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Analysis of a Comparative Survey Conducted in 2019 and 2020 for Two Different Types of Bottom Trawls Used on Board CCGS *M. Perley* During the Northumberland Strait Multi-Species Bottom Survey

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Canada

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

Marked differences in fishing efficiency were observed between the Otter Trawl and the Northumberland Trawl during comparative fishing experiments conducted on CCGS *M. Perley* in 2019 and 2020. The Northumberland Trawl had a higher fishing efficiency than the Otter Trawl for almost all taxa observed, and this fishing efficiency varied with depth and with the length of captured individuals. A binomial modelling framework yielded estimates of calibration coefficients to be applied to catch data. While uncertain, the application of calibration coefficients is necessary to maintain the continuity of the survey time-series. For American Lobster, catches from the Otter Trawl will need to be corrected for depth and length effects in order for the survey time-series to extend back to 2001. The calibration coefficients obtained for other taxa are presented but may need further refinement prior to inclusion in analyses supporting science advice.

INTRODUCTION

In 1999, Fisheries and Oceans Canada (DFO) initiated a bottom trawl survey in Northumberland Strait (Figure 1) to collect fishery-independent data for use in stock assessments for southern Gulf of St. Lawrence American Lobster (*Homarus americanus*) (Hanson 2001). Completed annually from 1999 to 2022, the sampling methods and study area have changed over the years (see details of 1999 to 2018 surveys in Asselin et al. 2021). A multi-species sampling plan, collecting systematic data on Lobster, crabs and fish, has been used since 2005. The dataset has contributed to three American Lobster stock assessments (Comeau et al. 2004, 2008; Rondeau et al. 2015), two updates to the stock status indicators of the American Lobster stock (DFO 2016, 2019), one southern Gulf of St. Lawrence Atlantic Rock Crab (*Cancer irroratus*) stock assessment (Rondeau et al. 2014) and three Northwest Atlantic Fisheries Organization (NAFO) Division 4T Winter Flounder (*Pseudopleuronectes americanus*) assessments (Morin et al. 2002, 2012; Surette and Rolland 2019).

From 2001 to 2009, the survey was completed by CCGS *Opilio* using a No. 286 otter trawl (OT) with “rockhopper” footgear (Figure 2 and Asselin et al. 2021). For the two years prior to the change in survey vessel, 2010 and 2011, a Nephrops trawl was used. From 2011 to 2018, the survey was completed by CCGS *M. Perley*, using a No. 286 OT with “rockhopper” footgear (Figure 2 and Asselin et al. 2021). In 2019, in an effort to increase the catch of a variety of species and size classes, a newly designed trawl was introduced, the “Northumberland Trawl” (NT).

Comparative fishing between the OT and the NT was completed in 2019 and 2020. To maintain the integrity of the survey time series, calibration coefficients for a number of key species are estimated using a binomial modelling framework that integrates depth and length effects on the fishing efficiency of each trawl.

MATERIALS AND METHODS

STUDY AREA

The study area is in Northumberland Strait, in the southern Gulf of St. Lawrence (Figure 1). Within the strait, water depths are mainly less than 30 m, resulting in higher than average bottom water temperatures than in the remainder of the Gulf of St. Lawrence, reaching above 23 °C in September (Chassé et al. 2014). Circulation is generally west to east, with strong tidal mixing (Koutitonsky 1991), and a weaker flow than in other areas of the southern Gulf of St. Lawrence (Chassé et al. 2014). Seafloor slope is minimal throughout most of the strait (Dutil et al. 2011) and seafloor sediments in western portions of the strait are composed of sand, gravel, pebbles and cobbles, while central and eastern portions of the strait have these same sediment types and large areas of pelites (i.e. mud or clay) (Loring and Nota 1973).

SURVEY DESIGN

In comparison with the OT, the NT has a wider horizontal opening, a narrower vertical opening and the netting is of a smaller mesh size (Appendix B). While both trawls are equipped with a rockhopper-type footgear, the NT’s footgear has a smaller diameter than that of the OT, resulting in the trawl being closer to the seafloor. For the comparative fishing experiment, stations were sampled twice, once with each trawl, within six days.

In 2020, travel restrictions related to the COVID-19 pandemic resulted in only the western portion of the study area being sampled (Figure 5). In both years, the survey was completed in July and

August, between 6:00 and 18:00 daily local time (i.e. ADT). Survey station selection was based on a 2 nautical miles x 2 nautical miles (3.7 km X 3.7 km) grid of all possible sample stations in the study area (see Asselin et al. 2021 for additional details on survey design). In 2019, 45 of 90 planned survey stations were randomly selected for comparative fishing and in 2020 all 50 planned stations were included in the comparative fishing experiment.

CCGS *M. Perley* is the main survey vessel for the Northumberland Strait multi-species bottom trawl survey since 2012, and was used to conduct the comparative fishing experiments. For the OT, the targeted set duration and speed were 15 minutes and 2.5 kts, respectively. The NT was fished at a targeted speed of 2.5 kts. Initially, set duration was kept at 15 minutes for the NT but, after four sets in 2019, the targeted set duration was reduced to 10 minutes. These initial four sets indicated the catch from a 10 minute tow with the NT was sufficient to obtain a representative sample of taxa, in terms of species assemblage and size distribution.

Trawls were equipped with Notus wingspread sensors on the wings and a Star Oddi temperature/depth sensor on the headline. These sensors provided detailed measurements of trawl geometry.

FIELD METHODS

General sampling methods for the Northumberland Strait multi-species bottom trawl survey are described in Asselin et al. (2021). For each set, the captain completed a ‘set card’ where time (to the minute), position (latitude and longitude) and depth (m) were recorded at the start and end of each set.

The full catch was sorted to species, or to the lowest taxonomic group possible, and weighed. Random sub-sampling (e.g. “Dutch shuffle”) of fish was conducted when more than approximately 200 individuals of one species were caught in a set. Random sub-sampling was used at times for large lobster catches (above approximately 50 kg in a set). For Lobster and crab, carapace size (length for Lobster, width for crab, to the mm), stage of moult and sex were recorded. For females, the presence or absence of eggs and, when present, the stage of development of the eggs (i.e. new or old) were recorded. With the exception of Atlantic Herring (*Clupea harengus*), fish length (fork length or total length, dependent on tail shape) was measured on a 0.5 cm offset board to the nearest larger cm. Atlantic herring were measured on a wooden herring board, with a pinched tail, to the lower 0.5 cm. Due to the challenges in field differentiating between Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*), these were not separated and were recorded under the common name ‘Gaspereau’ (*Alosa sp.*). Similarly, Sand Lance (*Ammodytes* sp.) was used for both Northern Sand Lance (*Ammodytes dubius*) and American Sand Lance (*Ammodytes americanus*) as they are closely related and their ranges overlap (Staudinger et al. 2020). Small cod (*Gadidae* sp. < 15 cm fork length) were recorded together due to difficulties in differentiating between small specimens of Atlantic Cod (*Gadus morhua*) and Greenland Cod (*Gadus ogac*) (Methven and McGowan 1998).

ANALYTICAL METHODS

Fishing sets data were examined to remove records where the proper deployment of the trawl may have been impacted (e.g. an old Lobster trap in the trawl). Only representative sets were kept for analyses.

To test for the impacts of water depth on swept area and catchability, water depth for each set was calculated as the average of the start and end depths of the set. The start and end depths were determined by adding the draft of the vessel, 3.1 m, to the sounding depths indicated on set cards. The distance of each set was calculated using the start and end positions indicated on the set card. Erroneous values were removed (e.g. errors in latitudes or longitudes) and replaced with the average distances for 10 minute and 15 minute sets, as appropriate.

Data from the Notus wing sensors were used to estimate the average wingspread of the trawl (i.e. the size of the horizontal opening) for each set and the average wingspread of each trawl for all sets combined. Measurements were filtered to remove values above 12 m and below 5 m as these were outside the range of realistic wingspread values for both trawls. To reduce potential bias from measurements at the start and end of the sets, when the trawl may not have been fully deployed, measurements within 1 minute of the start or end times of the set, as given on the set card, were removed. Lastly, average wingspread was only calculated for sets with a minimum of three wingspread measurements. Linear regression was used to test if water depth significantly predicted the average wingspread of each trawl.

The swept area of each set was calculated as the distance multiplied by the average wingspread of the tow. For sets without valid wingspread estimates, the wingspread was calculated using the water depth and the results of the linear regression.

To determine if the tow duration of the set (i.e. the bottom-time of the trawl, between touch down and lift off of the footgear) was impacted by water depth, pressure data from the Star Oddi sensor were graphed. Only data from sets with a target duration of 10 minutes and 15 minutes for the NT and the OT, respectively, were used. The graphs were visually examined and the start and end points of the sets were identified based on the portion of the set when pressure measurements were highest and relatively stable, indicating the trawl was being dragged along the bottom. Each graph was visually examined five times and the median values for the start and end times were used in further analyses, with the duration of each set equal to the median end time minus the median start time. Linear regression was used to test if water depth significantly predicted the tow duration of 10 minute and 15 minute sets.

As small cod (< 15 cm fork length) were recorded together during the survey and Atlantic Cod, Greenland Cod and Atlantic Tomcod (*Microgadus tomcod*) are morphologically similar within the size ranges captured during the survey, catches of the three species were analyzed as “cod” for the comparative experiment. Similarly, catches of two morphologically similar species of Toad Crab, *Hyas coarctatus* and *Hyas araneus* were also combined for analysis. Following Fowler and Showell (2009), only catches from species or species groups with 25 or more specimens from each trawl were analysed. To reduce potential bias due to differences in species availability to the two trawls (e.g. for pelagic species that are highly mobile), data were examined for the presence of very large captures by only one trawl at a station. Where identified, the station was removed from further analysis for the specific species only. For length-based analyses, species with sufficient data were included, generally species with a minimum of 100 specimens caught by each trawl.

Catch observations consist of the abundance, weight and length frequency of captured individuals. For the comparative fishing experiments, these observations were available from a pair of fishing sets at the same station, one conducted using the OT and the other conducted using the NT.

It is common to examine this type of data in a binomial framework through Generalized Linear Models (GLMs) (McCullagh 2019) and to thus estimate the relative fishing efficiency of the two trawls. The response variable used is the catch abundance, and the GLMs that were examined use a logit link and a binomial error structure. Fitted models can be used to predict the calibration coefficients required to make catches from the two trawls comparable. Only data from stations fished by both gear types (i.e. the OT and the NT) were used in the models.

For each pair of tows conducted at the same station i, the pooled catch is computed for each species s:

$$C_{is} = C_{is}^{OT} + C_{is}^{NT} \qquad (1)$$

Where C_{is}^{OT} and C_{is}^{NT} is the catch of species s by the OT and the NT, respectively. The fishing efficiency of the NT can be compared to that of the OT by computing $p_{is}^{NT} = C_{is}^{NT}/C_{is}$, the proportion of the combined catch that comes from the NT. A logit transformation of this proportion forms the basis of the binomial GLM, where the simplest intercept-only model can be formulated as:

$$logit(p_{is}^{NT}) = \log(p_{is}^{NT}/1 - p_{is}^{NT}) = \beta_0 + \tau_i \qquad (2)$$

To standardize the catch by swept area, an offset term consisting of the log of the quotient of the NT swept area (a_i^{NT}) and the OT swept area (a_i^{OT}) was used ($\tau_i = \log(a_i^{NT}/a_i^{OT})$).

For all species included in the analysis, GLMs were initially formulated with no covariates. We then tested models including depth and length effects. The term “length” is used for both length and width measurements, as appropriate for the species (i.e. length for fish, carapace length for Lobster and carapace width for crabs). Depth, length, and, following Benoît and Swain (2003) and Fowler and Showell (2009), squared length, were included as covariates in the models. In total, up to seven models were tested for each species:

M1

$$logit(p) = \beta_0 \qquad (3)$$

M2

$$logit(p) = \beta_0 + \beta_1 d \quad (4)$$

M3

$$logit(p) = \beta_0 + \beta_2 l \quad (5)$$

M4

$$logit(p) = \beta_0 + \beta_1 d + \beta_2 l \quad (6)$$

M5

$$logit(p) = \beta_0 + \beta_1 d + \beta_2 l + \beta_3 l^2 \quad (7)$$

M6

$$logit(p) = \beta_0 + \beta_2 l + \beta_3 l^2 \quad (8)$$

M7

$$logit(p) = \beta_0 + \beta_1 d + \beta_2 l + \beta_4 \cdot (d \cdot l) \qquad (9)$$

where, for each species, $logit(p)$ is the overall calibration coefficient on the logit scale, β_0, β_1, β_2, β_3 and β_4 are the β coefficients of the intercept, the depth (d), the length (l), the squared length (l^2) and the length by the depth interactions ($d \cdot l$), respectively. Under the first model, a value of $\beta_s = 0$ corresponds to $p_s^{NT} = 0.5$, which would be the case if both trawls had captured the exact same thing. Positive values of β_s would indicate a higher fishing efficiency on the NT, and negative values of β_s would indicate a higher fishing efficiency on the OT.

Histograms of the length and depth distributions of each species were visually examined and species biology was considered to determine which of the nine possible models should be tested. The selected models were then run and model selection was based on an Akaike's Information Criterion (AIC) within 2 of the lowest (Burnham and Anderson 2002) and on the statistical significance of the covariates in the models. Model diagnostics, including residual plots and q-q plots, were examined to ensure proper model fit. All analyses were completed in R (R Core Team 2022).

RESULTS

The average wingspread of the NT was larger than the average wingspread of the OT, 8.76 m (CV= 0.02, n=87 sets) and 8.21 m (CV=0.01, n=101 sets), respectively. In addition, the average wingspread per set was variable for both trawls but increased significantly ($p<0.001$) with depth (Figure 3). Using the results of the linear regression, for each trawl, the slope and intercept can be used with set depth to estimate the wingspread (WS) of the trawl using the equation:

$$WS = m(h) + b$$

Where m is the slope, h is the water depth of the set and b is the intercept. Values for m and b for the OT and the NT are in Table 2. The average distances fished for 10 minute and 15 minute sets were 0.79 km (CV=0.005, n=89) and 1.19 km (CV=0.005, n=109), respectively. Based on the average wingspreads and average distances, the average swept areas of 10 minute sets with the NT and 15 minute set with the OT were 6,926 m^2 and 9,764 m^2, respectively.

Bottom time, based on pressure data from the Star Oddi sensor, was relatively stable for both trawls. For the OT, bottom time decreased minimally, but statistically significantly (slope = -0.007, p = 0.024), with depth (Figure 4).

Due to logistical challenges, not all comparative stations were completed. In 2019 and 2020, 31 and 46 comparative stations were successfully fished with both trawls, respectively (Figure 5), in water depths ranging from 7 to 47 m.

A total of 42 species or species groups were caught by one or both trawls (Table 1). For 16 species or species groups, a minimum of 25 specimens were caught in each of the OT and the NT. Two stations with unusually large captures of a species with one trawl only were identified: one for Rainbow Smelt (*Osmerus mordax*) with the NT and one for Toad Crab with the OT. These data were removed from analysis which reduced the total capture of Toad Crab below the 25 specimen threshold for analysis. Of the 15 remaining species, eight had sufficient data for length based analyses.

Only M1 was tested for American Plaice (*Hippoglossoides platessoides*) as there were insufficient data to support the use of more complex models. For Sand Lance, Windowpane Flounder (*Scophthalmus aquosus*) and Yellowtail Flounder (*Limanda ferruginea*), due to limited size ranges and evidence of clumping in the depth distributions of their catches, models with depth or quadratic length effects were excluded (i.e. M1 and M3 were tested). Similarly, for Atlantic Herring and Atlantic Mackerel (*Scomber scombrus*), as these are highly mobile pelagic species and, for herring, high levels of aggregation were observed, models with depth or quadratic length effects were excluded (i.e. *M1* and *M3* were tested). For Atlantic Rock Crab, Lady Crab (*Ovalipes ocellatus*), Rainbow Smelt and Winter Skate (*Leucoraja ocellata),* due to limited data, models with quadratic length effects were excluded (i.e. *M1*, *M2*, *M3*, *M4* and *M7* were tested). All models were tested for Gaspereau, American Lobster, Cunner (*Tautogolabrus adspersus*), Cod and Winter Flounder, as these had sufficient data to support all the models.

