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Maritimes Region

Estimating Incidental Catch of Non-Target Species from the Commercial Fishery for Atlantic Halibut in Maritimes Region

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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

This document provides an evaluation of bycatch from the 3NOPs4VWX5Z Atlantic Halibut (*Hippoglossus hippoglossus*) longline fishery in Maritimes Region, updating and extending work that was completed in 2014. Notably a new method for data extraction from regional databases was used to address previous limitations in identifying the fleet, which removed subjectivity and ensured consistency in the definition of the fleet. This had little effect on landings or the proportion of observed landings of Atlantic Halibut, yet had substantial implications for calculating observer coverage rates and understanding bycatch.

Observation rates have declined since the 2014 assessment, and effort was disproportionately allocated to Northwest Atlantic Fisheries Organization (NAFO) Divisions with relatively low fishing activity. Seasonal patterns show that the majority of fishing activity occurs between April and September (Q2: April to June–Q3: July–September), with less activity in the late fall and winter (Q1: January–March and Q4: October–December).The proportion of total catches that were Atlantic Halibut increased for essentially all NAFO Divisions and fishing quarters from the 2009–2013 to 2014–2020 time periods. The percentage of Atlantic Halibut catches that were discarded was twice as high in the 2009–2013 time period as it was in 2014–2020.

The catch profiles from fished sets (either combined catches or kept catches) were extremely variable among years, NAFO Divisions and fishing quarters. A diversity index suggested catches becoming more dominated by large amounts of specific species, which likely means bycatch is declining given that Atlantic Halibut landings are increasing. A log-linear regression was proposed as a way to predict total bycatch weight from kept Atlantic Halibut landings, accounting for differences among NAFO Division and time period. From 2009–2020, there are relatively few instances where bycatch of a particular species or species group seems to be increasing, and nearly all examples come from 4X. Calculating the mean proportion landed indicates there were several species or species categories that tended to be landed in conjunction with Atlantic Halibut, as would be expected under multi-species groundfish licences.

It is difficult to determine what these predictions imply for the status of individual bycatch species. Bycatch can decline due to factors such as improvements in the status of the target species, worsening status of the bycatch species, and/or changes in the distribution of effort or other operational characteristics of the fleet that influence catchability. This assessment represents general trends; the predictions should be taken as relative rather than absolute amounts. These patterns could be used to inform more targeted research on the status of individual bycatch species.

BACKGROUND

Bycatch and bycatch mitigation have been identified as major concerns to fishery management worldwide (Davies et al. 2009, ICES 2020). In Canada, the Policy on Managing Bycatch under the Sustainable Fisheries Framework (DFO 2013) has two main objectives: (1) to ensure that Canadian fisheries are managed in a manner that supports the sustainable harvesting of aquatic species and that minimizes the risk of fisheries causing serious or irreversible harm to bycatch species, and (2) to account for total catch, including retained and non-retained bycatch.

Monitoring non-retained catch from fisheries in Maritimes Region is done through the at-sea observer program, which typically samples a low number of trips in a given fishery (Gavaris et al. 2010, Clark et al. 2015). Any method that attempts to extrapolate limited observed bycatch data to an entire fleet are predicated on the ability to reliably identify all of the fishing events associated with a fleet and to associate discrete observed data with known fishing events. In Maritimes Region, this requires the integration of information from two databases: Maritimes Fishery Information System (MARFIS) which contains commercial logbook data, and the Industry Surveys Database (ISDB) which contains at-sea observer records as well as survey data.

Bycatch associated with the 3NOPs4VWX5Z Atlantic Halibut (*Hippoglossus hippoglossus*) longline fishery was evaluated, during the 2014 framework assessment, based on at-sea observations from the commercial fishery and commercial index phase of the joint Fisheries and Oceans, Canada (DFO)-Industry Halibut Survey (Themelis & den Heyer 2015). Analyses summarized commercial landings, reported at-sea observer coverage, developed ratio estimators by species, and scaled up observed catches to fleetwide totals for Atlantic Halibut-directed commercial longline trips in 2013. Several uncertainties related to data extraction and quality control that would have influenced results were detailed, including: incomplete or missing data fields, uncertainty in identifying Atlantic Halibut-directed fishing, and inconsistent information recorded in MARFIS versus the ISDB.

In 2020, a new method was developed for linking information from MARFIS and the ISDB. This method is in development as an R package, called Mar.fleets. The package simplifies and standardizes the processes used to extract data from MARFIS and the ISDB and for the first time, explicitly matches individual trip records from the two sources. Mar.fleets was specifically designed to address the issues identified in the previous Halibut framework (in addition to other issues), in a way that was applicable for any fishery in Maritimes Region. The main benefits of Mar.fleets for bycatch analyses are:

- it ensures standardized and repeatable data extraction.
- users can quickly and accurately find missing or erroneous information in the fields that define the fishery (e.g., licence or vessel numbers, confirmation codes), which are critical to identifying the commercial trips that were also observed.
- it aggregates all types of data from a single fleet into one place, meaning that a consistent output can be used for all aspects of an assessment (i.e., to calculate total removals, catch-at-length, etc.).
- it sequentially identifies all of the fishing activity for groups of vessels (e.g., the Atlantic Halibut fleet) for a given time period, allowing a 1:1 match of commercial and observed trips.
- it extracts the catch profiles of the fleet from the matched, observed data.

The majority of analyses in this Research Document are based on output from Mar.fleets, which has been used to address the following Terms of Reference (TOR):

“Review ecosystem impacts of the fishery: describe and review the methodology used to estimate incidental catch of non-target species and identify any notable changes in the occurrence of these species relative to previous years”.

The National Catch Monitoring initiative defined bycatch as:

“*Bycatch: a) retained catch that includes species, and specimens of the target species, such as specimens of a particular sex, size or condition, that the fisher is not licensed to direct for but may or must retain; and, b) all non-retained catch, including catch released from gear and entanglements, whether alive, injured or dead, and whether of the target species or the non-target species*.” (Beauchamp et al. 2019)

For the purposes of this assessment, a similar definition to Beauchamp et al. (2019) was used even though it is recognized that groundfish fleets are licensed to direct for several species in Maritimes Region. Atlantic Halibut above 81 cm is considered the target species, and catches of undersize Atlantic Halibut (< 81 cm) as well as all other retained and/or discarded species are considered bycatch.

OBJECTIVES

To address the bycatch TOR, this Research Document aims to estimate bycatch amounts from Maritimes Region Atlantic Halibut fleet through sequential analyses that provide:

- a comparison of different data extraction methods to obtain information from MARFIS and the ISDB.
- summaries of commercial fishing effort by season, year and NAFO Division.
- calculation of observer coverage levels.
- analyses of multivariate catch data to identify possible groupings in species assemblages.
- development of a predictive model to estimate bycatch amounts for all commercial trips from the observed data.
- summaries of species-specific catches, focusing on a comparison between 2009–2013 and 2014–2020.

COMPARISON OF DATA EXTRACTION METHODS

What is colloquially referred to as a ‘fleet’ does not correspond to information that is actually stored in MARFIS or the ISDB. Referring to ‘the Halibut fleet’ implies that specific vessels only target Atlantic Halibut, which is seldom the case in this multi-species groundfish fishery. When recording fishing activity in Maritimes Region, at-sea observers categorize each trip as targeting a specific species, which is a subjective classification of the fleet in the ISDB. It has been standard practice for DFO Science to use these ISDB codes (trip type code and/or species sought code) to identify observed sets belonging to a specific fishery. To calculate observer coverage or to assess bycatch, it becomes necessary to extract all of the commercial trips from MARFIS using the same definition of the fleet. However, the challenge has been that a similar field (trip type or species sought) was not available, inconsistently recorded and/or unreliable to identify records from MARFIS. As a result, considerable effort was expended in the 2014 framework to identify Halibut-directed commercial fishing on the basis of hook size (Themelis & den Heyer 2015).

As an alternative, Mar.fleets uses licencing information to define a commercial fleet, because licence conditions ultimately determine fishery characteristics (e.g., allowable gear types, NAFO

Division or other management areas, and retained species). Within a specific date range, the functions in Mar.fleets identify all possible vessels fishing with the allowable gear types in the allowable areas with specific licence types and subtypes. This is considered the fleet. Then, all commercial trip records from a member of the fleet are extracted from MARFIS. Finally, the extracted MARFIS trips are used to identify and extract matching trips from the ISDB. By definition, a commercial trip record must exist in order for there to be an observed trip record. Explicit matching from MARFIS to the ISDB (as opposed to using variables specific to the ISDB) removes subjectivity and ensures consistency in the definition of the fleet.

Refinements to the Mar.fleets package are ongoing to extend its applicability to other commercial fisheries in Maritimes Region. These analyses are based on Mar.fleets version 2021.10.14. To help ensure repeatability, all specifications used to extract annual data as well as the version number of the package and data extraction date are listed in tables A1, A2 and A3 of Appendix 1.

AMOUNT OF INFORMATION EXTRACTED

Hereafter, the data extraction method used in the previous bycatch assessment will be referred to as the 'original method' and Mar.fleets as the 'new method'. When reporting results from the original method, the data extractions were updated to include all years (i.e., from 2014 onwards) rather than truncating the series at 2013. All data extractions were done on October 14, 2021 and will not include edits after that time. The main comparisons are done between two time periods: 2009–2013 (as in Themelis & den Heyer 2015) and 2014–2020.

For the commercial catch data in MARFIS, the original method and the new method extracted a very similar suite of commercial trips. For all years, the total number of vessels and licences were nearly identical, and the number of commercial trips as well as landed weight (round weight) of Atlantic Halibut were similar (Table 1). The original method extracted all commercial trips using longline that landed Atlantic Halibut, which resulted in a low number of records that were not licenced as described above (e.g., cusk licences).

For the at-sea observed data in the ISDB (including Commercial Index Trips), the new method extracted substantially more observed trips, primarily in the middle of the time series. However, the amount of observed catch of Atlantic Halibut was similar (Table 2). This apparent discrepancy demonstrates that at-sea observed trips which predominantly caught Atlantic Halibut (by weight) were characterized by the observers as Atlantic Halibut-directed trips (species sought code = 30). Yet, fisheries observers were excluding trips that primarily landed other species by giving them a different species sought code. Thus, the old method of data extraction could not find these trips.

Mar.fleets defines the fleet by licence, vessel, NAFO Division, and gear rather than by the catches, so it can find previously-excluded trips. In other words, the new method has little effect on our understanding of landings or the proportion of observed landings of Atlantic Halibut, yet has substantial implications for calculating observer coverage rates and understanding bycatch.

This is a limited-entry fishery but temporal patterns indicate that more licenced participants are becoming active, causing the size of the commercial fishery to increase from the previous assessment. The average number of trips, active vessels and active licences increased by 24%, 48%, and 42% respectively between 2009–2013 and 2014–2020 (new method). Average landings increased by 92%, with 2020 being the highest value in the time series (Table 1). For the observer data, a comparison of 2009–2013 with 2014–2020 indicates that the average number of observed trips declined by 23% between the two time periods and the average amount of observed catch was essentially identical (new method; Table 2).

ASSESSMENT OF DATA QUALITY

Understanding observer coverage and estimating fleetwide bycatch amounts requires information on the locations that fishing has taken place (Bellido et al. 2011). There are two types of locations that are collected for individual fishing events (sets) undertaken by the Atlantic Halibut fleet: NAFO Division and geographic coordinates (i.e., latitude and longitude).

For the commercial data, the proportion of sets in which either NAFO Division or latitude/longitude were missing has slightly declined since the early 2000's (Table 3). In the majority of recent years, approximately 5% of records were missing location information, representing hundreds of sets each year (Table 3).

To further evaluate the accuracy of the location information archived in MARFIS and in the ISDB, location information was summarized and compared for the 2009–2013 and 2014–2020 time periods. Table 4 gives the counts of:

- the number of geographic coordinates that fell on land.
- the number of records with missing location information.
- the number outside of defined NAFO Divisions.

Location relative to NAFO Division was also calculated from the geographic coordinates of specific sets. This demonstrated how frequently the recorded NAFO Division differed from the location of fishing given by the latitude and longitude (Table 4).

It has been previously stated that geographic coordinates were more likely to be missing than NAFO Division (H. Stone, Pers. Comm.) and this is supported in both the 2009–2013 and 2014–2020 time periods. However, the differences are fairly small, 1512 sets versus 1462 sets in 2009–2013 and 2781 sets versus 2662 sets in 2014–2020 (Table 4). There is no indication that errors in location information are becoming less frequent. For example, a greater number of sets had coordinates on land in 2014–2020 versus 2009–2013, although more total sets were fished in the latter time period. Both the observer data as well as geographic coordinates in MARFIS suggest that there is fishing effort in 4T although recorded NAFO Divisions in commercial MARFIS records do not (Table 4). It is unknown at this point whether these discrepancies represent errors in the recorded data (i.e., logbook and at-sea observer records) or inaccuracies in data entry when information is archived in MARFIS or the ISDB.

Previous analyses of observer coverage for the Atlantic Halibut fleet separated commercial and observed trips by vessel length when calculating coverage rates. A large-scale validation exercise for Mar.fleets (completed outside of these analyses) found discrepancies in the vessel characteristics data stored in MARFIS and the ISDB. The issues included unit problems (e.g., ISDB uses meters, MARFIS uses feet) and differing information for single vessels (i.e., a different length archived in MARFIS verses in the ISDB). Also, the definitions of < 45 and > 45 feet used previously by DFO Science were different than the < 45 and > 45 licence subtypes considered by the Commercial Data Division and Licencing. These issues could not be resolved prior to preparing this Research Document, so different components of the fleet were not analyzed separately.

DISTRIBUTION OF EFFORT

The number of sets undertaken by the commercial fleet was aggregated by NAFO Division (3N, 3O, 3Ps, 4V, 4W, 4X, 5Y and 5Z; Table 5) and by fishing quarter (Q1: January–March, Q2: April–June; Q3: July–September; Q4: October–December; Table 6) to detect spatial and temporal trends in effort. This used the reported NAFO Division rather than the one calculated from geographical coordinates. Note that previous analyses have combined data from 5Y with 4X, rather that keeping these divisions separate. Previous analyses were also done at the trip-level rather than the set-level, but this would have required assigning an assumed NAFO Division for a trip based on the location of the majority of sets.

The vast majority of annual fishing effort for Atlantic Halibut occurs in NAFO Divisions 4VWX, with relatively low amounts in 3NOPs and 5YZ (Table 5). This pattern has remained relatively consistent over time, with increasing representation of 4V since 2014. Effort has declined only in 5Z, from an average of 313 sets during 2009–2013 to an average of 84 sets in 2014–2020. Average effort has more than doubled in 3NO, and 4V, with lesser increases in 3Ps, 4WX and 5Y. Seasonal patterns show that the majority of fishing activity occurs between April and September (Q2 and Q3), with less activity in the late fall and winter (Q1 and Q4; Table 6).

OBSERVER COVERAGE

Pre-departure notifications, more typically called ‘hail-outs’, are used in Maritimes Region to select commercial trips for at-sea observation. The selection process is intended to be random, ideally leading to a random sample of annual commercial trips (Beauchamp et al. 2019). If observed trips were truly a random sample of the annual fishing effort, it would be possible to multiply observed bycatch by the simple ratio of observed to non-observed trips to develop fleet-wide estimates of total bycatch. However, depending on the level of observer coverage, the precision of such estimates could be low (Benoît & Allard 2009).

The seasonal and spatial differences in fishing effort identified above could be associated with non-random deployments of at-sea observers in this fishery. Specific NAFO Divisions and fishing quarters could be associated with disproportionately high or low observer deployments, and partitioning the data by NAFO Division and/or quarter would be expected to lead to better bycatch estimates (Themelis & den Heyer 2015). Because NAFO Division and fishing quarter are characteristics of a set, observation rates were calculated from aggregated set-level data for the 2009–2013 and 2014–2020 time periods. Reported NAFO Division rather than calculated NAFO Division (from geographic coordinates) was used to represent the location of the set.

Discrepancies in reported location between commercial and observed sets as well as missing data affected calculations, leading to values greater than one (implying > 100% of sets were observed). However, these data are still informative on the relative difference in coverage rates among NAFO Divisions and quarters, but shouldn’t be used as definitive estimates. Relative observer coverage was clearly disproportionate across NAFO Divisions and fishing quarters, being lowest in the Divisions with the majority of the fishing effort (e.g., 4WX) and highest in divisions with minimal effort (3NOPs and 5Z; Table 7). Similarly, relative coverage rates tended to be lower in Q1 and Q4, and higher in Q2 and Q3 (Table 7). For the majority of NAFO Divisions and quarters, rates declined from the 2009–2013 to the 2014–2020 time period.

If data are not separated by NAFO Division and fishing quarter, it is possible to evaluate trends in coverage at a trip-level. Across the entire fishery, the observation rate for Atlantic Halibut trips declined from a maximum of 5.1% in 2011 to 2.0% in 2019 (Table 8). In 2020, only 1.0% of trips were observed because of the COVID pandemic response. At-sea observers were unable to deploy during the full shut-down (April 2–May 26) and may have been deployed less frequently during the partial shut-down (May 27–August 11). There has been a similar decline in the percentage of the catch that has been observed, peaking in 2007 at 26% and dropping to approximately 5% from 2018–2020 (Table 8).

OPERATIONAL CONSTRAINTS

While on a trip, a single observer might not witness every fishing event. If a set is not actually witnessed by the observer, the observer obtains information from the captain's log and codes this particular set as unobserved (Source = 1). All instances where the codes were swapped (e.g., every set was coded as unobserved on an observed trip) were identified and remedied prior to further analyses. For each year, the proportion of observed sets relative to unobserved sets was high (Table 9).

There is a possibility that the captain may not be able to record all bycatch species in the same manner as the observer on these sets. As a quick method for evaluation, the list of species recorded for observed sets was extracted and compared to the list of species recorded for unobserved sets. While a large suite of bycatch species was on both, the species list for observed sets was approximately 3x longer. We conclude that sets were likely to have fewer bycatch species recorded when they were not directly witnessed by the observer. Therefore, to estimate the catch from an entire observed trip, the catches on observed sets are prorated by the ratio of total number of sets to the observed number of sets (Sameoto & Glass 2012).

CATCHES OF ATLANTIC HALIBUT

The new method for extracting data from MARFIS and the ISDB markedly changes previous understanding of the proportion of the catch that is landed Atlantic Halibut. Values reported in this research document more accurately characterize fishing under the multi-species groundfish licences that are components of the Atlantic Halibut fleet.

For the 2009–2013 time period, the NAFO Division associated with > 80% of the catch being landed Atlantic Halibut was 3Ps, but only in Q3 and Q4 (Table 10). The proportions tended to be above 50% in Q2 and Q3, but were much more variable in Q1 and Q4. Proportions were consistently near zero in 5Z. For comparison, values reported in Themelis & den Heyer (2015) tended towards one (100%) for the majority of NAFO Divisions and quarters (original method for data extraction). The proportion of the catch that was landed Atlantic Halibut increased in the 2014–2020 time period, in essentially all NAFO Divisions and quarters (Table 10). More of the proportions were > 80%, particularly in Q2 for the most commonly fished NAFO Divisions of 4VWX.

Average discards of undersize Atlantic Halibut in the 2009–2013 time period were more than double the average in 2014–2020 (Table 11). Similarly, the percentage of caught Atlantic Halibut (kept + discarded) that was discarded dropped from 9.7% to 4.2% between the two time periods. Discarded Atlantic Halibut represented approximately 2% of the total catch in 2009–2013, but only 1.2% in 2014–2020.

BYCATCH ANALYSES

The bycatch analyses of Themelis & den Heyer (2015) estimated catches of 19 species, representing wolffish, skates, other gadoids, dogfish and other sharks. This Research Document included those species, as well as other species or species categories (e.g., unidentified skates) that were caught in the majority of years from 2002–2020. This increased the number of species/species categories to 31. Note that discarded Atlantic Halibut is a separate category from landed Atlantic Halibut. The full list of bycatch species encountered in the Atlantic Halibut fishery is shown in Appendix 2 for the 2009–2013 (Table A4) and 2014–2020 (Table A5) time periods.

Grenadiers were a species group in which at least one species was captured in the majority of years, yet each individual species was only captured sporadically. Thus, Grenadier Unspecified, Marlin-Spike (*Nezumia bairdii*), Roughhead (*Macrourus berglax*), and Roughnose Grenadier (*Coryphaenoides rupestris*) were combined into a single category for analyses. The dogfishes were also combined, with Black Dogfish (*Centroscyllium fabricii*), Spiny Dogfish (*Squalus acanthias*) and Dogfishes (NS) grouped as a single category. Other species groupings could be explored in future analyses.

There was extremely little information on observed catches in NAFO Division 5Y (n = nine sets from 2009–2020 inclusive). These were assumed to be similar and combined with NAFO Division 5Z when estimating bycatch.

EFFORT METRICS

Some type of metric that characterizes relative fishing effort at the set-level is required to scale observed catches to trip totals (accounting for operational limitations) and then to fleetwide totals. This metric must be recorded or have the potential to be derived for all commercial and observed sets. Landed weight of Atlantic Halibut was chosen as a proxy for fishing effort in Themelis & den Heyer (2015), given variability owing to inconsistent reporting on hooks, number of strings, and soak time associated with longline sets in the commercial catch data.

We evaluated how the kept weight of Atlantic Halibut was related to other types of effort metrics as options to explore in future analyses. Calculating the trip duration from hail information and plotting it relative to kept Atlantic Halibut weight demonstrates that landings can be similar from trips ranging from 1–20 days, with peak landings associated with trips approximately 10–15 days (Figure 1).

