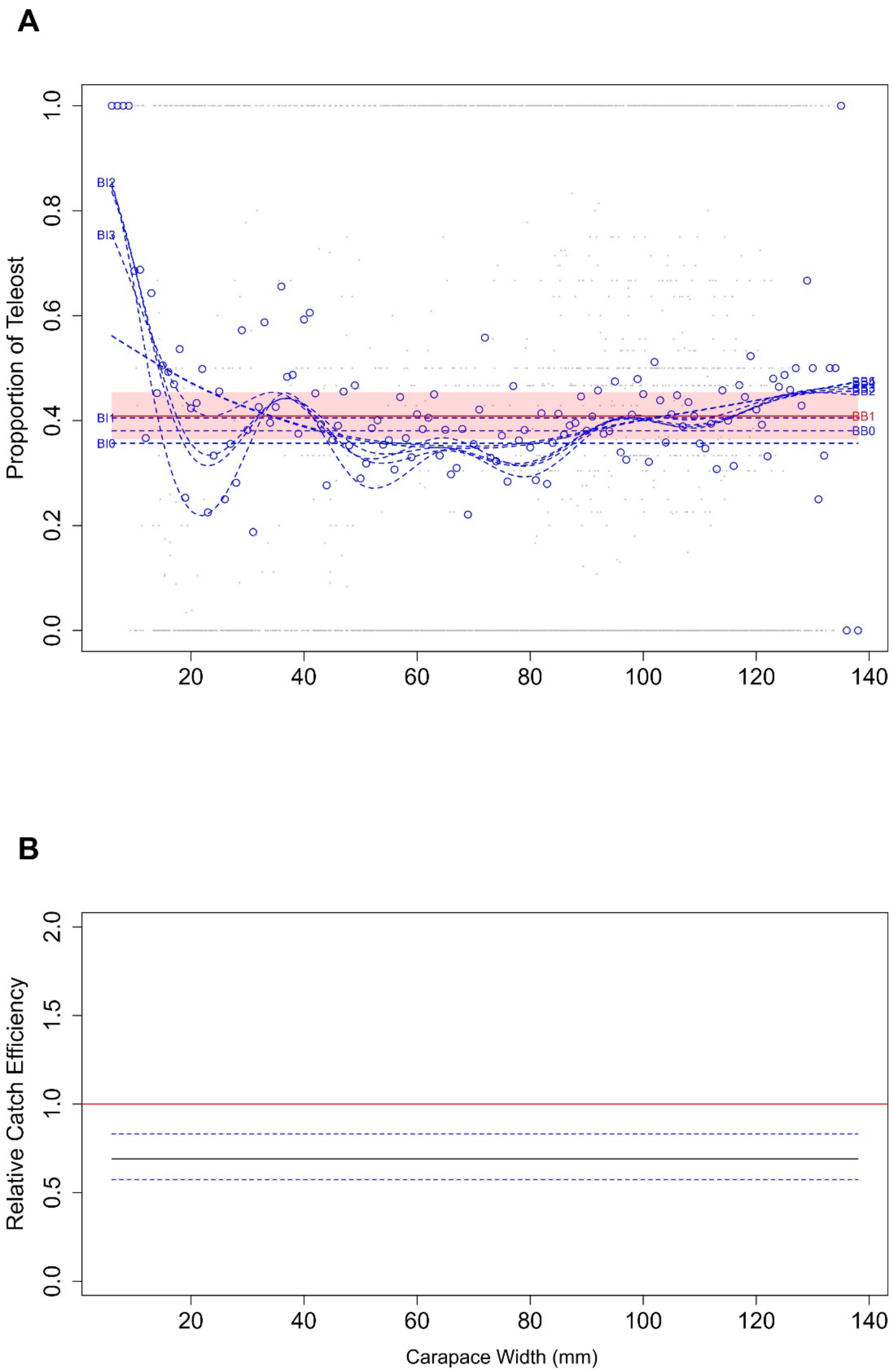


Figure 16. Snow Crab conversion factor estimate, from beta-binomial one (BB1) model, between the CCGS Teleost *and CCGS* Capt Jacques Cartier/John Cabot *for fall Div. 2HJ3KL. (A) Estimated size-specific catch proportion functions,* $logit(p_{Ai}(l))$*, for each converged model, with the selected model plotted using a red line along with its approximate 95% CI (shaded area), as well as the size class-specific mean empirical proportion of total catch in a pair made by the CCGS* Teleost *(blue dots). (B) Estimated relative catch efficiency (conversion factor) function from the best model (black line) with 95% CI (dashed blue lines). The horizontal red line indicates equivalent efficiency between vessels.*