Catch data, raw and modeled catch ratios and calibration factors for the selected model are presented in Figures 6 to 20. Calibration coefficients are presented in Table 3. For American Lobster, while *M5* was selected as the best model based on AIC, the quadratic length covariate and the sparseness of data at large sizes resulted in an unrealistic upward trend in the β for length at sizes above 90 mm in carapace length (Figure 21). At carapace lengths above 90 mm, the β for 90 mm should be used.

DISCUSSION

When changes in fishing equipment or vessel occur, comparative surveys are essential to preserving the integrity of a trawl survey time series. Integral to the analysis of a comparative dataset is the assumption of equal availability to the two fishing events being compared. For a change in vessel, equal availability is optimized by conducting the comparative fishing with the two vessels fishing in close proximity to each other, both spatially and temporally (e.g. Benoît and Swain 2003; Fowler and Showell 2009). For this survey, with a change in trawl but not in vessel, we controlled for spatial variation by conducting both fishing events in the same location. Due to the logistical challenge of changing trawls on CCGS *M. Perley*, it was not possible to conduct the two fishing events in sequence. Instead, to reduce temporal variability in availability, we completed the two fishing events within a six-day period. For widely distributed species that do not undertake large-scale directional movements in July (e.g. American Lobster and Winter Flounder), this assumption of equal availability is likely met. For highly mobile and highly aggregated species (e.g. Atlantic Herring), while our results indicate a higher trawl efficiency with the NT (Figure 8), differences in availability between the two fishing events likely occurred. To reduce the potential bias from changes in availability, we worked within the limitations of the data available and did not test models with depth or quadratic length effects.

The calibration coefficients presented here are to be used to convert OT catch data from the Northumberland Strait multi-species bottom trawl survey to NT catch data. While the Northumberland Strait multi-species bottom survey was initiated in 1999, fishing and sampling methods have been largely consistent since 2001 for lobster and crabs and since 2005 for fish (Asselin et al. 2021). Two vessels were used over the time series, CCGS *Opilio* and CCGS *M. Perley*, but a calibration experiment was not completed between the two vessels. In 2010 and 2011, a Nephrops trawl was used (Asselin et al. 2021) and a calibration experiment was not conducted, resulting in a 2-year gap in the survey time series. This makes it more difficult to assess the potential effects of the change in survey vessel. A highly experienced Coast Guard captain who completed the survey with both CCGS *Opilio* and CCGS *M. Perley*, indicated that, based on his knowledge of the geometry of both vessels, the impact of the vessel change would be negligible (Denis Léger, personal comment, September 26, 2022). During surveys conducted in 2002 and 2003, when CCGS *Opilio* was used with the OT, data from SCANMAR wing sensors were used to calculate an average wingspread of 9.0 m (95% C.I. of 8.2 to 9.2 m, n=149 sets, Comeau et al. 2008). Our result of an average wingspread of 8.21 m for the OT when fished by CCGS *M. Perley* is at the lower end of the 95% C.I. calculated by Comeau et al. (2008) but many of the stations fished in 2002 were located northwest of our study area in Northumberland Strait (Figure 3 in Asselin et al. 2021), which includes deeper waters and may partially explain the difference as our results indicate the wingspread of the OT increases with depth. As depth and other factors have been shown to impact wingspread (e.g. Godo and Engas 1989; Weinberg and Kotwicki 2008) we recommend the use of trawl mensuration instruments (e.g. Notus sensors) to determine the actual wingspread of each set. In the absence of set specific wingspread data, the equation presented here should increase the accuracy of wingspread estimates for both the OT and the NT as the impact of depth is included in the equation. However, for sets fished by CCGS *Opilio* (2005-2009), our equation may lead to a negative bias in the wingspread and, as the wingspread is used to calculate the swept area, result in a positive bias in density and biomass estimates.

Logistical challenges during the course of the comparative study reduced the number of stations in the deeper, western end of Northumberland Strait. While Northumberland Strait is shallow over all (i.e. depths < 40 m), the full depth relationships may not have been well characterized by our dataset. Additional sampling may be necessary for species that are more common in the western end of the study area (e.g. American Plaice, Asselin et al. 2021). Certain key species, such as White Hake (*Urophycis tenuis*), were not included in our analysis due to the limited catch rates. In addition, some species that were caught frequently by the NT were relatively rare when fishing with the OT [e.g. Longhorn Sculpin (*Myoxocephalus octodecemspinosus*), Ocean Pout (*Zoarces americanus*)]. For others, such as Atlantic Rock Crab and Lady Crab, the size distributions of the catch did not fully overlap, with the NT capturing smaller individuals than the OT. Caution is recommended when applying the calibration coefficients to historical catches from the OT for these small sizes. Specifically, the use of non-length-based calibration coefficients could lead to positively biased biomass estimates when applied to OT data. For simplicity and ease of interpretation, the analyses conducted herein did not examine non-parametric smoothing techniques for model covariates and only parametric relationships were examined. Future work could include additional sampling of under-represented species (e.g. White Hake) or other modeling approaches (e.g. beta-binomial, hierarchical with non-parametric smoothing).

For American Lobster, the inclusion of a quadratic length covariate and the low capture rate at large sizes resulted in unrealistic values for β at carapace lengths above 90 mm. At these large sizes, a change in trawl efficiency is not expected, either in terms of Lobster size or behaviour, and we deemed the β to be a result of the modelling approach. The use of the calibration coefficient for 90 mm carapace length is recommended for Lobsters above 90mm carapace length.

For stock assessment, the use of the calibration coefficients presented here enables analyses of the Northumberland Strait multi-species bottom trawl survey time series back to 2001 for lobster and crab and 2005 for fish. Fishery-independent trawl survey data are critical for many fisheries stock assessment as, in comparison to fishery-dependent data, they are not impacted by changes in fishing effort and can detect changes in the biomass of pre-recruits. For all species analysed, the NT was shown to have higher capture rates than the OT, and thus estimates of biomass from NT catches are a closer approximation of true biomass. This change in fishing gear, and future analyses that incorporate the use of the calibration coefficients presented here, will better represent the species assemblage within the Northumberland Strait multi-species bottom trawl survey study area and contribute to a better understanding of the ecosystem as a whole.

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TABLES

Table 1. Catch summary for comparative sets with the Otter Trawl (OT) and the Northumberland Trawl (NT) in Northumberland Strait, 2019 and 2020. The species code is that used in the Oracle database storing the survey data at Fisheries and Oceans Canada, Gulf Region. The AphiaID is the code used in the World Register of Marine Species.

Common name	Scientific name	Species code	AphiaID	Total sets OT	Total sets NT	Total count OT	Total count NT	Total count
Alligatorfish	*Aspidophoroides monopterygius*	340	159459	0	2	0	3	3
American Lobster	*Homarus americanus*	2550	156134	74	75	14,184	23,702	37,886
American Plaice	*Hippoglossoides platessoides*	40	127137	13	20	66	272	338
American Shad	*Alosa sapidissima*	61	158670	2	1	4	2	6
Arctic Staghorn Sculpin	*Gymnocanthus tricuspis*	302	127198	0	1	0	1	1
Atlantic Halibut	*Hippoglossus hippoglossus*	30	127138	0	1	0	1	1
Atlantic Herring	*Clupea harengus*	60	126417	19	25	730	5,338	6,068
Atlantic Mackerel	*Scomber scombrus*	70	127023	20	24	419	812	1,231
Atlantic Rock Crab	*Cancer irroratus*	2513	158057	16	43	40	91	131

Common name	Scientific name	Species code	AphiaID	Total sets OT	Total sets NT	Total count OT	Total count NT	Total count
Atlantic Salmon	*Salmo salar*	65	127186	0	1	0	1	1
Black Fingered Mud Crab	*Panopeus herbstii*	2518	158436	1	5	1	6	7
Cod	*Gadus morhua, Gadus ogac, Microgadus ogac*	-	-	42	54	2,264	3,515	5,779
Cunner	*Tautogolabrus adspersus*	122	159785	26	39	117	488	605
Daubed Shanny	*Leptoclinus maculatus*	623	127072	1	3	1	16	17
Fourbeard Rockling	*Enchelyopus cimbrius*	114	126450	0	1	0	1	1
Gaspereau	*Alosa sp.*	62	158669	18	32	316	464	780
Greenland Halibut	*Reinhardtius hippoglossoides*	31	127144	1	3	1	3	4
Grubby	*Myoxocephalus aenaeus*	303	159519	3	6	3	9	12
Lady Crab	*Ovalipes ocellatus*	2539	158434	15	16	73	172	245
Longhorn Sculpin	*Myoxocephalus octodecemspinosus*	300	159520	11	28	19	285	304
Lumpfish	*Cyclopterus lumpus*	501	127214	0	1	0	2	2
Moustache Sculpin	*Triglops murrayi*	304	127205	0	1	0	1	1
Northern Shortfin Squid	*Illex illecebrosus*	4511	153087	4	7	4	12	16
Ocean Pout	*Zoarces americanus*	640	159267	2	17	2	31	33
Rainbow Smelt	*Osmerus mordax*	63	126737	50	56	7,255	17,074	24,329
Rock Gunnel	*Pholis gunnellus*	621	126996	1	1	1	1	2
Sand Lance	*Ammodytes sp.*	611	125909	10	16	2,928	39,018	41,946
Sea Raven	*Hemitripterus americanus*	320	159518	1	5	1	11	12
Sea Scallop	*Placopecten magellanicus*	4321	156972	0	3	0	3	3
Shorthorn Sculpin	*Myoxocephalus scorpius*	301	127203	0	3	0	3	3
Silver Hake	*Merluccius bilinearis*	14	158962	0	1	0	1	1
Snakeblenny	*Lumpenus lampretaeformis*	622	154675	2	7	2	26	28

Common name	Scientific name	Species code	AphiaID	Total sets OT	Total sets NT	Total count OT	Total count NT	Total count
Snow Crab	*Chionoecetes opilio*	2526	107315	1	2	1	4	5
Striped Bass	*Morone saxatilis*	24	151179	0	1	0	2	2
Three-Spined Stickleback	*Gasterosteus aculeatus*	361	126505	2	0	2	0	2
Toad Crab	*Hyas sp.*	2520	106903	5	5	9	15	24
White Hake	*Urophycis tenuis*	12	126504	7	9	9	37	46
Windowpane Flounder	*Scophthalmus aquosus*	143	158907	21	36	67	338	405
Winter Flounder	*Pseudopleuronectes americanus*	43	158885	68	73	2,029	11,552	13,581
Winter Skate	*Leucoraja ocellata*	204	158553	16	26	37	183	220
Wrymouth	*Cryptacanthodes maculatus*	630	159675	1	3	2	3	5
Yellowtail Flounder	*Limanda ferruginea*	42	158879	24	29	124	615	739

Table 2. Results of simple linear regression of wingspread and water depth for the Otter Trawl (OT) and the Northumberland Trawl (NT)

Trawl	*Slope*	*Intercept*	*R-squared*	*F*	*P-Value*
OT	0.093	6.269	0.570	131.071	*<0.001*
NT	0.070	7.294	0.264	30.534	*<0.001*

Table 3. Recommended calibration coefficients for historical catches from the Otter trawl from selected model for key fish, lobster and crab species

Common name	Model	Intercept	SE	P	D	SE	P	L	SE	P	L^2	SE	P	D × L	SE	P
American Lobster	M5	2.986	0.137	0.000	0.035	0.002	0.000	-0.066	0.004	0.000	0.0003	0.0000	0.0000	-	-	-
American Plaice	M1	1.819	0.137	0.000	-	-	-	-	-	-	-	-	-	-	-	-
Atlantic Herring	M3	4.616	0.158	0.000	-	-	-	-0.124	0.008	0.000	-	-	-	-	-	-
Atlantic Mackerel	M3	-5.921	0.795	0.000	-	-	-	0.256	0.029	0.000	-	-	-	-	-	-
Atlantic Rock Crab	M4	2.319	0.745	0.002	0.052	0.032	0.098	-0.027	0.008	0.001	-	-	-	-	-	-
Cod	M5	0.913	0.289	0.002	0.036	0.005	0.000	-0.169	0.032	0.000	0.006	0.001	0.000	-	-	-
Cunner	M4	1.370	0.542	0.011	0.073	0.025	0.004	-0.049	0.026	0.062	-	-	-	-	-	-
Gaspereau	M7	18.177	3.524	0.000	-0.761	0.160	0.000	-0.541	0.155	0.000	-	-	-	0.023	0.007	0.001
Lady Crab	M3	3.708	0.932	0.000	-	-	-	-0.033	0.012	0.005	-	-	-	-	-	-
Rainbow Smelt	M7	-1.473	0.240	0.000	0.198	0.018	0.000	0.158	0.015	0.000	-	-	-	-0.011	0.001	0.000
Sand Lance	M3	1.198	0.201	0.000	-	-	-	0.124	0.014	0.000	-	-	-	-	-	-
Windowpane Flounder	M3	2.667	0.538	0.000	-	-	-	-0.044	0.029	0.137	-	-	-	-	-	-
Winter Flounder	M5	-0.132	0.246	0.592	0.062	0.005	0.000	0.107	0.029	0.000	-0.002	0.001	0.003	-	-	-
Winter Skate	M4	0.768	0.790	0.331	0.117	0.042	0.005	-0.024	0.013	0.059	-	-	-	-	-	-
Yellowtail Flounder	M3	4.127	0.489	0.000	-	-	-	-0.124	0.027	0.000	-	-	-	-	-	-

FIGURES

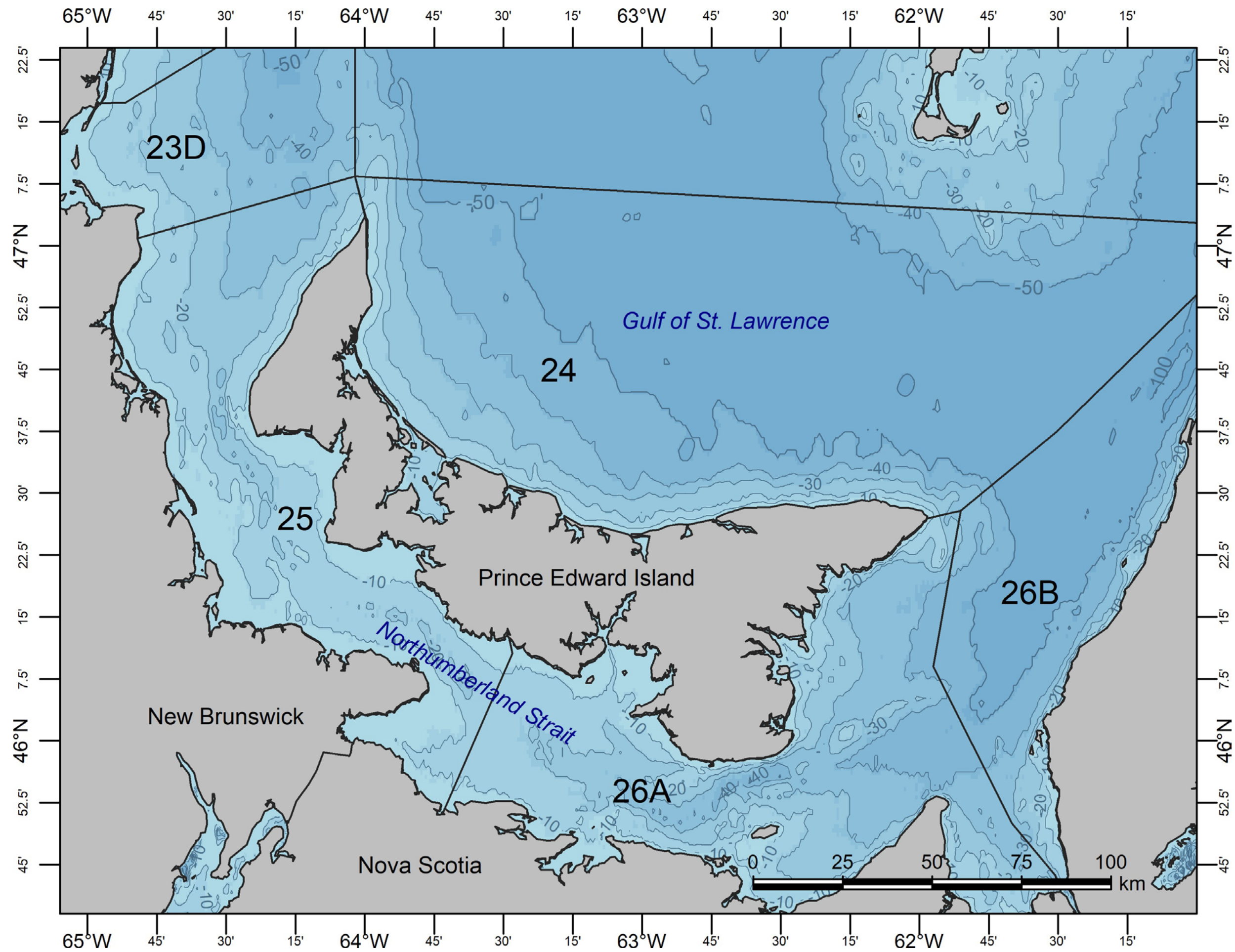

Figure 1. Northumberland Strait in the southern Gulf of St. Lawrence and locations of Lobster Fishing Areas [23 (sub-area D), 24, 25, 26A and 26B] in the southern Gulf of St. Lawrence.