At the set-level, there is an entered field in MARFIS representing the number of gear units (intended to be # hooks and # strings for this fleet) as well as a calculated set duration from date/time information. While the number of gear units was recorded originally for this fleet, this field has been missing (NA) for essentially all sets completed from 2005 onwards. The duration field was more consistently filled in, with the percentage of missing values (NA) ranging from zero to 5.3% since 2004 (Table 12). While this seemed promising, a closer look demonstrated that 98% of the data took only two values: 0 or 24 hours. Other values were multiples of 24. This means that the time of day is not being entered in the date/time fields, only the date, so there is no information on soak time for individual sets.

In subsequent analyses, kept Atlantic Halibut weight is retained as a proxy for fishing effort and the implications of this choice are discussed in the conclusions.

CHANGES IN CATCH PROFILES

Diversity indices offer a simple and straightforward way to assess changes in the suite of bycatch species intercepted over time. These metrics were originally developed to evaluate biological community structure. The Shannon's diversity index (H) quantifies the uncertainty in predicting the species identity of an individual taken at random from a dataset. High values (closer to one) are related to two factors: (1) a larger suite of species, and (2) roughly equal proportional abundances of each species. In a dataset dominated by large amounts of a single species, uncertainty in prediction goes down, and H tends towards zero. If only Atlantic Halibut were caught on a set, the value for H was zero. This metric was calculated using the R package 'vegan' (Oksanen et al. 2020) from a matrix of the combined catch of each bycatch species (or species category) in addition to separate categories for kept and discarded Atlantic Halibut.

The suite of species captured on a single fishing set in each year and NAFO Division is extremely variable, as shown by *H* index values ranging from zero to approximately 1.5 (Figure 2). A simple loess smooth was used to assess trends over time, for all data as well as each quarter individually. Overall trends were gradually declining in 3NOPs and 4WX (Figure 2), suggesting that catches by the Atlantic Halibut fleet are becoming more dominated by large amounts of specific species. Trends from individual quarters are much more variable and predictions are influenced by missing data, yet seem to follow the same general pattern.

Given that Atlantic Halibut landings are increasing, declining trends in the *H* index implies that bycatch is also generally declining. There may be several reasons for this, one possibility is hook exclusion (Luo 2020). As more and more hooks are occupied by Atlantic Halibut, the number available for bycatch declines. Another possibility could be related to changes in abundance of the bycatch species themselves. As a population declines, it may be encountered less frequently as bycatch. This makes it difficult to infer the overall risk posed by the Atlantic Halibut fleet to various bycatch species.

DIFFERENCES AMONG NAFO DIVISIONS AND QUARTERS

The 2014 assessment suggested that differences in fishing methods and vessel capacity, in the proportion of landings observed and in biological community structure, likely influenced the catch profiles among NAFO Divisions and fishing quarters (Themelis & den Heyer 2015). This was why the ratio estimators used to scale up observed to fleetwide bycatch in that assessment were specific to NAFO Division and quarter. In this assessment, multivariate analyses were used to help determine if NAFO Division and quarter were important explanatory variables of catch profiles. In other words, are catches from specific NAFO Divisions or fishing quarters expected to be similar? Two different data sets were evaluated: (1) set-level combined catches of the 31 bycatch species or species categories, and (2) set-level kept catches of 17 species, representing those that were consistently landed in the majority of years from 2002–2020.

For each year, the data on catch profiles by NAFO Division and quarter were transformed into a distance matrix, before non-metric multi-dimensional scaling (NMDS) was used to identify the main axes of variability in multi-dimensional space. The common Bray-Curtis dissimilarity index was used to calculate the distance matrix, prior to centering and scaling the data for NMDS. The Bray-Curtis dissimilarity measures community resemblance in terms of species composition and abundance, expressed as a percentage difference (De Caceres et al. 2013). A value of zero means the two communities (here, the catch profiles of two sets) are identical. Dissimilarities were calculated using the R package ‘vegclust’ (De Caceres et al. 2010). The metaMDS function in the R package ‘vegan’ (Oksanen et al. 2020) was used to calculate the NMDS axes.

The catch profile from each set (either combined catches or kept catches) was extremely variable among years, NAFO Divisions and fishing quarters. Preliminary evaluation demonstrated that there were specific sets that had no species in common with the majority of the data and/or no or few species in common with another set. In these instances, it is not meaningful to calculate dissimilarity indices to preform ordination because these sites cannot be meaningfully related to other subsets in the data. These sets were found using the function ‘disconnected’, with a maximum dissimilarity value of 0.4 and were removed prior to NMDS ordination (Oksanen et al. 2020). This value was small enough to give NMDS axes that did not contain extreme outliers (e.g., values of one), but did mean that a portion of the data was not used in the ordination.

The number of dimensions to calculate for NMDS must be set *a priori*. The goal is to retain the minimum number of axes without introducing high levels of distortion, measured by ordination stress. Stress is a quantitative measure of ordination fit that indicates how well the algorithm has arranged the points in multi-dimensional space, while preserving the ranked distances between them (Dexter et al. 2018). Values ranged from 0.130 to 0.167 among years for NMDS fits in three dimensions for data representing the combined catches of all bycatch species. Values ranged from 0.124 to 0.190 for NMDS fits in two dimensions to data representing kept species only. Values < 0.2 are considered sufficient to represent the main patterns in the data (Dexter et al. 2018).

Visualization of the NMDS axes in which sets are categorized by NAFO Division and quarter do not show consistent groupings in the data. Specific sets within a group are often located more closely in multivariate space to sets in other groups than with each other. An example is given for kept catch profiles in 2004 (Figure 3). This suggests that the suite of species caught is not consistent within NAFO Divisions or fishing quarters. The categorical factors were fit onto each ordination using ‘envfit’ to assess the magnitude of correlation, using R^2 as an indication of goodness of fit. For the majority of years, NAFO Division has a much higher correlation with the NMDS ordination than fishing quarter, even though the amount of variance that the factor explains is relatively low (i.e., R^2 between 0.30 and 0.58 for combined catches, and between 0.27 and 0.65 for kept catches; Table 13).

Multivariate ordination is not ideal for evaluating whether catch amounts of individual species vary. Wilk’s rank MANOVA (implemented using the ‘rrcov’ R package; Todorov & Filzmoser 2009) demonstrated highly significant differences among NAFO Divisions (p-value << 0.001). This method accounts for correlation among variables when evaluating significance. Individual ANOVA gave further insight into differences among NAFO Divisions for specific species. Because these do not correct for multiple tests, p-values > 0.01 were considered non-significant. The focus was on NAFO Division rather than quarter because this factor was more strongly correlated to the catch profiles in the NMDS analyses.

While there could be highly significant differences in catches of the majority of species among NAFO Divisions (p-values ≤ 0.001; Table 14), there were several with relatively little evidence of regional differences. These included American Lobster (*Homarus americanus*), American Plaice (*Hippoglossoides platessoides*), Blue Shark (*Prionace glauca*), Greenland Shark (*Somniosus microcephalus*), Shortfin Mako (*Isurus oxyrinchus*), seals (non-specified), Silver Hake (*Merluccius bilinearis*), skates (non-specified), Smooth Skate (*Malacoraja senta*), Spinytail Skate (*Bathyraja spinicauda*), and wolffish (unidentified). For these species, NAFO Division may not be informative when predicting fleetwide bycatch. However, NAFO Division was retained here for continuity with the previous assessment and because the predictor seemed to be informative for the majority of species.

BYCATCH ESTIMATION METHOD

The 2014 bycatch assessment developed ratio estimators for individual species (aggregating trip-level data from 2009–2013) and then applied those ratios to estimate fleetwide bycatch amounts in 2013 (Themelis & den Heyer 2015). This was a commonly-used approach for estimating bycatch of individual species for un-observed commercial trips (Gavaris et al. 2010, Campana et al. 2011, Clark et al. 2015, Oliver et al. 2015). The ratios were specific to each NAFO Division and fishing quarter, and calculated as the combined weight (kept + discarded) of a specific bycatch species divided by the weight of landed Atlantic Halibut.

A critical assumption when using ratio estimators is that catches of individual non-target species are linearly-related to landed catches of the target species. To assess linearity, catch weights (kept + discarded) of individual bycatch species were plotted relative to landed weight of Atlantic Halibut for all sets. None of the individual species demonstrated a linear relationship with landed Atlantic Halibut, with most having the highest catches of the bycatch species when kept Atlantic

Halibut landings were very low. An example for Spotted Wolffish (*Anarhichas minor*) is given in Figure 4. This suggests that ratios will be poor predictors of fleetwide bycatch amounts. In many situations, catches of particular non-target species tend to be sporadic with a high proportion of zeros (Bellido et al. 2011) particularly in set-level data.

As an alternative, the total weight (kept + discarded) of all bycatch species combined was evaluated to determine if linearly related to landed Atlantic Halibut weight using a log-linear regression. Biologically, this would represent a scenario where successful trips have higher catch weights of all species (Atlantic Halibut as well as bycatch) and less successful trips would have lower catch weights. Additional potential predictors considered in the log-linear model were NAFO Division, time period (2009–2013; 2014–2020) and fishing quarter. Total bycatch amounts beyond 50,000 kg per trip were removed (n = 5) as were a low number of trips with zero kept Atlantic Halibut (n = 34, < 3% of trips) or zero total bycatch (n = 23, < 2% of trips). Trips that spanned categories (i.e., occurred in two NAFO Divisions or quarters) were split into two, to avoid having to arbitrarily decide which NAFO Division or quarter represented the bulk of the sets.

It is recognized that this analytical approach (i.e., log-linear regression of trip-level data with zeros removed) is not ideal for several reasons, which are discussed more fully in the Additional Considerations section. However, it is presented here as a practical demonstration of the utility of landed Atlantic Halibut weight (kept Atlantic Halibut) as a proxy for fishing effort, as well as a standardized method that can be used to generate bycatch estimates for all species.

Preliminary assessment revealed that trips were rare or did not occur in all quarters and in all NAFO Divisions (i.e., Q1 and Q4 in 3NOPs, and Q1 and Q2 in 5YZ), so fishing quarter was dropped from consideration. Model selection from the remaining nested options was done using step-wise removal of multiplicative interactions and/or predictor variables and assessing reductions in Akaike information criterion (AIC) (Johnson & Omland 2004). The retained model included an interactive term between NAFO Division and kept Atlantic Halibut weight, plus an additive term for time period. This model was preferred over the next best model on the basis of AIC (AIC = 3,898 verses 3,939).

Partial predictions from the regression show a fair fit to data at the trip-level; visual evaluation of model diagnostics did not show substantial deviations from model assumptions. However, there was autocorrelation at lag 1 detected in model residuals, indicating that the predictors do not capture all of the patterns in the data.

Total bycatch amounts tended to be positively related to kept Atlantic Halibut catches, but with different slopes among NAFO Divisions (Figure 5). Estimated intercepts were lower in 3NOPs4VWX during the 2014–2020 time period, indicating that total bycatch weight tended to be lower for a given amount of kept Atlantic Halibut weight in 2014–2020 compared to 2009–2013. This is consistent with the results from the diversity analyses that also suggested bycatch was declining. However, y intercepts were all greater than zero, suggesting that bycatch species are still being intercepted by the fleet even when Atlantic Halibut are not being landed. The data exhibit the greatest variability around the predicted relationship in 4X, the NAFO Division associated with the highest amount of fishing effort. Unfortunately, the predicted slope for 4X is essentially flat (Figure 5), suggesting that total bycatch can be similar over a very wide range of values for Atlantic Halibut landings. In contrast, the predicted slope for 5YZ is very slightly negative, indicating progressively lower levels of bycatch as kept weights of Atlantic Halibut increase.

BYCATCH ESTIMATES

To generate fleetwide bycatch estimates by species, total bycatch amounts were predicted from the log-linear model for each commercial trip. Then, the observed catch profiles (i.e., the suite of species and the relative proportions intercepted) from each year and NAFO Division were assumed to be representative and used to partition predicted total bycatch amounts by species. Trends in predicted catches (kept + discarded) during 2009–2020 are shown in Appendix 3. Similar to the previous bycatch assessment (Themelis & den Heyer 2015), this method accounts for differences in effort as well as differences in catches profiles among NAFO Divisions. Unlike the previous assessment, ratios were not developed and fishing quarter was not considered in the predictions (yet time period was). Therefore, these values are not comparable with the previous assessment.

From 2009–2020, there are relatively few instances where bycatch of a particular species or species group seems to be increasing, and nearly all examples come from 4X (e.g., American Lobster; Monkfish, Goosefish and Angler; Spotted and Striped Atlantic Wolffish; discarded Atlantic Halibut; Appendix 3). As would be expected under multi-species groundfish licences, there are several species or species categories that tend to be landed in conjunction with Atlantic Halibut: American Plaice, Atlantic Cod (*Gadus morhua*), Cusk (*Brosme brosme*), Haddock (*Melanogrammus aeglefinus*), Turbot (*Scophthalmus maximus*), Pollock (*Pollachius virens*), redfish species, White Hake (*Urophycis tenuis*), and Monkfish, Goosefish and Angler (Appendix 3). It is important to note that the bycatch predictions for individual species from the regression model were not explicitly compared to reported landed weights in the commercial data. If this method is used in the future, the magnitude of deviation would give some indication of the robustness and/or likely biases associated with the prediction approach.

Bycatch rates (kg/set) were summarized for the 2009–2013 and 2014–2020 time periods for each NAFO Division (Table 15). Several species were captured at relatively low rates across NAFO Divisions, including American Lobster, American Plaice, Blue Shark, grenadier species, Pollock, redfish species, seal species, Shortfin Mako Shark, Silver Hake, Smooth Skate, Spinytail Skate and unidentified wolffish (Table 15). Some of the species that tended to be landed in addition to Atlantic Halibut also had higher capture rates (e.g., Atlantic Cod, Cusk, Haddock, and White Hake). Bycatch rates for several species were highest in Division 5YZ (Table 15) and could be an order of magnitude larger in comparison with other areas (e.g., Atlantic Cod, Haddock, Pollock, Barndoor Skate (*Dipturus laevis*), and Monkfish, Goosefish, Angler). Wolffish species, Greenland Shark and Porbeagle Shark (*Lamna nasus*) tended to be captured at higher rates in 3NOPs, possibly reflecting their more northerly distributions. Several of the skate species and White Hake also tended to be caught at higher rates in 3NOPs, in addition to 5YZ. Bycatch rates tended to be lower for many species in 4VWX. However, it is important to remember that these NAFO Divisions represent the majority of the fishery so the total weight of bycatch would be greater there than in other areas.

It is difficult to determine what these predictions imply for the status of individual bycatch species. Bycatch can decline due to factors such as improvements in the status of the target species, worsening status of the bycatch species, and/or changes in the distribution of effort or other operational characteristics of the fleet that influence catchability. This assessment represents general patterns and characteristics that could be used to inform more targeted research on the status of individual species.

CONCLUSIONS

Using Mar.fleets for data extraction removed subjectivity and ensured consistency in the definition of the fleet. This had little effect on the previous understanding of landings or the proportion of observed landings of Atlantic Halibut, yet had substantial implications for calculating observer coverage rates and understanding bycatch.

Observation rates have declined since the 2014 assessment, with the lowest value observed in 2020. The manner in which trips are selected for observation may be contributing to the decline. In a given year, the anticipated number of observed trips is determined relative to the size of the fishery in the previous year (i.e., taking a proportion of the total number of trips in the previous year and then allocating that number of trips among hail-outs in the current year; G Croft, Pers. Comm.). For this fishery, the number of trips undertaken by the fleet has been progressively increasing.

Observation effort was disproportionately allocated to NAFO Divisions with relatively low fishing activity. For longline fleets in 5Z, there is a requirement for 100% coverage in a coral conservation zone, 50% coverage in winter and 50–100% in summer. For 3NO, there is a requirement that midshore and offshore licence holders carry an observer if fishing effort will occur in more than one group of NAFO Divisions on a single trip (the groups are defined in licence conditions). These requirements likely explain the disproportionate amount of coverage in these areas. The proportion of total catches that were Atlantic Halibut increased for essentially all NAFO Divisions and fishing quarters from the 2009–2013 to 2014–2020 time periods. The percentage of Atlantic Halibut catches that were discarded was twice as high in the 2009–2013 time period as it was in 2014–2020. Seasonal patterns show that the majority of fishing activity occurs between April and September (Q2 and Q3), with less activity in the late fall and winter (Q1 and Q4).

Some type of effort metric is required to scale up observed catches to fleetwide totals. The utility and data completeness of four alternatives (trip duration, set duration, number of gear units and kept Atlantic Halibut catch) were evaluated. Similar to the previous assessment, kept Atlantic Halibut was used as the proxy for effort owing to data limitations for the other options. Similarly, an evaluation of data accuracy relative to position (both geographical position and NAFO Division) indicates that a small portion of records do not have location information. There is no indication that errors in location are becoming less frequent. It is unknown at this point whether discrepancies represent errors in the recorded data (i.e., logbook and at-sea observer records) or inaccuracies in data entry when information is archived in MARFIS or the ISDB.

The catch profiles from fished sets (either combined catches or kept catches) were extremely variable among years, NAFO Divisions and fishing quarters. A diversity index suggested catches becoming more dominated by large amounts of specific species, which likely means bycatch is declining given that Atlantic Halibut landings are increasing. Using multivariate ordination for visualization did not show consistent groupings in the data relative to NAFO Division or fishing quarter. However, NAFO Division tended to be more highly correlated with the ordination. For individual species, there could be highly significant differences in catches among NAFO Divisions, yet there were others that showed little or no evidence of regional differences.

A log-linear regression was proposed as a way to predict total bycatch weight from kept Atlantic Halibut landings, accounting for differences among NAFO Division and time period. Although this analytical approach was not ideal, it represented a standardized method that could be used to generate bycatch estimates for 31 species (or species categories) intercepted by the Atlantic Halibut fleet. Total bycatch amounts were positively related to kept Atlantic Halibut catches in 3NOPs4VWX, but not in 5YZ. Biologically, a positive relationship demonstrates that successful trips have higher catch weights of all species (Atlantic Halibut as well as bycatch). Unfortunately, the data exhibited the greatest variability in 4X and the predicted slope was essentially flat, suggesting that total bycatch can be similar over a very wide range of values for Atlantic Halibut landings.

Predictions of total bycatch from the log-linear model were partitioned into amounts by species based on their relative proportions in the catch profiles from each year and NAFO Division. From 2009–2020, there are relatively few instances where bycatch of a particular species or species group seems to be increasing, and nearly all examples come from 4X. Calculating the mean proportion landed indicates there were several species or species categories that tended to be landed in conjunction with Atlantic Halibut, as would be expected under multi-species groundfish licences.

Bycatch rates (kg/set) were consistently low for several species, both among time periods and across NAFO Divisions. For those with higher bycatch, rates could be an order of magnitude larger in 5YZ than in other areas and tended to be higher when the species was landed in conjunction with Atlantic Halibut. While bycatch rates tended to be lower for many species in 4VWX, it is important to remember that these NAFO Divisions represent the majority of the fishery so the total weight of bycatch would be greater there than in other areas.

It is difficult to determine what these predictions imply for the status of individual bycatch species. Bycatch can decline due to factors such as improvements in the status of the target species, worsening status of the bycatch species, and/or changes in the distribution of effort or other operational characteristics of the fleet that influence catchability. This assessment represents general trends, and the predictions should be taken as relative rather than absolute amounts. These patterns could be used to inform more targeted research on the status of individual bycatch species.

ADDITIONAL CONSIDERATIONS

From a statistical standpoint, there are several ways that the log-linear model used in this assessment could be improved. Two options would be using set-level data with a random effect for trip, and retaining zeros in the analyses by assuming a compound-Poisson distribution for the response. However, these changes represent significant statistical complexity that may not be warranted given the characteristics of the data.

It is critical to note that landed Atlantic Halibut weight was essentially uninformative about total bycatch in NAFO Division 4X in particular, which represents the majority of the fishery. Preliminary plots of the set-level data demonstrated even less indication of a linear relationship than trip-level data. When generating fleetwide bycatch estimates, the predictive power of any method using kept Atlantic Halibut as an effort metric is expected to be low. These analyses also assumed that the observed catches in each NAFO Division were representative of the catch profile for the commercial fishery. The validity of this assumption (i.e., that the observer data was unbiased relative to geographical location or vessel characteristics) could not be assessed in advance of this framework.

Spatial analyses are a commonly-suggested alternative approach to bycatch estimation for individual species (e.g., Stock et al. 2019). Before such approaches could be developed, a substantial quality control exercise would need to occur to verify the geographical positions and NAFO Divisions reported in the commercial data. Also, it is unlikely that a single predictive model for bycatch could be developed (as was done here). Single-species analyses would likely be required because of the level of variability in interception rates (i.e., commonly-encountered species would have much more data available to model) as well as possible differences in the correlation structure among the catches (i.e., how well a Matern function or similar describes the spatial variability in catches).

Understanding what these predictions imply in terms of the status of individual bycatch species will require additional research. The Atlantic Halibut fleet is one of several commercial fisheries that affect the individual bycatch species assessed here. Understanding population trends or fishing mortality would require analyses that combined data from multiple fleets and fisheries, accounting for differences in interception rates among them. Then, reference points would need to be developed in order to assess status. Information from this document could be used to select which species might be a priority for more in-depth characterization of removals.