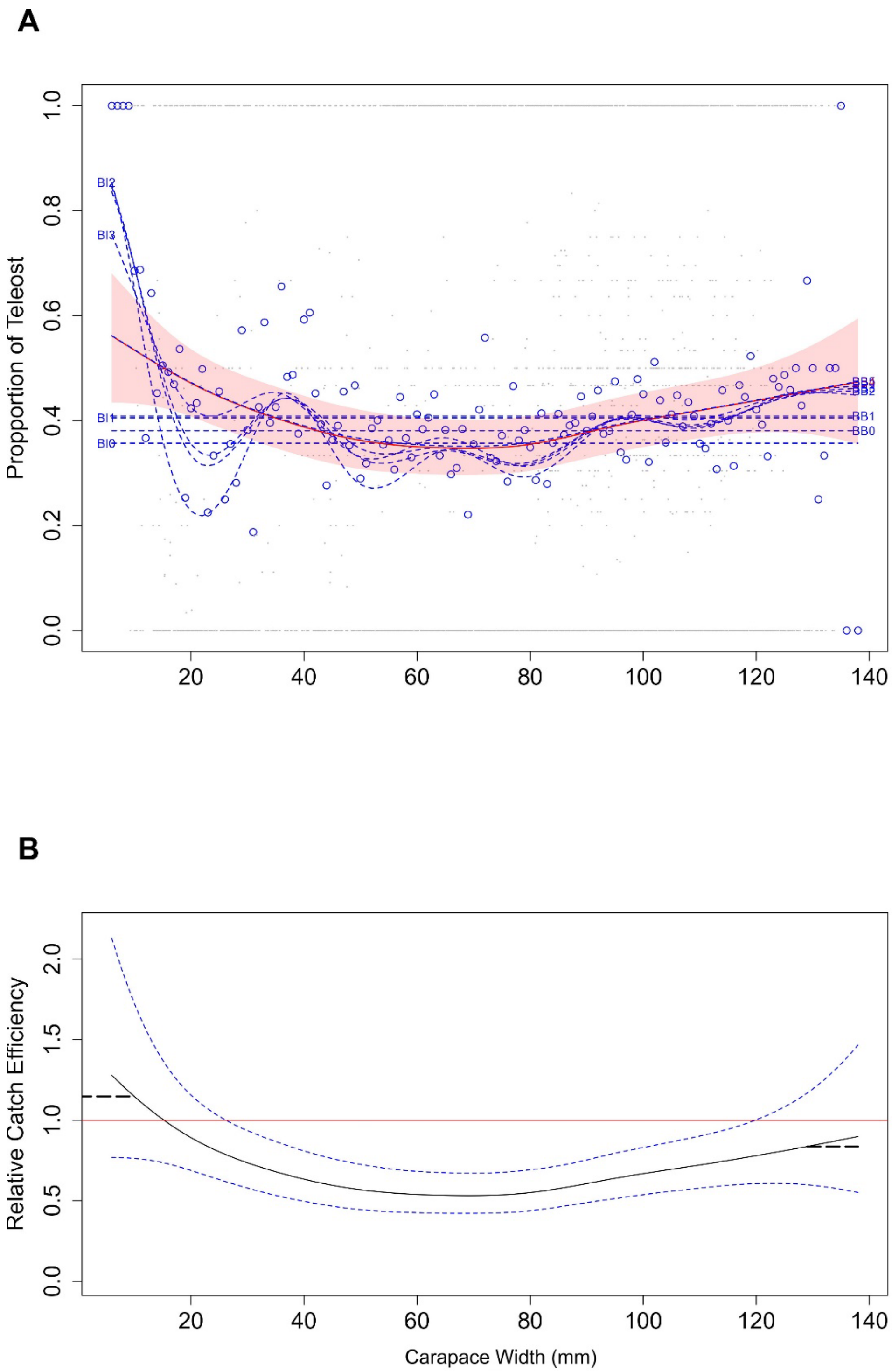


Figure 17. Snow Crab conversion factor estimate from beta-binomial four (BB4) model, between the CCGS Teleost *and CCGS* Capt Jacques Cartier/John Cabot *for fall Div. 2HJ3KL. (A) Estimated size-specific catch proportion functions, $logit(p_{Ai}(l))$, for each converged model, with the selected model plotted using a red line along with its approximate 95 % CI (shaded area), as well as the size class-specific mean empirical proportion of total catch in a pair made by the CCGS* Teleost *(blue dots). (B) Estimated relative catch efficiency (conversion factor) function from the best model (black line) with 95 % CI (dashed blue lines). The horizontal red line indicates equivalent efficiency between vessels.*