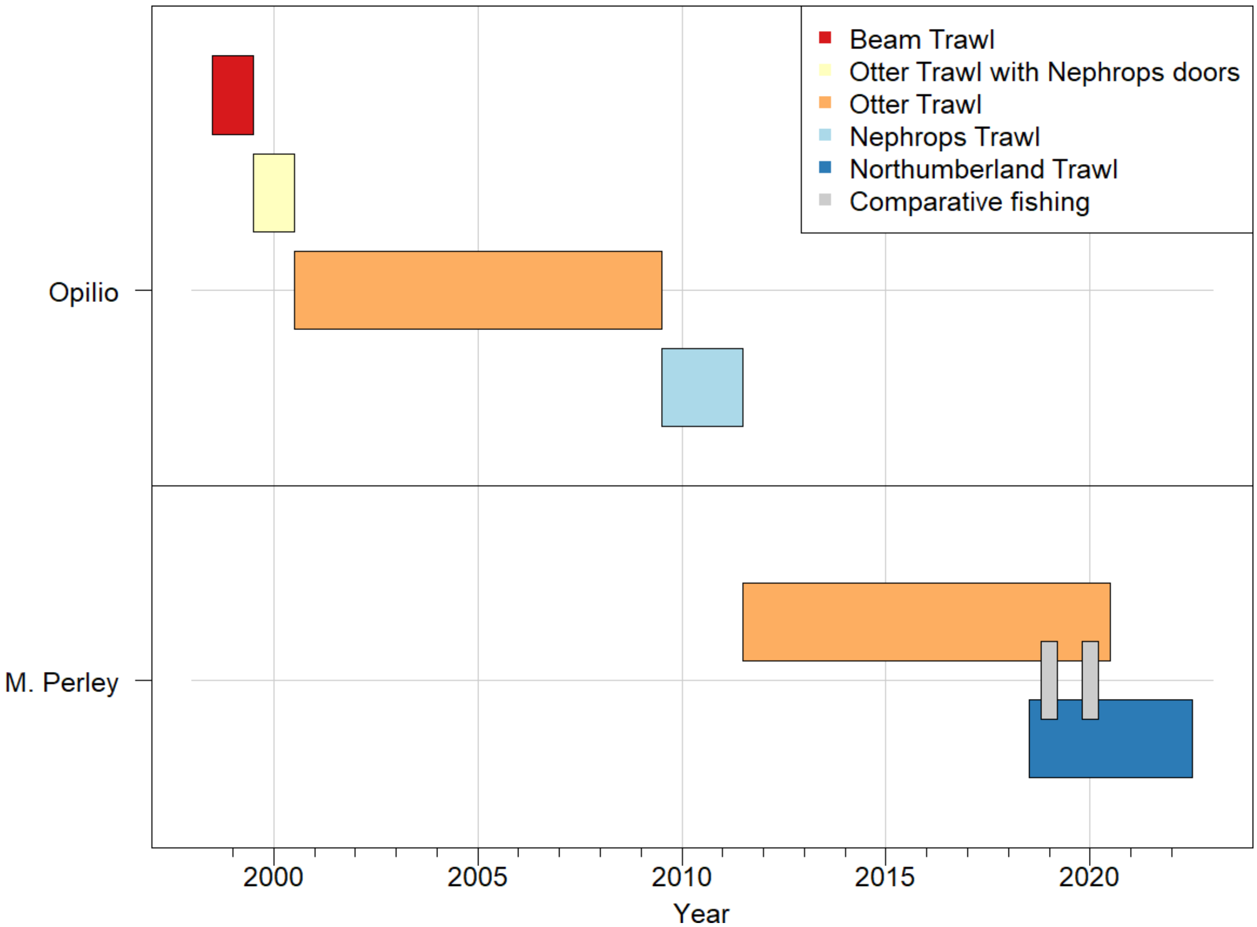

Figure 2. Timeline of survey platforms used in the Northumberland Strait survey. The x axis denotes the timespan of the survey. The y axis identifies the vessels that completed the survey. The rectangles represent the time window when each vessel was used. The comparative fishing experiments of 2019 and 2020 are identified by grey polygons overlapping the trawls under comparison. The trawl types shown are the Beam Trawl, No. 286 otter trawl (denoted as Otter Trawl), the Nephrops Trawl and the Northumberland Trawl.

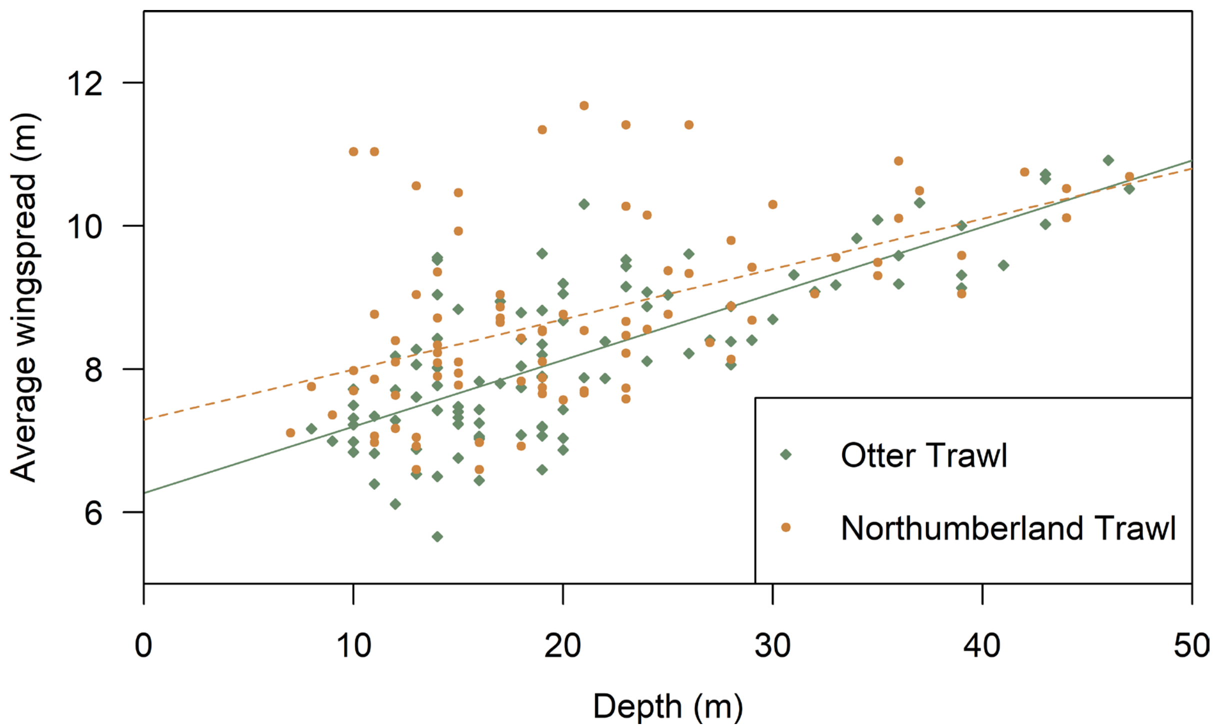

Figure 3. Linear regression of wingspread (m) to depth for the Otter Trawl and the Northumberland Trawl.

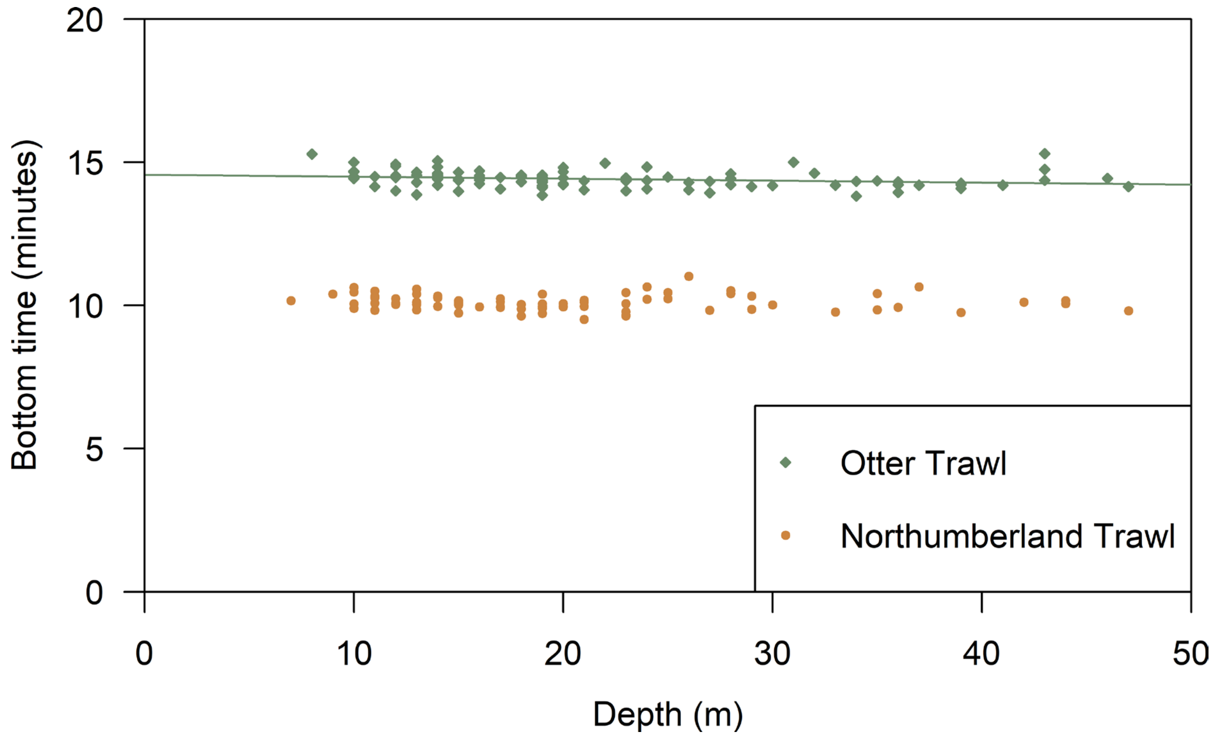

Figure 4. Plot of bottom time against water depth for the Otter Trawl and the Northumberland Trawl.

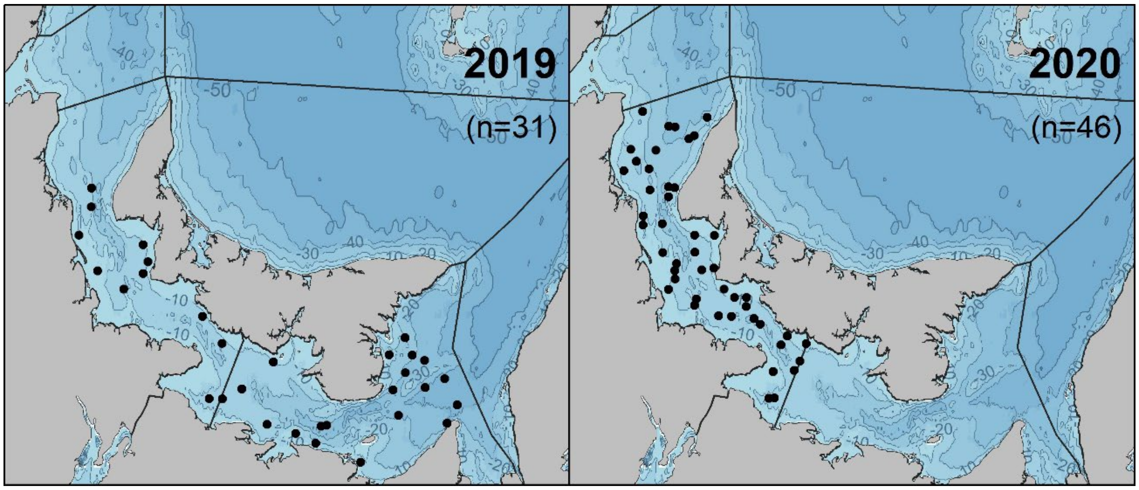

Figure 5. Comparative stations sampled in 2019 (left) and 2020 (right) during the Northumberland Strait multi-species bottom trawl survey.