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TABLES

Table 1. A comparison of methods for extracting commercial catch data from Maritimes Fishery Information System. The new method uses licence type and subtype, vessel, Northwest Atlantic Fisheries Organization Division, and gear to identify the Atlantic Halibut fleet. The original method considered any commercial trips that landed Atlantic Halibut to be part of the fleet. Grey shading was added to aid interpretability. Average values for two time periods are given: 2009–2013 and 2014–2020.

Year	Number of Trips New Method	Number of Trips Original Method	Number of vessels New Method	Number of vessels Original Method	Number of Licences New Method	Number of Licences Original Method	Landings (mt) New Method	Landings (mt) Original Method
2002	3,046	3,046	471	471	471	471	914.22	883.76
2003	2,880	2,876	415	414	425	425	1,032.33	1,001.20
2004	3,159	3,156	416	416	420	420	995.02	962.70
2005	3,083	3,088	414	417	423	423	1,003.44	977.84
2006	3,287	3,287	420	420	433	433	1,117.37	1,104.44
2007	3,436	3,440	419	419	429	429	1,292.49	1,280.19
2008	3,232	3,231	394	394	400	400	1,143.13	1,126.51
2009	2,665	2,664	359	359	379	379	1,315.11	1,300.29
2010	2,388	2,387	338	338	343	343	1,430.44	1,416.49
2011	2,245	2,240	285	285	302	302	1,441.02	1,415.79
2012	2,435	2,435	305	305	334	335	1,586.46	1,555.97
2013	2,527	2,529	363	363	381	381	1,979.80	1,969.00
2014	2,568	2,568	456	457	466	466	2,050.49	2,014.60
2015	2,763	2,763	434	434	447	447	2,519.12	2,467.44
2016	2,892	2,888	472	471	484	483	2,400.18	2,298.53
2017	2,967	2,963	512	512	506	506	2,600.04	2,447.21
2018	3,293	3,291	519	519	536	536	3,427.17	3,207.39
2019	3,461	3,458	519	519	522	522	3,583.83	3,543.59
2020	3,324	3,327	505	505	504	504	4,249.53	4,222.26
2009–2013	2,452	2,451	330	330	348	348	1,551	1,532
2014–2020	3,038	3,037	488	488	495	495	2,976	2,886

Table 2. A comparison of methods for extracting at-sea observer data from the Industry Surveys Database .The new method is based on 1:1 matches with the commercial trips identified in Table 1. The original method identified observed trips for Atlantic Halibut on the basis of a Species Sought Code=30 in the ISDB. Grey shading was added to aid interpretability.

Year	Number of Trips New Method	Number of Trips Original Method	Catch (kept + discarded) (mt) New Method	Catch (kept + discarded) (mt) Original Method
2002	46	50	68.29	189.01
2003	73	50	89.89	186.83
2004	83	48	99.45	111.73
2005	91	43	112.95	108.30
2006	88	52	91.28	100.24
2007	86	88	349.17	377.17
2008	117	84	266.43	317.83
2009	79	53	195.42	251.59
2010	118	80	194.54	245.12
2011	114	81	179.12	213.73
2012	124	90	200.88	326.53
2013	91	74	197.72	319.80
2014	72	56	150.57	264.31
2015	89	68	197.85	227.42
2016	108	94	204.02	215.34
2017	101	93	223.33	219.82
2018	74	82	182.40	220.62
2019	69	79	195.22	235.51
2020	32	27	213.07	210.63
2009–2013	105	76	194	271
2014–2020	78	71	195	228

Table 3. The numbers and proportions of commercial catch set records (Maritimes Fishery Information System data) in which Northwest Atlantic Fisheries Organization (NAFO) Division and/or geographic location were missing.

Year	Commercial Sets (#)	Missing NAFO (#)	Proportion Missing NAFO	Missing Geographic Location	Proportion Missing Geographic Location
2002	4,430	0	0	956	0.216
2003	4,375	36	0.008	742	0.170
2004	4,427	548	0.124	516	0.117
2005	4,432	403	0.091	398	0.090
2006	4,880	427	0.088	423	0.087
2007	5,392	376	0.070	370	0.069
2008	5,140	426	0.083	425	0.083
2009	5,253	267	0.051	258	0.049
2010	5,498	224	0.041	218	0.040
2011	5,787	300	0.052	284	0.049
2012	6,093	307	0.050	298	0.049
2013	6,608	294	0.044	284	0.043
2014	6,619	300	0.045	285	0.043
2015	6,384	344	0.054	328	0.051
2016	6,556	356	0.054	329	0.050
2017	6,909	349	0.051	327	0.047
2018	7,692	345	0.045	339	0.044
2019	8,636	461	0.053	445	0.052
2020	9,957	486	0.049	469	0.047

Table 4. The number of commercial sets (Maritimes Fishery Information System (MARFIS) data) and observed sets (Industry Surveys Database (ISDB) data) for 2009–2013 and 2014–2020 by recorded Northwest Atlantic Fisheries Organization (NAFO) Division, as well as the NAFO Division that each record would have been in from the reported latitude and longitude. Differences show instances where the reported latitude and longitude do not match the reported NAFO Division for sets, note in particular the inclusion of 4T.

Time Period	Location	MARFIS Reported NAFO	MARFIS Reported Lat/Long	ISDB Reported NAFO	ISDB Reported Lat/Long
2009–2013	3N	121	121	553	552
2009–2013	3O	117	117	218	215
2009–2013	3P	985	964	741	743
2009–2013	4T	0	20	7	8
2009–2013	4V	3,655	3,581	1,359	1,345
2009–2013	4W	5,722	5,676	866	878
2009–2013	4X	15,832	15,600	3,826	3,813
2009–2013	5Y	202	195	3	4
2009–2013	5Z	1,596	1,595	3,313	3,307
2009–2013	On Land	0	317	0	2
2009–2013	Missing	1,512	1,462	0	0
2009–2013	Outside NAFO Divisions	0	94	0	19
2014–2020	3N	623	624	570	571
2014–2020	3O	1,241	1,238	848	845
2014–2020	3P	1,841	1,815	402	405
2014–2020	4T	0	52	14	13
2014–2020	4V	11,202	11,084	1,398	1,413
2014–2020	4W	10,744	10,632	962	952
2014–2020	4X	23,762	23,500	2,874	2,862
2014–2020	5Y	391	369	6	6
2014–2020	5Z	585	584	1,809	1,808
2014–2020	On Land	0	529	0	1
2014–2020	Missing	2,781	2,662	0	0
2014–2020	Outside NAFO Divisions	0	81	0	7

Table 5. The number of commercial sets by year and Northwest Atlantic Fisheries Organization (NAFO) Division as well as averages for two time periods: 2009–2013 and 2014–2020. The number of sets where the NAFO Division is unknown (NA) is also shown.

Year	3N	3O	3PS	4V	4W	4X	5Y	5Z	NA
2002	9	95	226	398	882	2,545	19	256	0
2003	28	57	240	468	927	2,315	11	293	36
2004	22	43	189	477	833	1,982	32	301	548
2005	46	71	226	512	755	2,184	19	216	403
2006	50	47	267	477	719	2,619	11	263	427
2007	173	59	161	398	737	3,059	21	408	376
2008	64	39	134	387	816	2,906	22	346	426
2009	22	12	177	472	975	2,971	48	309	267
2010	21	9	251	689	979	2,969	48	308	224
2011	19	18	138	716	1,162	3,030	41	363	300
2012	24	32	154	798	1,205	3,205	29	339	307
2013	35	46	222	925	1,331	3,472	36	247	294
2014	202	109	307	1,226	1,351	2,938	43	143	300
2015	163	98	296	1,284	1,341	2,714	41	103	344
2016	58	218	219	1,536	1,392	2,642	56	79	356
2017	73	307	204	1,453	1,504	2,905	52	62	349
2018	58	256	179	1,572	1,728	3,454	57	43	345
2019	11	133	211	1,819	1,808	4,059	87	47	461
2020	58	120	375	2,152	1,586	5,018	54	108	486
2009–2013	24.2	23.4	188.4	720.0	1,130.4	3,129.4	40.4	313.2	278.4
2014–2020	89.0	177.3	255.9	1,577.4	1,530.0	3,390.0	55.7	83.6	377.3

Table 6. The number of commercial sets by year and fishing quarter as well as averages for two time periods: 2009–2013 and 2014–2020. Q1: January–March; Q2: April–June; Q3: July–September; Q4: October–November.

Year	Q1	Q2	Q3	Q4
2002	765	1,106	2,239	320
2003	598	1,077	2,389	311
2004	552	1,513	1,859	503
2005	623	1,405	1,797	607
2006	648	1,453	2,196	583
2007	629	1,681	2,495	587
2008	653	1,351	2,589	547
2009	765	1,524	2,307	657
2010	1,025	1,720	2,241	512
2011	799	1,632	2,624	732
2012	950	2,024	2,392	727
2013	757	1,987	2,985	879
2014	977	2,165	2,627	850
2015	775	2,200	2,408	1,001
2016	896	2,308	2,288	1,064
2017	932	2,639	2,461	877
2018	949	3,050	2,756	937
2019	1,095	3,503	2,625	1,413
2020	1,509	3,780	3,119	1,549
2009–2013	859.2	1,777.4	2,509.8	701.4
2014–2020	1,019.0	2,806.4	2,612.0	1,098.7

Table 7. Set-level observer coverage by Northwest Atlantic Fisheries Organization (NAFO) Divisions and quarter (Q1: January–March; Q2: April–June; Q3: July–September; Q4: October–December) from two time periods (2009 – 2013 and 2014 – 2020). Values > 1 (shown in bold) indicate discrepancies in reported data implying > 100% of sets were observed.

Time Period	NAFO Division	Q1	Q2	Q3	Q4
2009–2013	3N	0.00	**4.70**	**4.03**	0.00
2009–2013	3O	**1.57**	**1.09**	**1.89**	**1.75**
2009–2013	3PS	0.58	**1.72**	0.84	0.41
2009–2013	4V	0.23	0.42	0.16	0.14
2009–2013	4W	0.18	0.09	0.07	0.01
2009–2013	4X	0.14	0.24	0.24	0.07
2009–2013	5Y	0.00	0.00	0.00	0.00
2009–2013	5Z	0.00	**4.47**	**2.09**	**1.94**
2014–2020	3N	0.00	0.43	**2.34**	**1.97**
2014–2020	3O	0.00	0.92	0.45	0.00
2014–2020	3PS	0.06	0.28	0.88	0.00
2014–2020	4V	0.03	0.17	0.08	0.02
2014–2020	4W	0.07	0.05	0.05	0.12
2014–2020	4X	0.07	0.11	0.11	0.05
2014–2020	5Y	0.00	0.01	0.00	0.00
2014–2020	5Z	0.00	**3.97**	**2.82**	**2.45**

Table 8. Trends in observer coverage over time, calculated as a percentage of trips and as a percentage of the combined catch of Atlantic Halibut.

Year	Commercial trips (#)	Observed trips (#)	Observation rate (% of trips)	Observation rate (% of catch)
2002	3,041	46	1.5	6.9
2003	2,876	73	2.5	8.3
2004	3,153	83	2.6	9.4
2005	3,078	91	3.0	10.8
2006	3,280	88	2.7	8.1
2007	3,434	86	2.5	26.1
2008	3,229	117	3.6	22.9
2009	2,664	79	3.0	14.7
2010	2,386	118	4.9	13.1
2011	2,238	114	5.1	12.0
2012	2,432	124	5.1	12.3
2013	2,524	91	3.6	9.8
2014	2,564	72	2.8	7.2
2015	2,761	89	3.2	7.6
2016	2,888	108	3.7	8.5
2017	2,964	101	3.4	8.5
2018	3,288	74	2.3	5.2
2019	3,454	69	2.0	5.4
2020	3,322	32	1.0	5.0

Table 9. The proportion of sets on commercial trips for Atlantic Halibut that were carrying an observer onboard and the individual set was observed.

Year	Observed	Unobserved	Proportion
2002	713	0	1.00
2003	906	49	0.95
2004	1,266	6	1.00
2005	1,309	4	1.00
2006	1,175	56	0.95
2007	1,473	9	0.99
2008	2,448	14	0.99
2009	1,840	36	0.98
2010	1,839	9	1.00
2011	2,134	0	1.00
2012	2,080	26	0.99
2013	1,716	31	0.98
2014	1,247	93	0.93
2015	1,263	18	0.99
2016	1,320	1	1.00
2017	1,107	23	0.98
2018	767	0	1.00
2019	787	17	0.98
2020	755	14	0.98

Table 10. Proportion of the total catch (kept + discarded) that was landed Atlantic Halibut by Northwest Atlantic Fisheries Organization Division and fishing quarter, comparing the 2009–2013 and 2014–2020 time periods. NA indicates no data.

Time Period	NAFO Division	Q1	Q2	Q3	Q4
2009–2013	3N	NA	0.71	0.72	0.25
2009–2013	3O	0.42	0.43	0.65	0.62
2009–2013	3PS	0.54	0.62	0.82	0.88
2009–2013	4V	0.74	0.70	0.77	0.63
2009–2013	4W	0.87	0.78	0.66	0.05
2009–2013	4X	0.25	0.57	0.36	0.04
2009–2013	5Y	NA	NA	NA	NA
2009–2013	5Z	0.00	0.00	0.01	0.01
2014–2020	3N	NA	0.59	0.76	0.52
2014–2020	3O	NA	0.51	0.37	NA
2014–2020	3PS	0.62	0.83	0.84	NA
2014–2020	4V	0.96	0.84	0.84	0.65
2014–2020	4W	0.39	0.84	0.71	0.96
2014–2020	4X	0.85	0.86	0.71	0.35
2014–2020	5Y	NA	1.00	NA	NA
2014–2020	5Z	0.00	0.01	0.06	0.00

Table 11. The discarded weight of Atlantic Halibut by year, the percent discarded relative to kept Atlantic Halibut and the percent discarded relative to total Atlantic Halibut catch (kept + discarded).

Year	Halibut discards (kg)	Discards to Kept Halibut (%)	Discards to Total Catch (%)
2002	2,596	4.00	0.67
2003	3,481	4.00	0.69
2004	2,480	2.60	0.34
2005	2,591	2.30	0.36
2006	7,476	8.90	1.22
2007	8,720	2.60	0.79
2008	13,765	5.40	0.87
2009	18,152	10.20	1.62
2010	21,996	12.70	2.20
2011	14,143	8.60	1.71
2012	19,355	10.70	2.57
2013	11,311	6.10	2.06
2014	7,884	5.50	0.53
2015	10,930	5.80	0.96
2016	9,164	4.70	1.70
2017	9,615	4.50	1.84
2018	9,275	5.40	1.63
2019	4,716	2.50	1.14
2020	2,530	1.20	0.62
2009–2013	16,991	9.66	2.03
2014–2020	7,731	4.23	1.20

Table 12. Summary of data completeness of alternative effort metrics for Atlantic Halibut sets.

Year	Gear units missing	Gear units recorded	Gear units missing (%)	Duration missing	Duration recorded	Duration missing (%)
2002	782	3,661	17.60	4,414	29	99.35
2003	793	3,609	18.01	3,940	462	89.50
2004	708	3,750	15.88	11	4,447	0.25
2005	4,464	0	100.00	7	4,457	0.16
2006	4,912	0	100.00	13	4,899	0.26
2007	5,418	0	100.00	25	5,393	0.46
2008	5,159	0	100.00	51	5,108	0.99
2009	5,267	0	100.00	89	5,178	1.69
2010	5,516	0	100.00	68	5,448	1.23
2011	5,807	0	100.00	2	5,805	0.03
2012	6,111	0	100.00	0	6,111	0.00
2013	6,646	0	100.00	0	6,646	0.00
2014	6,635	0	100.00	50	6,585	0.75
2015	6,375	30	99.53	57	6,348	0.89
2016	6,573	13	99.80	260	6,326	3.95
2017	6,915	14	99.80	365	6,564	5.27
2018	7,724	0	100.00	241	7,483	3.12
2019	8,686	0	100.00	17	8,669	0.20
2020	9,987	0	100.00	11	9,976	0.11

Table 13. The strength of correlations between the non-metric multi-dimensional scaling ordination and Northwest Atlantic Fisheries Organization (NAFO) Division and fishing quarter for each year, assessed using R^2 goodness of fit. Grey shading was added to aid interpretability.

Year	Factor	Combined catches R^2	Kept Species R^2
2002	NAFO Division	0.536	0.557
2002	Quarter	0.278	0.398
2003	NAFO Division	0.344	0.490
2003	Quarter	0.353	0.300
2004	NAFO Division	0.517	0.556
2004	Quarter	0.150	0.265
2005	NAFO Division	0.407	0.465
2005	Quarter	0.201	0.157
2006	NAFO Division	0.299	0.470
2006	Quarter	0.123	0.080
2007	NAFO Division	0.410	0.376
2007	Quarter	0.098	0.014
2008	NAFO Division	0.508	0.487
2008	Quarter	0.084	0.117
2009	NAFO Division	0.484	0.550
2009	Quarter	0.150	0.172
2010	NAFO Division	0.454	0.410
2010	Quarter	0.136	0.227
2011	NAFO Division	0.452	0.572
2011	Quarter	0.086	0.211
2012	NAFO Division	0.405	0.510
2012	Quarter	0.146	0.303
2013	NAFO Division	0.462	0.631
2013	Quarter	0.103	0.045
2014	NAFO Division	0.577	0.647
2014	Quarter	0.183	0.181
2015	NAFO Division	0.512	0.619
2015	Quarter	0.062	0.189
2016	NAFO Division	0.304	0.298
2016	Quarter	0.028	0.181
2017	NAFO Division	0.339	0.365
2017	Quarter	0.076	0.174
2018	NAFO Division	0.337	0.428
2018	Quarter	0.112	0.089
2019	NAFO Division	0.476	0.614
2019	Quarter	0.218	0.271
2020	NAFO Division	0.494	0.266
2020	Quarter	0.079	0.017

Table 14. Summary of single-species ANOVA to evaluate differences in set-level catch (kept + discarded) among Northwest Atlantic Fisheries Divisions for each year. Species with relatively few significant results are identified by grey shading. Note that the species names represent the common name archived in the Industry Survey Database. NA indicates no data.

Species Category	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
AMERICAN LOBSTER	0.097	<0.001	0.012	0.014	<0.001	<0.001	0.506	0.443	0.017	0.230	<0.001	0.109	0.312	0.289	0.003	0.022	0.629	0.629	0.046
AMERICAN PLAICE	0.795	<0.001	<0.001	<0.001	0.213	0.496	<0.001	NA	<0.001	0.001	0.127	0.975	0.058	<0.001	NA	NA	NA	NA	NA
BARNDOOR SKATE	<0.001	<0.001	<0.001	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
BLUE SHARK	0.089	0.102	0.621	0.000	<0.001	0.770	0.001	0.053	0.321	0.204	0.735	0.019	0.262	0.093	0.005	0.090	0.117	0.117	<0.001
COD (ATLANTIC)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CUSK	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NA	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
DOGFISHES (NS)	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.016	<0.001	<0.001	<0.001	<0.001	<0.001	0.052	<0.001	<0.001	<0.001	0.023	0.023	<0.001
GREENLAND SHARK	0.328	0.667	0.130	<0.001	0.719	0.292	0.001	NA	0.973	0.921	<0.001	<0.001	NA	NA	0.247	0.076	NA	NA	0.106
GRENADIERS (ALL)	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NA	0.580	NA	NA	NA	0.002
HADDOCK	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LITTLE SKATE	NA	NA	0.028	<0.001	0.084	<0.001	0.005	0.069	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	NA
MONKFISH, GOOSEFISH ANGLER	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.014	<0.001	<0.001	0.006	0.001	0.006	<0.001	<0.001	<0.001	<0.001
NORTHERN WOLFFISH	<0.001	<0.001	<0.001	<0.001	0.523	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.012	0.164	0.230	0.230	<0.001
POLLOCK	<0.001	<0.001	<0.001	<0.001	0.278	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.039	0.089	<0.001	<0.001	<0.001	<0.001	<0.001

Species Category	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
PORBEAGLE, MACKEREL SHARK	0.098	0.007	0.024	<0.001	<0.001	<0.001	<0.001	0.001	0.002	0.177	<0.001	<0.001	<0.001	<0.001	0.708	0.003	<0.001	<0.001	NA
REDFISH UN-SEPARATED	<0.001	0.002	0.024	0.009	<0.001	<0.001	0.209	<0.001	<0.001	<0.001	<0.001	<0.001	0.231	0.001	<0.001	<0.001	0.531	0.531	0.249
SEALS (NS)	0.794	NA	0.438	NA	NA	0.006	NA	NA	NA	0.702	NA	0.066	0.053	0.388	0.797	0.517	NA	NA	NA
SHORTFIN MAKO	0.008	NA	0.656	0.874	0.959	0.815	<0.001	0.559	0.168	0.988	0.891	0.975	0.002	0.392	0.780	0.764	NA	NA	NA
SILVER HAKE	NA	<0.001	0.560	0.041	<0.001	NA	<0.001	<0.001	0.704	<0.001	<0.001	0.688	0.001	0.322	<0.001	0.173	0.832	0.832	0.376
SKATES (NS)	0.610	<0.001	<0.001	0.082	<0.001	<0.001	<0.001	0.208	0.003	0.009	<0.001	<0.001	0.271	0.034	0.001	<0.001	0.440	0.440	0.003
SMOOTH SKATE	<0.001	NA	0.023	0.542	NA	<0.001	0.412	0.193	0.033	<0.001	0.090	<0.001	0.992	0.480	0.003	<0.001	NA	NA	0.740
SPINYTAIL SKATE	NA	<0.001	NA	0.363	0.210	0.080	0.075	NA	0.050	0.006	NA	<0.001	0.992	0.447	0.938	NA	0.224	0.224	NA
SPOTTED WOLFFISH	0.051	0.175	<0.001	0.312	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	0.081	0.005	0.005	<0.001
STRIPED ATLANTIC WOLFFISH	0.455	<0.001	<0.001	<0.001	<0.001	<0.001	0.496	0.002	<0.001	0.312	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
THORNY SKATE	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TURBOT, GREENLAND HALIBUT	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.004	0.004	<0.001
WHITE HAKE	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
WHITE SKATE	NA	NA	NA	NA	NA	<0.001	<0.001	<0.001	<0.001	NA	NA	0.687	NA	NA	NA	NA	NA	NA	NA

Species Category	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
WINTER SKATE	<0.001	0.058	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	0.005	0.058
WOLFFISH, UNIDENT.	<0.001	0.006	0.017	0.034	<0.001	<0.001	<0.001	<0.001	0.937	0.006	0.743	0.975	0.992	0.367	0.497	NA	NA	NA	NA
ATLANTIC HALIBUT (DISCARD)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ATLANTIC HALIBUT (KEPT)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 15. Estimates of total fleetwide catch (kg/set) for the 2009–2013 and 2014–2020 time periods. Grey shading was added to aid interpretability.