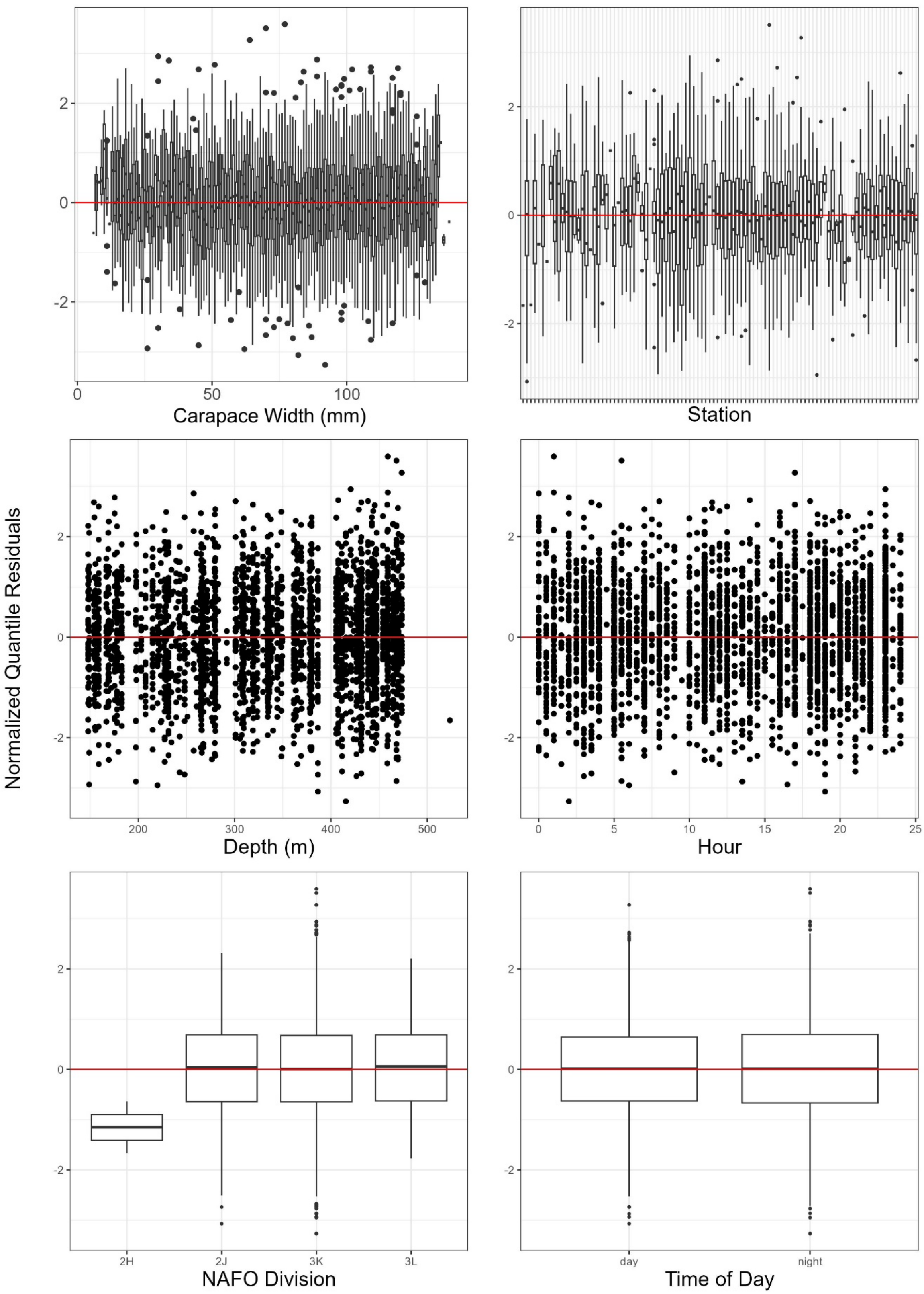


Figure 18. Normalized quantile residuals as a function of CW, station, depth, hour, NAFO Division, and diel period for Snow Crab, beta-binomial one (BB1) model for size disaggregated conversion factor analysis for the CCGS Teleost*, and CCGS* Capt Jacques Cartier/John Cabot *for fall Div. 2HJ3KL.*

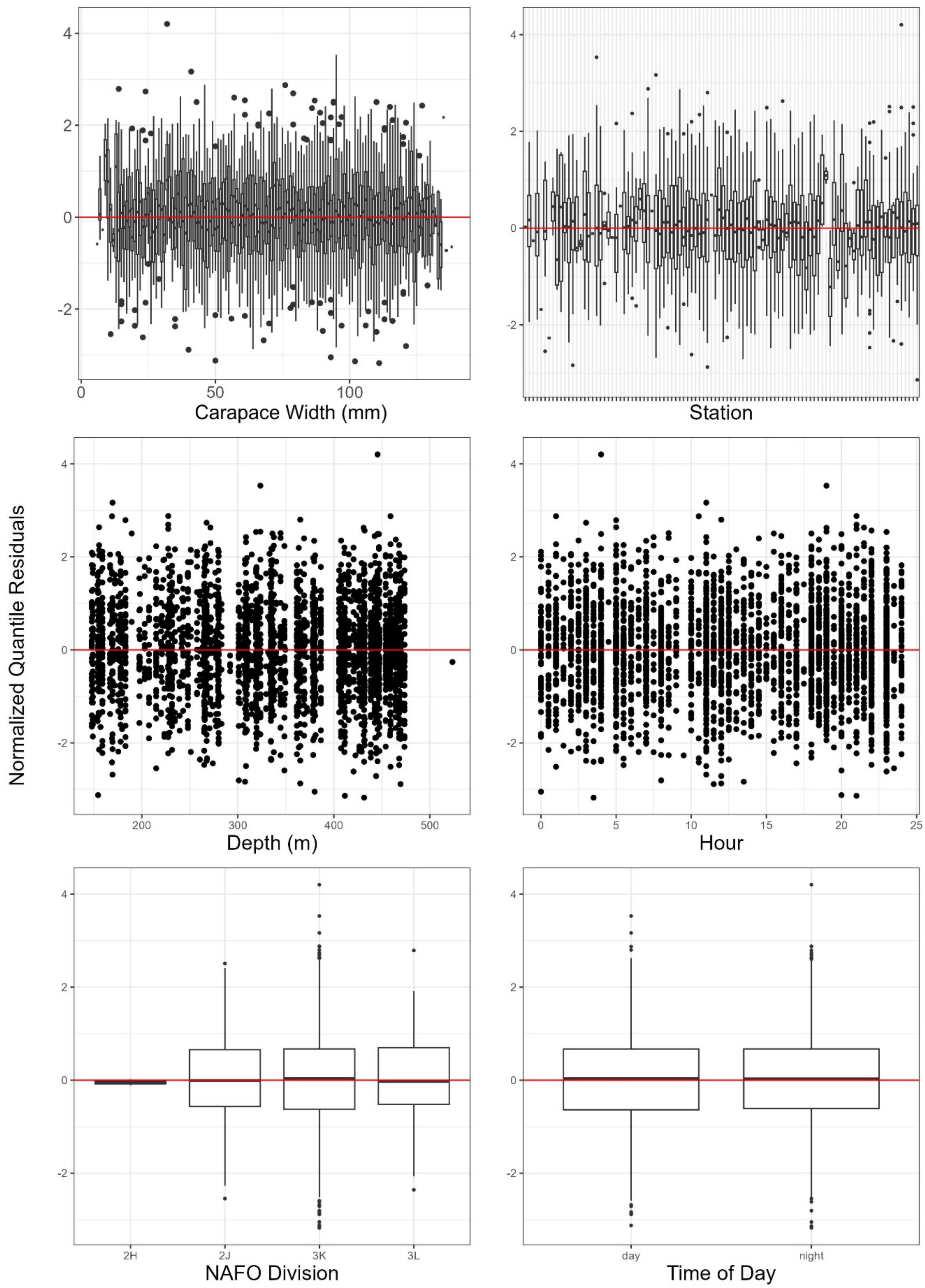


Figure 19. Normalized quantile residuals for as a function of CW, station, depth, hour, NAFO Division, and diel period for Snow Crab, beta-binomial four (BB4) model for size disaggregated conversion factor analysis for the CCGS Teleost*, and CCGS* Capt Jacques Cartier/John Cabot *for fall Div. 2HJ3KL.*

