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# On the Relative Catchability of Atlantic Cod 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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## ABSTRACT

Multispecies bottom trawl surveys have been conducted annually in the spring and fall in the Newfoundland and Labrador region using a Campelen 1800 survey trawl aboard the Canadian Coast Guard Ship (CCGS) *Teleost* and CCGS *Alfred Needler* (or its sister ship the *Wilfred Templeman*) since 1995. The data collected during 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 a number of ecosystem indicators. The CCGS *Wilfred Templeman* was previously retired, and the CCGS *Alfred Needler* and CCGS *Teleost* will no longer be used for these surveys after 2022 and 2023, respectively, and will be replaced by the Offshore Fishery Science Vessels (OFSVs) CCGS *John Cabot* and CCGS *Capt. Jacques Cartier*. The Campelen 1800 survey trawl will continue to be used, with a few modifications. Comparative fishing has been ongoing since 2021 to determine differences in catchability between the outgoing vessels and the new vessels with the modified Campelen trawl. Limited spatial distribution of comparative fishing from 2021-2022 only allowed for development of conversion factors of the CCGS *Alfred Needler* in fall for North Atlantic Fisheries Organization (NAFO) divisions 3KL, before this vessel's decommissioning in February 2022. As a result, further spring comparative fishing was undertaken between the CCGS *Teleost* and CCGS *John Cabot*. Results indicate an equal catchability between the CCGS *Teleost* and CCGS *John Cabot* for spring 2023. This result is consistent across space, season, and vessel with all available data indicating no conversion factor is required for Atlantic Cod (*Gadus morhua*) in the Newfoundland and Labrador surveys moving from the CCGS *Teleost* and the CCGS *Alfred Needler* to the CCGS *Capt. Jacques Cartier* and CCGS *Cabot*.

# INTRODUCTION

Multispecies 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* (see Warren et al. 1997, Cadigan 2006) 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 a number of ecosystem indicators. The *Needler* and *Teleost* will no longer be used for these surveys after 2022 and 2023, respectively, and will be replaced by new Offshore Fishery Science Vessels (OFSVs), the CCGS *John Cabot* and CCGS *Capt. Jacques Cartier* (hereafter the "*Cabot*", and "*Cartier*"). Comparative fishing – direct side by side fishing comparison between the old and new vessels – has been ongoing since 2021 (Wheeland et al. 2023). This is a standard approach to determining differences in catchability due to different survey protocols (vessel, gear, etc.), and is used here to compare catchability between the outgoing vessels with the standard Campelen trawl and the new vessels with the modified Campelen trawl.

A peer-review of the NL Comparative Fishing program from 2021-2022 occurred in July 2023 (DFO 2024). At this meeting, sample size and spatial coverage of paired tows were found to be generally insufficient to estimate standard conversion factors for the *Needler* survey time-series in North Atlantic Fisheries Organization (NAFO) Divisions 3LNOPs in the spring or in Div. 3NO in the fall. With the *Needler* decommissioned in February 2022 no additional comparative fishing is possible with this vessel. The *Needler* has been the primary vessel for the 3LNOPs spring survey time series since 2009, and was preceded by its sistership the CCGS *Wilfred Templeman*, however there are several years where the *Teleost* was used for part or all of the spring survey area when the *Needler* was unavailable. Therefore, comparative fishing was completed with the *Teleost* and *Cabot* during spring 2023 with a targeted approach in 3Ps, and a shadow survey in divisions 3LNO.

Analysis from the fall 2021-2022 comparative fishing program concluded that no conversion was required (i.e. catchability is equivalent between vessels) for Atlantic Cod survey catches between the *Needler* and *Cabot* in Div. 3KL. Similarly, there was no significant conversion between the *Teleost* and both *Cabot* and *Cartier* across their survey range in the fall (Div. 2HJ3K, deep water in Div. 3L), however this conclusion at the time was made for cod >20 cm; further work was requested before extending to the full size range of cod in this area due to limited sampling in shallow strata. Data were insufficient at the time to conclude whether these conclusions could be extended to Div. 3NO or inform on spring conversion factors.

Full results from the fall comparative fishing program, and analysis framework and model descriptions for conversion factor determination are outlined in Trueman et al. In press. Here we apply the same analytical framework to data collected in the spring of 2023 between the *Teleost* and the *Cabot* in Div. 3LNOPs and compare these with the fall results to inform on relative catchability of Atlantic Cod across the NL multispecies trawl surveys.

# METHODS

## SPRING 2023 COMPARATIVE FISHING

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 (see Theiss et al. 2018) was planned at 80% of the standard survey allocation. Paired tows were achieved at roughly 60% of these 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, however a targeted program focused on strata important to Atlantic Cod and snow crab *Chiononectes opilio*, was undertaken at the end of the survey season. Notably, this comparative work in subDiv. 3Ps occurred in mid-June (June 8-19, 2023), later than the usual survey time in this area (typically April through early May).

## CONVERSION FACTOR MODELLING

In the analysis of comparative fishing data, the goal is to estimate the relative fishing efficiency by numbers and/or weight 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 (length for most species, width for crab species) and station (i.e., set location) effects on the relative catch efficiency were fit for all species with sufficient sample size (minimum 25 paired tows) and length information to estimate size-disaggregated conversion factors for catch numbers by length. Length 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 is also applied to the over-dispersion 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 length interaction effect. However, to accurately model 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. Full model formulation is detailed in Yin and Benoît (2022) with the conversion factor $\rho(l)$ (the quantity of interest) defined as the ratio of catchabilities between vessels $A$ and $B$ at length $l$.

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 length $\rho(l)$, with the conversion factor being the ratio of catchabilities between the old and new vessels. When $\rho$ <1 indicates the new vessels catch a greater amount, while a $\rho$ >1 indicates the new vessel catches less. If $\rho$ = 1, conversion of catches between vessels is not required. For size-disaggregated models, when the 95% confidence interval (CI) of a rho 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 estimate from the 0.5 and 99.5 length percentiles should be used as a constant below or above those lengths, respectively, in order to account for very low sample size at these extreme lengths.

# RESULTS

During the spring 2023 comparative fishing Atlantic Cod were caught in 106 paired sets, with 48 of those sets in 3Ps. Cod that were caught ranged in length from 8 to 109 cm (Figure 2). To determine if length impacted catchability, size disaggregated modelling was conducted from all paired sets completed across 3LNOPs. Of the suite of models assessed, the model selected for conversion factor implementation based on lowest BIC was a binomial model with no length effect (fixed), and station effect (random) on the intercept (Table 4, for full model details see Appendix 1), which resulted in a constant conversion across length. However, the 95% confidence intervals for the model overlapped with one (i.e. equal catch efficiency between vessels), and thus no conversion is required between the *Teleost* and *Cabot* for Atlantic Cod in spring for Div. 3LNOPs (Figure 3).

Assessment of the station effect (Figure 4) and model residuals (Figure 5) indicated the model selected was a good fit to the data, and length sensitivity testing (Figure 6) demonstrated a consistent model shape across the length ranges tested. Size aggregated analysis of abundance and biomass both agree with the conclusion that no conversion factor is required for Atlantic Cod in the spring for divisions 3LNOPs, between the *Teleost* and *Cabot* (Figure 7).

To ensure the applicability of this analysis for individual stocks and Ecosystem Production Units (EPUs), conversion factor analysis was also conducted for 3Ps paired sets only (48 sets), 3NO sets (39 sets), as well as across 3LNO (58 sets), For all areas, confidence intervals on the estimate of rho overlapped with one (equal catchability) between the two vessels, concluding no conversion factor is required regardless of NAFO division breakdown (Figure 7).

An additional analysis was conducted to incorporate fall and spring data together to examine whether a difference across seasonality or area is evident when all data are combined for this species (Figure 9). Though the lowest ΔBIC value indicated the best model fit for this analysis was a length effect model, ΔBIC =2 between this and a less complicated binomial model with no length effect (Table 4). Additionally, this length effect was highly sensitive to the extreme tails of the length range; general additive models (GAMs) can be impacted by data sparseness in the tails, which is evident from the length sensitivity testing which demonstrated length trimming resulted in no significant length effect in best model selected (Figure 11). The model selected (Figure 10) was therefore the one with no length effect. Residuals (Figure 12) and station effect (Figure 13) indicate a good fit to the data, and showed no significant difference across season ($p = 0.42$) or NAFO division. Size aggregated analysis also demonstrated no evidence of a significant difference in catches between vessels, and no suggestion of a length effect, with both abundance and biomass catch from data with seasons combined indicating no conversion required between the *Teleost* and new vessels (Figure 14).

## DISCUSSION

The spring comparative fishing program between the *Teleost* and *Cabot* yielded no significant difference in relative catchability between these two vessels. This was consistent across NAFO Divisions and is also consistent with data previously examined from the fall of 2021 and 2022 for Div. 2HJ3K, and between the *Needler* and the *Cabot* in fall across Div. 3KL (DFO 2023).

Although data do not allow direct estimation of conversion factors for the *Needler* in 3NOPs in spring or 3LNO in fall (DFO 2023), all available analyses indicate no statistical difference in catchability of Atlantic Cod between the *Teleost* or the *Needler* with the *Cartier* and *Cabot* during the NL multispecies trawl survey. This is also consistent with results from the Northern Gulf of St. Lawrence comparative fishing program (summer survey, NAFO Div. 4RS) where the same vessel (*Teleost* ) and gear change was made (Benoît and Yin. *in press*).