	2009–2013							2014–2020						
	3N	3O	3PS	4V	4W	4X	5YZ	3N	3O	3PS	4V	4W	4X	5YZ
AMERICAN LOBSTER	0.00	0.00	0.00	0.00	0.00	0.31	3.68	0.00	0.00	0.00	0.01	0.04	0.29	2.11
AMERICAN PLAICE	1.07	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BARNDOOR SKATE	92.48	1.05	10.20	6.02	44.90	34.15	992.62	4.08	1.37	2.68	7.84	13.79	28.16	586.31
BLUE SHARK	0.42	7.34	5.03	1.57	1.01	2.01	29.21	0.15	0.00	0.00	0.38	3.34	1.44	11.57
ATLANTIC COD	186.27	15.18	419.07	56.30	14.81	149.37	2683.36	244.32	73.81	207.29	13.61	6.02	73.27	2,644.83
ATLANTIC HALIBUT (DISCARD)	63.54	179.86	152.23	65.85	46.71	48.97	8.48	10.38	7.05	0.98	29.05	30.79	79.17	4.09
CUSK	36.03	65.32	97.53	23.54	52.66	46.86	522.76	4.30	48.43	10.27	17.05	13.93	21.85	513.92
DOGFISHES (ALL SP.)	1.75	40.05	199.32	10.88	7.14	37.18	203.28	0.43	29.44	2.91	14.75	13.42	55.41	154.99
GREENLAND SHARK	229.95	152.03	15.97	0.00	0.00	1.97	13.55	0.00	0.00	0.00	0.08	8.08	0.00	42.58
GRENADIERS (ALL SP.)	43.60	0.29	15.66	0.33	0.01	0.01	0.00	6.58	0.07	0.00	0.00	0.01	0.00	0.00
HADDOCK	96.82	74.81	31.99	1.40	0.67	101.43	9,241.95	11.19	19.90	2.24	0.29	0.49	11.64	2,971.29
LITTLE SKATE	47.19	184.90	3.44	0.08	0.14	1.56	67.66	0.00	0.00	0.00	0.16	0.02	0.21	32.67
MONKFISH GOOSEFISH ANGLER	0.06	0.00	0.68	0.06	0.21	0.98	5.83	0.00	0.12	0.08	0.01	0.30	1.90	40.22
NORTHERN WOLFFISH	259.62	135.44	41.98	4.63	10.17	0.16	0.19	27.18	3.85	0.00	1.80	2.19	0.05	0.00
POLLOCK	0.06	0.00	0.43	0.22	2.37	8.23	136.60	0.00	0.00	0.00	0.51	1.51	11.33	81.82
PORBEAGLE SHARK	40.85	18.80	22.98	7.81	2.62	1.90	5.64	25.10	4.98	3.38	3.74	0.40	1.43	2.13
REDFISH UNSEP.	0.80	0.00	1.81	0.80	1.64	2.09	0.65	0.11	0.12	0.23	1.01	0.59	0.55	16.44
SEALS (NS)	0.00	0.00	0.00	0.00	0.00	10.51	0.00	0.00	0.00	0.00	0.83	0.96	1.57	0.00
SHORTFIN MAKO	0.00	0.00	0.00	0.00	0.00	0.56	9.73	0.95	0.36	0.00	0.31	0.13	0.07	0.00
SILVER HAKE	3.10	0.00	0.00	0.20	0.24	0.07	0.02	0.00	0.02	0.00	0.54	0.06	0.07	0.16
SKATES (NS)	0.00	0.00	0.00	0.49	2.42	32.18	42.60	4.02	21.00	0.30	0.76	0.19	1.96	9.42
SMOOTH SKATE	2.23	7.29	23.06	0.02	0.06	0.02	18.39	0.09	0.13	0.00	0.00	0.17	0.03	0.33

	2009–2013							2014–2020						
	3N	3O	3PS	4V	4W	4X	5YZ	3N	3O	3PS	4V	4W	4X	5YZ
SPINYTAIL SKATE	0.98	0.00	4.28	0.25	0.00	0.00	1.14	0.00	2.83	0.00	0.14	0.00	0.00	0.01
SPOTTED WOLFFISH	91.64	1.11	3.52	2.21	0.81	0.01	0.00	7.32	0.50	0.00	0.72	0.02	0.60	0.04
STRIPED ATLANTIC WOLFFISH	7.94	0.00	1.89	0.45	0.15	0.71	3.15	20.86	0.16	1.99	0.21	0.30	1.66	0.16
THORNY SKATE	190.38	144.43	147.39	6.32	3.40	3.63	208.74	265.20	144.06	365.15	1.26	0.65	0.60	24.45
TURBOT (GREENLAND HALIBUT)	5.65	11.23	31.21	1.05	8.48	1.27	0.40	4.70	1.96	0.93	0.92	11.60	0.01	0.00
WHITE HAKE	520.99	938.26	432.15	82.00	40.27	61.44	294.24	287.94	563.10	189.94	40.48	29.58	12.65	256.57
WHITE SKATE	203.04	135.18	98.60	0.35	0.40	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINTER SKATE	82.90	25.60	203.21	3.51	2.88	1.88	182.90	0.00	0.00	54.95	0.47	0.15	8.79	144.92
WOLFFISH (NS)	0.00	0.00	0.00	0.00	2.19	0.12	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.02

FIGURES

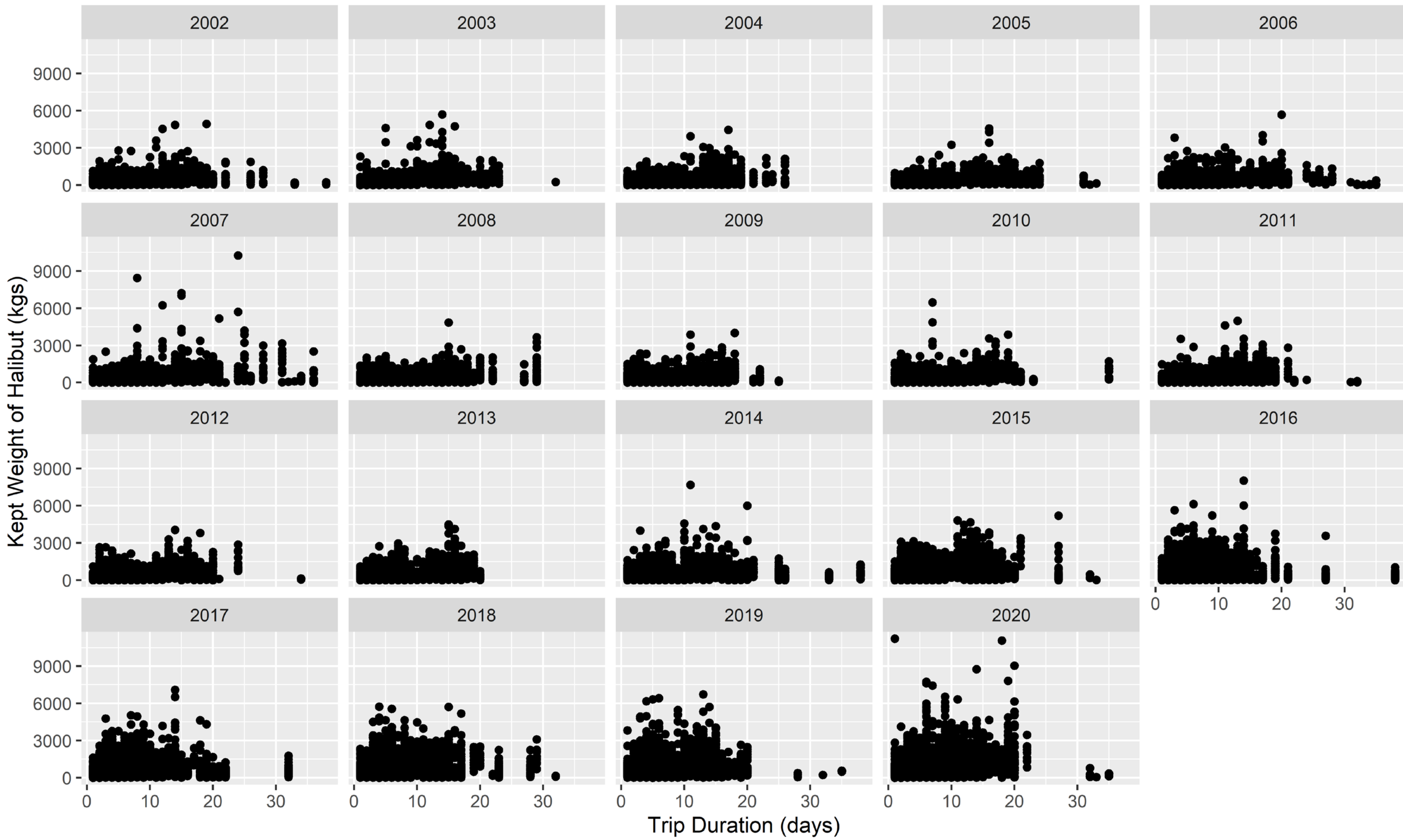

Figure 1. Trip length expressed as a number of days relative to kept weight of Atlantic Halibut in kgs by year.

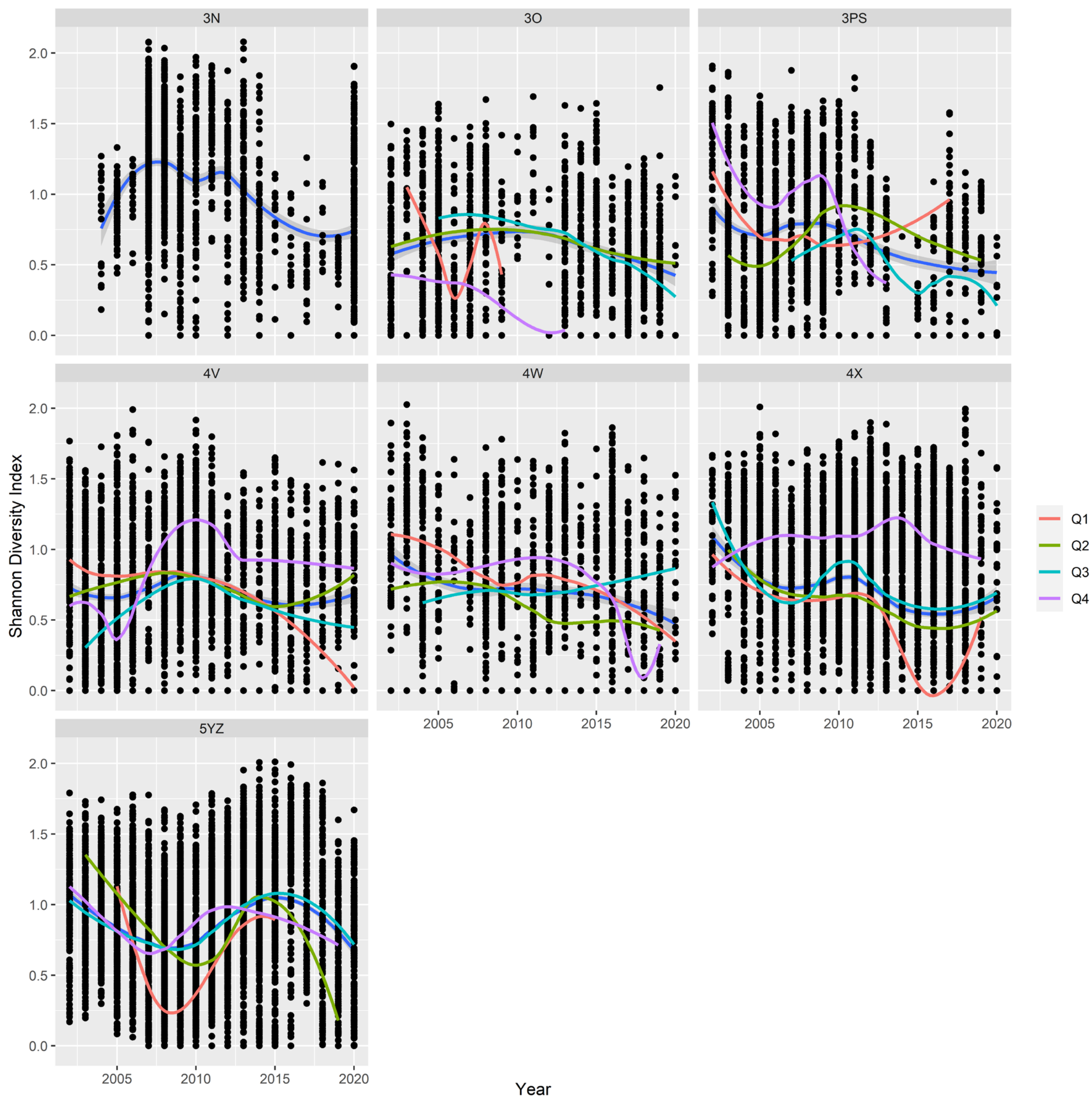

Figure 2. Changes in the suite of species (kept + discarded) intercepted by the Atlantic Halibut fleet over time by Northwest Atlantic Fisheries Organization (NAFO) Division, characterized using the Shannon Diversity Index (H). The set-level H values (points) are categorized by fishing quarter when fitting a loess smooth for Q1 to Q4 (coloured lines). Given the lack of information in all fishing quarter and NAFO Division combinations, an overall loess fit with standard error is also shown (blue lines and band). Q1: January–March, Q2: April–June; Q3: July–September; Q4: October–December.

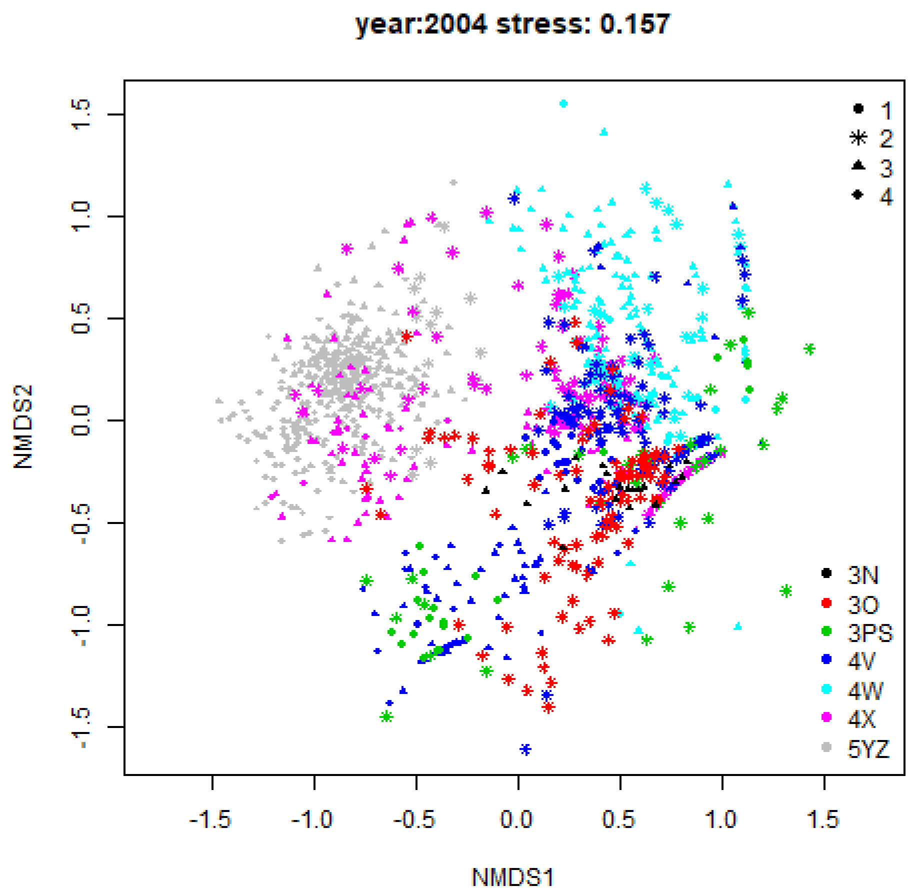

Figure 3. Plot of the two non-metric multi-dimensional scaling (NMDS) axes for set-level kept catch, using 2004 as an example. The Northwest Atlantic Fisheries Organization Divisions are categorized by colour and the fishing quarters are categorized by point shape. 1: January–March, 2: April–June; 3: July–September; 4: October–December.

Figure 4. Combined catch weight of Spotted Wolffish relative to landed weight of Atlantic Halibut for at-sea observed sets that occurred from 2009 to 2020, separated by fishing quarter and Northwest Atlantic Fisheries Organization Division. Quarter 1: January–March, quarter 2: April–June; quarter 3: July–September; quarter 4: October–December.

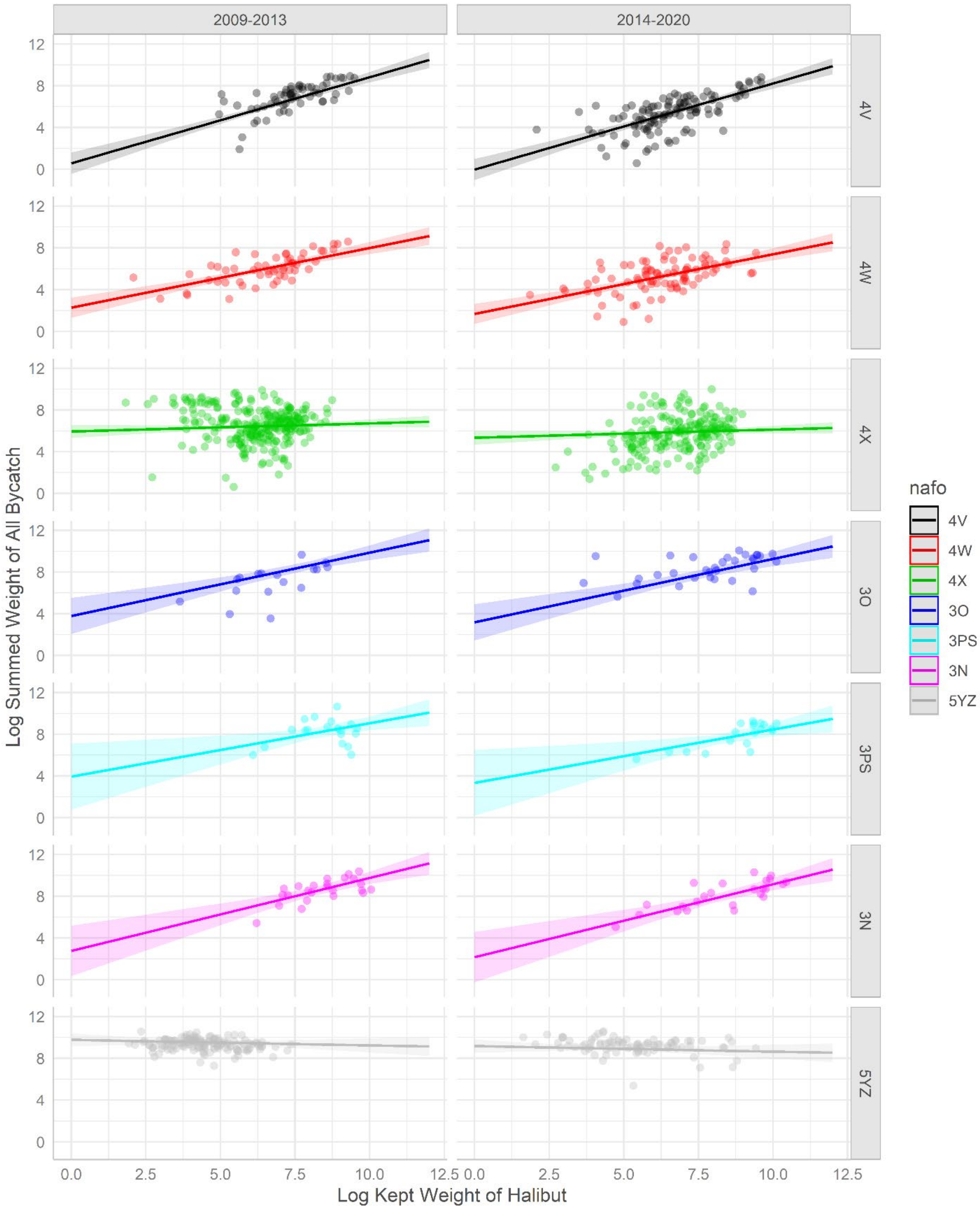

Figure 5. Partial predictions from a log-linear regression model showing the relationship between total bycatch weight and kept Atlantic Halibut weight, by Northwest Atlantic Fisheries Organization (NAFO) Division and time period.