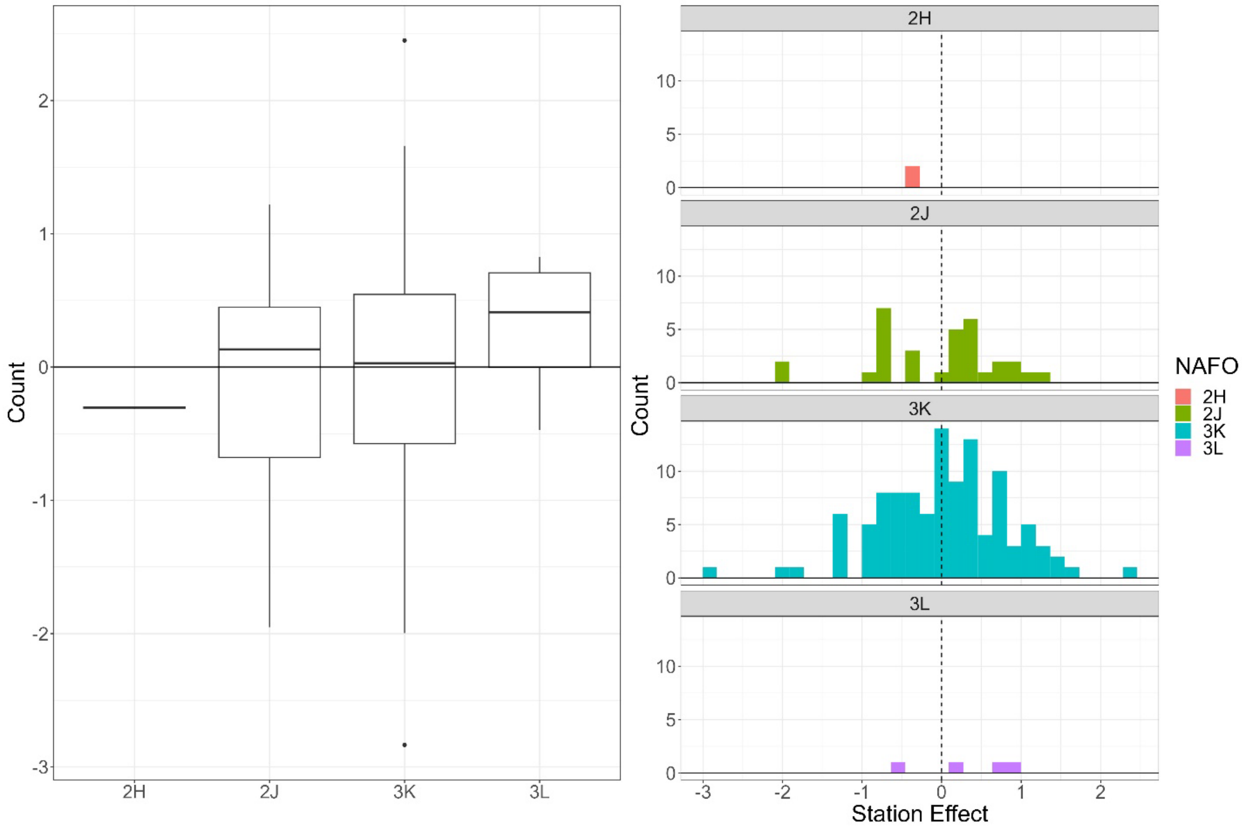


Figure 20. Boxplot (left) and histogram (right) of station effect by NAFO Division for beta-binomial one (BB1) model for Snow Crab conversion factor analysis of CCGS Teleost *and CCGS* Capt Jacques Cartier/John Cabot *in fall Div. 2HJ3KL.*

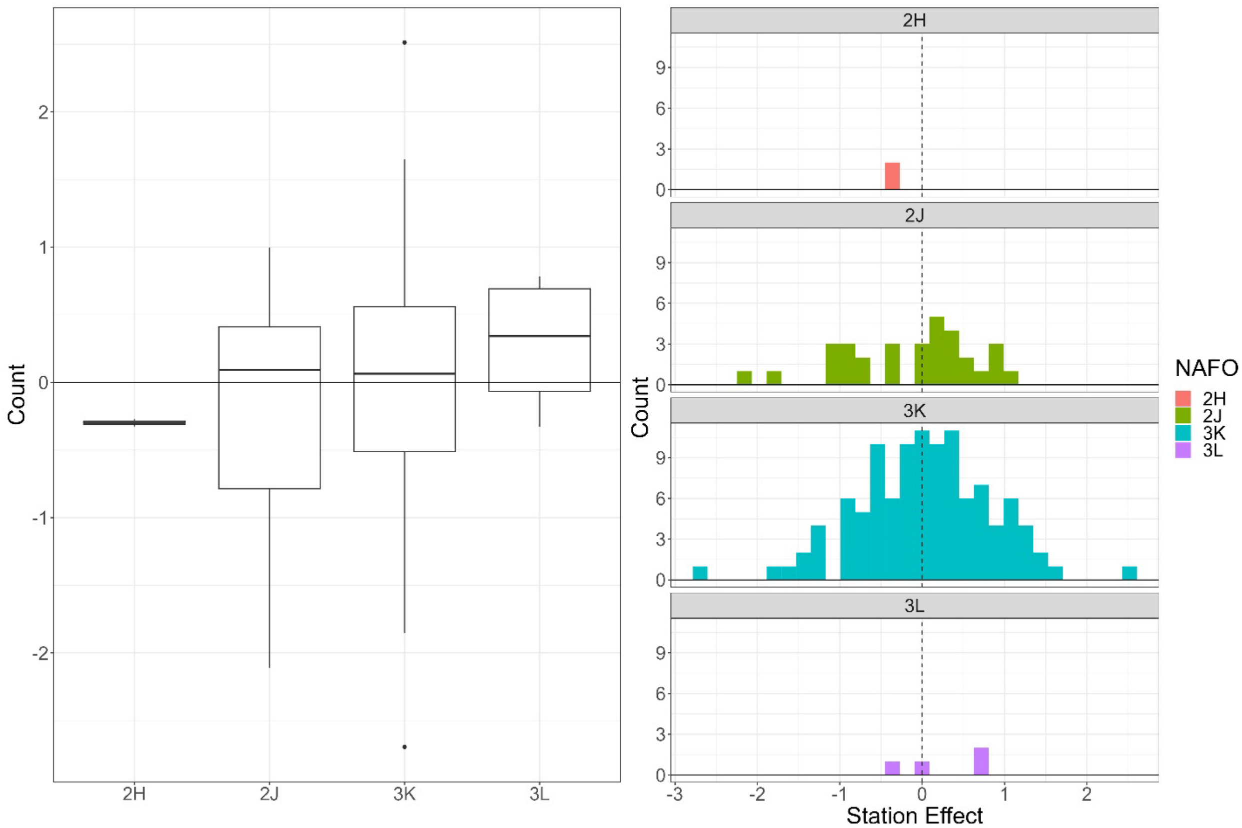


Figure 21. Boxplot (left) and histogram (right) of station effect by NAFO division for beta-binomial four (BB4) model for Snow Crab conversion factor analysis of CCGS Teleost *and CCGS* Capt Jacques Cartier/John Cabot *in fall Div. 2HJ3KL.*