There is no evidence of significant differences in relative catchability across NAFO Divisions or between seasons regardless of vessel pairing. It is therefore considered reasonable to extend the application of the comparative fishing conclusions where they could be throughout the standard range of the NL multispecies surveys for Atlantic Cod.

The suite of analyses presented here cover a broad size and depth range, and are considered sufficient to close the research recommendation from Newfoundland & Labrador Comparative

Fishing Analysis – Part 1 (DFO 2024) as they pertain to Atlantic Cod, without the need of collecting further paired data.

## CONCLUSIONS

Conversion factors are not required for Atlantic Cod for the NL spring or fall multispecies trawl surveys for the new OFSVs. Survey data from the *Cabot* and *Cartier* fishing the modified Campelen trawl can be used as a direct continuation of the previous time series for Atlantic Cod in NL.

## ACKNOWLEDGEMENTS

The Comparative Fishing program could not have been undertaken without the massive effort, sacrifice, and dedication from sea-going staff and shore support! Thanks also to all CG crew aboard these vessels, without whom fishing operations would not be possible.

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# TABLES

*Table 1. Summary of successful paired sets per vessel pair, year and season, where AN represents the CCGS Alfred Needler, CAB represents the CCGS John Cabot, CAR represents the CCGS Capt. Jacques Cartier, and TEL represents the CCGS Teleost .*

| 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** |

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

| Model | $log(\rho)$ | Length Effect | Station Effect |
|---|---|---|---|
| $BI0$ | $\beta_0$ | 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 length effect and station effect in the relative catch efficiency, and the length effect on the variance parameter. A smoothing length 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 length effect, or added to both the intercept and the smoother to allow for interaction between the two effects.*

| Model | $log(\rho)$ | $log(\phi)$ | Length Effects | Station Effect |
|---|---|---|---|---|
| $BB0$ | $\beta_0$ | $\gamma_0$ | constant/constant | not considered |
| $BB1$ | $\beta_0 + \delta_{0,i}$ | $\gamma_0$ | constant/constant | intercept |
| $BB2$ | $\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b}$ | $\gamma_0$ | 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 |
| $BB4$ | $\mathbf{X}_f^T \boldsymbol{\beta}_f + \mathbf{X}_r^T \mathbf{b} + \delta_{0,i}$ | $\gamma_0$ | 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 |
| $BB6$ | $\mathbf{X}_f^T (\boldsymbol{\beta}_f + \boldsymbol{\delta}_i) + \mathbf{X}_r^T (\mathbf{b} + \boldsymbol{\epsilon}_i)$ | $\gamma_0$ | 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. Relative evidence for length-disaggregated binomial and beta-binomial models for the CCGS Teleost and CCGS John Cabot/Capt. Jacques Cartier, and CCGS Alfred Needler 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, North Atlantic Fisheries Organization (NAFO) divisions, and vessel pairing (either "TEL", and "AN") applicable per row. Note that AIC/BIC comparison should only be considered per row, and not across 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 is not included in the table.*

| | AIC | | | | | | | | | | BIC | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data Grouping | BI0 | BI1 | BI2 | BI3 | BB0 | BB1 | BB2 | BB3 | BB4 | BB5 | BI0 | BI1 | BI2 | BI3 | BB0 | BB1 | BB2 | BB3 | BB4 | BB5 |
| Spring 3LNOPs (TEL) | 3029 | 2772 | 3028 | 2768 | 2923 | 2767 | 2922 | 2926 | - | - | 3036 | 2787 | 3050 | 2797 | 2938 | 2789 | 2951 | 2969 | - | - |
| Spring 3LNO (TEL) | 1629 | 1479 | 1625 | 1479 | 1560 | 1475 | 1561 | 1564 | 1475 | 1479 | 1636 | 1492 | 1645 | 1505 | 1574 | 1495 | 1587 | 1604 | 1508 | 1525 |
| Spring 3NO (TEL) | 761 | 715 | 763 | 712 | 736 | 713 | 738 | 742 | 712 | 715 | 767 | 727 | 782 | 737 | 748 | 732 | 763 | 779 | 743 | 759 |
| Spring 3Ps (TEL) | 1401 | 1297 | 1405 | 1297 | 1367 | 1298 | 1369 | 1373 | 1298 | - | 1408 | 1310 | 1424 | 1323 | 1379 | 1317 | 1395 | 1411 | 1330 | - |
| Fall 2HJ3KL (TEL) | 7391 | 7019 | 7393 | 7019 | 7248 | 7003 | 7252 | 7254 | 7003 | 7004 | 7399 | 7034 | 7416 | 7049 | 7263 | 7025 | 7282 | 7299 | 7041 | 7056 |
| Fall 3KL (AN) | 3909 | 3680 | 3911 | 3681 | 3830 | 3675 | 3832 | 3833 | - | - | 3916 | 3694 | 3932 | 3709 | 3845 | 3696 | 3861 | 3875 | - | - |
| Fall & Spring 2HJ3KLNOPs (TEL) | 10556 | 9934 | 10559 | 9929 | 10319 | - | 10323 | 10328 | 9907 | 9909 | 10564 | 9951 | 10584 | 9962 | 10335 | - | 10356 | 10377 | 9949 | 9966 |
| | ΔAIC | | | | | | | | | | ΔBIC | | | | | | | | | |
| Data Grouping | BI0 | BI1 | BI2 | BI3 | BB0 | BB1 | BB2 | BB3 | BB4 | BB5 | BI0 | BI1 | BI2 | BI3 | BB0 | BB1 | BB2 | BB3 | BB4 | BB5 |
| Spring 3LNOPs (TEL) | 262 | 5 | 262 | 1 | 156 | 0 | 155 | 159 | - | - | 249 | 0 | 263 | 10 | 151 | 2 | 164 | 183 | - | - |
| Spring 3LNO (TEL) | 154 | 4 | 150 | 3 | 85 | 0 | 86 | 89 | 0 | 4 | 143 | 0 | 152 | 13 | 81 | 3 | 95 | 111 | 16 | 33 |
| Spring 3NO (TEL) | 49 | 3 | 51 | 0 | 24 | 1 | 26 | 30 | 0 | 3 | 40 | 0 | 54 | 10 | 21 | 5 | 35 | 52 | 16 | 32 |
| Spring 3Ps (TEL) | 104 | 0 | 108 | 0 | 70 | 1 | 72 | 76 | 1 | - | 97 | 0 | 114 | 13 | 69 | 7 | 84 | 101 | 20 | - |
| Fall 2HJ3KL (TEL) | 389 | 16 | 391 | 16 | 246 | 0 | 249 | 251 | 1 | 1 | 374 | 9 | 391 | 24 | 238 | 0 | 257 | 274 | 16 | 31 |
| Fall 3KL (AN) | 234 | 5 | 236 | 6 | 156 | 0 | 158 | 158 | - | - | 222 | 0 | 238 | 15 | 150 | 2 | 167 | 181 | - | - |
| Fall & Spring 2HJ3KLNOPs (TEL) | 649 | 27 | 652 | 22 | 412 | - | 416 | 420 | 0 | 1 | 616 | 2 | 635 | 13 | 387 | - | 407 | 428 | 0 | 18 |