APPENDIX 1: DATA EXTRACTION SPECIFICATIONS

Mar.fleets provides a function for data extraction that is specific to the Atlantic Halibut fleet, called fleet_halibut(). There are several user-supplied, coded values and default parameters associated with this function.

Table A1. Parameter list from 2020 data extracted using the fleet_halibut() function of Mar.fleets. Note that the hardcoded parameters define specific characteristics of the Atlantic Halibut fleet as determined by licence conditions and cannot be changed by the user. The names of each parameter and an example of the associated value are given.

SOURCE	PARAMETER	VALUE
user-supplied	areaFile	"Areas_Halibut_sf"
user-supplied	data.dir	"C:/mydocs/wrangledData"
user-supplied	dateEnd	"2020-12-31"
user-supplied	dateStart	"2020-01-01"
user-supplied	isdbSpp	30
user-supplied	keepSurveyTrips	TRUE
user-supplied	marfGear	c(12, 41, 51, 59)
user-supplied	marfSpp	130
user-supplied	returnISDB	TRUE
user-supplied	returnMARFIS	TRUE
user-supplied	tripcd_id	c(30, 7057, 7058)
user-supplied	useLocal	TRUE
hardcoded for this fleet	area	"see <results>$params$fleet$..."
hardcoded for this fleet	gearSpecs	"see <results>$params$fleet$..."
hardcoded for this fleet	lics	"see <results>$params$fleet$..."
default value (overwritable by user)	areaFileField	"Strata"
default value (overwritable by user)	debug	FALSE
default value (overwritable by user)	debugISDBTripIDs	"<NULL>"
default value (overwritable by user)	debugISDBTripNames	"<NULL>"
default value (overwritable by user)	debugLics	"<NULL>"
default value (overwritable by user)	debugMARFTripIDs	"<NULL>"
default value (overwritable by user)	debugVRs	"<NULL>"
default value (overwritable by user)	dropUnmatchedISDB	TRUE
default value (overwritable by user)	manualMatch	FALSE
default value (overwritable by user)	maxSetDiff_Hr	48
default value (overwritable by user)	maxSetDiff_Km	100
default value (overwritable by user)	maxTripDiff_Hr	48
default value (overwritable by user)	nafoDet	2
default value (overwritable by user)	oracle.dsn	"PTRAN"
default value (overwritable by user)	oracle.password	*****
default value (overwritable by user)	oracle.username	"_none_"
default value (overwritable by user)	usepkg	"roracle"
metadata	Date Run	10/14/2021
metadata	Mar.fleets version	2021.10.14

Table A2. The Northwest Atlantic Fisheries Organization (NAFO) Divisions that describe the fishery and are coded into the data extraction by Mar.fleets.

FLEET	FLEET_AREA_ID	AREA_TYPE	AREA
HALIBUT	3NOPS4VWX5	NAFO	5
HALIBUT	3NOPS4VWX5	NAFO	3N
HALIBUT	3NOPS4VWX5	NAFO	3O
HALIBUT	3NOPS4VWX5	NAFO	3PS
HALIBUT	3NOPS4VWX5	NAFO	4V
HALIBUT	3NOPS4VWX5	NAFO	4W
HALIBUT	3NOPS4VWX5	NAFO	4X

Table A3. The licence characteristics that describe the fishery and are coded into the data extraction by Mar.fleets. NA indicates that the code or description is not available.

Species code	Species Description	Licence Type Code	Description of Licence Type	Licence Subtype Code	Description of Licence Subtype
130	HALIBUT	24	WRITTEN PERMISSION	40	BROODSTOCK COLLECTION
199	GROUNDFISH, UNSPECIFIED	0	EXEMPTED VB	-99	NA
199	GROUNDFISH, UNSPECIFIED	1	VESSEL BASED LIMITED	-99	NA
199	GROUNDFISH, UNSPECIFIED	11	CC VESSEL BASED LIMITED	-99	NA
199	GROUNDFISH, UNSPECIFIED	10	ENTERPRISE ALLOCATION	14	MIDSHORE
199	GROUNDFISH, UNSPECIFIED	10	ENTERPRISE ALLOCATION	15	OFFSHORE
199	GROUNDFISH, UNSPECIFIED	15	CC ENTERPRISE ALLOCATION	19	INSHORE
199	GROUNDFISH, UNSPECIFIED	1	VESSEL BASED LIMITED	24	FIXED GEAR GROUNDFISH < 45'
199	GROUNDFISH, UNSPECIFIED	11	CC VESSEL BASED LIMITED	24	FIXED GEAR GROUNDFISH < 45'
199	GROUNDFISH, UNSPECIFIED	0	EXEMPTED VB	28	FIXED GEAR 45–65 FEET GROUNDFISH

APPENDIX 2: SPECIES LISTS

Table A4. Complete list of species caught on observed Atlantic Halibut-directed trips during 2009–2013 and summed catch weights.

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
ABYSSAL SKATE	RAJA BATHYPHILA	0.00	50.00	50.00
AMERICAN EEL	ANGUILLA ROSTRATA	0.00	137.00	137.00
AMERICAN LOBSTER	HOMARUS AMERICANUS	630.00	1,581.60	2,211.60
AMERICAN PLAICE	HIPPOGLOSSOIDES PLATESSOIDES	160.00	0.00	160.00
ANTHOZOA SEA ANEMONES	ACTINIARIA C.	0.00	1.00	1.00
ARCTIC SKATE	RAJA HYPERBOREA	0.00	5.00	5.00
ARIOSOMA SP.	ARIOSOMA SP.	5.00	2.00	7.00
ASTERIAS SP.	ASTERIAS SP.	0.00	1.00	1.00
ASTEROIDEA S.C.	ASTEROIDEA S.C.	0.00	7.00	7.00
ATLANTIC ROCK CRAB	CANCER IRRORATUS	0.00	63.00	63.00
ATLANTIC TORPEDO	TORPEDO NOBILIANA	0.00	49.94	49.94
BARNACLES	CIRRIPEDIA S.C.	0.00	2.00	2.00
BARNDOOR SKATE	DIPTURUS LAEVIS	45,877.00	125,698.35	171,575.35
BASKET STARS	GORGONOCEPHALIDAE, ASTERONYCHIDAE F.	0.00	8.00	8.00
BATHYRAJA RICHARDSONI	BATHYRAJA RICHARDSONI	0.00	45.00	45.00
BLACK DOGFISH	CENTROSCYLLIUM FABRICII	41.00	20,794.24	20,835.24
BLUE SHARK	PRIONACE GLAUCA	120.00	6,137.40	6,257.40
BRILL/WINDOWPANE	SCOPHTHALMUS AQUOSUS	1.00	0.00	1.00
BUBBLE GUM CORAL	PARAGORGIA ARBOREA	0.00	76.00	76.00
BUTTERFISH	PEPRILUS TRIACANTHUS	0.00	1.10	1.10
COD(ATLANTIC)	GADUS MORHUA	628,739.11	1,259.61	629,998.72
COMMON MUSSELS	MYTILUS EDULIS	0.00	60.00	60.00
CONGER EEL	CONGER OCEANICUS	0.00	16.00	16.00
CORAL (NS)	ANTHOZOA	0.00	8.00	8.00
CUSK	BROSME BROSME	133,107.03	1,031.07	134,138.10
DEEPWATER CHIMAERA	HYDROLAGUS AFFINIS	0.00	40.00	40.00
DOGFISHES (NS)	SQUALIDAE F.	174.00	9,151.00	9,325.00
EEL-UNIDENTIFIED	ANGUILLIDAE F.	0.00	2.00	2.00
EELS,CONGER	CONGRIDAE F.	0.00	4.00	4.00
FOREIGN ARTICLES,GARBAGE	FOREIGN ARTICLES,GARBAGE	0.00	560.00	560.00
GADOIDS	GADOIDEI S.O.	0.00	7.00	7.00

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
GOLD-BANDED/BAMBOO CORAL	KERATOISIS ORNATA	0.00	103.00	103.00
GREAT BLACK-BACKED GULL	LARUS MARINUS	0.00	5.00	5.00
GREENLAND COD	GADUS OGAC	9.00	0.00	9.00
GREENLAND SHARK	SOMNIOSUS MICROCEPHALUS	0.00	34,494.63	34,494.63
GRENADIERS (NS)	MACROURIDAE F.	1,160.00	7.13	1,167.13
HADDOCK	MELANOGRAMMUS AEGLEFINUS	1,484,359.32	2,613.03	1,486,972.35
HAKE (NS)	GADIFORMES	214.00	0.00	214.00
HAKE (NS)	UROPHYCIS SP.	1,754.00	0.00	1,754.00
HALIBUT(ATLANTIC)	HIPPOGLOSSUS HIPPOGLOSSUS	1,035,356.84	97081.13	1,132,437.96
HERMIT CRABS	PAGURIDAE F.	0.00	2.00	2.00
HERRING GULL	LARUS ARGENTATUS	0.00	3.00	3.00
HERRING(ATLANTIC)	CLUPEA HARENGUS	0.00	2.00	2.00
HORSE MUSSELS	MODIOLUS MODIOLUS	0.00	24.00	24.00
JENSEN'S SKATE	RAJA JENSENI	0.00	2,857.23	2,857.23
JONAH CRAB	CANCER BOREALIS	0.00	230.50	230.50
LITTLE SKATE	LEUCORAJA ERINACEA	567.00	14,910.86	15,477.86
LOBSTER LARVAE	HOMARUS AMERICANUS LARVAE	0.00	8.00	8.00
LONGFIN SQUID, LONGFIN INSHORE SQUID	LOLIGO PEALEII	0.00	3.29	3.29
LONGHORN SCULPIN	MYOXOCEPHALUS OCTODECEMSPINOSUS	24.00	155.00	179.00
LONGNOSE GRENADIER	CAELORINCHUS CAELORINCHUS	13.00	0.00	13.00
MARLIN-SPIKE GRENADIER	NEZUMIA BAIRDII	4.00	528.21	532.21
MONKFISH, GOOSEFISH, ANGLER	LOPHIUS AMERICANUS	1,750.95	67.18	1,818.13
NORTHERN GANNET	MORUS BASSANUS	0.00	1.01	1.01
NORTHERN HAGFISH	MYXINE GLUTINOSA	0.00	24.17	24.17
NORTHERN STONE CRAB	LITHODES MAJA	0.00	27.11	27.11
NORTHERN WOLFFISH	ANARHICHAS DENTICULATUS	109.00	34,407.32	34,516.32
OCEAN POUT (COMMON)	MACROZOARCES AMERICANUS	0.00	15.00	15.00
OFF-SHORE HAKE	MERLUCCIUS ALBIDUS	135.00	8.00	143.00
PELONAIA SP.	PELONAIA SP.	0.00	1.00	1.00
POLLOCK	POLLACHIUS VIRENS	25,789.17	85.00	25,874.17

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
PORBEAGLE,MACKEREL SHARK	LAMNA NASUS	6,779.78	5,971.32	12,751.10
PORCUPINE CRAB	NEOLITHODES GRIMALDII	0.00	2.00	2.00
PORTUGUESE SHARK	CENTROSCYMNUS COELOLEPIS	0.00	142.58	142.58
PURPLE SUNSTAR	SOLASTER ENDECA	0.00	1.00	1.00
RED DEEPSEA CRAB	CHACEON QUINQUEDENS	0.00	14.00	14.00
REDFISH	SEBASTES MARINUS	0.00	10.00	10.00
REDFISH UNSEPARATED	SEBASTES SP.	3,249.08	148.43	3,397.51
ROCK GRENADIER(ROUNDNOSE)	CORYPHAENOIDES RUPESTRIS	250.00	55.00	305.00
ROSEFISH(BLACK BELLY)	HELICOLENUS DACTYLOPTERUS	40.00	0.00	40.00
ROUGHHEAD GRENADIER	MACROURUS BERGLAX	141.00	84.00	225.00
ROUGHNOSE GRENADIER	TRACHYRINCUS MURRAYI	3,642.00	105.00	3,747.00
ROUND SKATE	RAJELLA FYLLAE	0.00	428.00	428.00
SCALLOP SHELLS	PECTINIDAE SHELLS	0.00	124.00	124.00
SCULPIN UNIDENTIFIED	COTTIDAE F. UNID.	0.00	20.00	20.00
SCULPINS	COTTIDAE F.	39.00	156.00	195.00
SEA CORN	PRIMNOA RESEDAEFORMIS	0.00	6.00	6.00
SEA CUCUMBERS	HOLOTHUROIDEA C.	0.00	21.00	21.00
SEA RAVEN	HEMITRIPTERUS AMERICANUS	76.00	410.39	486.39
SEA SCALLOP	PLACOPECTEN MAGELLANICUS	2,664.00	155.00	2,819.00
SEALS (NS)	PHOCIDAE F.	0.00	2,524.00	2,524.00
SEAROBINS	TRIGLIDAE F.	0.00	1.00	1.00
SEASNAIL UNIDENTIFIED	LIPARIS SP.	6.00	0.00	6.00
SHARK (NS)	SHARK (NS)	243.00	543.00	786.00
SHORTFIN MAKO	ISURUS OXYRINCHUS	708.00	1,422.00	2,130.00
SHORTHORN SCULPIN	MYOXOCEPHALUS SCORPIUS	0.00	49.00	49.00
SILVER HAKE	MERLUCCIUS BILINEARIS	464.00	98.00	562.00
SKATES (NS)	RAJIDAE F.	3,023.00	18,069.00	21,092.00
SMOOTH SKATE	MALACORAJA SENTA	30.00	3,614.51	3,644.51
SNOW CRAB (QUEEN)	CHIONOECETES OPILIO	0.00	54.01	54.01
SPIDER CRAB (NS)	MAJIDAE F.	0.00	2.00	2.00
SPINY CRAB	LITHODES/NEOLITHODES	0.00	7.00	7.00
SPINY DOGFISH	SQUALUS ACANTHIAS	2,335.00	28,047.61	30,382.61

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
SPINYTAIL SKATE	BATHYRAJA SPINICAUDA	15.00	419.11	434.11
SPONGES	PORIFERA P.	0.00	2.00	2.00
SPOTTED WOLFFISH	ANARHICHAS MINOR	8.00	11,051.90	11,059.90
SQUIRREL OR RED HAKE	UROPHYCIS CHUSS	952.00	0.00	952.00
STONES AND ROCKS	STONES AND ROCKS	0.00	1,629.00	1,629.00
STRIPED ATLANTIC WOLFFISH	ANARHICHAS LUPUS	813.00	1,092.09	1,905.09
SUMMER FLOUNDER	PARALICHTHYS DENTATUS	0.00	6.00	6.00
SUN STAR	SOLASTER PAPPOSUS	0.00	1.00	1.00
THORNY SKATE	AMBLYRAJA RADIATA	92.62	65,867.36	65,959.98
THRESHER SHARK	ALOPIAS VULPINUS	0.00	6.00	6.00
TILE FISH	LOPHOLATILUS CHAMAELEONTICEPS	101.00	0.00	101.00
TURBOT,GREENLAND HALIBUT	REINHARDTIUS HIPPOGLOSSOIDES	11,618.94	597.00	12,215.94
WHITE HAKE	UROPHYCIS TENUIS	256,915.43	2,862.26	259,777.69
WHITE SKATE	RAJA LINTEA	0.00	45,253.00	45,253.00
WINTER FLOUNDER	PSEUDOPLEURONECTES AMERICANUS	94.00	10.00	104.00

Table A5. Complete list of species caught on observed trips during 2014–2020 and summed catch weights.

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
AMERICAN EEL	ANGUILLA ROSTRATA	0.00	7.00	7.00
AMERICAN JOHN DORY	ZENOPSIS OCELLATA	0.00	2.00	2.00
AMERICAN LOBSTER	HOMARUS AMERICANUS	548.00	910.84	1,458.84
AMERICAN PLAICE	HIPPOGLOSSOIDES PLATESSOIDES	1.00	76.96	77.96
ASTEROIDEA S.C.	ASTEROIDEA S.C.	0.00	28.00	28.00
ATLANTIC ROCK CRAB	CANCER IRRORATUS	0.00	26.02	26.02
ATLANTIC TORPEDO	TORPEDO NOBILIANA	0.00	125.00	125.00
BANDED GUNNEL	PHOLIS FASCIATA	0.00	2.00	2.00
BARNDOOR SKATE	DIPTURUS LAEVIS	18,120.85	82,460.33	100,581.18
BASKET STARS	GORGONOCEPHALIDAE,ASTERONYCHIDAE F.	0.00	1,085.41	1,085.41
BASKING SHARK	CETORHINUS MAXIMUS	0.00	2,100.00	2,100.00
BLACK DOGFISH	CENTROSCYLLIUM FABRICII	0.00	5,301.63	5,301.63
BLUE SHARK	PRIONACE GLAUCA	0.00	3,798.75	3,798.75
BLUEFIN TUNA	THUNNUS THYNNUS	0.00	2,340.00	2,340.00
BRILL/WINDOWPANE	SCOPHTHALMUS AQUOSUS	0.00	20.93	20.93
BRITTLE STAR	OPHIUROIDEA S.C.	0.00	1.00	1.00
BUBBLE GUM CORAL	PARAGORGIA ARBOREA	0.00	1.00	1.00
BUTTERFISH	PEPRILUS TRIACANTHUS	0.00	2.00	2.00
CANCER CRAB (NS)	CANCRIDAE F.	0.00	4.00	4.00
CEPHALOPODA C.	CEPHALOPODA C.	0.00	1.00	1.00
COD(ATLANTIC)	GADUS MORHUA	516,355.16	1,114.56	517,469.72
CONGER EEL	CONGER OCEANICUS	0.00	11.00	11.00
CORAL (NS)	ANTHOZOA	0.00	1.00	1.00
CORYPHAENA EQUISELIS	CORYPHAENA EQUISELIS	0.00	8.00	8.00
CUNNER	TAUTOGOLABRUS ADSPERSUS	0.00	3.07	3.07
CUSK	BROSME BROSME	106,111.81	177.00	106,288.81

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
DEEPWATER CHIMAERA	HYDROLAGUS AFFINIS	0.00	5.00	5.00
DOGFISHES (NS)	SQUALIDAE F.	4,763.00	22,258.70	27,021.70
EEL-UNIDENTIFIED	ANGUILLIDAE F.	0.00	4.00	4.00
EELS, CONGER	CONGRIDAE F.	0.00	1.00	1.00
FOREIGN ARTICLES, GARBAGE	FOREIGN ARTICLES,GARBAGE	0.00	155,145.17	155,145.17
G.LAND BIRD	AVES C.	0.00	1.00	1.00
GREENLAND COD	GADUS OGAC	7.00	0.00	7.00
GREENLAND SHARK	SOMNIOSUS MICROCEPHALUS	0.00	6,087.00	6,087.00
GRUBBY OR LITTLE SCULPIN	MYOXOCEPHALUS AENAEUS	0.00	6.00	6.00
HADDOCK	MELANOGRAMMUS AEGLEFINUS	962,472.98	756.01	963,228.99
HAKE	MERLUCCIUS SP.	4.00	0.00	4.00
HAKE (NS)	GADIFORMES	39.00	0.00	39.00
HAKE (NS)	UROPHYCIS SP.	102.00	0.00	102.00
HALIBUT (ATLANTIC)	HIPPOGLOSSUS HIPPOGLOSSUS	1,334,041.30	55,216.85	1,389,258.15
HELOCID PTEROPOD	LIMACINA HELICINA	0.00	8.00	8.00
HERMIT CRABS	PAGURIDAE F.	0.00	74.57	74.57
HERRING (ATLANTIC)	CLUPEA HARENGUS	90.00	5.07	95.07
ICELAND SCALLOP	CHLAMYS ISLANDICA	0.00	3.00	3.00
JENSEN'S SKATE	RAJA JENSENI	0.00	84.63	84.63
JONAH CRAB	CANCER BOREALIS	0.00	137.37	137.37
LESSER BLACK-BACKED GULL	LARUS FUSCUS	0.00	2.00	2.00
LITTLE SKATE	LEUCORAJA ERINACEA	45.00	5,877.39	5,922.39
LONGFIN HAKE	UROPHYCIS CHESTERI	4.00	2.00	6.00
LONGHORN SCULPIN	MYOXOCEPHALUS OCTODECEMSPINOSUS	6.00	159.87	165.87
LONGNOSE CHIMERA	HARRIOTTA RALEIGHANA	0.00	18.32	18.32
MACKEREL (ATLANTIC)	SCOMBER SCOMBRUS	0.00	3.00	3.00
MONKFISH, GOOSEFISH, ANGLER	LOPHIUS AMERICANUS	7,003.05	99.20	7,102.25
NORTHERN HAGFISH	MYXINE GLUTINOSA	0.00	10.00	10.00