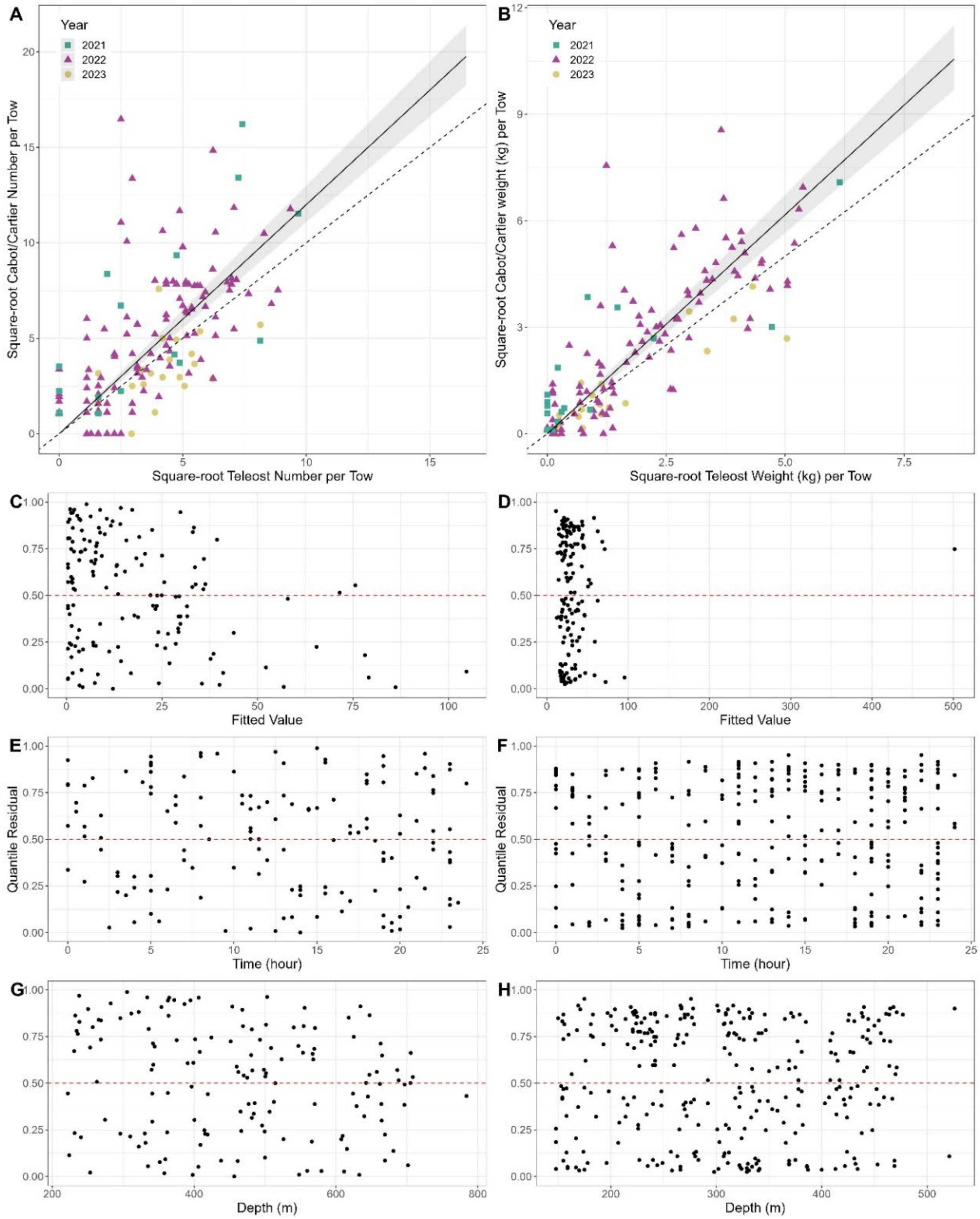


Figure 22. Results of size-aggregated analysis for the CCGS Teleost and CCGS Capt Jacques Cartier/John Cabot *for catch of Snow Crab, fall Div. 2HJ3KL. (A) Biplot of the square-root of CCGS* John Cabot *catch numbers against the square-root of CCGS* Teleost *catch numbers, where the solid black line and shaded interval show the estimated conversion and approximate 95 % CIs respectively, from the best size-aggregated model. (B) same as in (A), except for catch weights. Quantile residuals from the analysis of catch numbers, weights are plotted as a function of the following conditions within the paired sets: fitted values (C, D), time (E, F) and, depth (G, H).*