# FIGURES

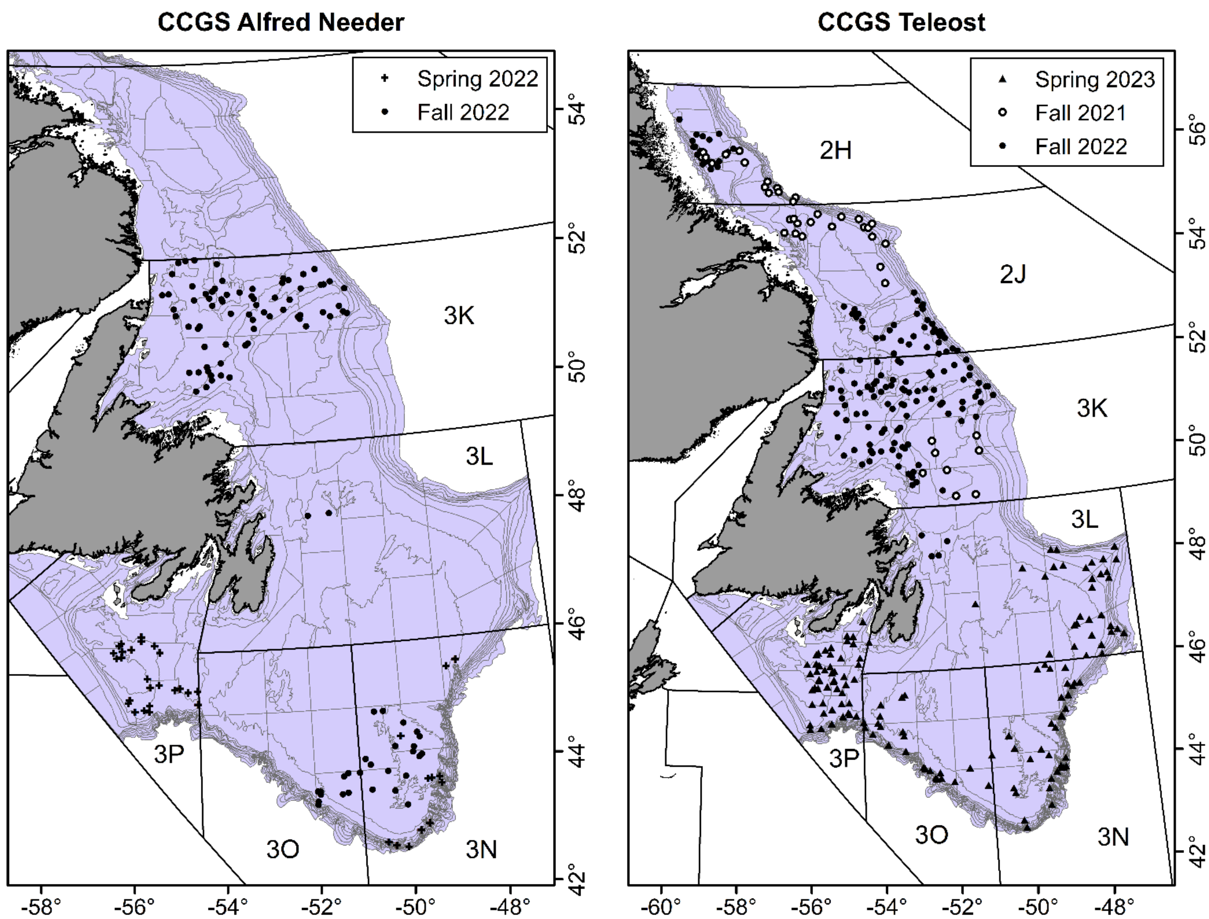



*Figure 1. Newfoundland and Labrador Multispecies survey areas (purple). Annually there is a spring survey (NAFO DIV. 3LNOPs) and fall survey (NAFO Div. 2HJ3KLNO). Points indicate the location of paired tows for each vessel. There are three cod stocks in Newfoundland and Labrador: Div. 2J3KL, Div. 3NO, Subdiv. 3Ps.*

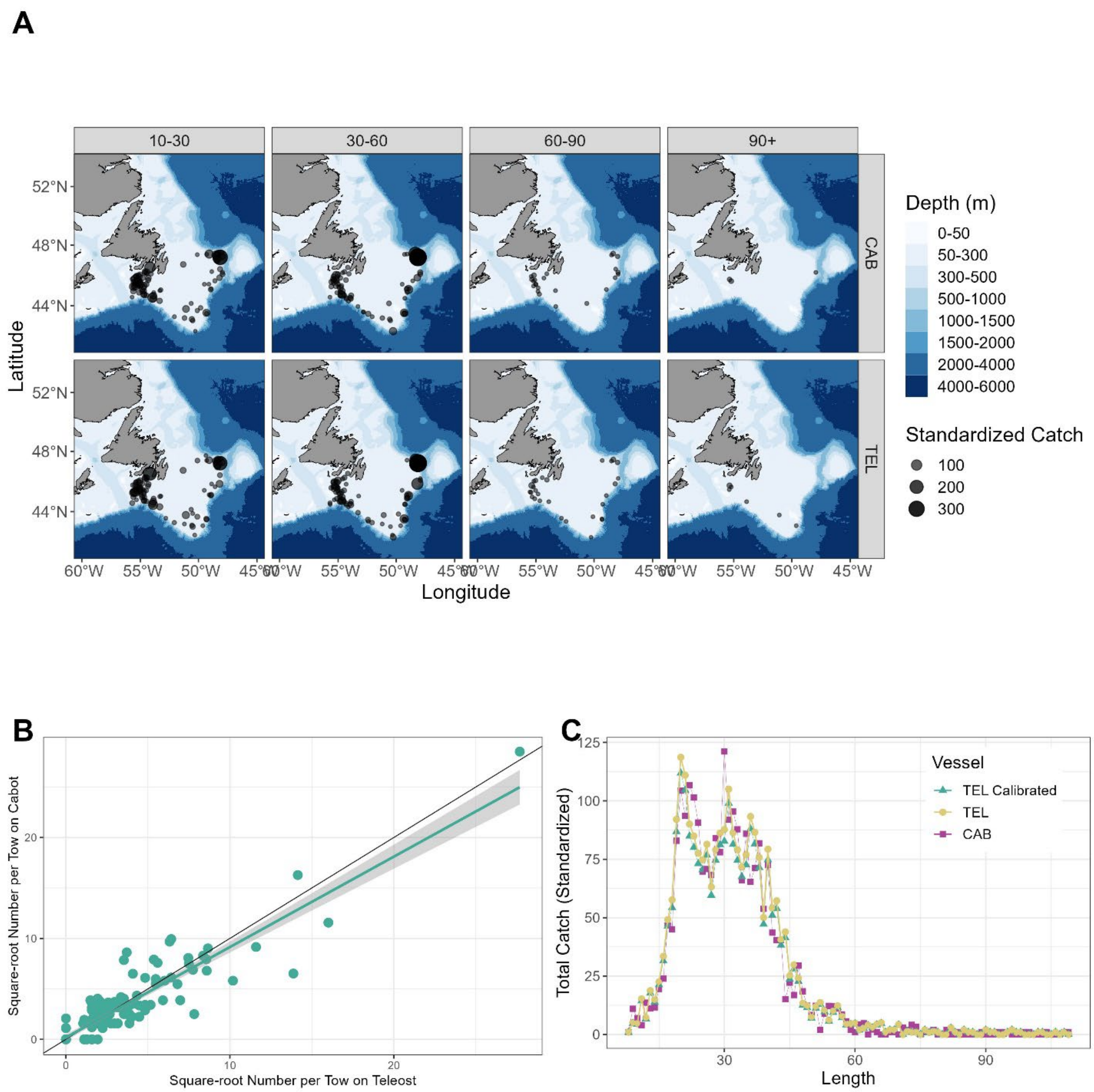



*Figure 2. Results for length-disaggregated comparative fishing analyses for Atlantic Cod (*Gadus morhua*), between the CCGS Teleost ("TEL") and CCGS John Cabot ("CAB") for Spring 3LNOPs. (A) map of catches by length group (length in cm specified in top panel) by the CCGS John Cabot (top) and the CCGS Teleost (bottom) in comparative fishing sets, where circle size is proportional catch weight (B) Biplot of the square-root of CCGS John Cabot catch numbers against the square-root of CCGS Teleost catch numbers. (C) Total length frequencies for catches made by the CCGS Teleost (yellow), by the CCGS John Cabot (purple), and Teleost catches with the conversion factor applied (green).*

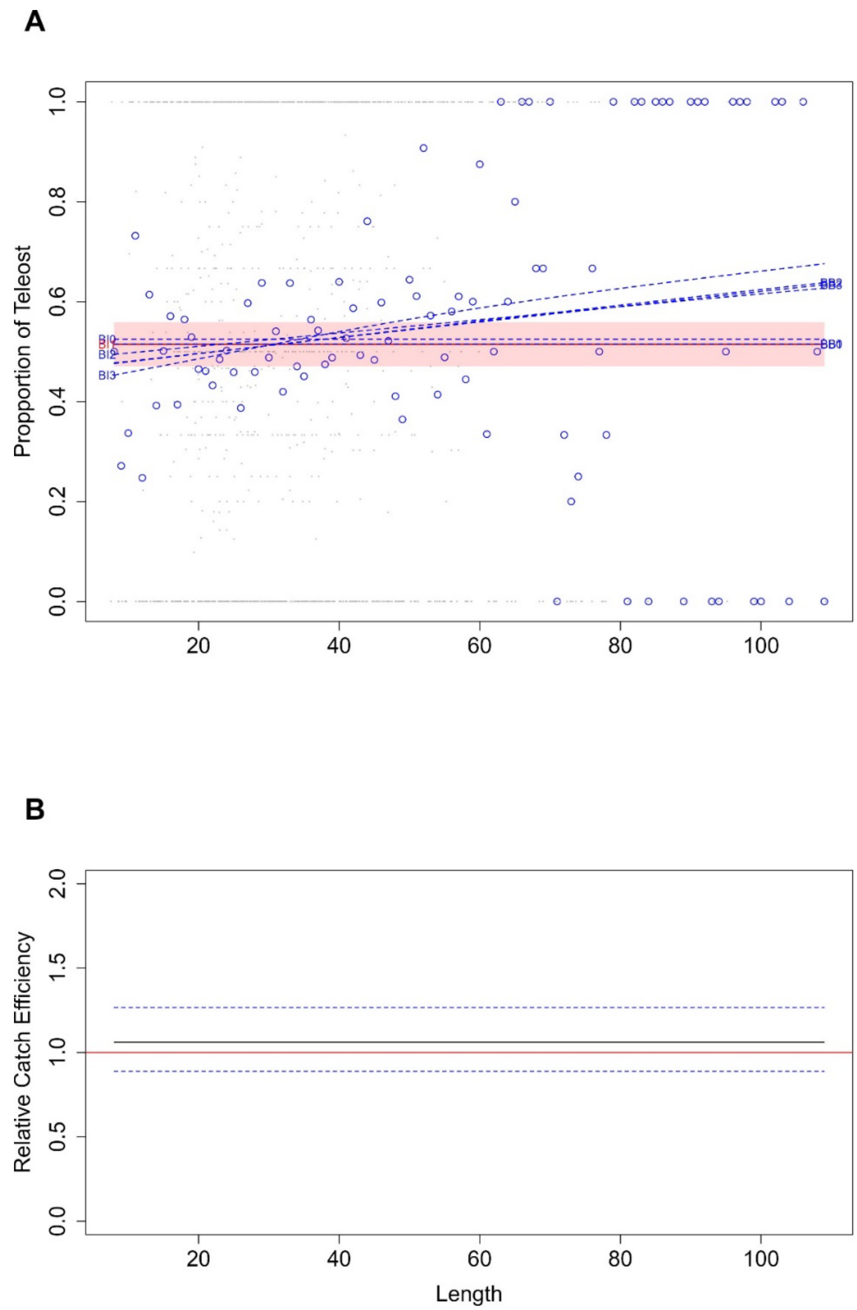



*Figure 3. Atlantic Cod (*Gadus morhua*) conversion factor, between the CCGS Teleost and CCGS John Cabot for Spring 3LNOPs. (A) Estimated length-specific catch proportion functions, $logit(p_{Ai}(l))$, for each converged model, with the selected model plotted using a red line along with its approximate 95% CI (shaded area), as well as the length 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.*