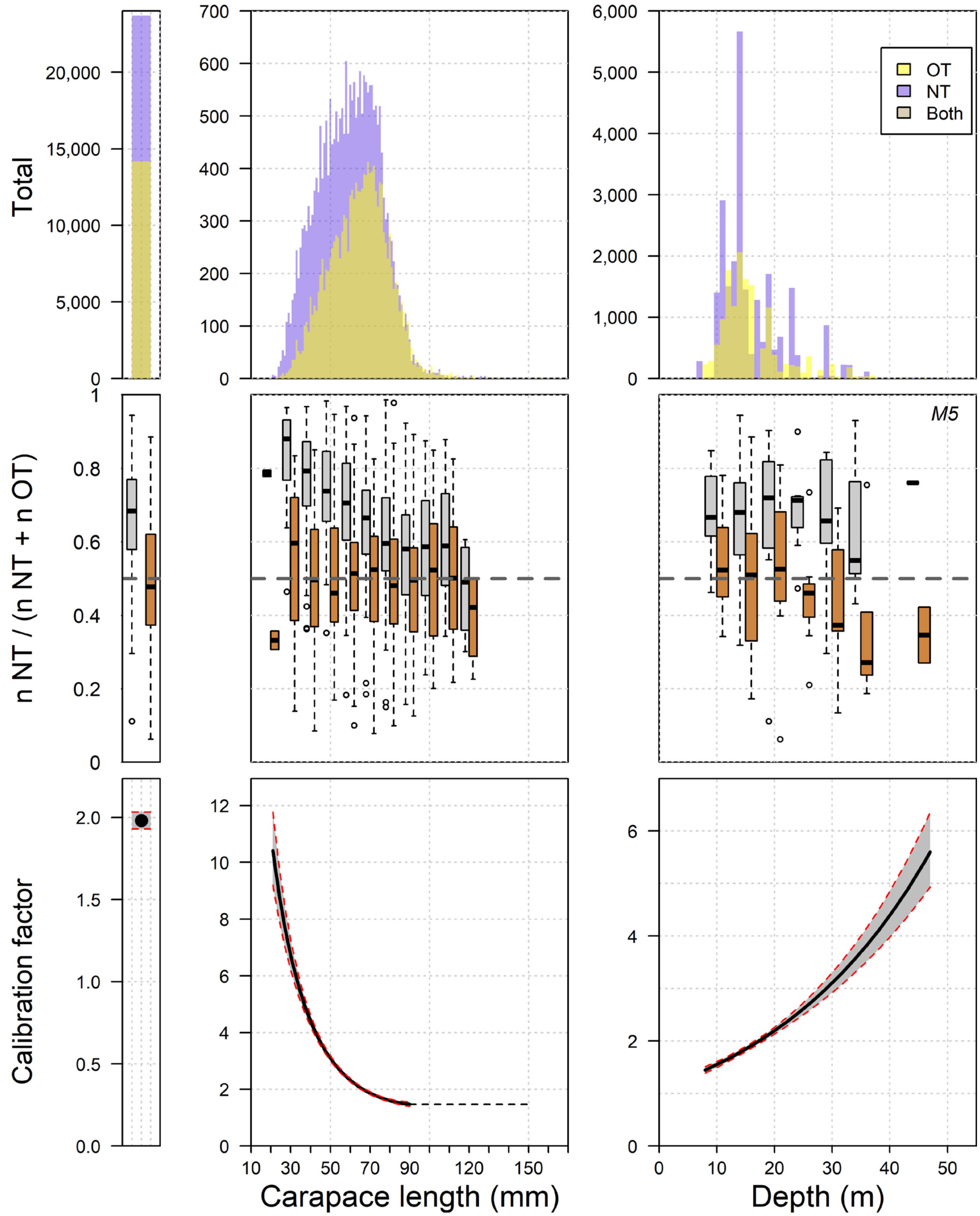

Figure 6. Raw data and model results for American Lobster. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

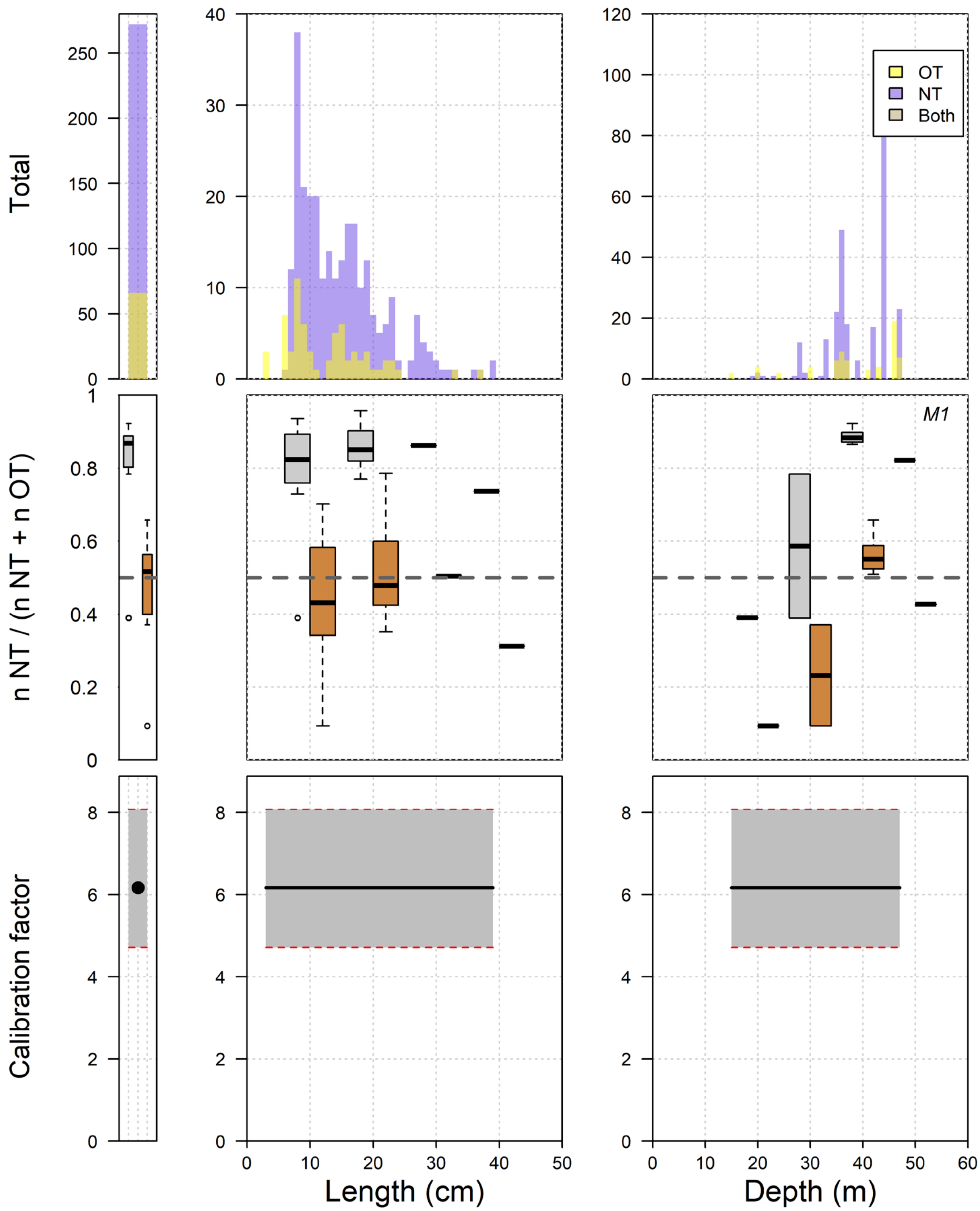

Figure 7. Raw data and model results for American Plaice. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

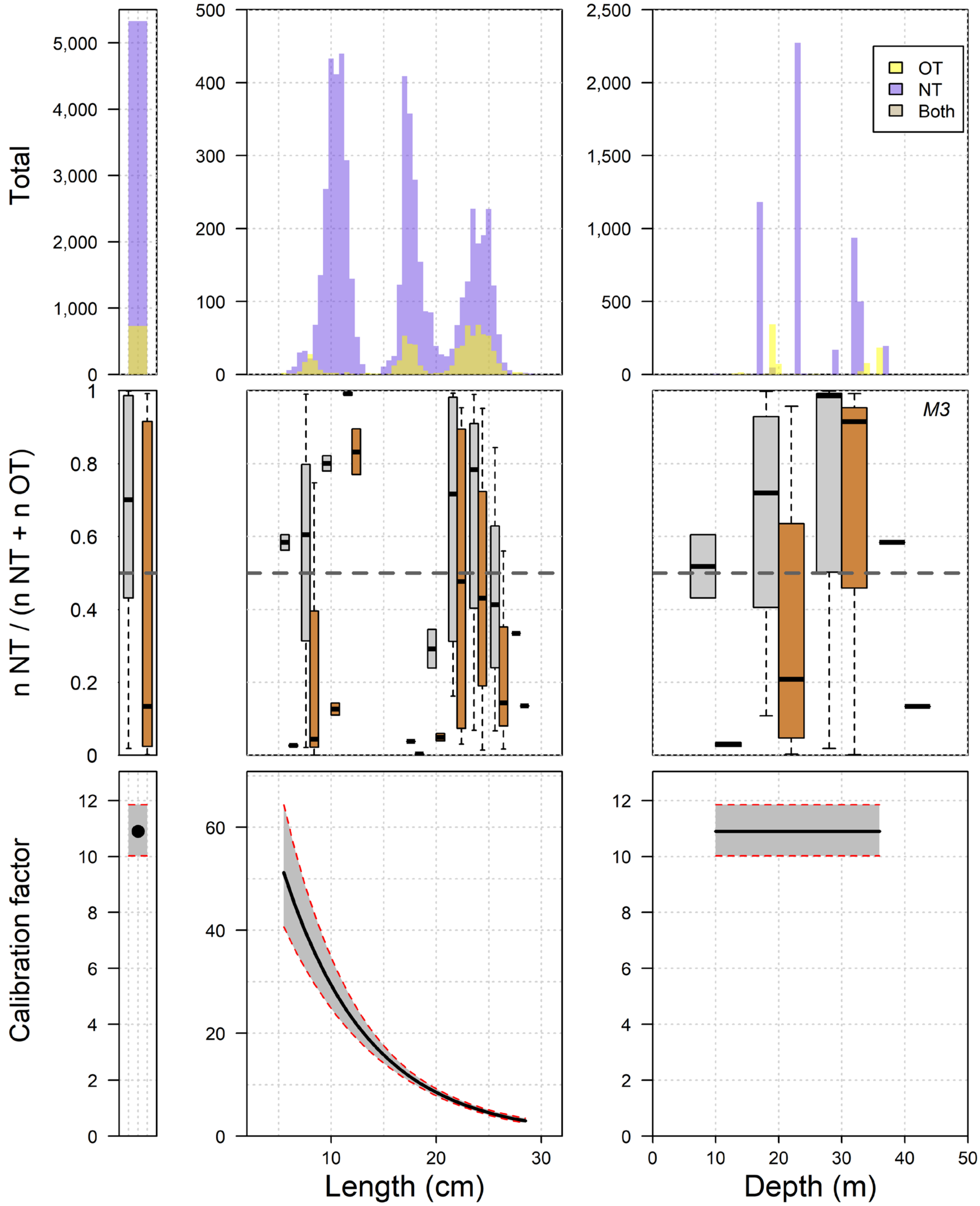

Figure 8. Raw data and model results for Atlantic Herring. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

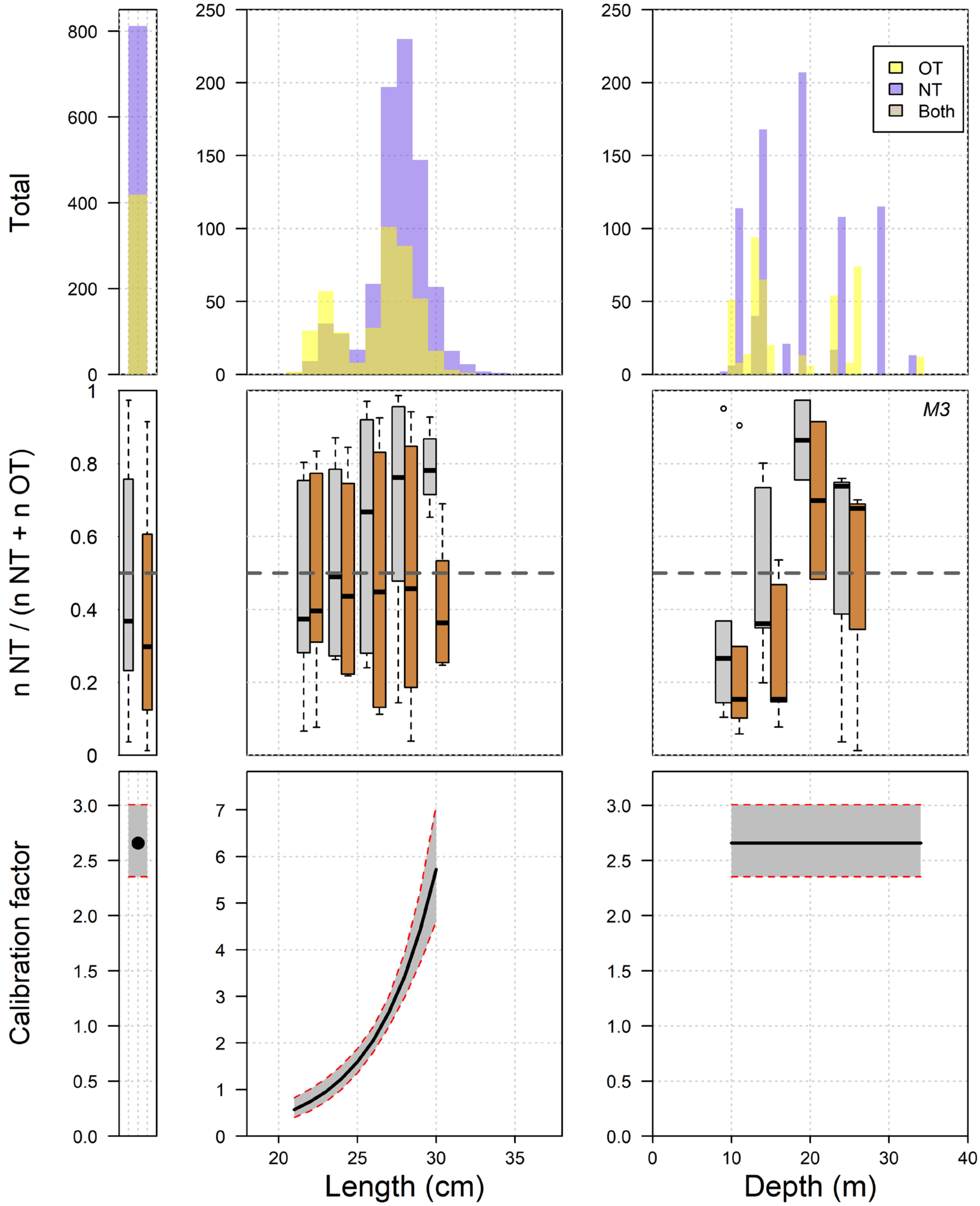

Figure 9. Raw data and model results for Atlantic Mackerel. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

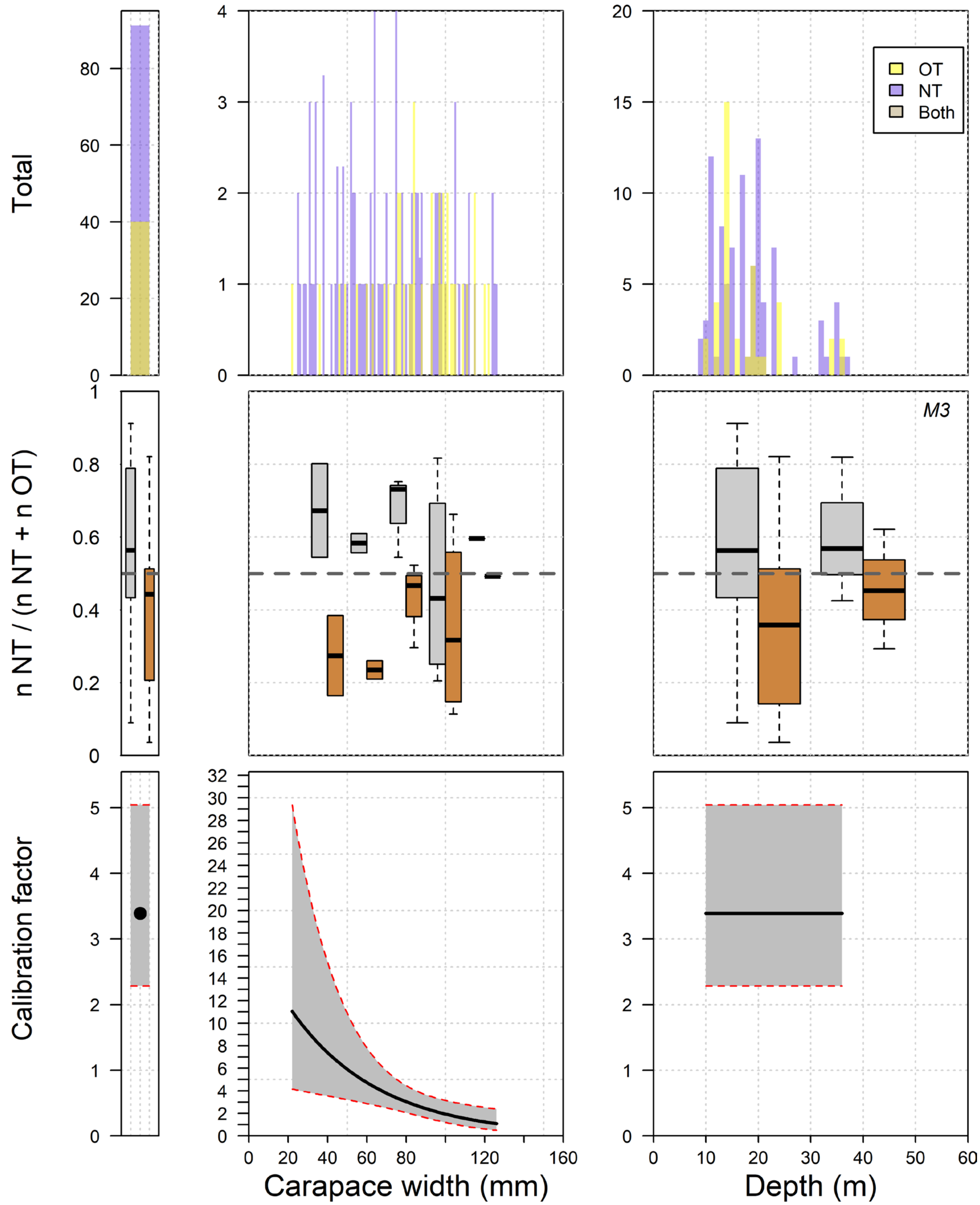

Figure 10. Raw data and model results for Atlantic Rock Crab. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