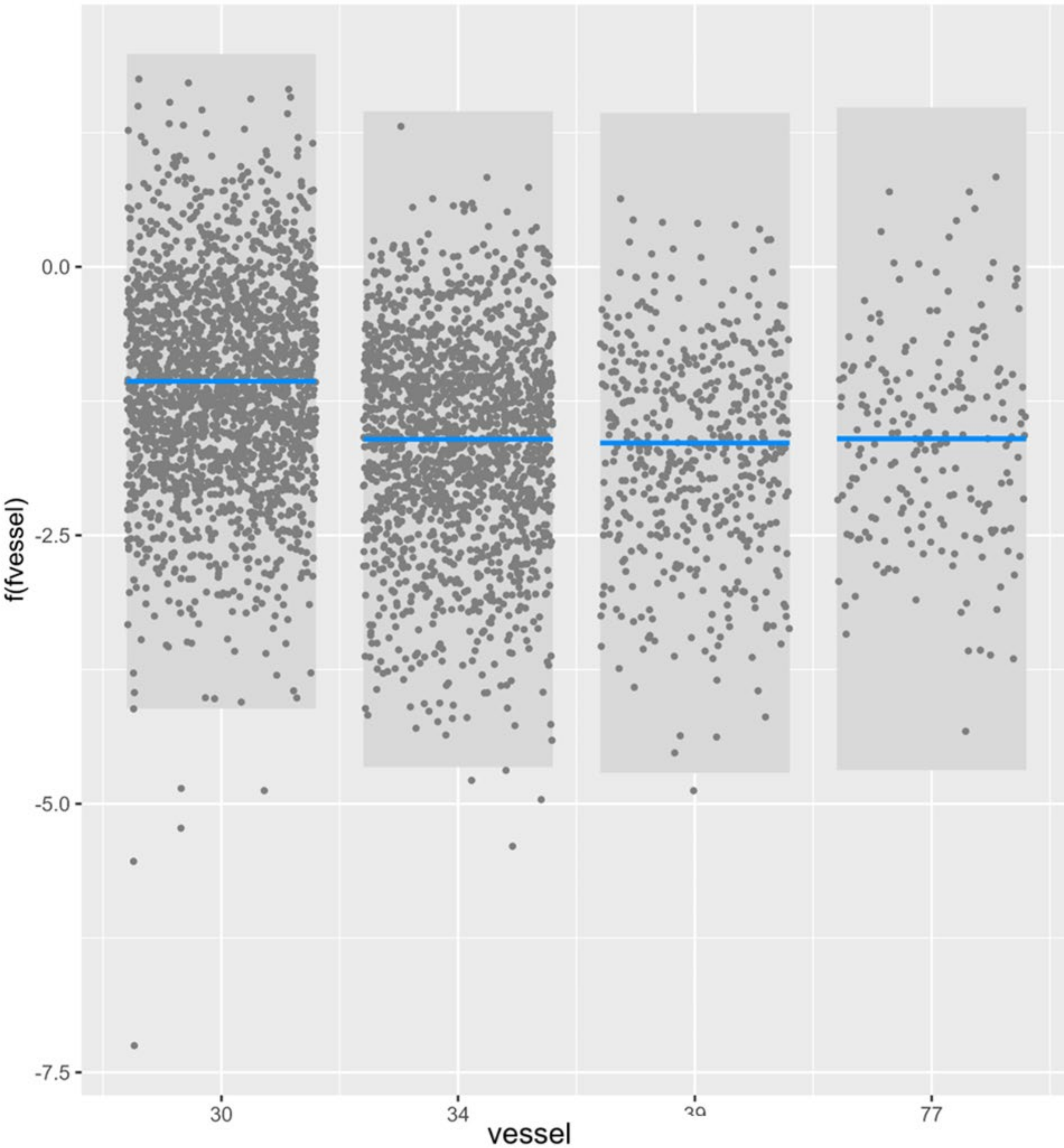


Figure 23. Exploitable Snow Crab (> 94 mm CW) spatiotemporal model conditional effects plot for the vessel covariate (CCGS Wilfred Templeman *[30], CCGS* Alfred Needler *[34], CCGS* Teleost *[39], and CCGS* John Cabot *[77]). Blue lines show means and shaded ribbons show 95% CIs.*