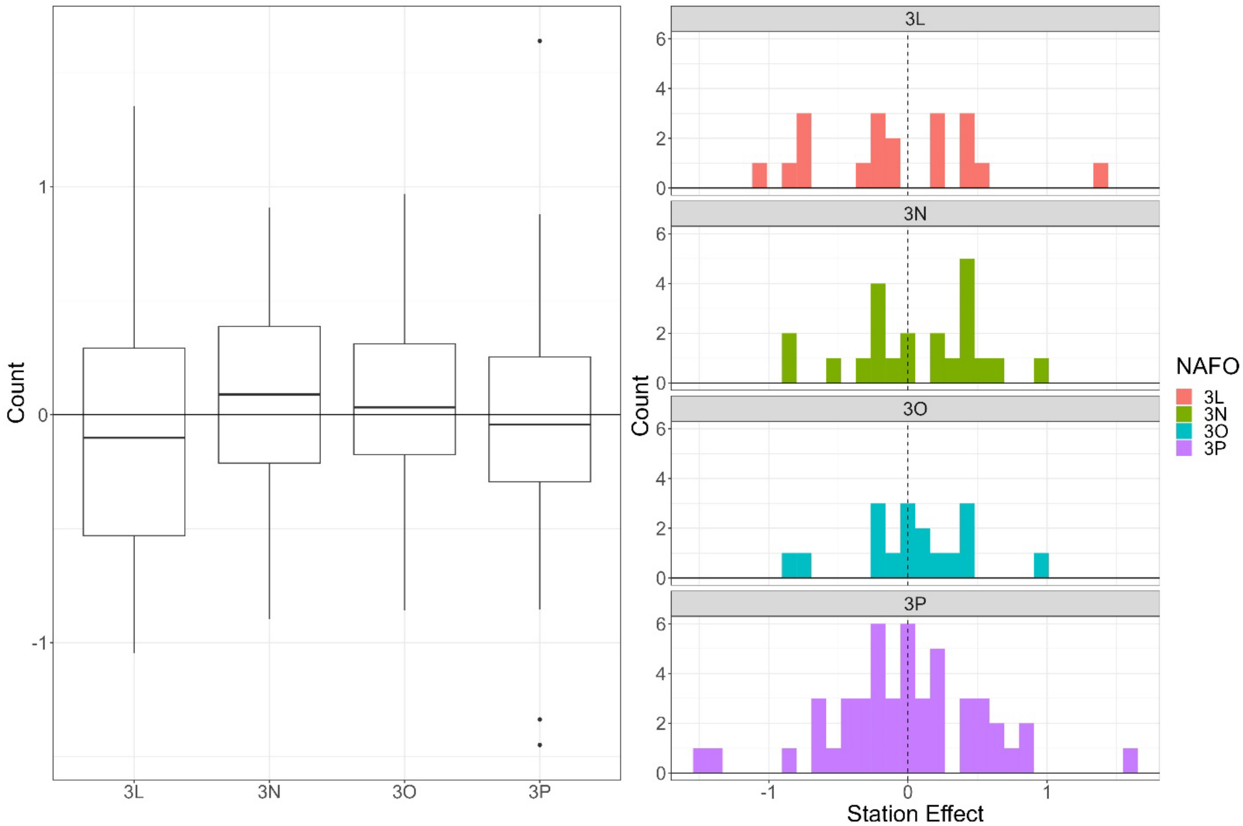



*Figure 4. Boxplot (left) and histogram (right) of station effect by NAFO division for best model selected for Atlantic Cod (*Gadus morhua*) conversion factor analysis of CCGS Teleost and CCGS John Cabot in Spring 3LNOPs.*

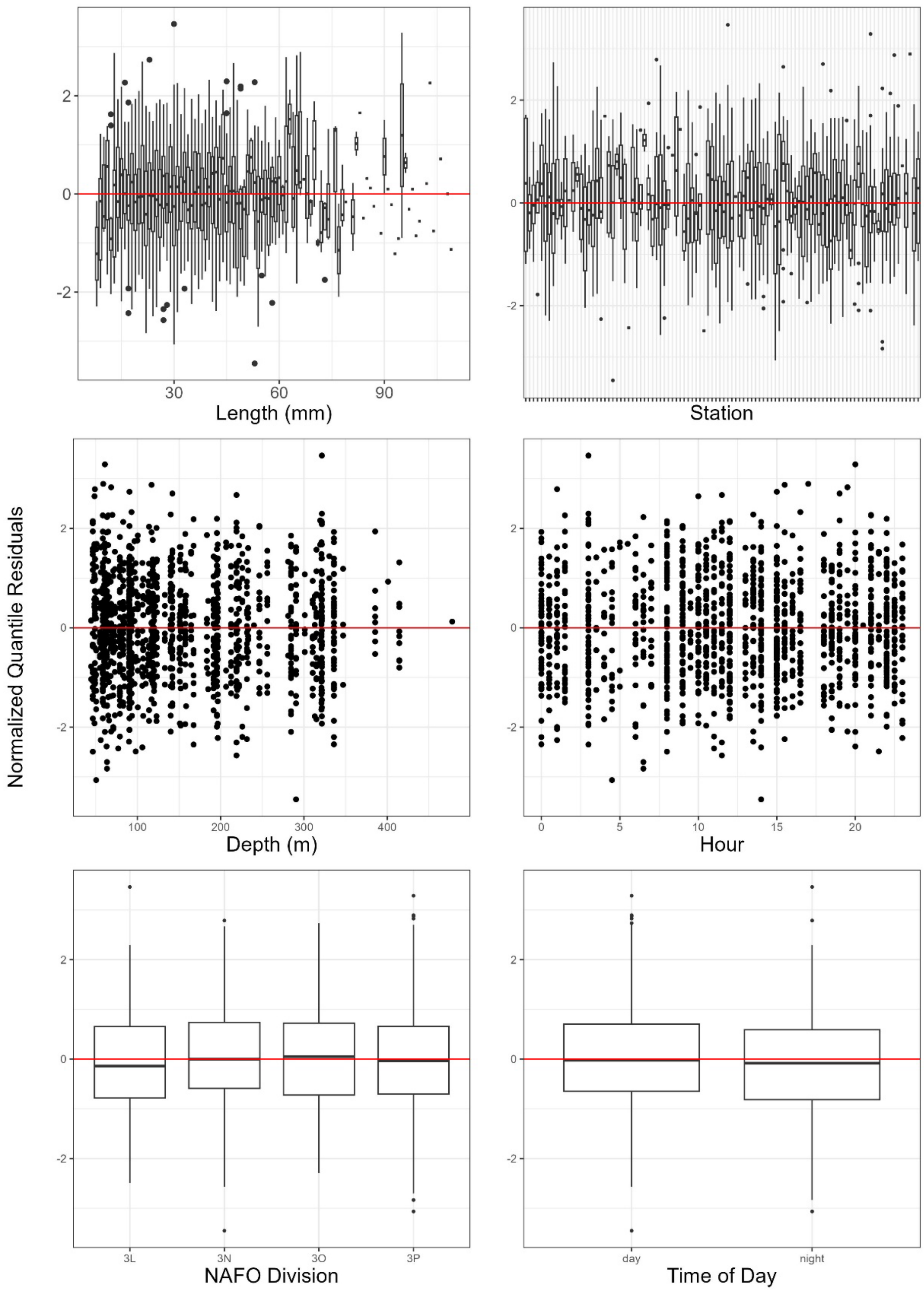



*Figure 5. Normalized quantile residuals for as a function of length, station, depth, hour, NAFO division, and diel period for Atlantic Cod (*Gadus morhua*), best model selected for length disaggregated conversion factor analysis for the CCGS Teleost , and CCGS John Cabot for Spring 3LNOPs.*