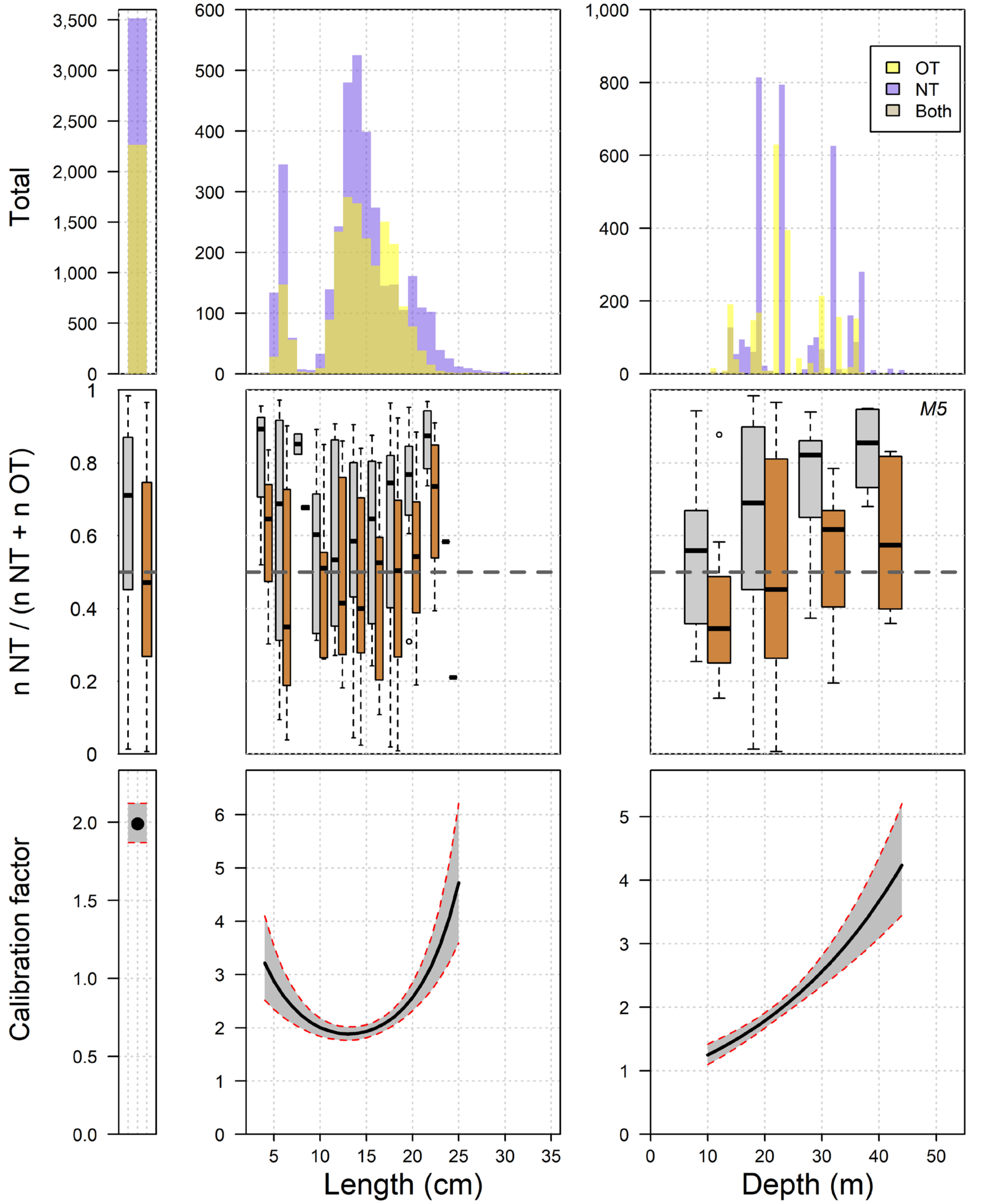

Figure 11. Raw data and model results for cod. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

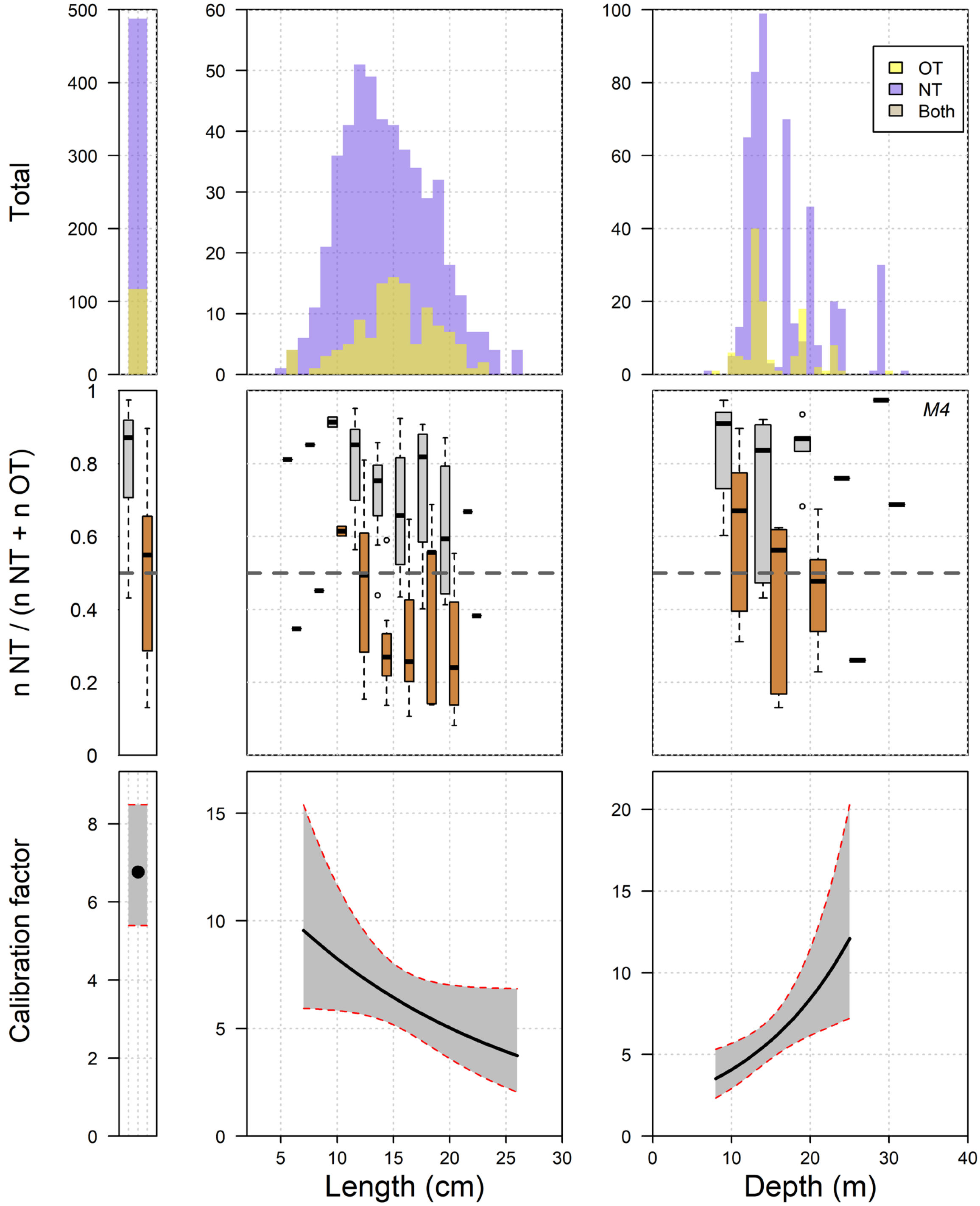

Figure 12. Raw data and model results for Cunner. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

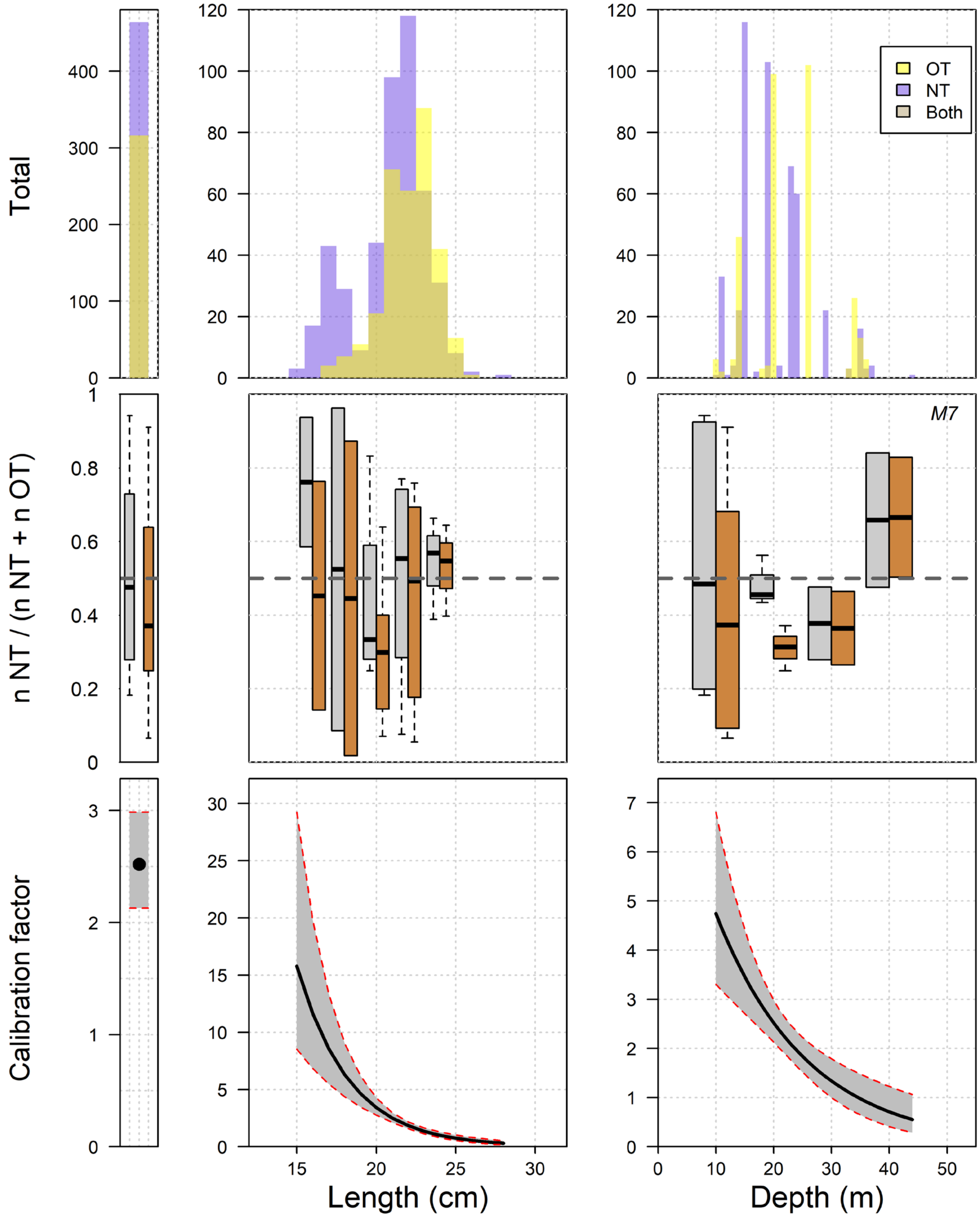

Figure 13. Raw data and model results for Gaspereau. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

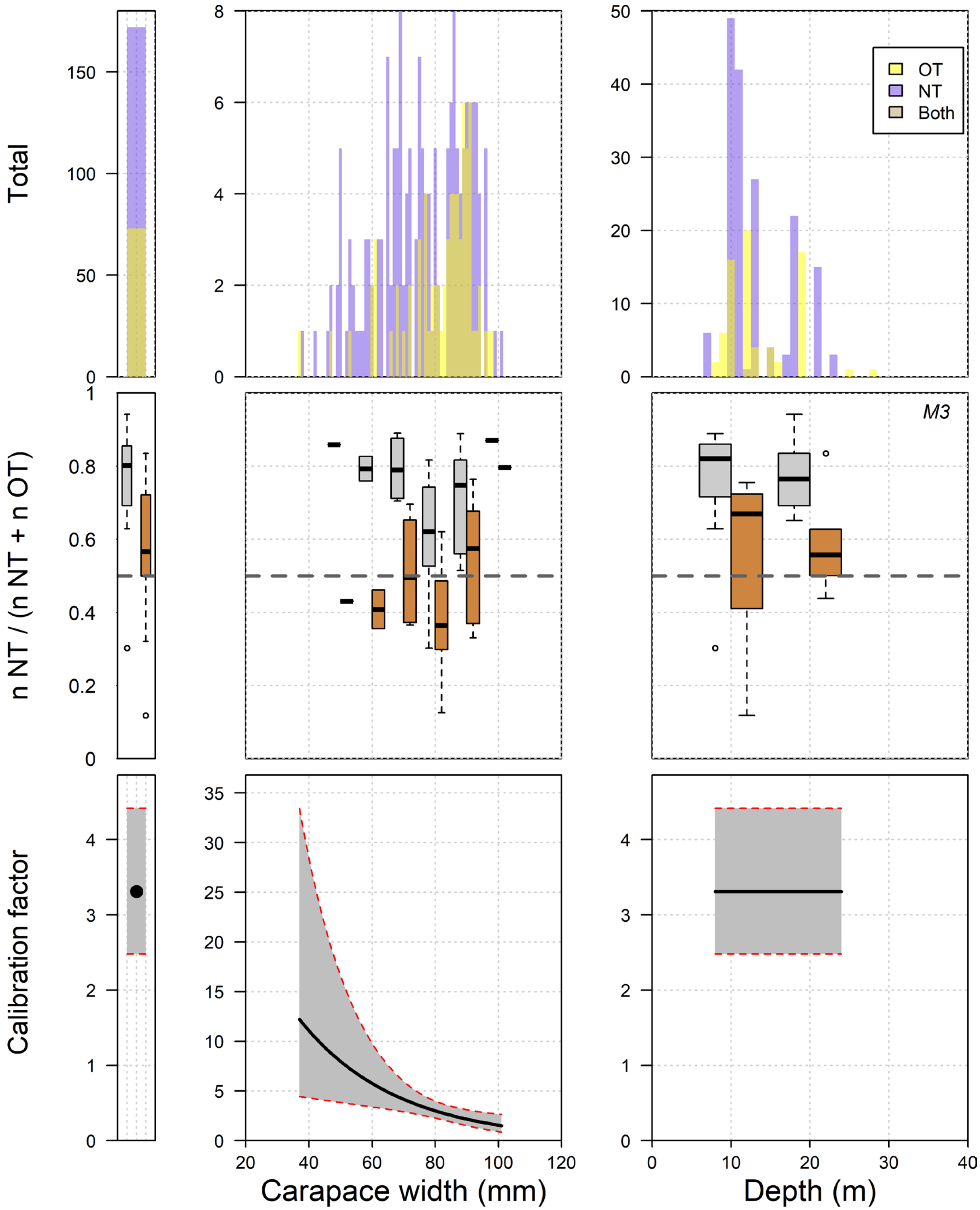

Figure 14. Raw data and model results for Lady Crab. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