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
NORTHERN STONE CRAB	LITHODES MAJA	0.00	57.00	57.00
NORTHERN WOLFFISH	ANARHICHAS DENTICULATUS	0.00	9,811.82	9,811.82
OCEAN POUT (COMMON)	MACROZOARCES AMERICANUS	1.00	180.54	181.54
OCEAN SUNFISH	MOLA MOLA	0.00	75.00	75.00
OFF-SHORE HAKE	MERLUCCIUS ALBIDUS	37.00	3.00	40.00
POLLOCK	POLLACHIUS VIRENS	35,439.69	209.00	35,648.69
PORBEAGLE, MACKEREL SHARK	LAMNA NASUS	1,619.00	11,554.45	13,173.45
PORCUPINE CRAB	NEOLITHODES GRIMALDII	0.00	1.00	1.00
RED DEEPSEA CRAB	CHACEON QUINQUEDENS	0.00	6.00	6.00
REDFISH UNSEPARATED	SEBASTES SP.	3,282.15	137.00	3,419.15
ROCK GRENADIER (ROUNDNOSE)	CORYPHAENOIDES RUPESTRIS	61.93	3.32	65.25
ROSEFISH (BLACK BELLY)	HELICOLENUS DACTYLOPTERUS	0.00	1.00	1.00
ROUGH SAGRE	ETMOPTERUS PRINCEPS	0.00	5.00	5.00
ROUGHHEAD GRENADIER	MACROURUS BERGLAX	528.00	1,217.22	1,745.22
ROUND SKATE	RAJELLA FYLLAE	0.00	204.00	204.00
SCALLOP SHELLS	PECTINIDAE SHELLS	0.00	4,514.27	4,514.27
SCALLOPS	PECTINIDAE F.	0.00	3.00	3.00
SCULPIN	ICELUS SP.	0.00	2.00	2.00
SCULPIN UNIDENTIFIED	COTTIDAE F. UNID.	0.00	3.50	3.50
SCULPINS	COTTIDAE F.	58.00	111.00	169.00
SEA ANEMONE	ANTHOZOA C.	0.00	7.00	7.00
SEA CORN	PRIMNOA RESEDAEFORMIS	0.00	1.00	1.00
SEA CUCUMBERS	HOLOTHUROIDEA C.	0.00	75.57	75.57
SEA LAMPREY	PETROMYZON MARINUS	0.00	2.00	2.00
SEA PEN	PENNATULA BOREALIS	0.00	1.66	1.66
SEA RAVEN	HEMITRIPTERUS AMERICANUS	108.00	1235.59	1343.59
SEA SCALLOP	PLACOPECTEN MAGELLANICUS	405027.98	80771.10	485799.08

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
SEA URCHINS	STRONGYLOCENTR OTUS SP.	0.00	95.97	95.97
SEALS (NS)	PHOCIDAE F.	0.00	3,427.00	3,427.00
SHAD AMERICAN	ALOSA SAPIDISSIMA	0.00	1.00	1.00
SHORT-FIN SQUID	ILLEX ILLECEBROSUS	1.00	8,131.00	8,132.00
SHORTFIN MAKO	ISURUS OXYRINCHUS	0.00	923.00	923.00
SHORTHORN SCULPIN	MYOXOCEPHALUS SCORPIUS	0.00	26.00	26.00
SILVER HAKE	MERLUCCIUS BILINEARIS	52,320.00	67.31	52,387.31
SKATE UNID. EGGS	RAJA EGGS	1.00	0.00	1.00
SKATES (NS)	RAJIDAE F.	8.00	7,038.31	7,046.31
SMOOTH SKATE	MALACORAJA SENTA	0.00	187.39	187.39
SNAILS AND SLUGS	GASTROPODA O.	0.00	56.51	56.51
SNAKE BLENNY	LUMPENUS LUMPRETAEFORMIS	0.00	1.07	1.07
SNOW CRAB (QUEEN)	CHIONOECETES OPILIO	1,233.00	116.66	1,349.66
SOFT SKATE	RAJA MOLLIS	0.00	6.00	6.00
SPINY CRAB	LITHODES/NEOLITH ODES	0.00	1.00	1.00
SPINY DOGFISH	SQUALUS ACANTHIAS	349.00	64,941.82	65,290.82
SPINYTAIL SKATE	BATHYRAJA SPINICAUDA	0.00	738.27	738.27
SPONGES	PORIFERA P.	0.00	2.00	2.00
SPOTTED WOLFFISH	ANARHICHAS MINOR	0.00	2,626.21	2,626.21
SQUIRREL OR RED HAKE	UROPHYCIS CHUSS	5,963.00	11.00	5,974.00
STONES AND ROCKS	STONES AND ROCKS	0.00	243,238.53	243,238.53
STRIPED ATLANTIC WOLFFISH	ANARHICHAS LUPUS	2,131.00	663.31	2,794.31
SUN STAR	SOLASTER PAPPOSUS	0.00	1.00	1.00
SWORDFISH	XIPHIAS GLADIUS	152.00	95.00	247.00
THORNY SKATE	AMBLYRAJA RADIATA	85.00	111,015.34	111,100.34
TIGER SHARK	GALEOCERDO CUVIER	0.00	363.00	363.00
TILE FISH	LOPHOLATILUS CHAMAELEONTICEP S	0.00	3.00	3.00

Common Name	Scientific Name	Kept Weight (kg)	Discard Weight (kg)	Total Weight (kg)
TOAD CRAB,UNIDENT.	HYAS SP.	0.00	3.00	3.00
TOMCOD(ATLANTIC)	MICROGADUS TOMCOD	4.00	1.00	5.00
TURBOT,GREENLAND HALIBUT	REINHARDTIUS HIPPOGLOSSOIDES	4,761.32	638.35	5,399.67
UNID. FISH	UNID. FISH (LARVAE,JUVENILE AND ADULTS)	0.00	1.00	1.00
WHITE HAKE	UROPHYCIS TENUIS	328,916.95	2,090.00	331,006.95
WINTER FLOUNDER	PSEUDOPLEURONECTES AMERICANUS	152.00	265.43	417.43
WINTER SKATE	LEUCORAJA OCELLATA	70.00	25,779.45	25,849.45
WITCH FLOUNDER	GLYPTOCEPHALUS CYNOGLOSSUS	350.00	6.27	356.27
WOLFFISH,UNIDENT.	ANARHICHADIDAE F.	9.00	51.00	60.00
WRYMOUTH	CRYPTACANTHODES MACULATUS	0.00	18.00	18.00

APPENDIX 3: SPECIES-SPECIFIC FLEETWIDE BYCATCH PREDICTIONS

Species-specific fleetwide bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The species or species category name is shown as the title of the plot. The numeric value in each panel represents the mean proportion over time of the combined catch (kept + discarded) that was landed, to give a sense of which species are retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

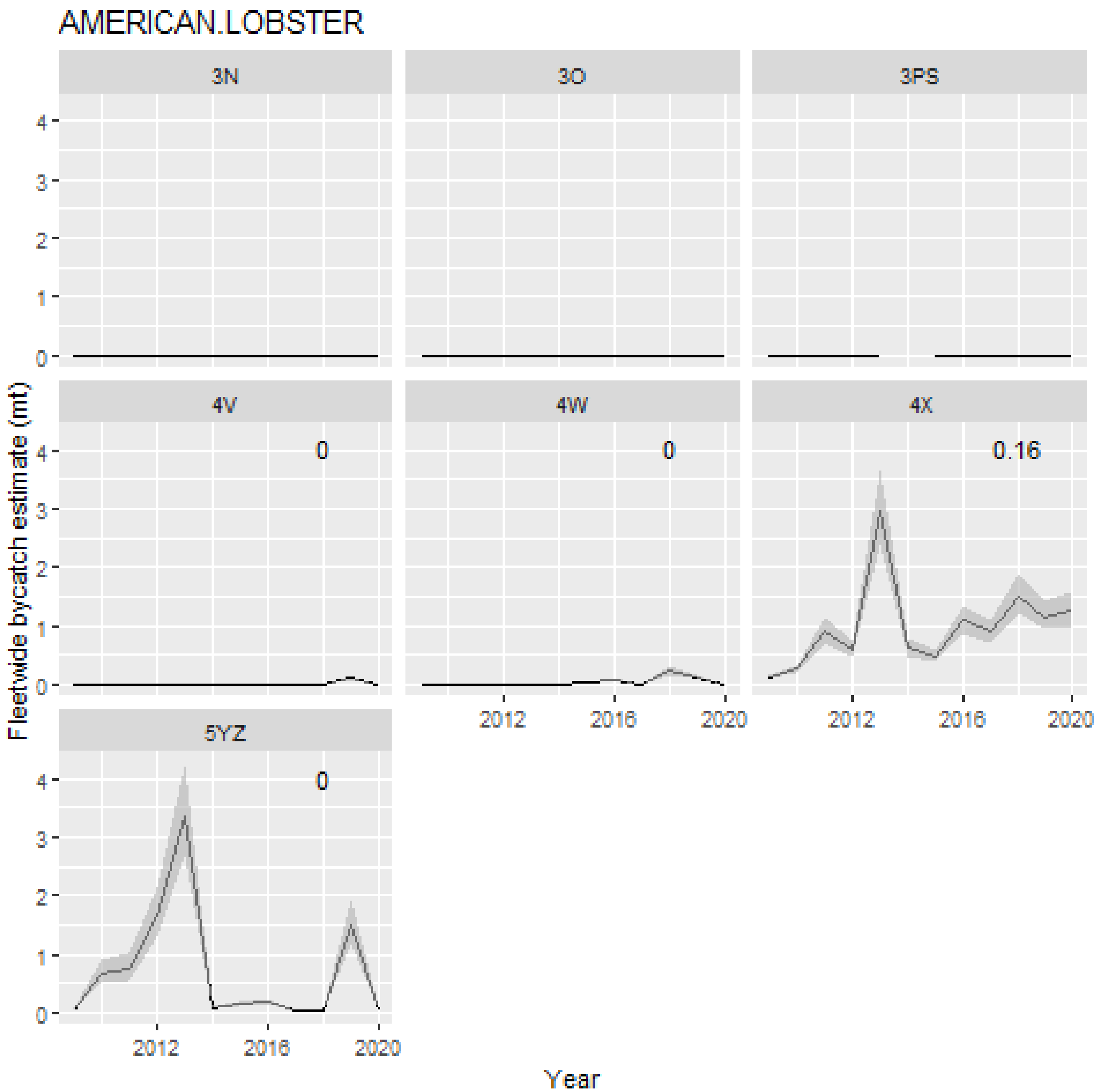

Figure A1. American Lobster bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined American Lobster catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

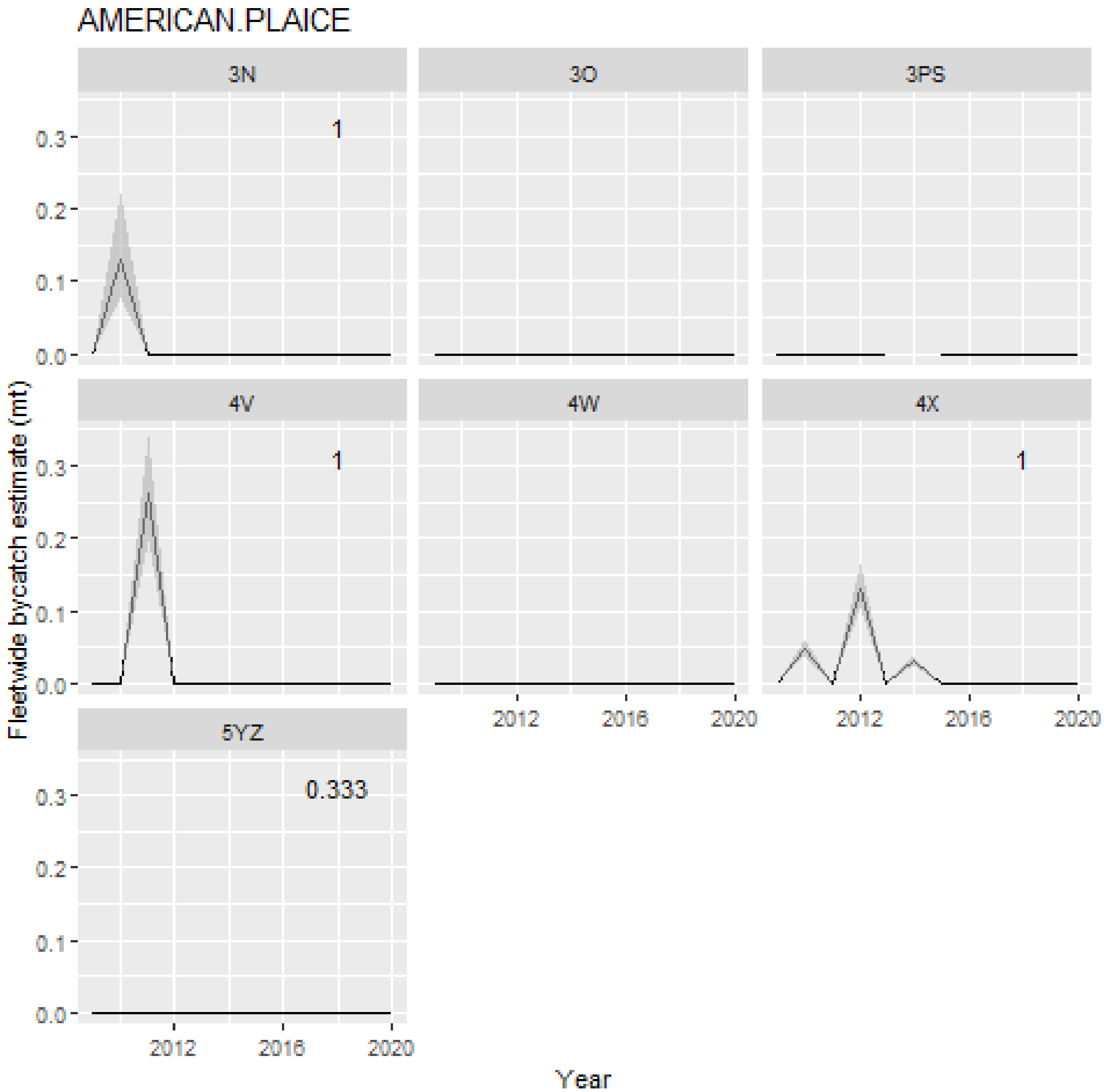

Figure A2. American Plaice bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined American Plaice catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

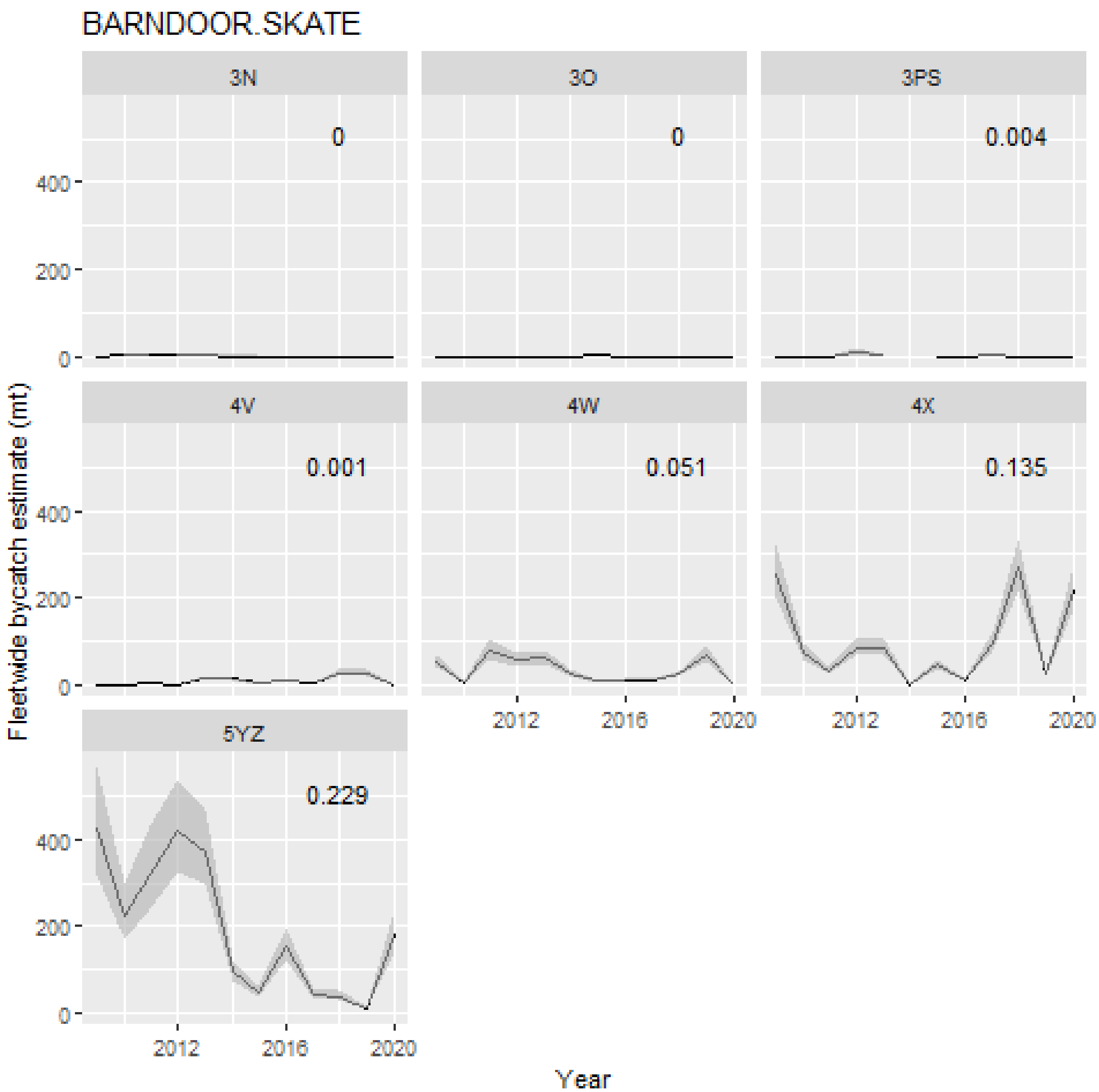

Figure A3. Barndoor Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Barndoor Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

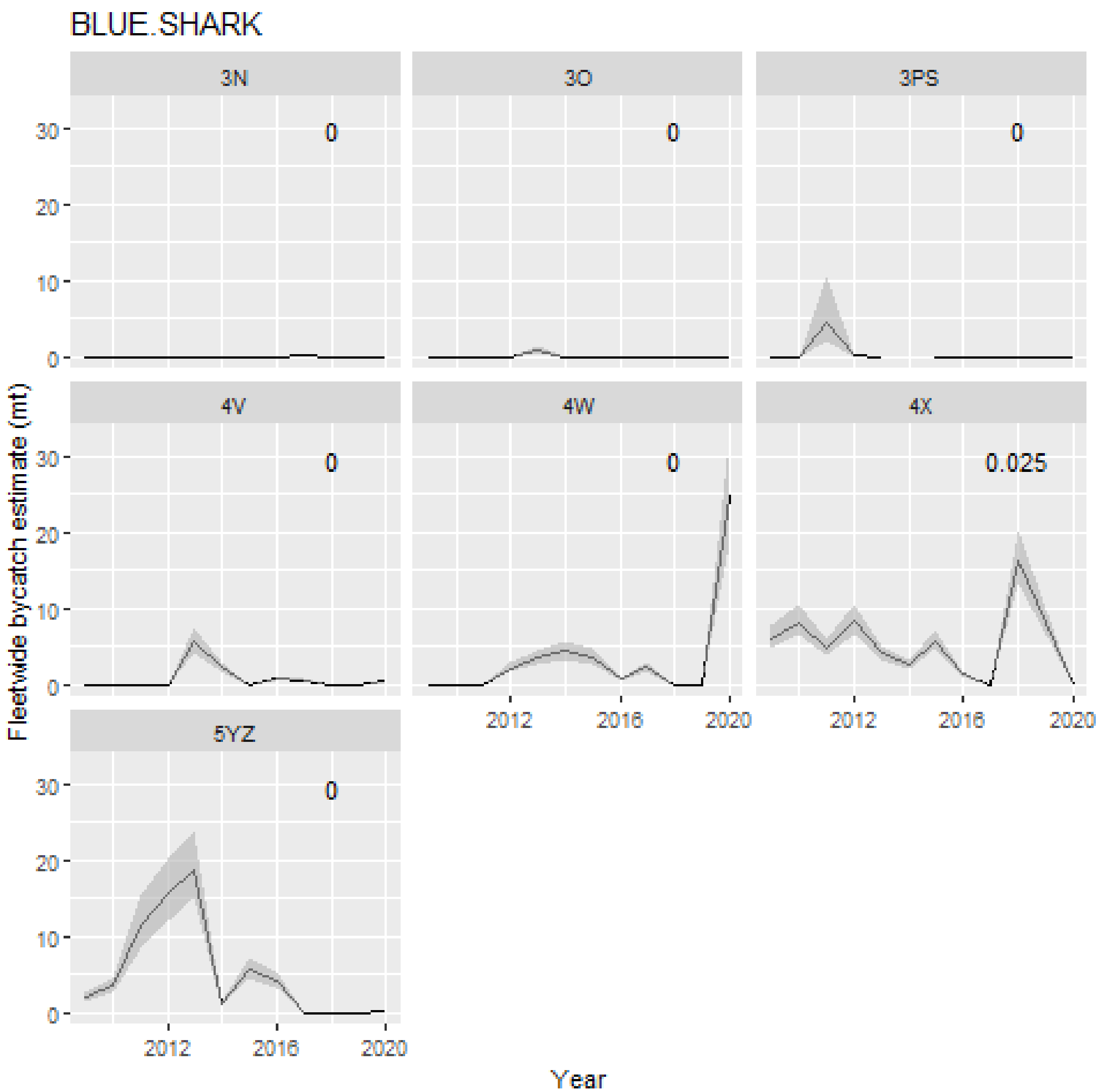

Figure A4. Blue Shark bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Blue Shark catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