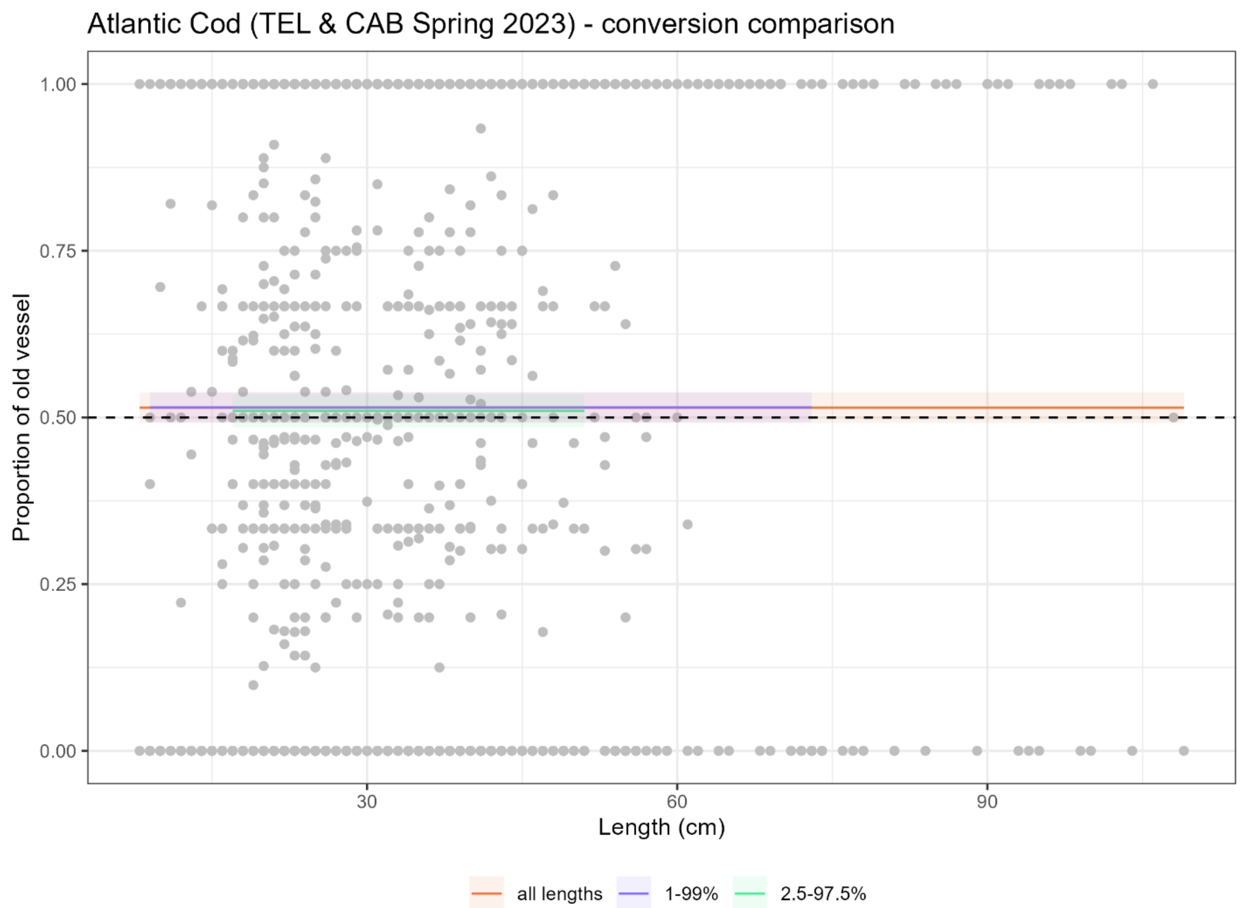



*Figure 6. Comparative fishing analysis for the CCGS Teleost and CCGS John Cabot in Spring 2023 3LNOPs, length tail sensitivity testing showing model fit to all data (full length range, orange), with 1% tails removed (blue), and 2.5% tails removed (green), for Atlantic Cod (*Gadus morhua*). Shaded regions for respective models represent the ± standard error for the estimated conversion factor.*

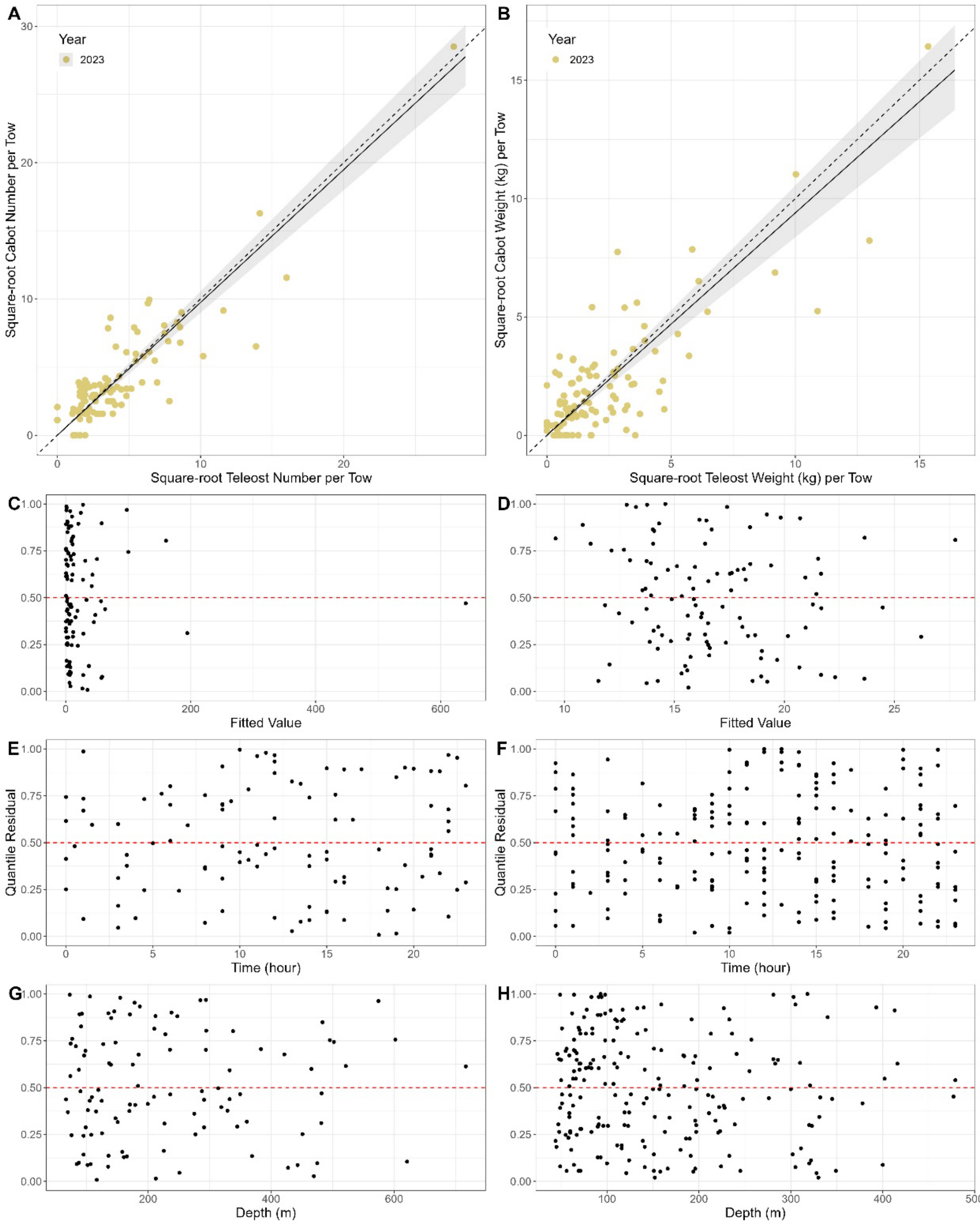



*Figure 7. Results of size aggregated analysis for the CCGS Teleost and CCGS John Cabot for catch of Atlantic Cod (*Gadus morhua*), Spring 3LNOPs. (A) Biplot of the square-root of CCGS John Cabot catch numbers against the square-root of CCGS Teleost catch numbers, where the solid black line and shaded interval show the estimated conversion and approximate 95% confidence intervals 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: (C, D) fitted values, (E, F) time and, (G, H) depth.*