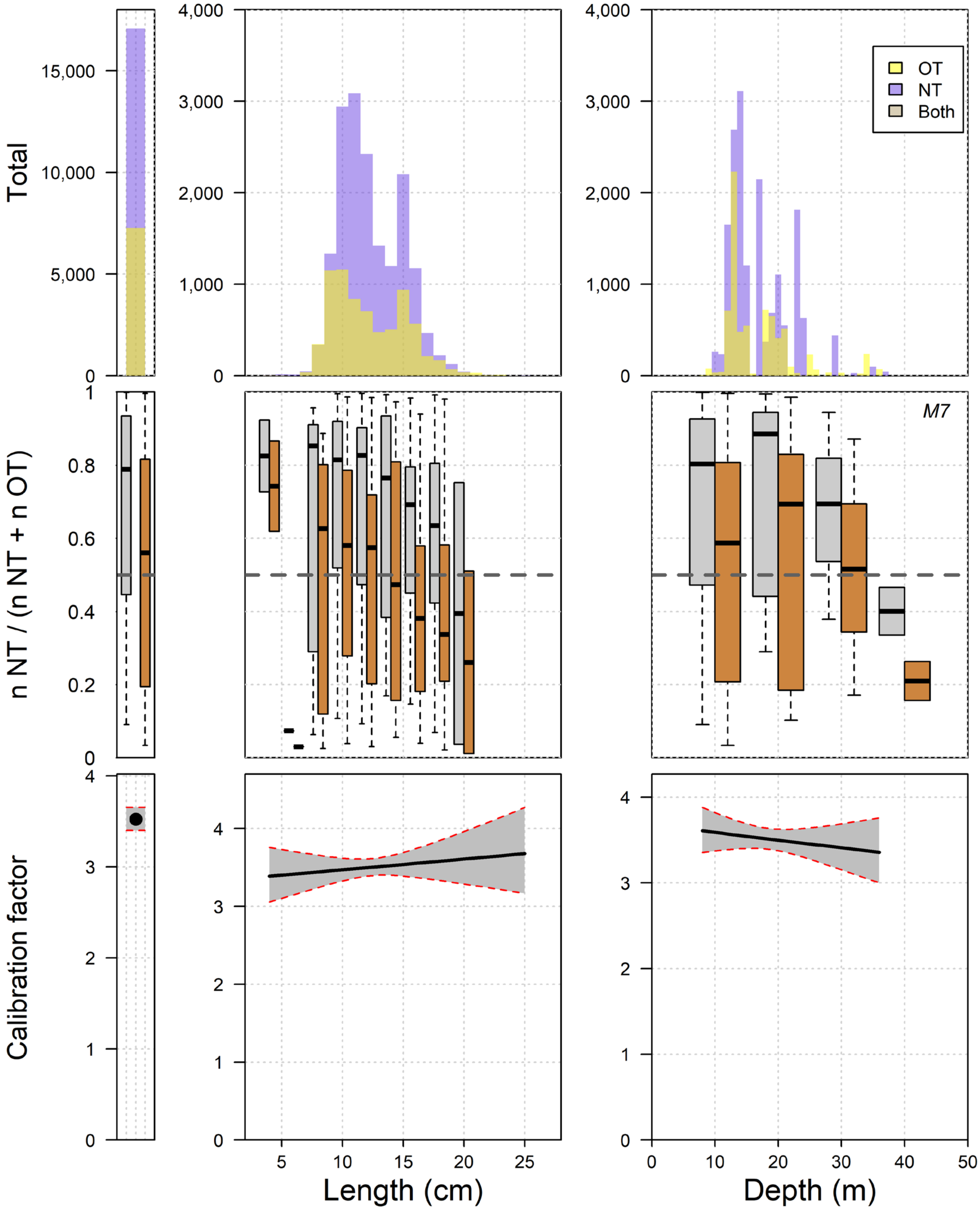

Figure 15. Raw data and model results for Rainbow Smelt. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

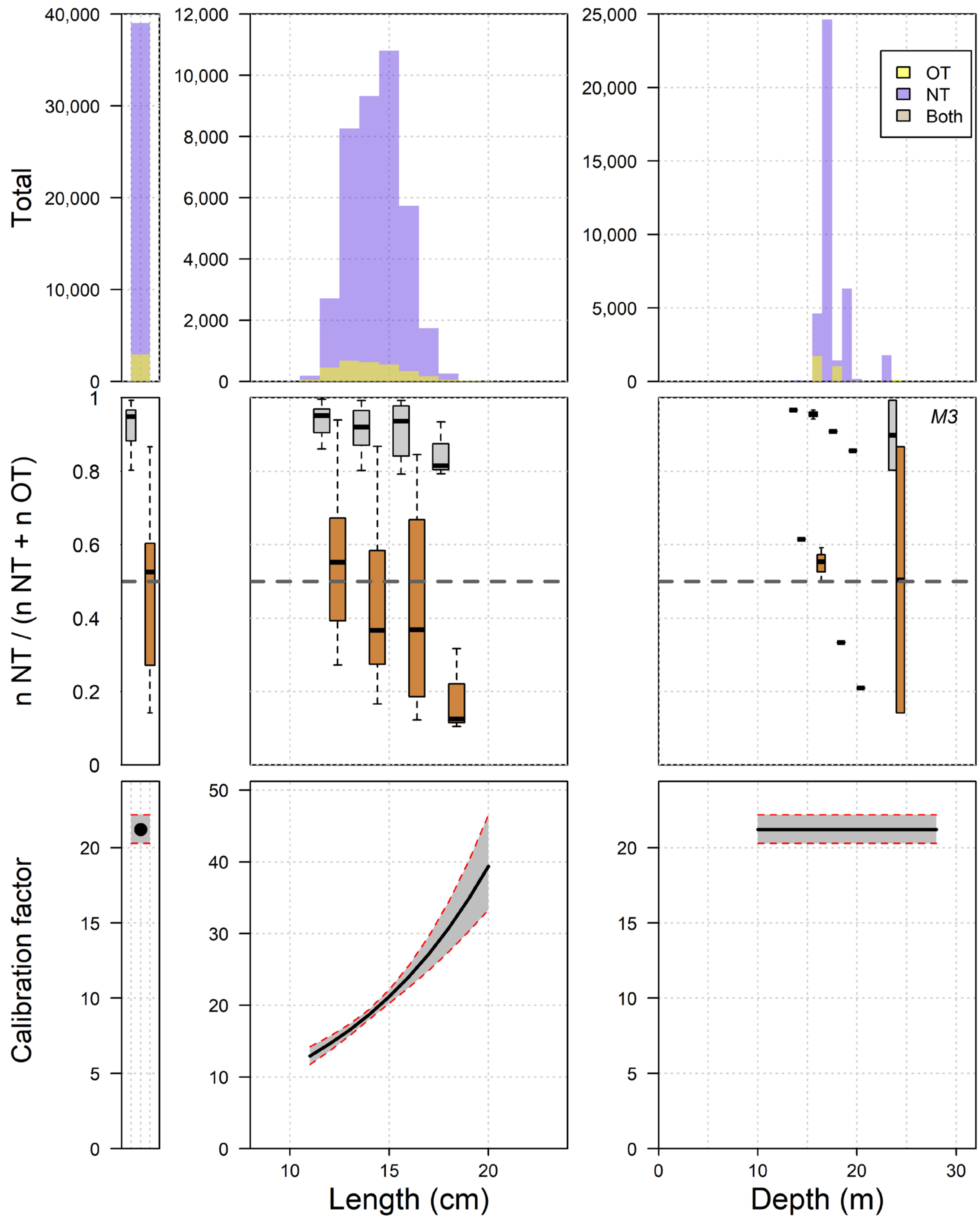

Figure 16. Raw data and model results for Sand Lance. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

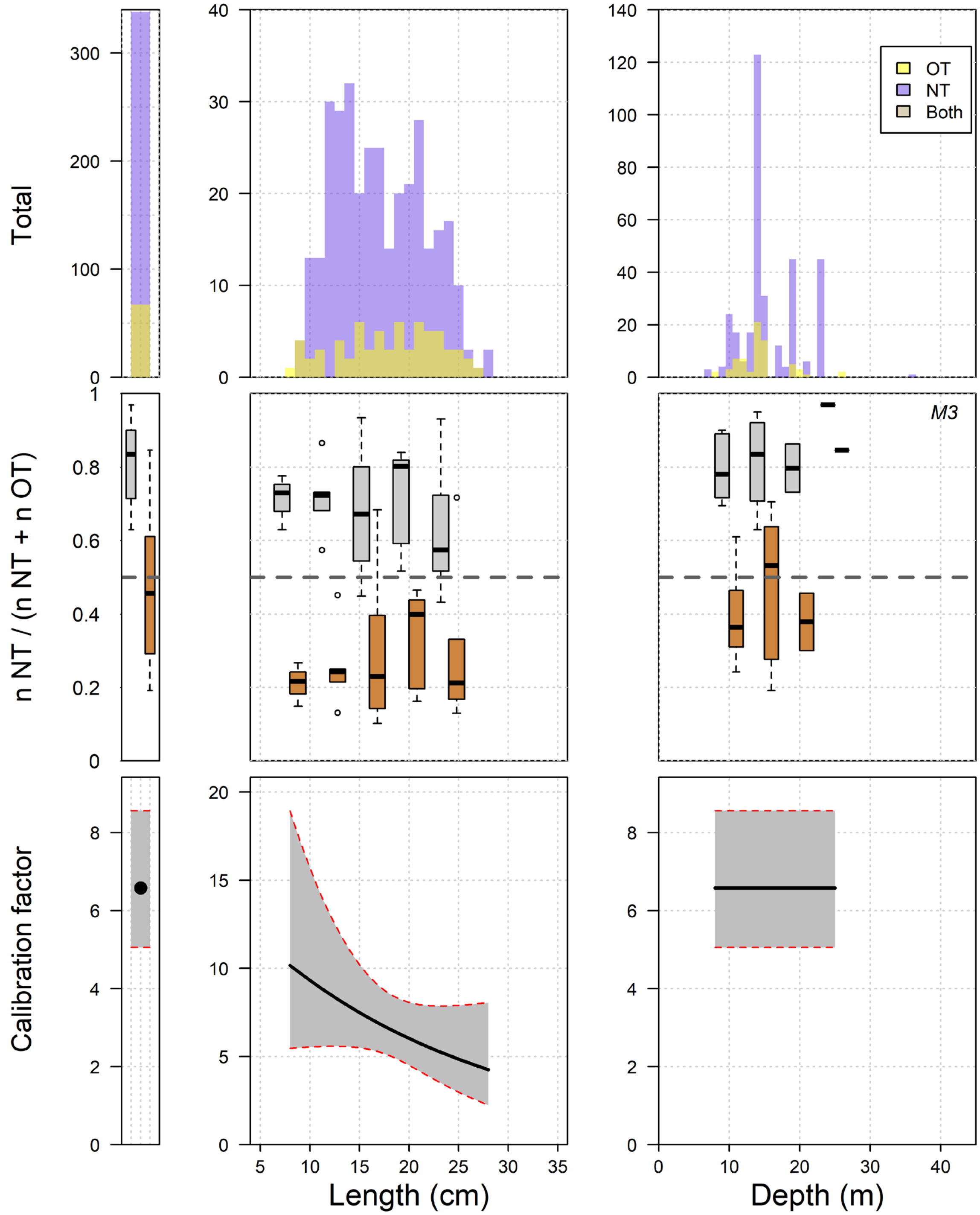

Figure 17. Raw data and model results for Windowpane Flounder. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

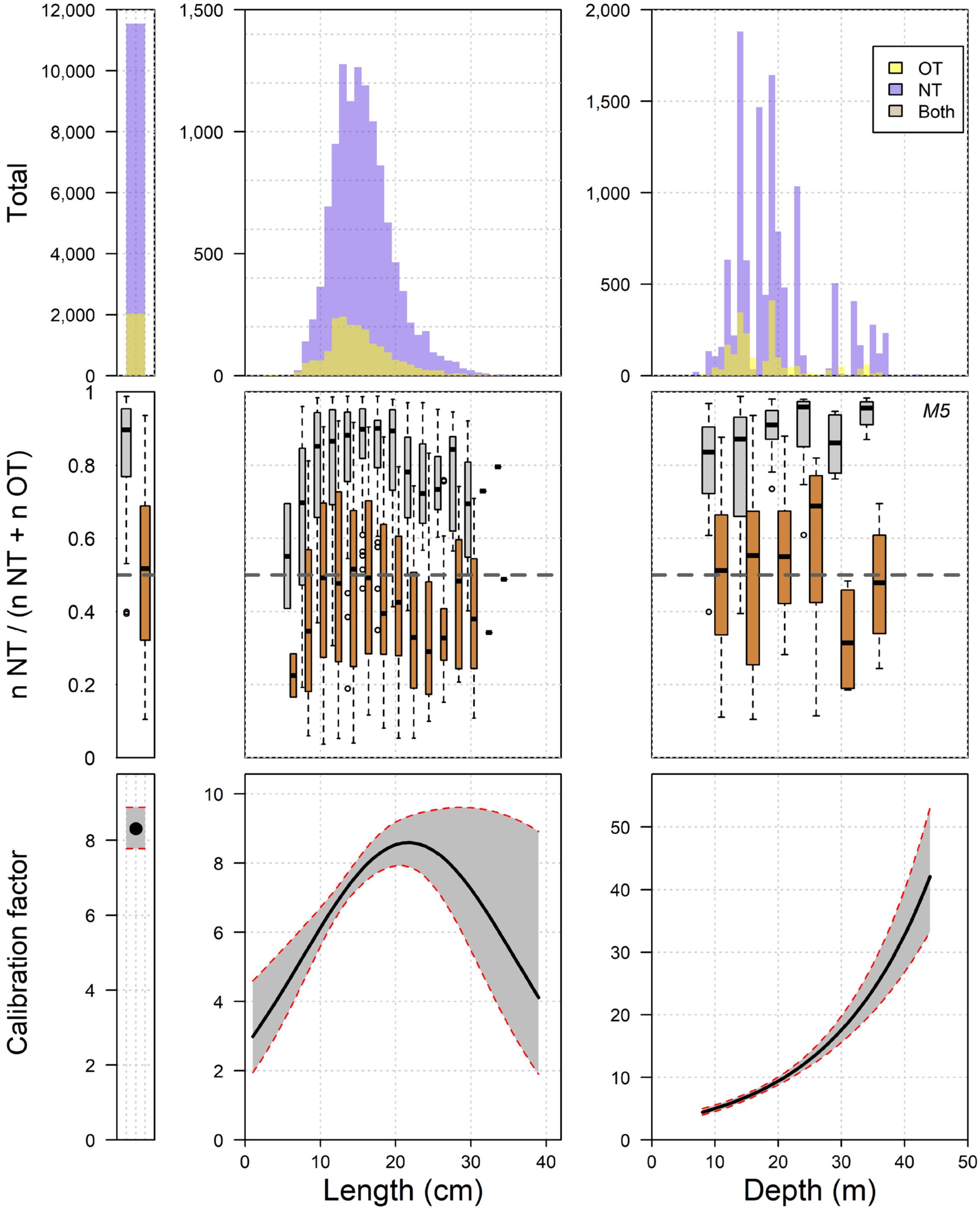

Figure 18. Raw data and model results for Winter Flounder. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