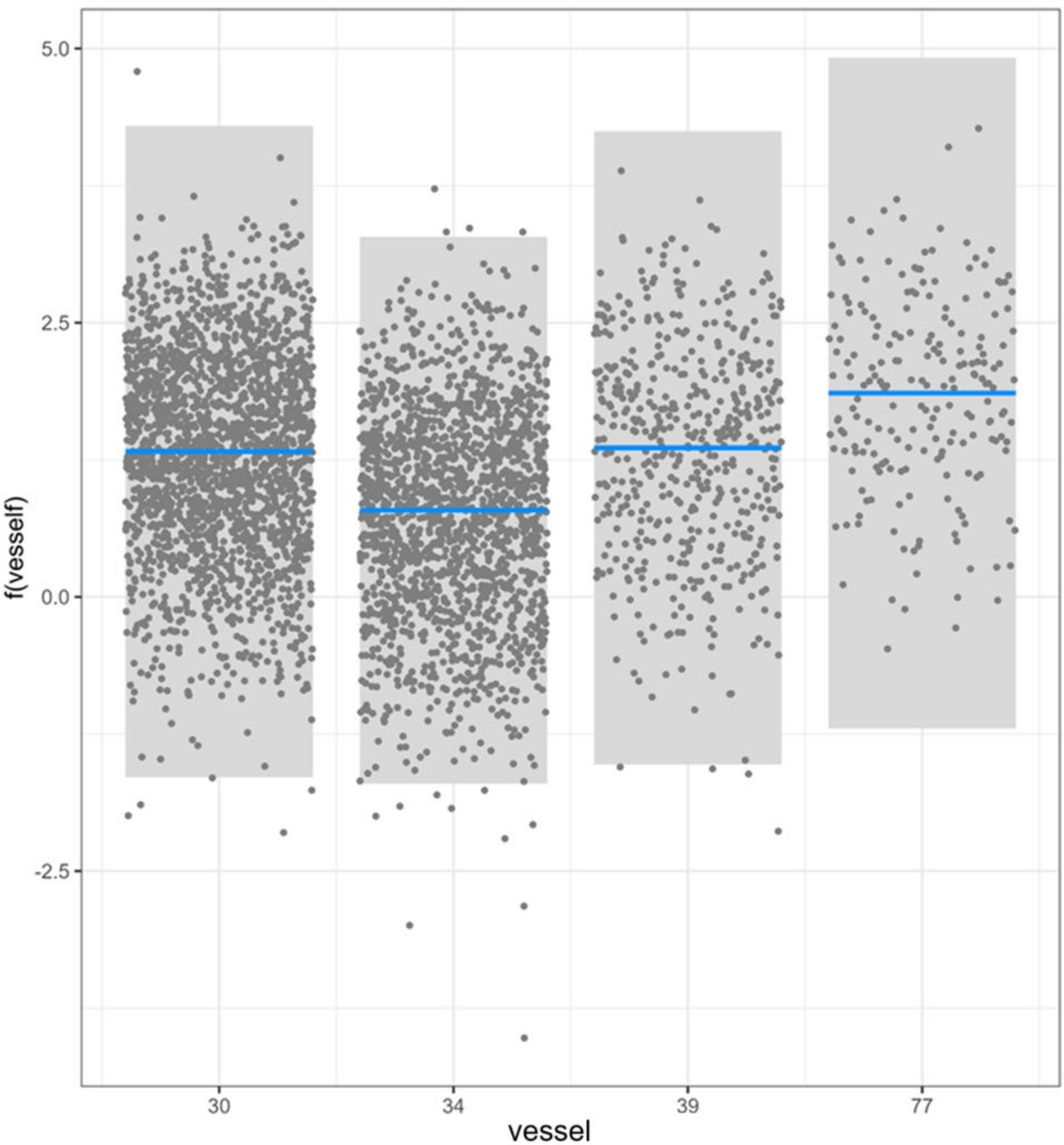


Figure 24. Pre-recruit (70–94 mm CW) Snow Crab spatiotemporal model conditional effects plot for the vessel covariate (CCGS Wilfred Templeman *[30], CCGS* Alfred Needler *[34], CCGS* Teleost *[39], and CCGS* John Cabot *[77]). Blue lines show means and shaded ribbons show 95 % CIs.*

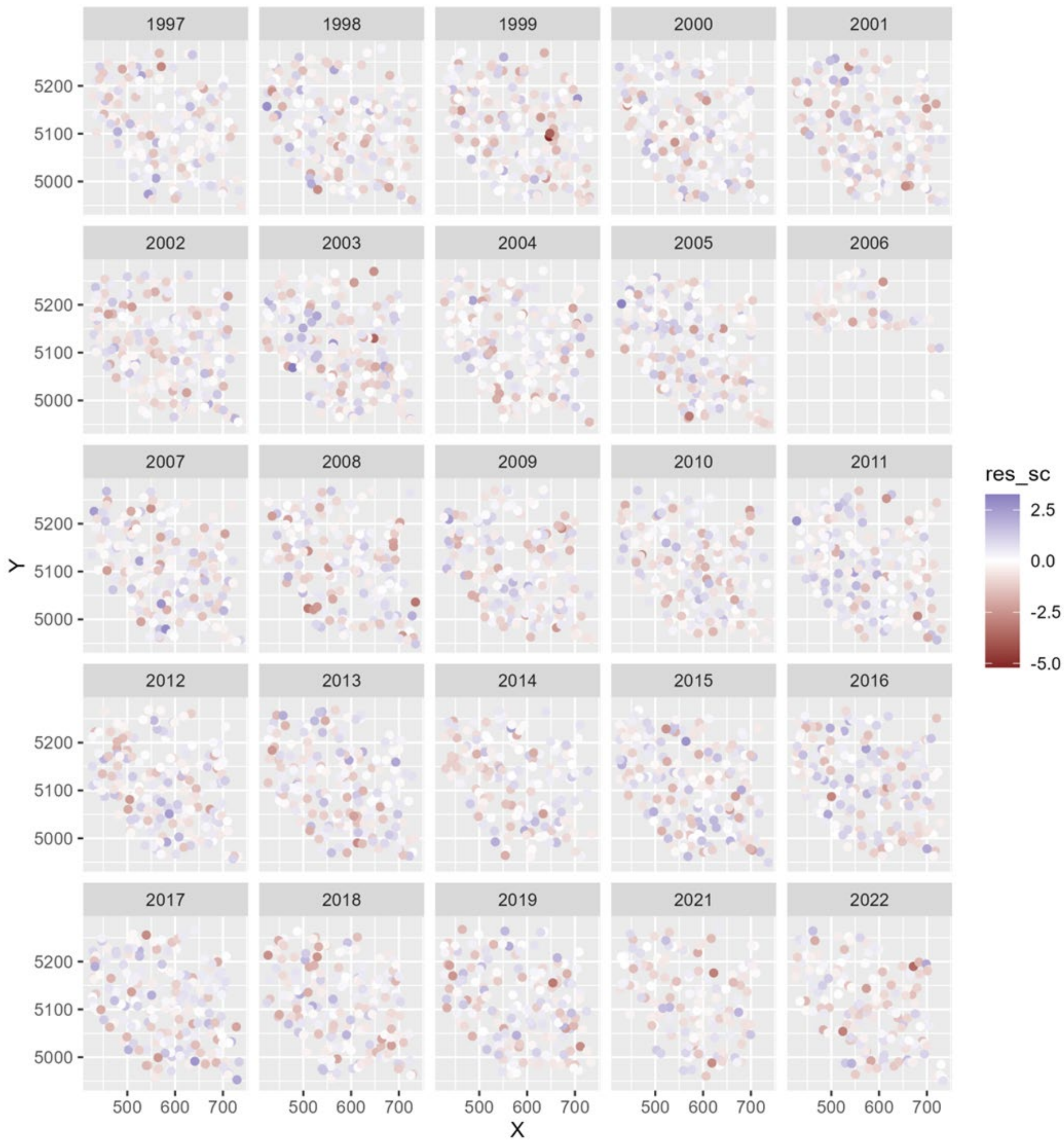


Figure 25. Spatial (X, Y) and temporal (annual panels) distribution of residuals from final Snow Crab exploitable biomass model (Eq. 1).