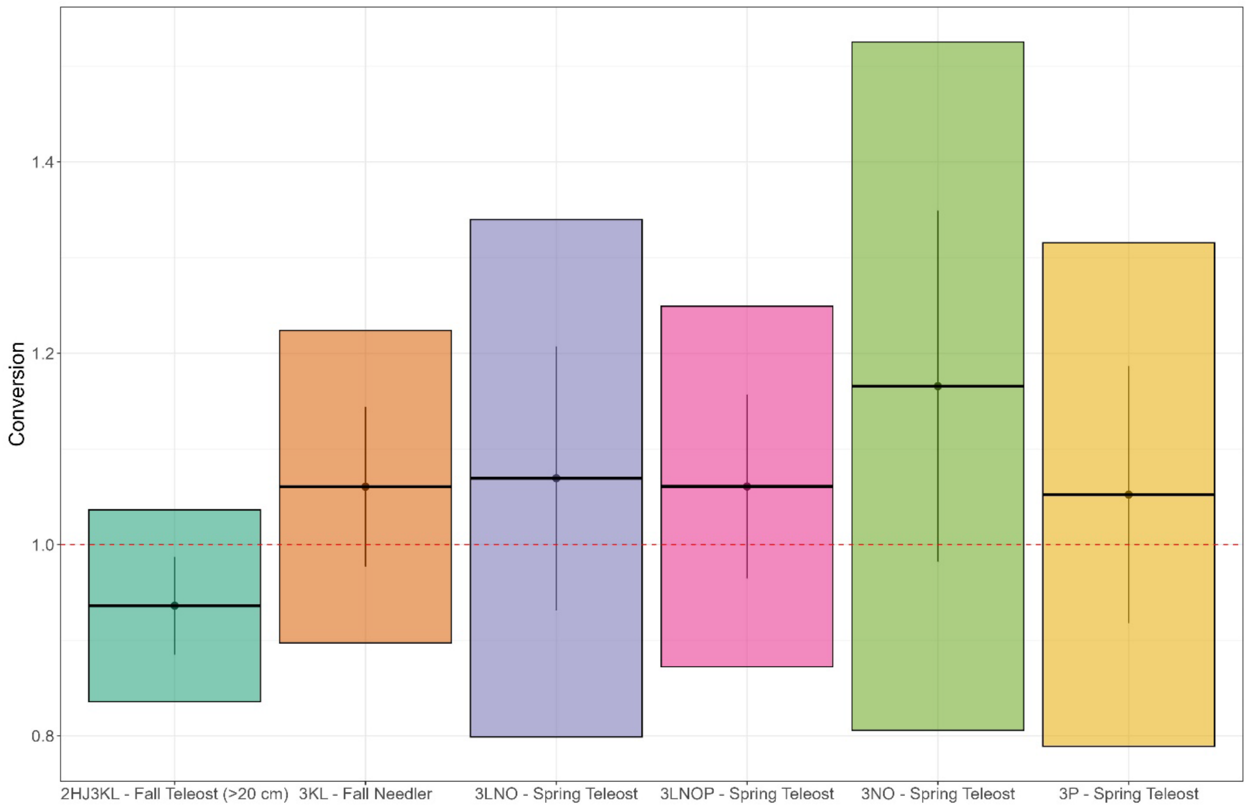



*Figure 8. Comparison of conversion factor estiamtion for Atlantic Cod (*Gadus morhua*) across comparative fishing seasons and vessel pairings. From left to right, CCGS Teleost and CCGS John Cabot/Capt. Jacques Cartier for fall 2HJ3K + 3L deep for >20 cm fish, CCGS Alfred Needler and CCGS John Cabot for fall 3KL, and CCGS Teleost and CCGS John Cabot spring 3LNO, 3LNOPs, 3NO, and 3Ps. Points represent the estimated conversion factor (rho), with bars showing the standard error, and the boxes outlining both represent the 95% confidence intervals (CIs). The red dashed line at one represents equal catch efficiency.*

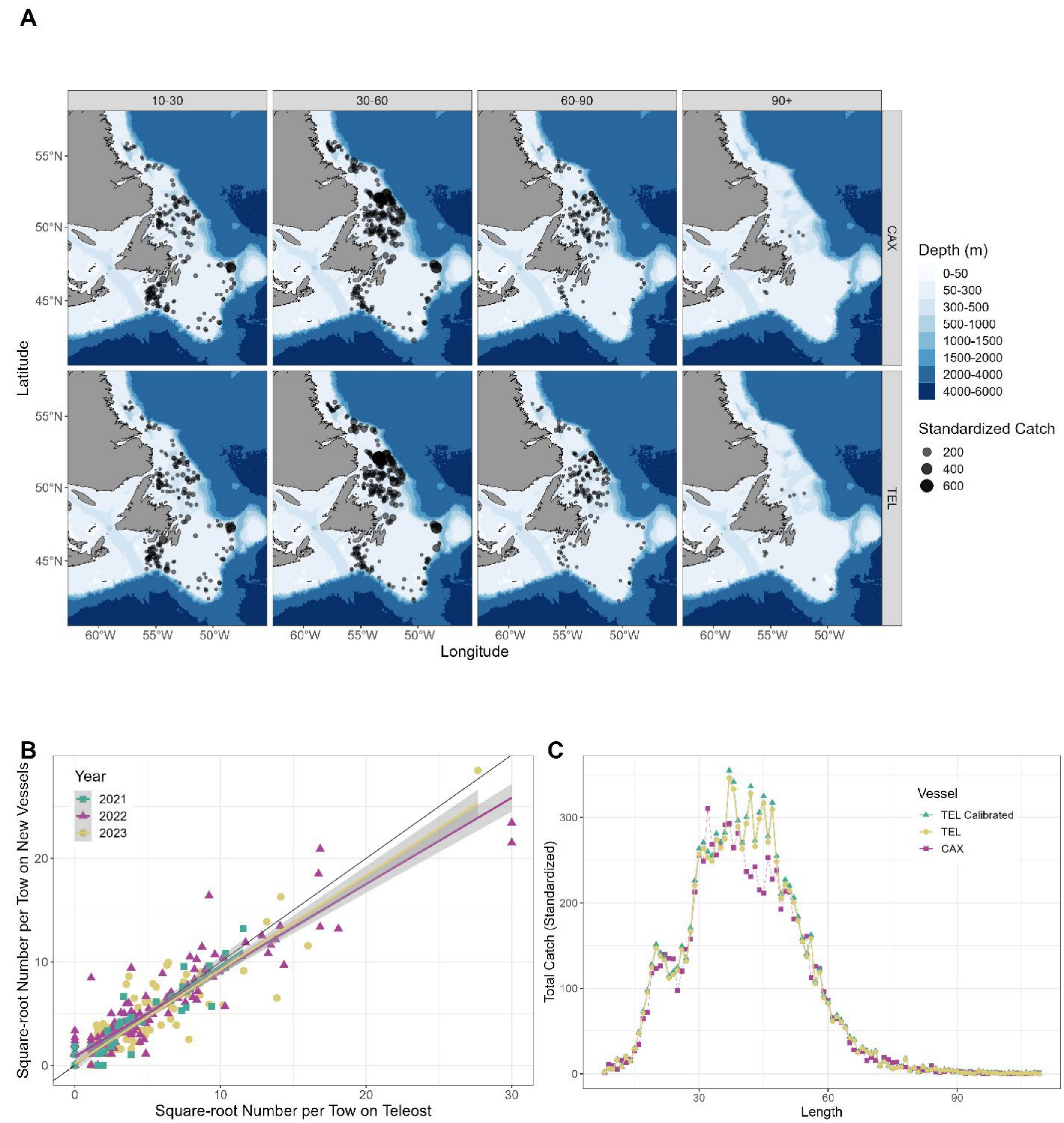
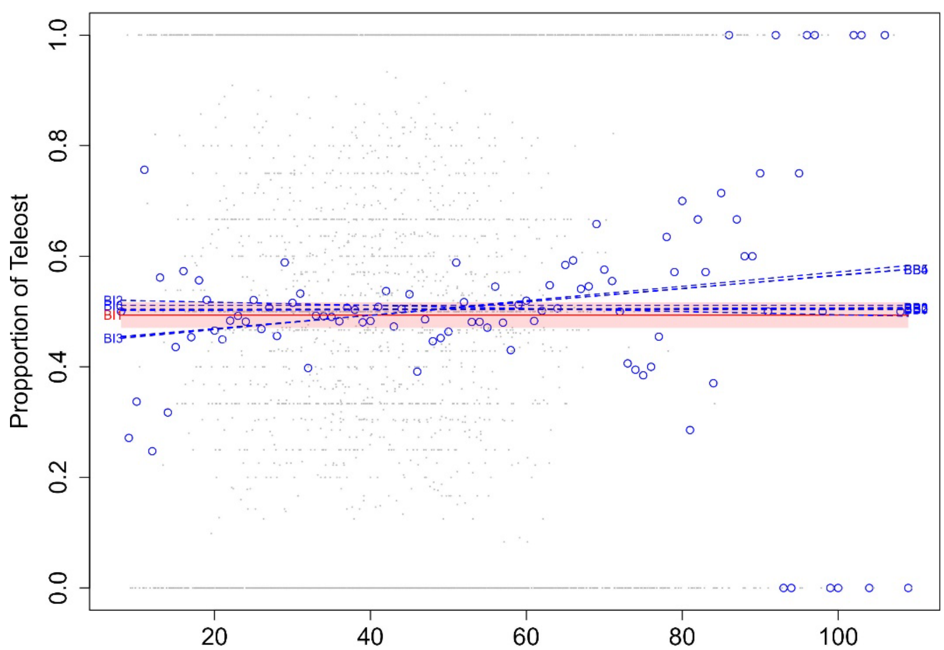



*Figure 9. Results for length-disaggregated comparative fishing analyses for Atlantic Cod (*Gadus morhua*), between the CCGS Teleost (“TEL") and CCGS John Cabot/Capt. Jacques Cartier (“CAX”) for Fall and Spring 2HJ3KLNOPs. (A) map of catches by length group (length in cm specified in top panel) by the CCGS John Cabot (top) and the CCGS Teleost (bottom) in comparative fishing sets, where circle size is proportional catch weight (B) Biplot of the square-root of CCGS John Cabot/Capt. Jacques Cartier catch numbers against the square-root of CCGS Teleost catch numbers. (C) Total length frequencies for catches made by the CCGS Teleost (yellow), by the CCGS John Cabot (purple), and Teleost catches with the conversion factor applied (green).*