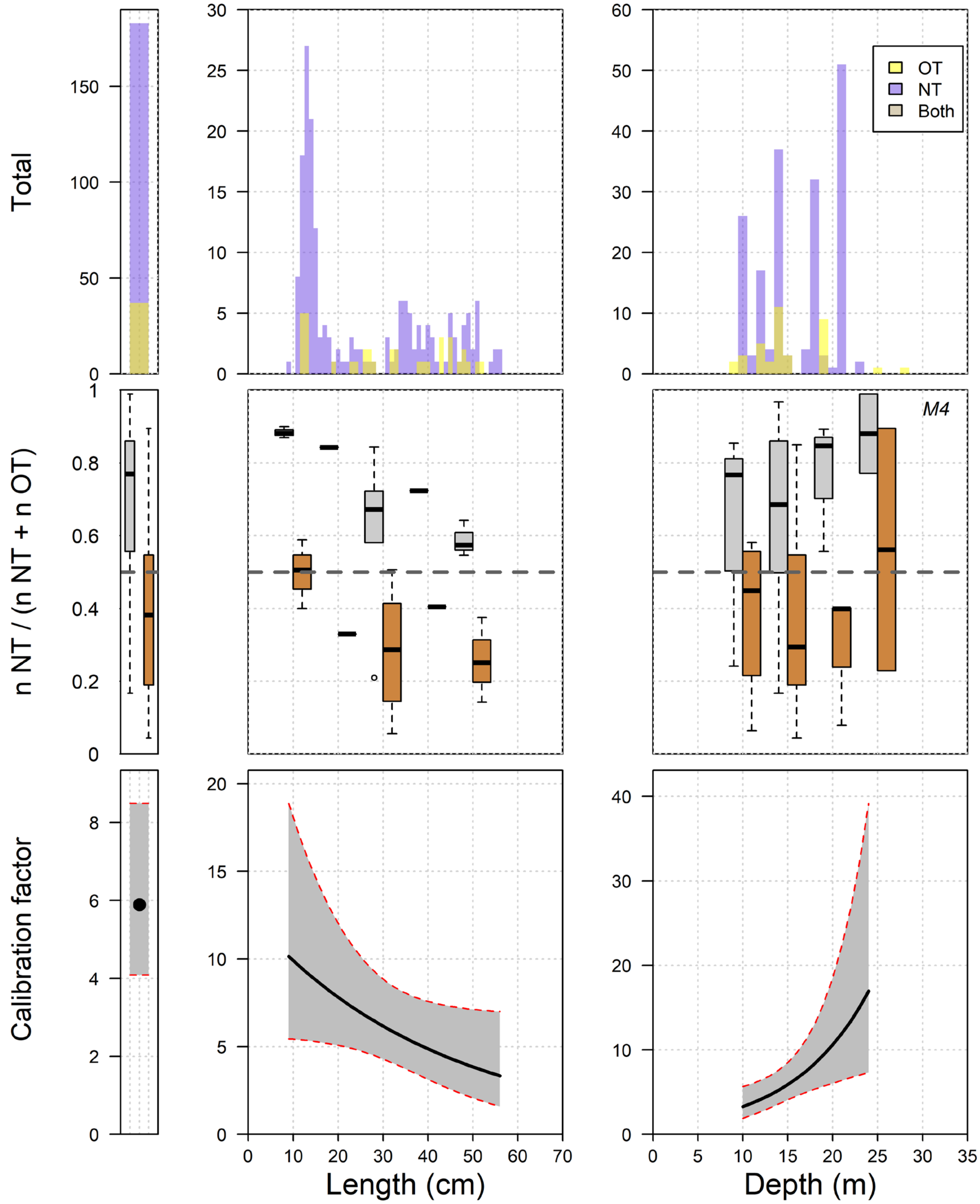

Figure 19. Raw data and model results for Winter Skate. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

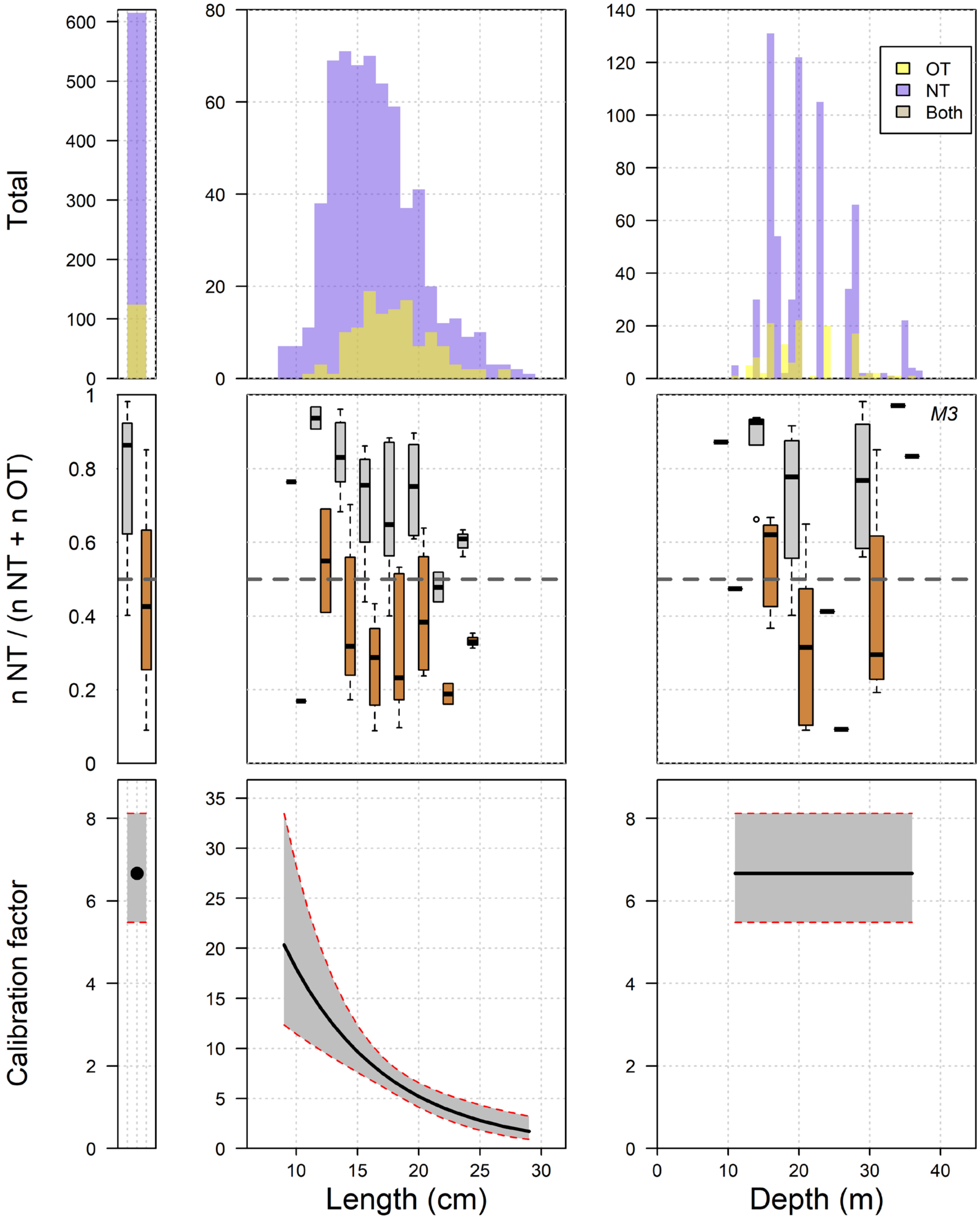

Figure 20. Raw data and model results for Yellowtail Flounder. In the top row, total catch, length distributions and depth distributions, respectively, for the Otter Trawl (in yellow) and the Northumberland Trawl (in blue); in the middle row, catch ratios for the raw data (grey) and the model calibrated data (orange), for the full catch, by length and by depth, respectively; and in the bottom row, the calibration factors (i.e. the exponentiated $logit(p)$) at average depth and length, throughout the length distribution at average depth and throughout the depth distribution at average length, respectively, for the selected model. The selected model is indicated in the top right corner of the middle right graph.

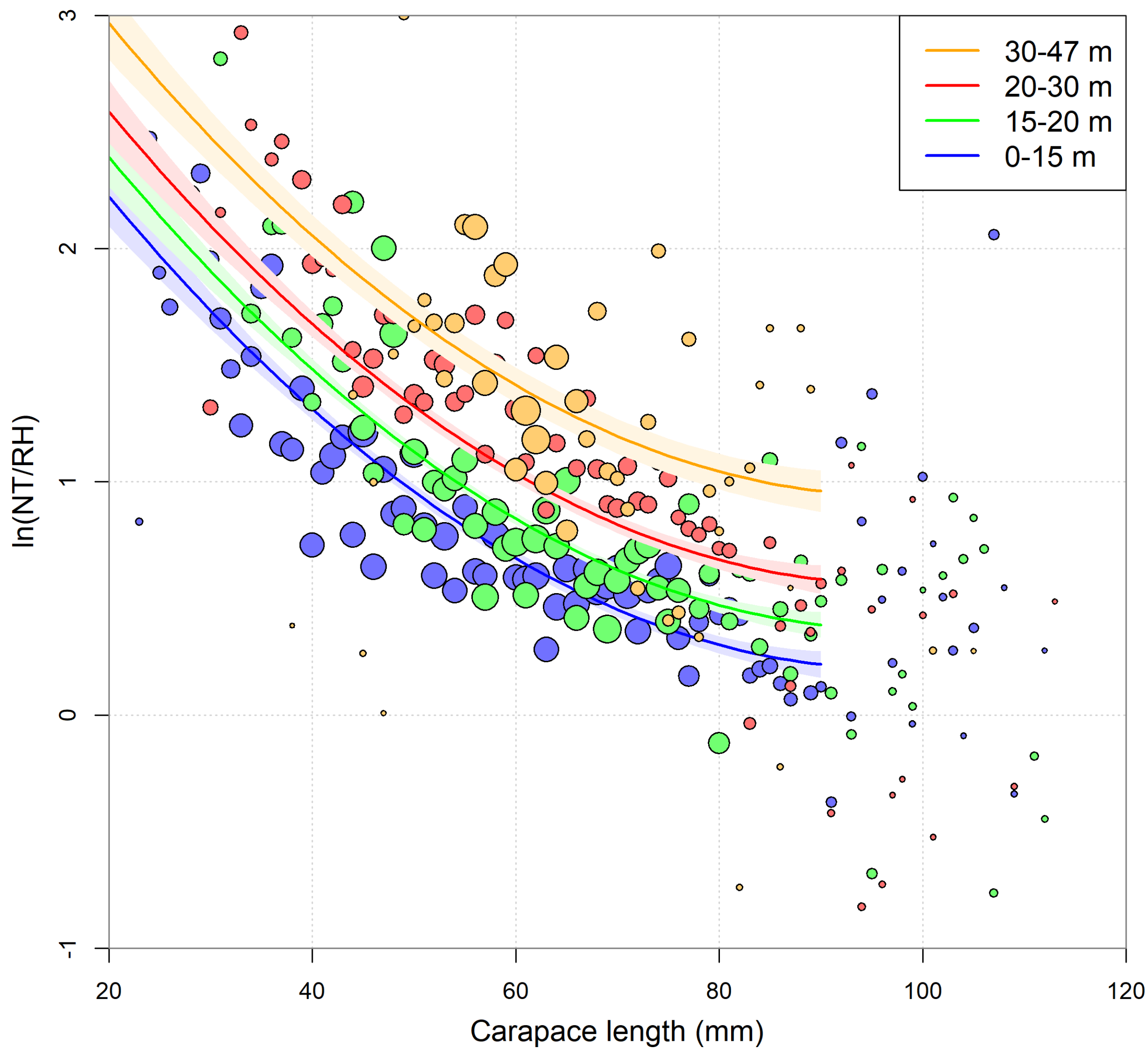

Figure 21. Relative catchability for American Lobster by carapace length and water depth. Empirical observations are shown as coloured circles. Circle sizes are proportional to the number of lobsters measured. Model fits are shown as thick coloured lines and shaded areas represent 95% confidence intervals.

APPENDIX A. DETAILS OF PAIRED SETS

Table A.1. Paired sets conducted during the 2019 and 2020 Northumberland Strait comparative survey on board CCGS M. Perley*. Each pair of sets is identified by its sequential number, year and station number. For each trawl used [Otter Trawl (OT) and Northumberland Trawl (NT)], the date and time [Atlantic Daylight Time (ADT)] when fishing started and are reported. For each paired set, the time difference between when fishing started and the depth difference are also presented. The sets are ordered chronologically based on the date and time when fishing started when using the Otter Trawl (OT).*

Pair	Year	Station	OT date/time	NT date/time	Time difference (hours)	Depth difference (m)
1	2019	253	2019-07-11 07:53	2019-07-09 09:51	46	1
2	2019	209	2019-07-11 09:41	2019-07-09 15:00	43	1
3	2019	238	2019-07-11 11:30	2019-07-10 12:33	23	0
4	2019	230	2019-07-11 13:44	2019-07-10 14:55	23	0
5	2019	231	2019-07-12 08:04	2019-07-13 08:26	24	0
6	2019	199	2019-07-12 09:45	2019-07-13 10:28	25	0
7	2019	153	2019-07-12 12:41	2019-07-13 15:48	27	0
8	2019	165	2019-07-12 14:42	2019-07-13 13:26	23	1
9	2019	332	2019-07-24 12:36	2019-07-25 11:40	23	0
10	2019	308	2019-07-24 14:46	2019-07-25 09:52	19	1
11	2019	999	2019-07-26 08:24	2019-07-25 15:55	16	0
12	2019	432	2019-07-26 09:30	2019-07-25 14:54	19	0
13	2019	415	2019-07-26 13:32	2019-07-31 14:40	121	0
14	2019	364	2019-07-27 07:52	2019-08-01 07:55	120	0
15	2019	494	2019-07-27 12:34	2019-07-31 13:16	97	0
16	2019	511	2019-07-28 10:50	2019-07-31 11:22	73	1
17	2019	521	2019-07-28 12:44	2019-08-01 13:09	96	1
18	2019	502	2019-07-28 14:32	2019-08-01 11:16	93	2
19	2019	975	2019-07-29 07:01	2019-07-31 07:34	49	1
20	2019	503	2019-07-29 10:26	2019-07-31 09:19	47	2
21	2019	832	2019-08-03 08:37	2019-08-02 15:19	17	1
22	2019	903	2019-08-03 10:14	2019-08-02 11:42	23	0

Pair	Year	Station	OT date/time	NT date/time	Time difference (hours)	Depth difference (m)
23	2019	936	2019-08-03 13:23	2019-08-07 10:11	93	1
24	2019	751	2019-08-04 07:49	2019-08-06 11:58	52	3
25	2019	795	2019-08-04 09:25	2019-08-07 07:43	70	2
26	2019	837	2019-08-04 11:10	2019-08-07 12:58	74	1
27	2019	887	2019-08-04 13:10	2019-08-07 11:20	70	1
28	2019	821	2019-08-04 14:26	2019-08-07 14:00	72	0
29	2019	778	2019-08-04 15:46	2019-08-07 15:12	71	0
30	2019	755	2019-08-04 16:42	2019-08-07 16:02	71	0
31	2019	711	2019-08-05 07:49	2019-08-06 16:00	32	1
32	2020	242	2020-07-10 08:41	2020-07-07 08:15	72	1
33	2020	179	2020-07-10 11:08	2020-07-07 10:31	73	1
34	2020	156	2020-07-10 13:03	2020-07-09 12:54	24	0
35	2020	162	2020-07-10 14:04	2020-07-07 14:24	72	2
36	2020	250	2020-07-11 07:37	2020-07-08 07:35	72	1
37	2020	176	2020-07-11 09:56	2020-07-08 14:35	67	0
38	2020	157	2020-07-11 12:43	2020-07-09 14:21	46	2
39	2020	233	2020-07-12 07:48	2020-07-09 07:52	72	1
40	2020	169	2020-07-12 11:00	2020-07-09 10:38	72	1
41	2020	152	2020-07-12 13:01	2020-07-08 12:38	96	0
42	2020	134	2020-07-12 14:09	2020-07-18 12:06	142	0
43	2020	111	2020-07-12 15:21	2020-07-18 12:59	142	1
44	2020	107	2020-07-12 16:48	2020-07-18 07:17	134	0
45	2020	130	2020-07-13 07:11	2020-07-17 14:42	104	3
46	2020	120	2020-07-13 09:33	2020-07-18 10:37	121	0
47	2020	212	2020-07-19 13:16	2020-07-17 08:16	53	1
48	2020	301	2020-07-20 08:29	2020-07-16 15:00	89	2
49	2020	258	2020-07-20 09:43	2020-07-16 09:10	97	1