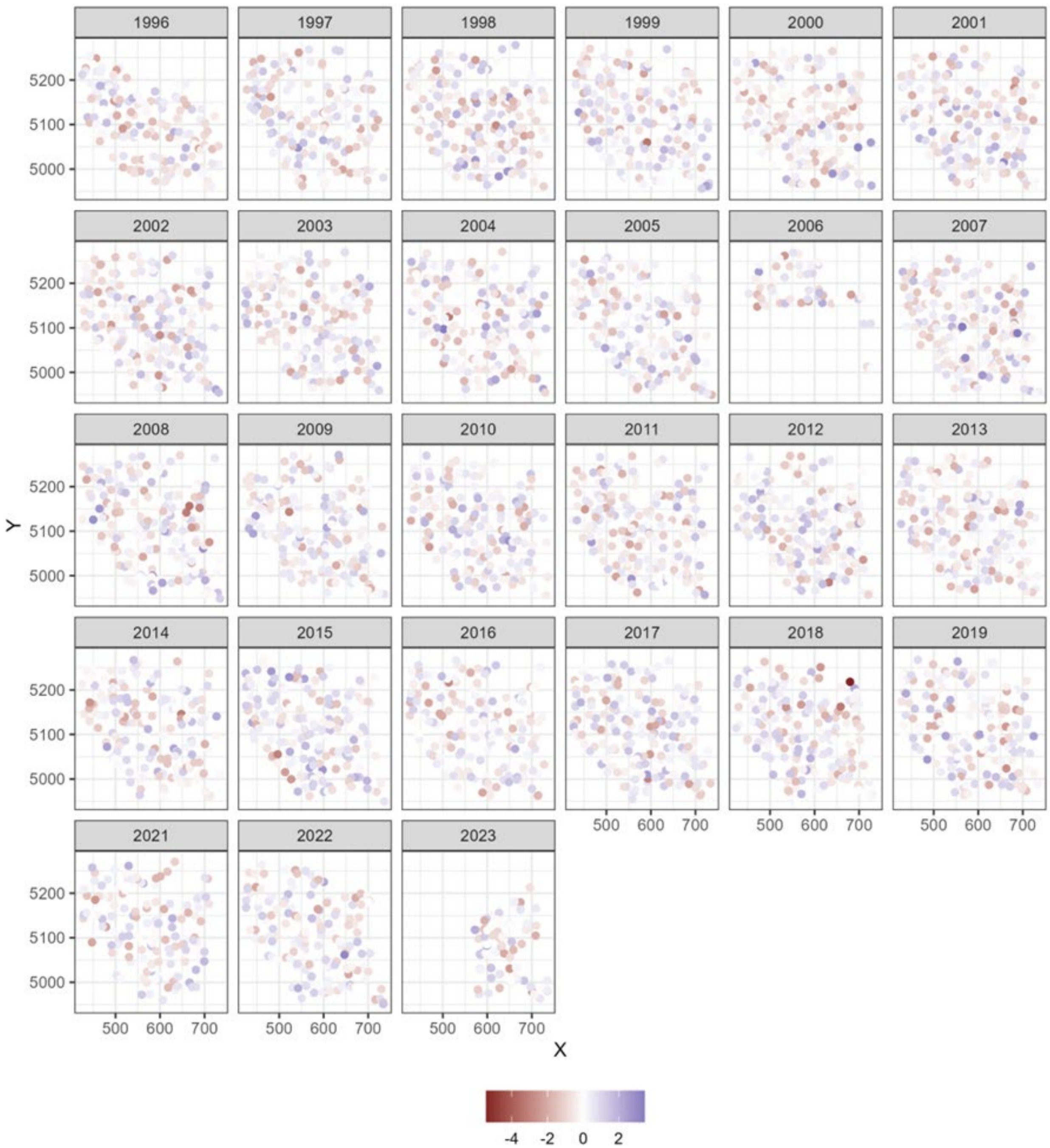


Figure 26. Spatial (X,Y) and temporal (annual panels) distribution of residuals from final Snow Crab pre-recruit biomass model (Eq. 1).

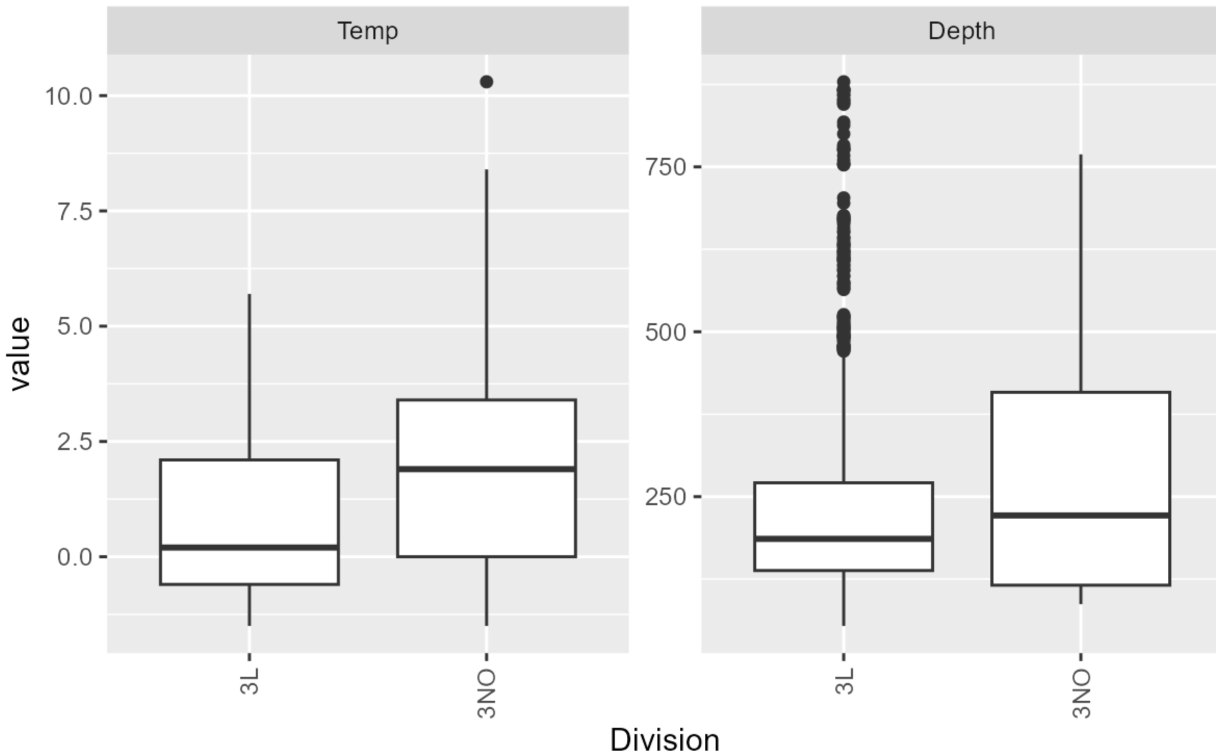


Figure 27. Comparison of bottom temperature (°C) and depth (m) range for catch of Snow Crab from the 15 strata in Div. 3LNO with the highest catch rates (mean number per tow) during the fall survey time series (1995–2020).