A




B

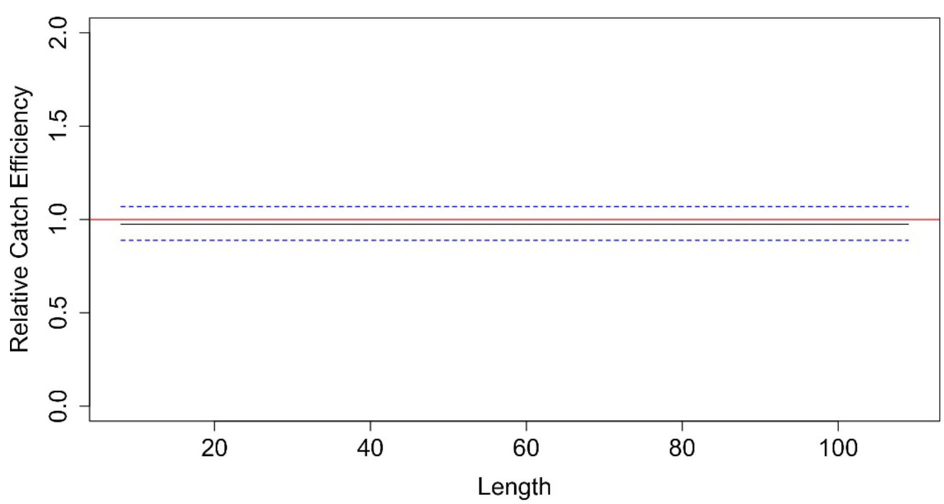



*Figure 10. Atlantic Cod (*Gadus morhua*) conversion factor, between the CCGS Teleost and CCGS John Cabot/Capt. Jacques Cartier for Fall and Spring 2HJ3KLNOPs. (A) Estimated length-specific catch proportion functions, $logit(p_{Ai}(l))$, for each converged model, with the selected model plotted using a red line along with its approximate 95% CI (shaded area), as well as the length 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.*

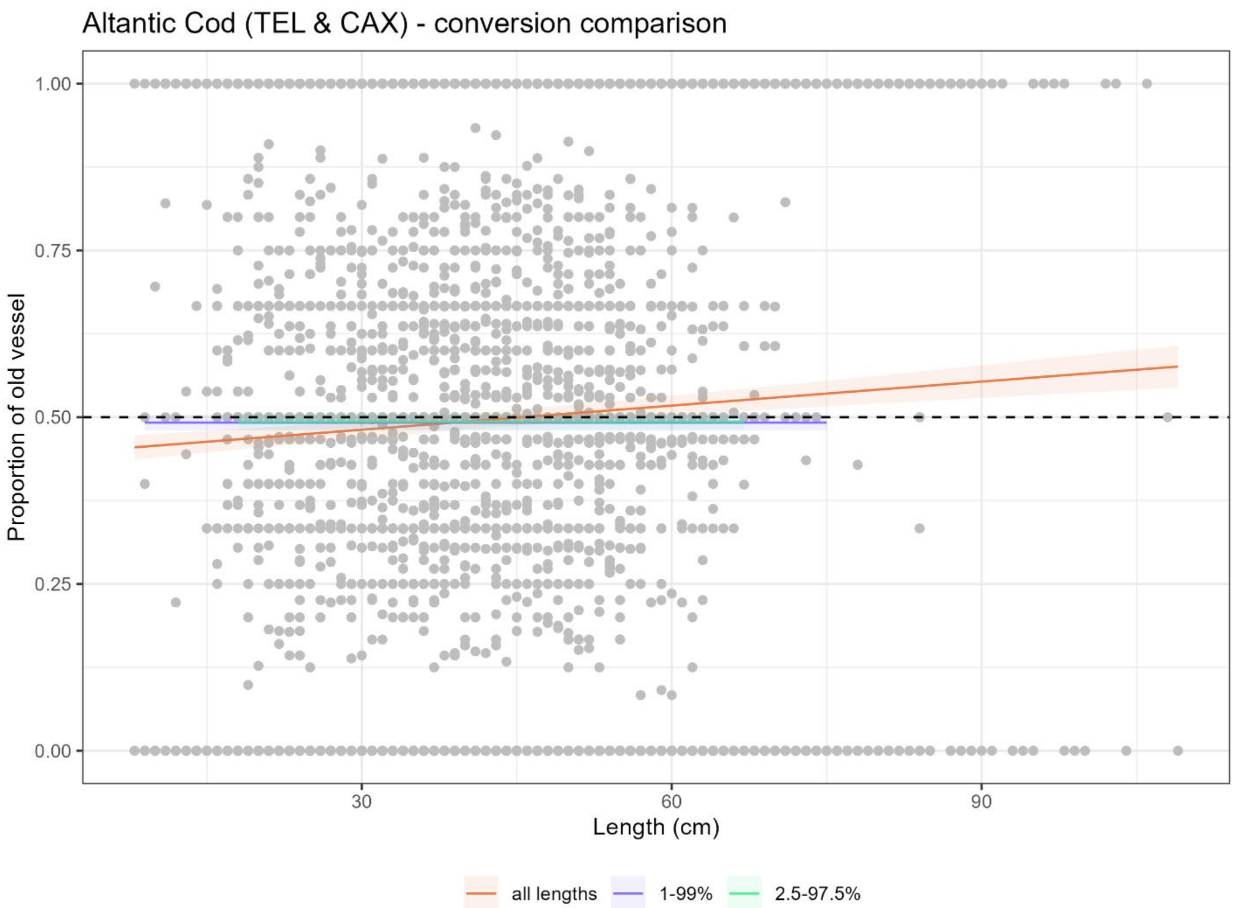



*Figure 11. Comparative fishing analysis for the CCGS Teleost and CCGS John Cabot/Capt. Jacques Cartier in Fall and Spring 2HJ3KLNOPs, length tail sensitivity testing showing model fit to all data (full length range, orange), with 1% tails removed (blue), and 2.5% tails removed (green), for Atlantic Cod (*Gadus morhua*). Shaded regions for respective models represent the ± standard error for the estimated conversion factor. Full length range (orange) dipicts length-based model (BB4) instead of final model selected (BI1), to demonstrate model sensitivies to tails of full length distrbution.*

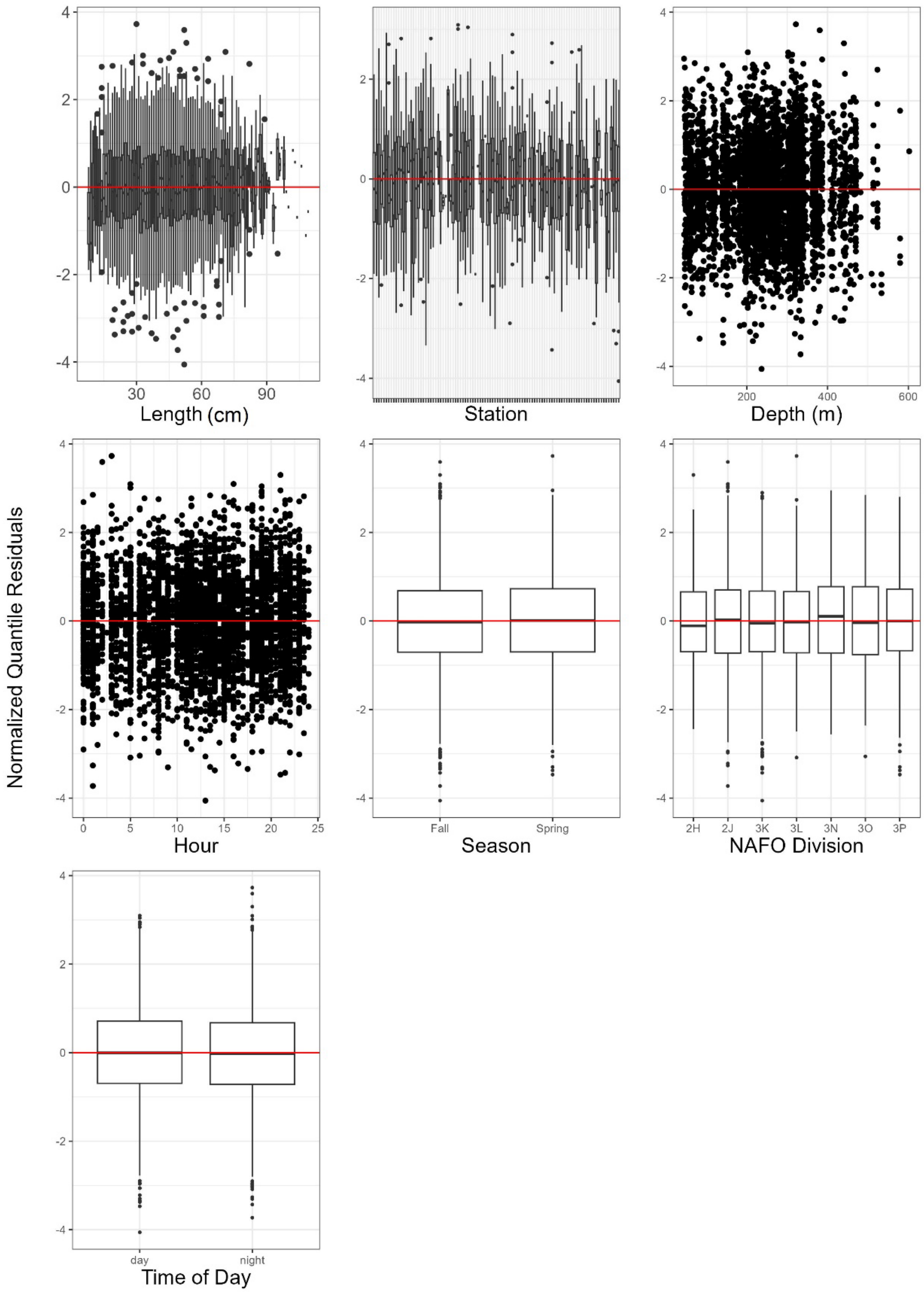



*Figure 12. Normalized quantile residuals for as a function of length, station, depth, hour, season, North Atlantic Fisheries Organization (NAFO) division, and diel period for Atlantic Cod (*Gadus morhua*), best model selected for length disaggregated conversion factor analysis for the CCGS Teleost , and CCGS John Cabot/Capt. Jacques Cartier for Fall and Spring 2HJ3KLNOPs.*