Pair	Year	Station	OT date/time	NT date/time	Time difference (hours)	Depth difference (m)
50	2020	282	2020-07-21 07:42	2020-07-25 07:37	96	0
51	2020	276	2020-07-21 09:48	2020-07-16 11:06	119	1
52	2020	290	2020-07-21 11:00	2020-07-16 13:20	118	2
53	2020	268	2020-07-21 13:46	2020-07-24 08:07	66	2
54	2020	224	2020-07-22 08:17	2020-07-24 09:53	50	0
55	2020	53	2020-07-22 14:44	2020-07-18 14:16	96	1
56	2020	72	2020-07-22 16:13	2020-07-18 15:50	96	0
57	2020	73	2020-07-22 16:57	2020-07-18 16:21	97	0
58	2020	102	2020-07-23 06:40	2020-07-18 17:13	109	0
59	2020	90	2020-07-23 07:25	2020-07-19 06:50	97	1
60	2020	63	2020-07-23 08:39	2020-07-23 10:15	2	1
61	2020	195	2020-07-29 14:13	2020-07-25 14:41	96	1
62	2020	237	2020-07-30 08:25	2020-07-25 09:20	119	4
63	2020	217	2020-07-30 09:53	2020-07-25 11:30	118	0
64	2020	198	2020-07-30 12:39	2020-07-29 10:43	26	0
65	2020	239	2020-07-30 14:14	2020-07-29 08:42	30	1
66	2020	317	2020-08-03 10:18	2020-07-31 10:55	71	2
67	2020	372	2020-08-03 15:00	2020-08-01 08:18	55	2
68	2020	429	2020-08-03 17:35	2020-07-31 17:25	72	1
69	2020	430	2020-08-04 07:33	2020-08-01 07:14	72	1
70	2020	375	2020-08-04 08:54	2020-07-31 15:12	90	2
71	2020	358	2020-08-04 09:45	2020-07-31 14:15	92	1
72	2020	335	2020-08-04 10:48	2020-07-31 13:10	94	1
73	2020	327	2020-08-04 12:41	2020-08-01 11:47	73	3
74	2020	331	2020-08-04 13:27	2020-08-01 09:50	76	1
75	2020	274	2020-08-05 09:44	2020-08-06 09:38	24	1
76	2020	306	2020-08-05 11:15	2020-08-06 10:49	24	6

Pair	Year	Station	OT date/time	NT date/time	Time difference (hours)	Depth difference (m)
77	2020	303	2020-08-05 13:14	2020-08-06 13:05	24	2

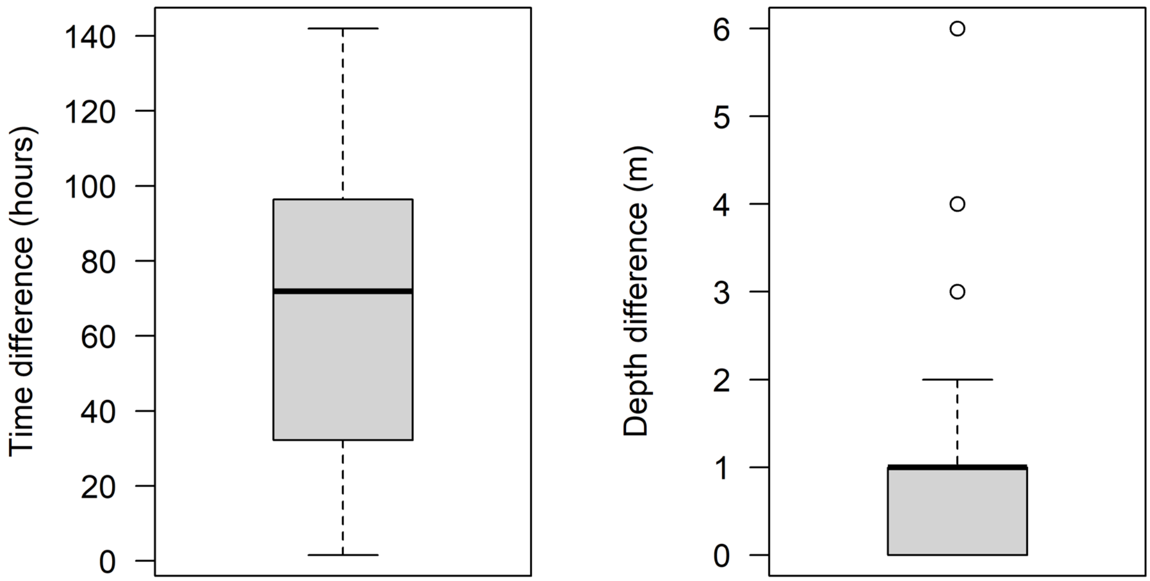

Figure A.1. Boxplots showing the amount of time in hours between the onset of fishing between paired sets (left panel) and the difference in water depth in meters between paired sets (right panel).

APPENDIX B. TRAWL SPECIFICATIONS

B.1. OTTER TRAWL NET PLAN AND FOOTGEAR

Gourock Rockhopper Otter Trawl No. 286

- Trawl 5½” mesh with liner, 5½” mesh,
- Headrope 58’6”, Footrope 72’
- 286 meshes around belly
- 4 panel net, double netting lower belly
- First 9’ of lengthening piece has 1¼”
- Last 9’ of codend has ½” liner

Table B.1. Mesh specifications for the Otter trawl (OT).

Section	Meshes	Size	Comments
Top belly	103 meshes X 53 meshes	50 meshes deep	-
Bottom belly	103 meshes X 53 meshes	50 meshes deep	-
Wedges			
No. 1	41 meshes X 6 meshes	29 meshes deep	-
No. 2	43 meshes X 43 meshes	19 meshes deep	-
No. 3	45 meshes X 40 meshes	15.5 meshes deep	-
No. 4	40 meshes X 6 meshes	19 meshes deep	-
Side Panels			
Little wedge	42 meshes X 4 meshes	19 meshes deep	Has cut away for lower wing and no full lower wing.
No. 2 Belly	53 meshes X 4 meshes	50 meshes deep	-

Rockhopper gear

- On footrope with 3/8 chain
- 3/8 chain has all swivels and lockups
- Rubber discs throughout
- Large precut 12” discs in bosom and wing, 12” apart in bosom, 24” apart in wing

B.2. NORTHUMBERLAND TRAWL RIGGING, NET PLAN AND FOOTGEAR

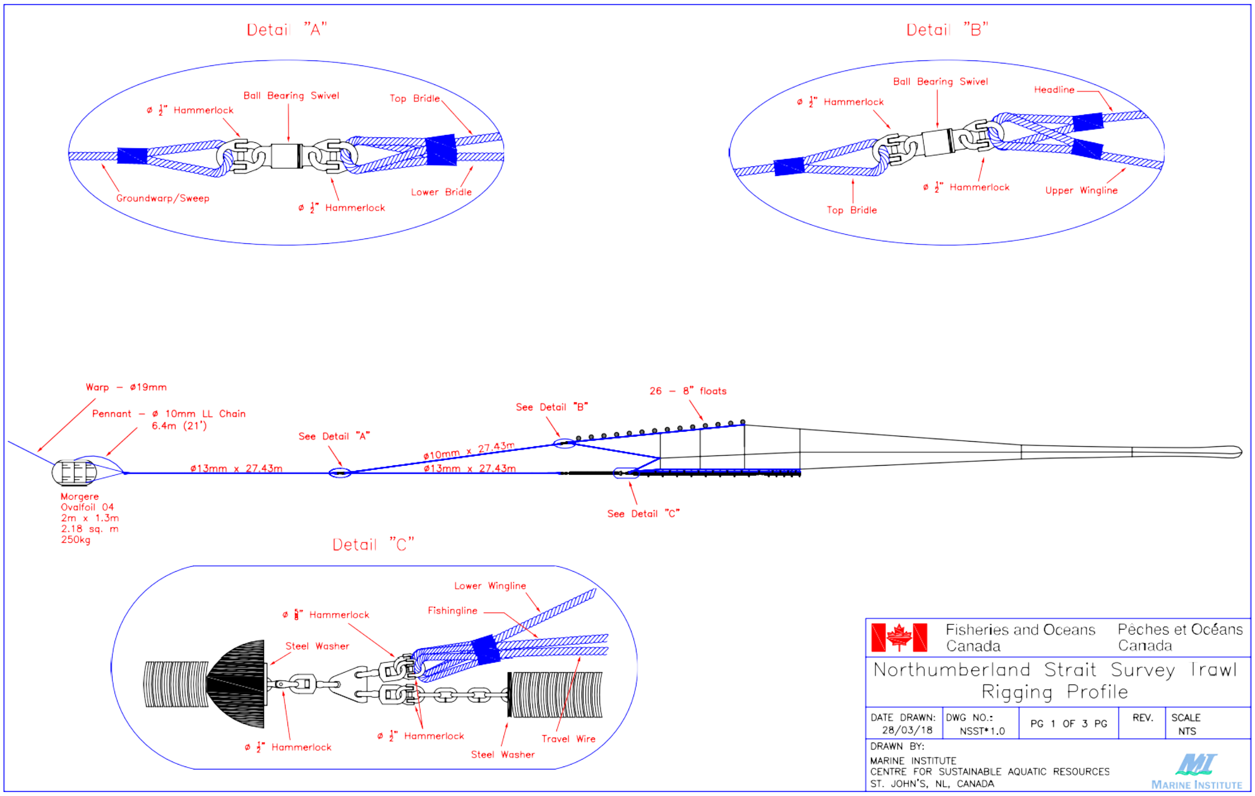

Figure B.1. Northumberland Trawl rigging profile.

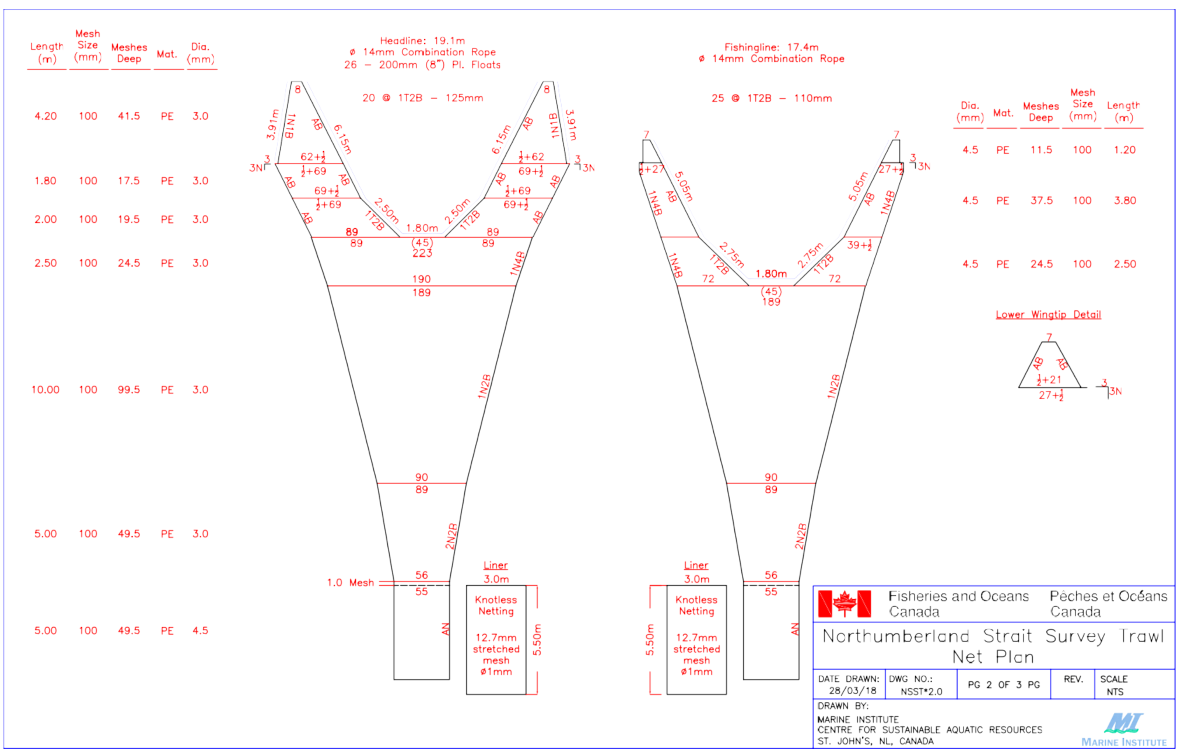

Figure B.2. Northumberland Trawl net plan.

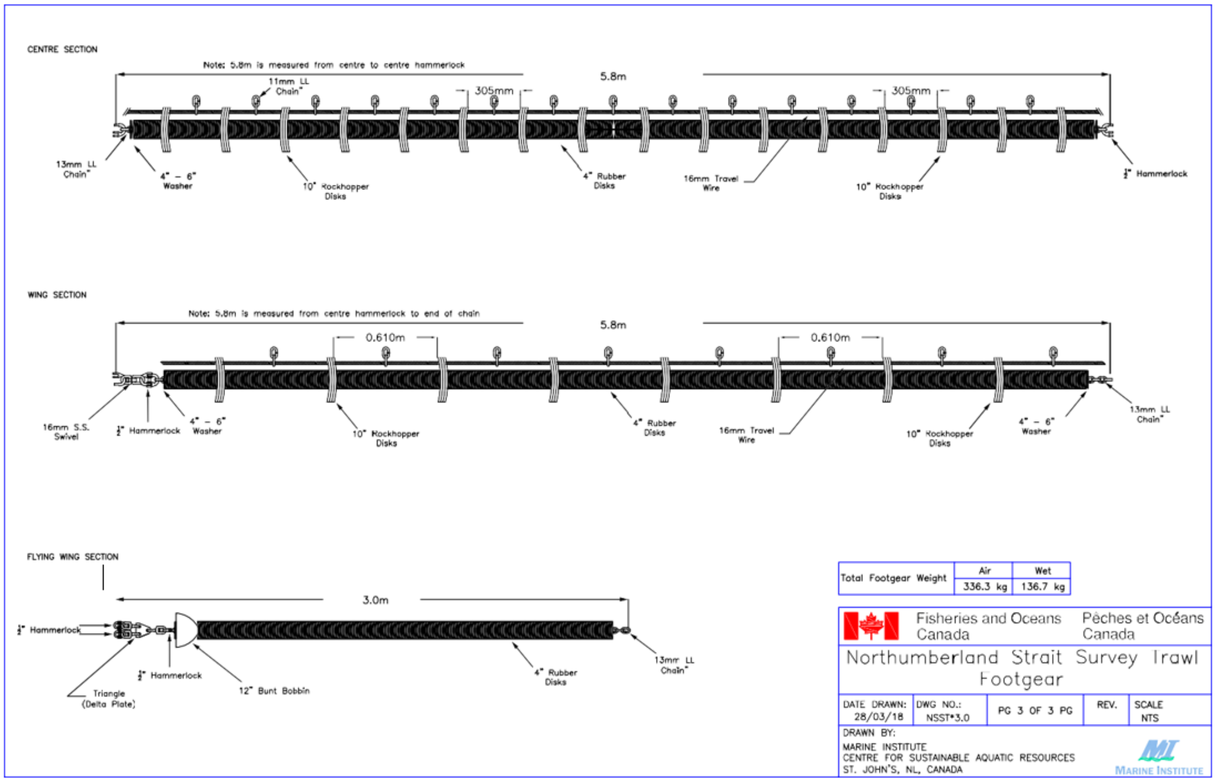

Figure B.3. Northumberland Trawl footgear