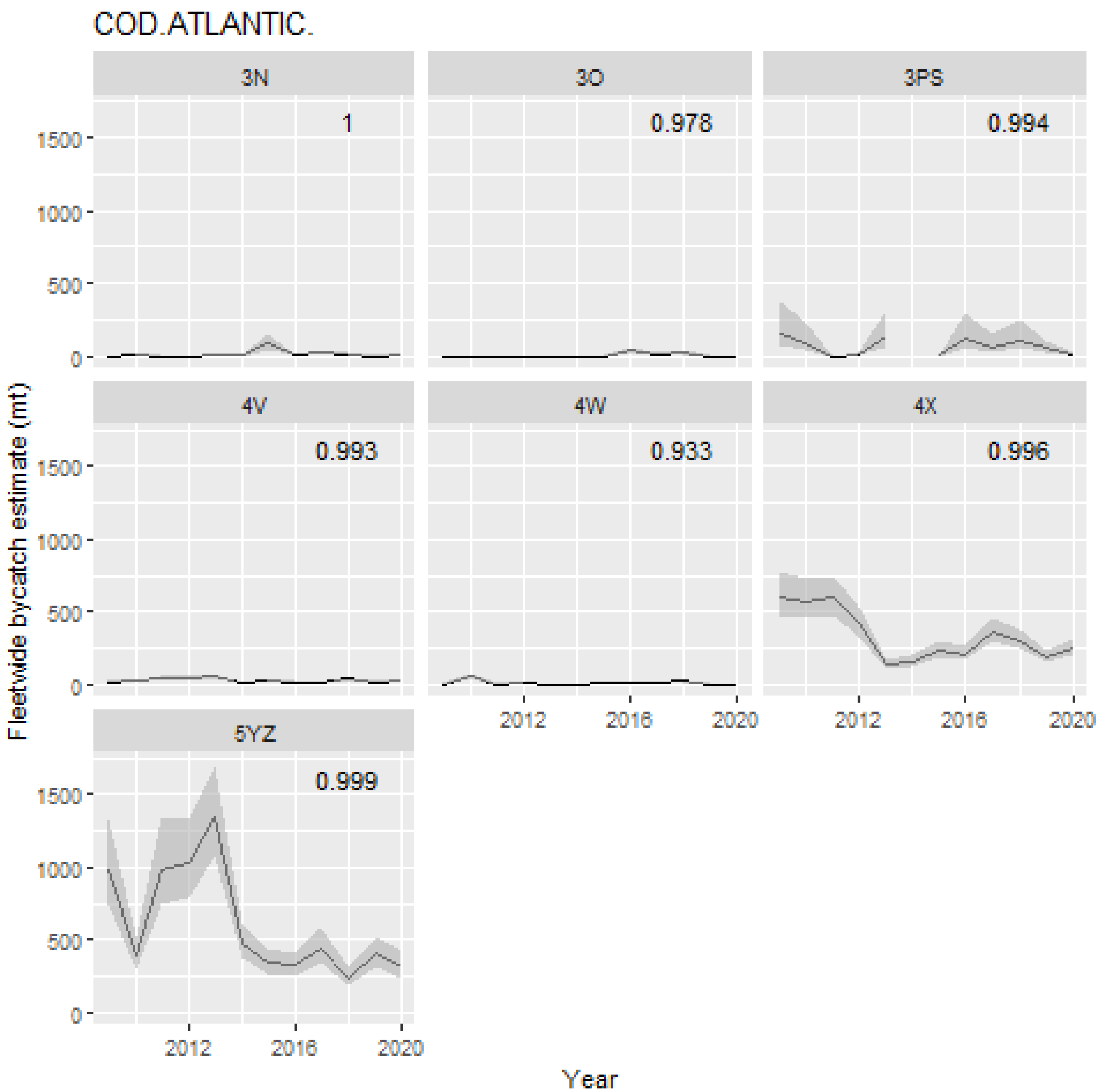

Figure A5. Atlantic Cod bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Atlantic Cod catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

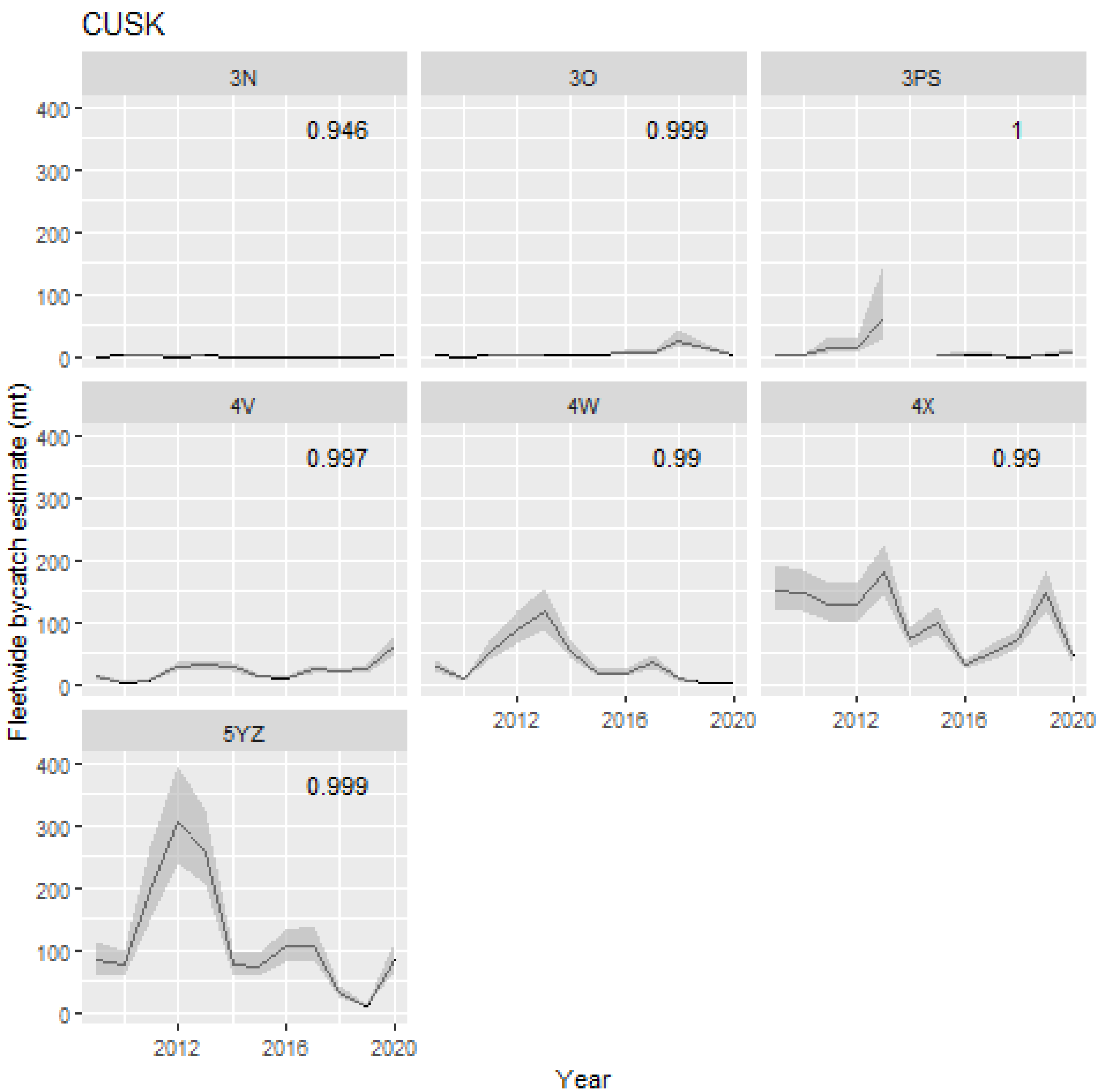

Figure A6. Cusk bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Cusk catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

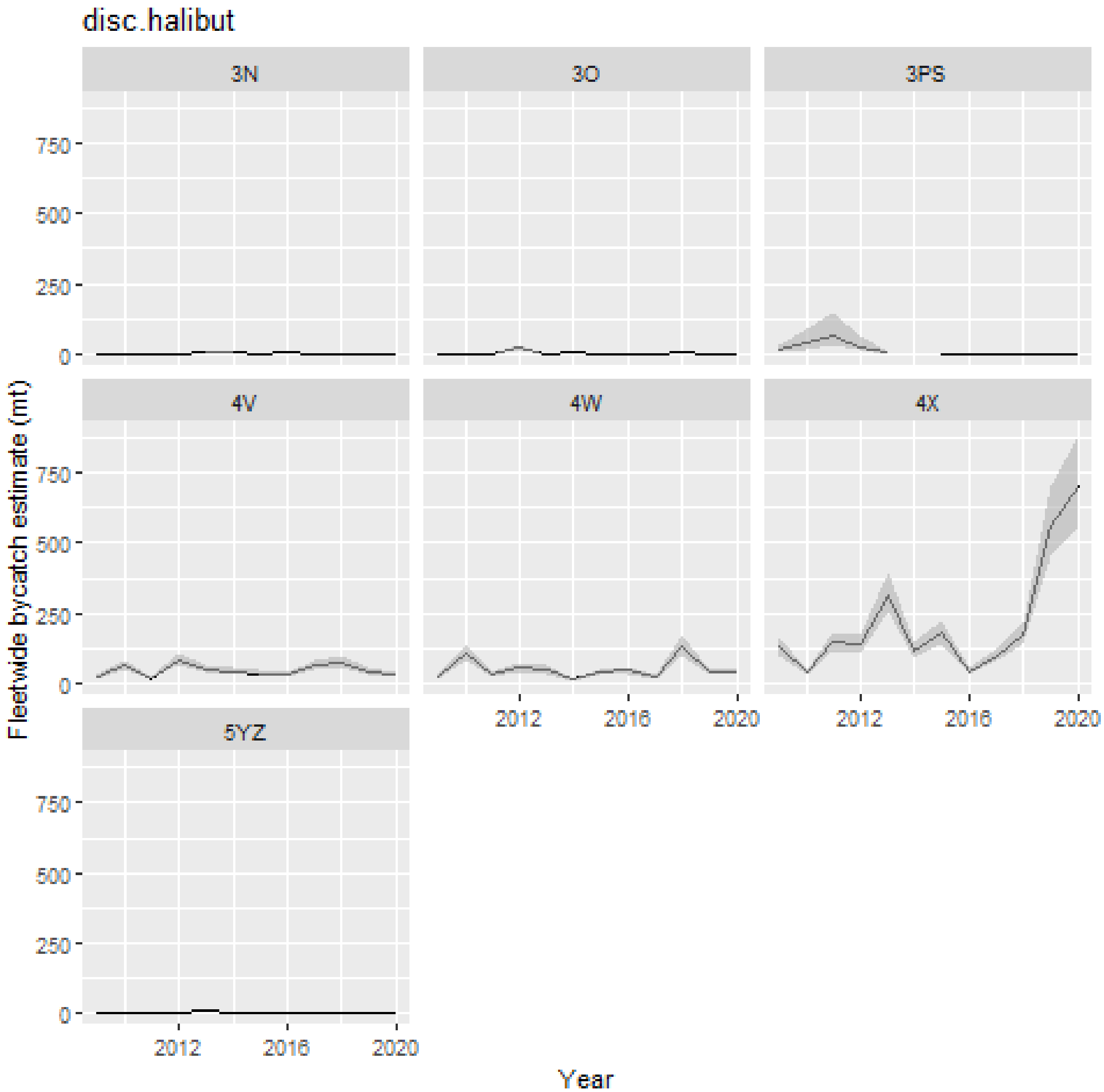

Figure A7. Discarded Atlantic Halibut bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Discarded Atlantic Halibut catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

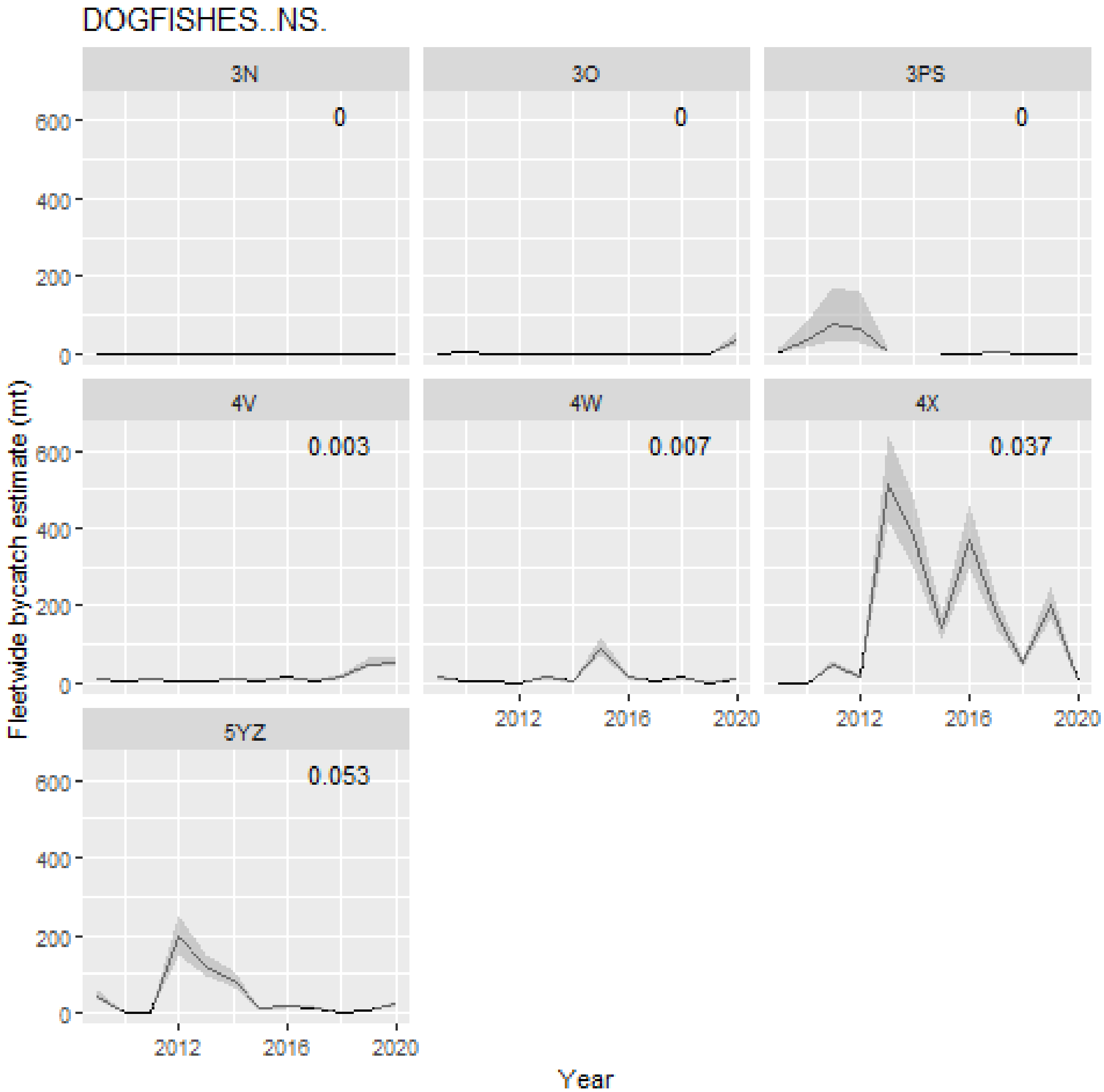

Figure A8. Dogfish (species non-specified (NS)) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Dogfish (NS) catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

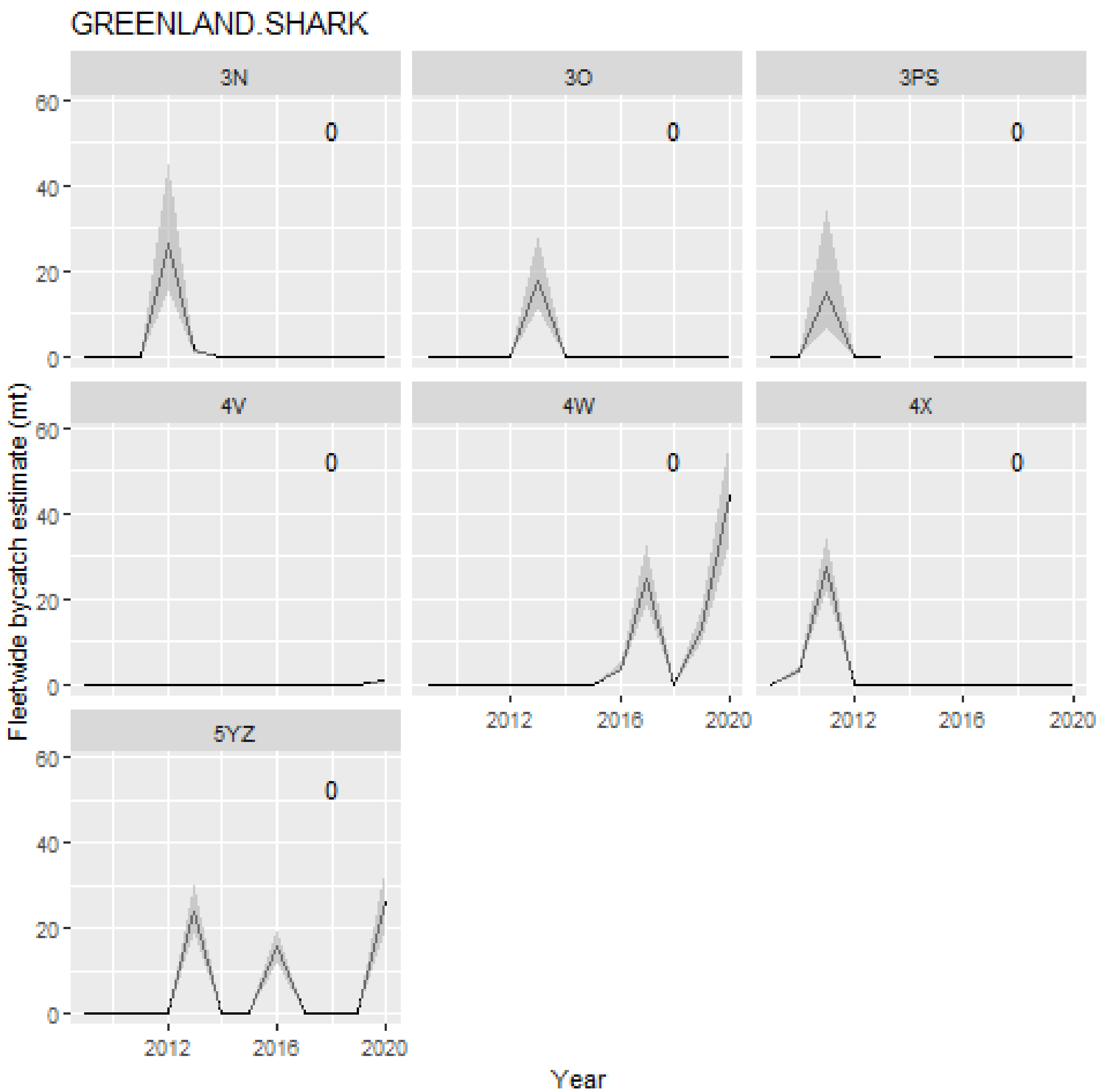

Figure A9. Greenland Shark bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Greenland Shark catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