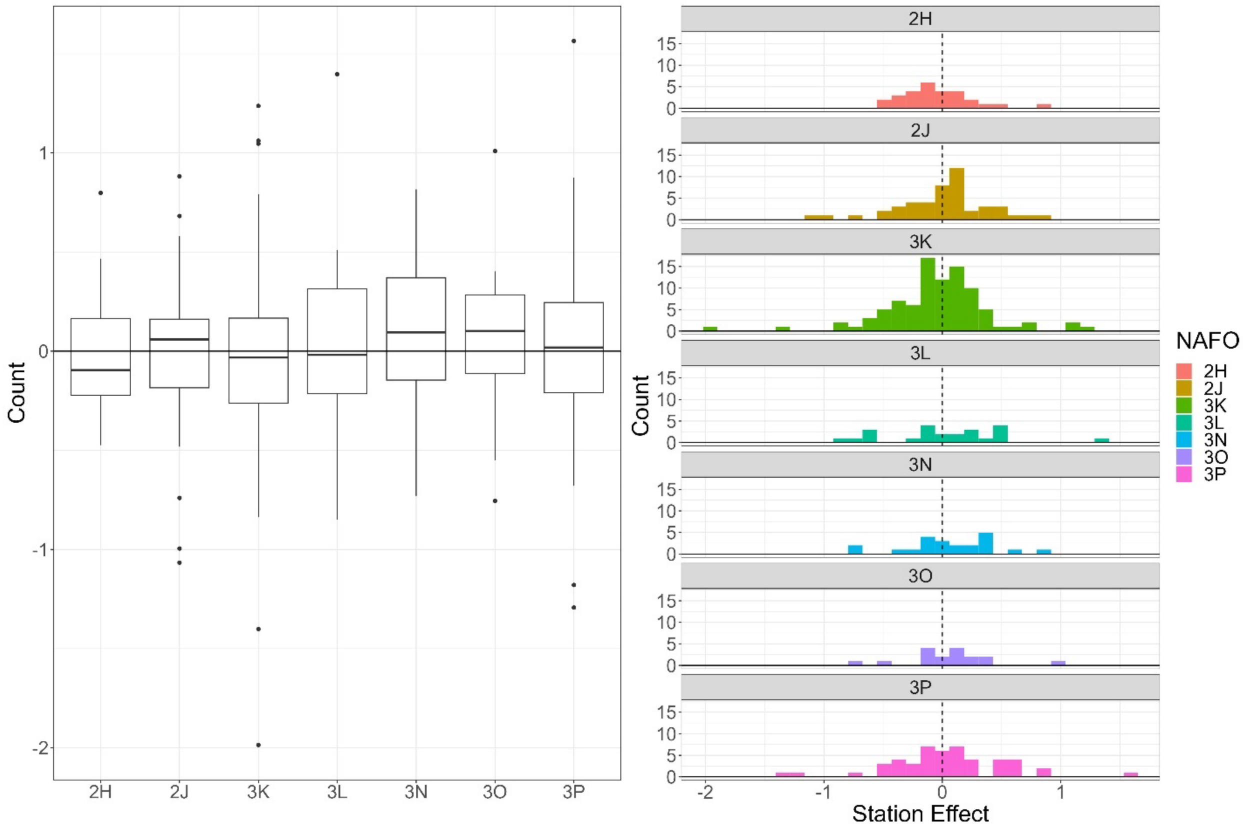



*Figure 13. Boxplot (left) and histogram (right) of station effect by North Atlantic Fisheries Organization (NAFO) division for best model selected for Atlantic Cod (*Gadus morhua*) conversion factor analysis of CCGS Teleost and CCGS John Cabot/Capt. Jacques Cartier in Fall and Spring 2HJ3KLNOPs.*

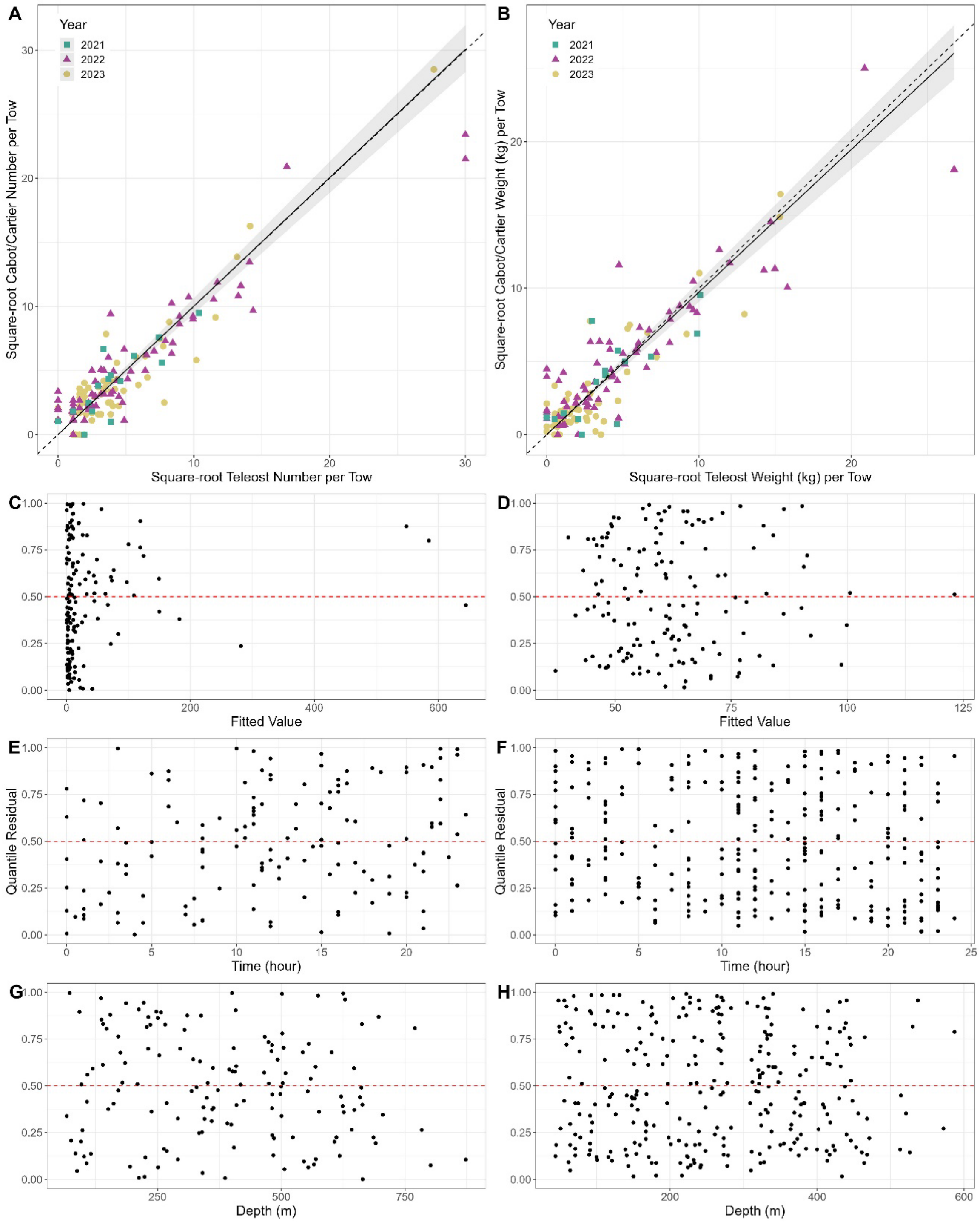



*Figure 14. Results of size aggregated analysis for the CCGS Teleost and CCGS John Cabot/Capt. Jacques Cartier for catch of Atlantic Cod (*Gadus morhua*), Fall and Spring 2HJ3KLNOPs. (A) Biplot of the square-root of CCGS John Cabot/Capt. Jacques Cartier catch numbers against the square-root of CCGS Teleost catch numbers, where the solid black line and shaded interval show the estimated conversion and approximate 95% confidence intervals 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: (C, D) fitted values, (E, F) time and, (G, H) depth.*