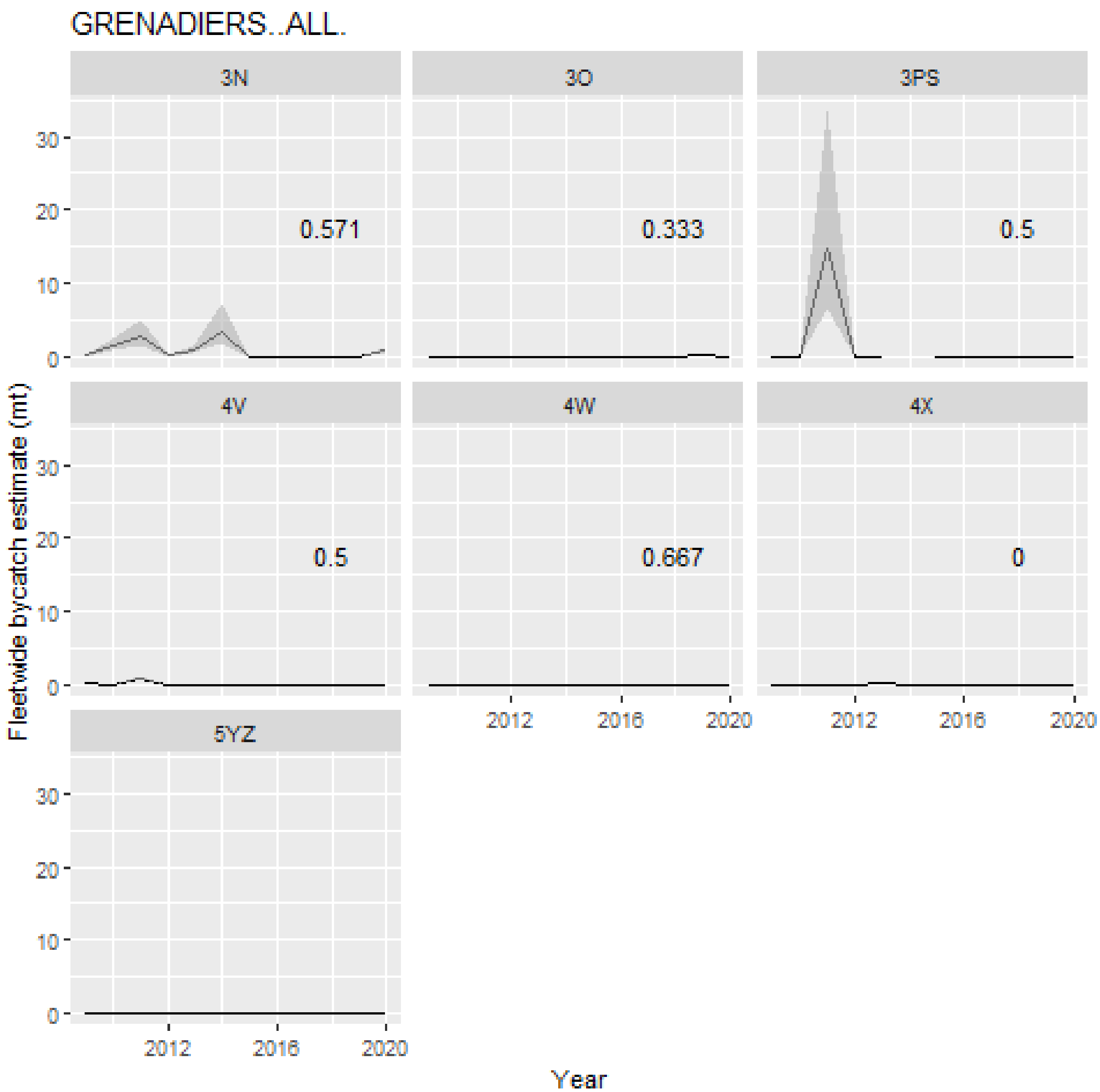

Figure A10. Grenadier (all species) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Grenadier catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

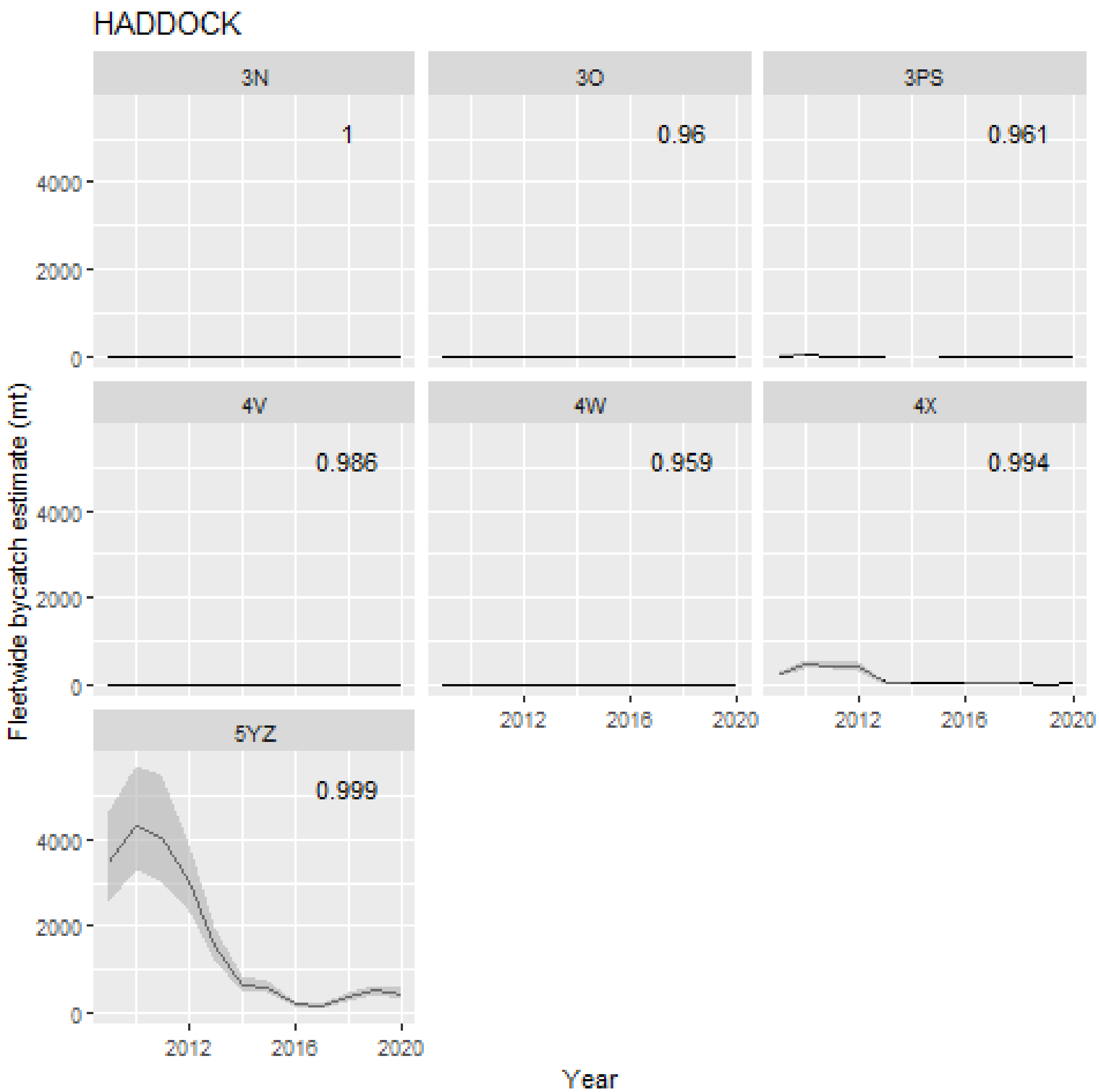

Figure A11. Haddock bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Haddock catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

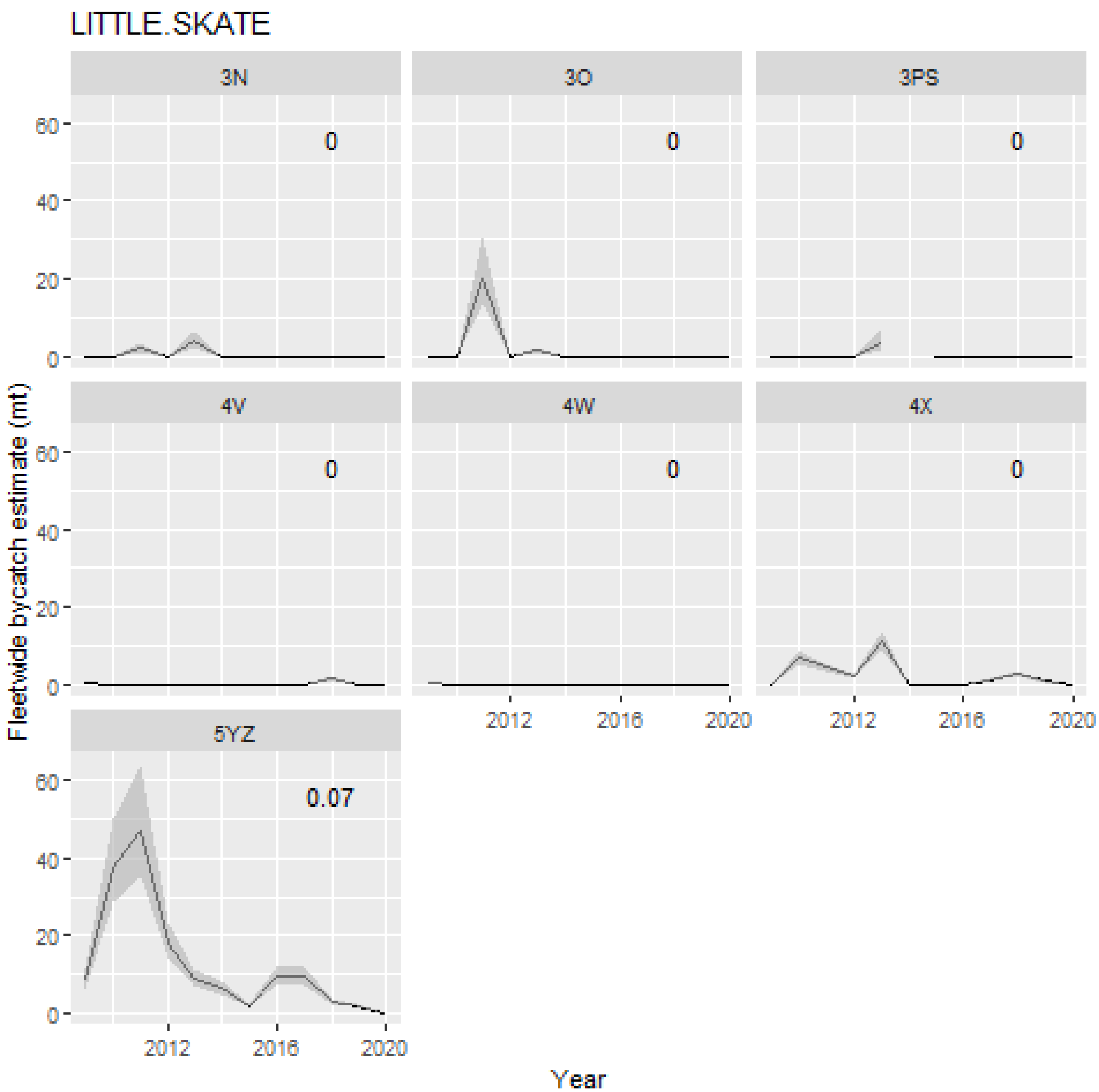

Figure A12. Little Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Little Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

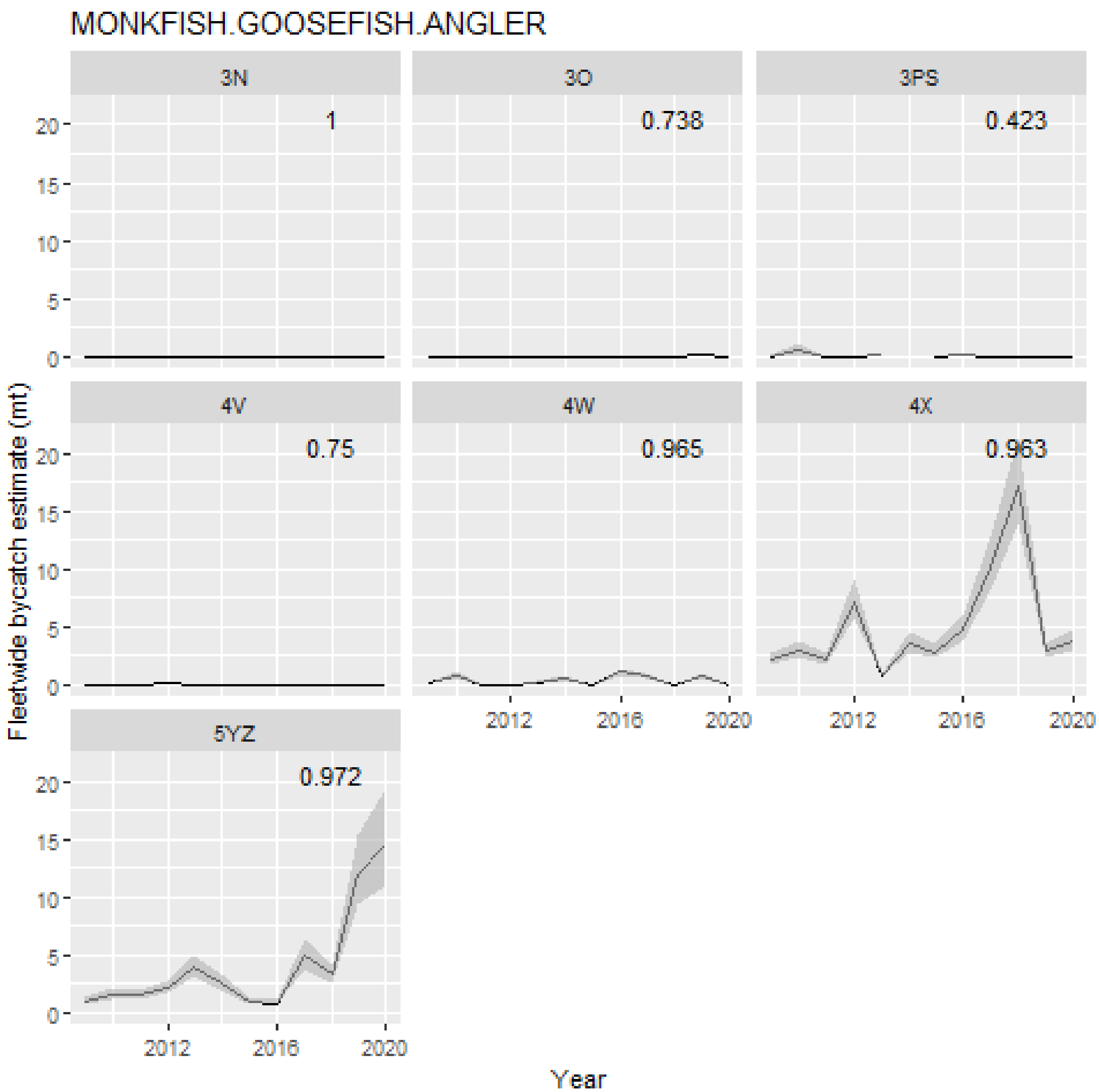

Figure A13. Monkfish, Goosefish and Anglerfish bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Monkfish, Goosefish and Anglerfish catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

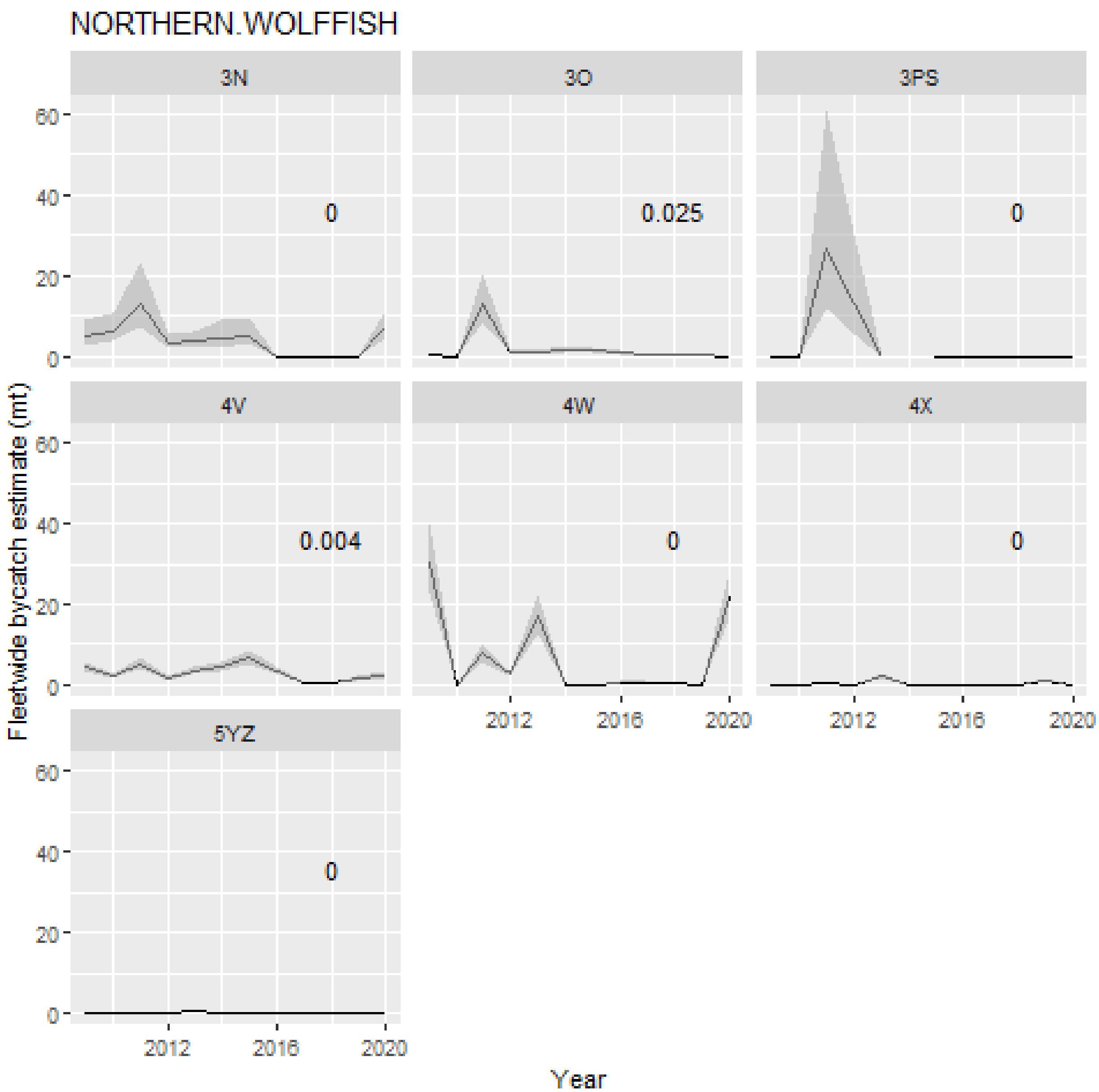

Figure A14. Northern Wolffish bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Northern Wolffish catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

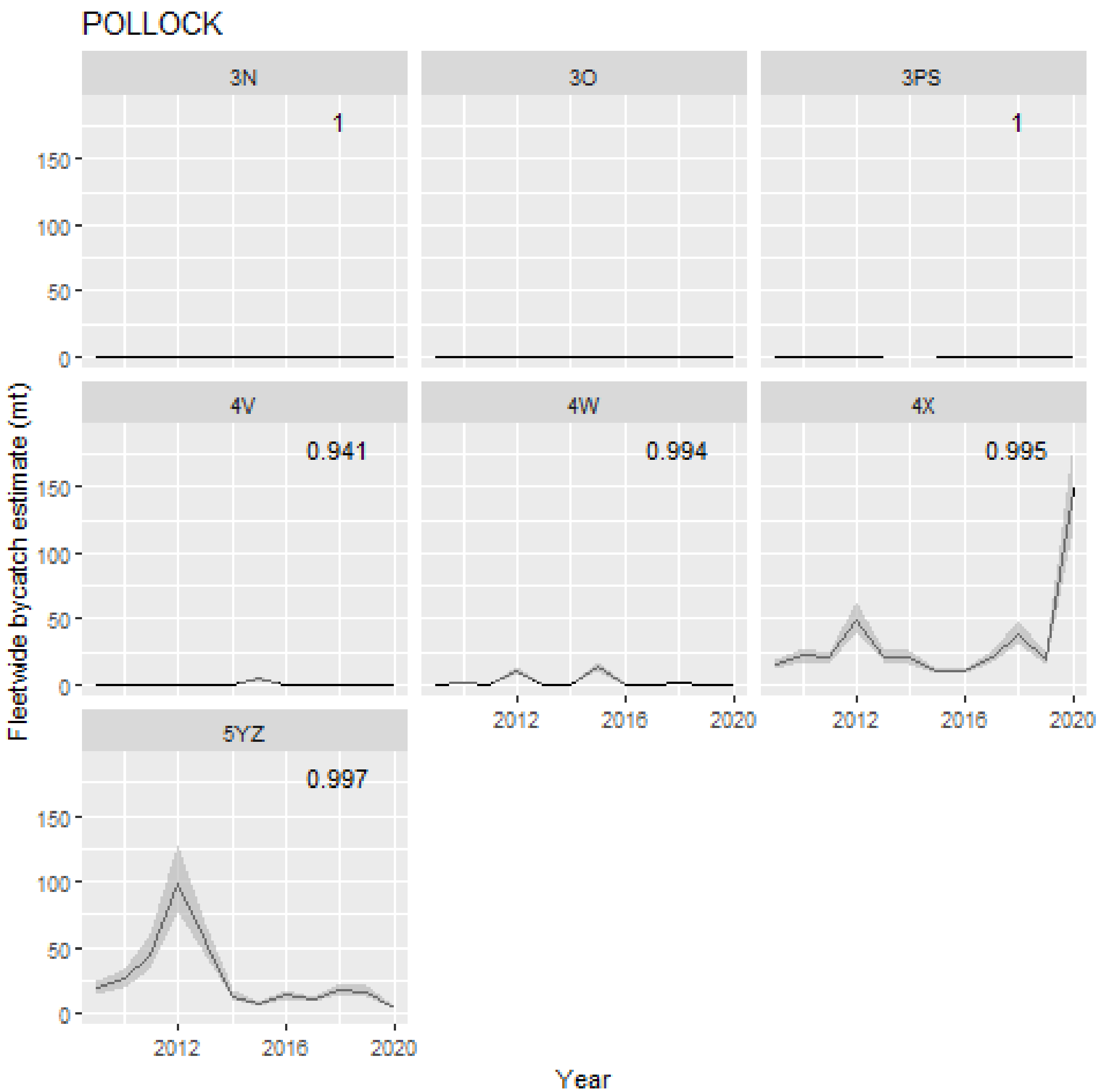

Figure A15. Pollock bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Pollock catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

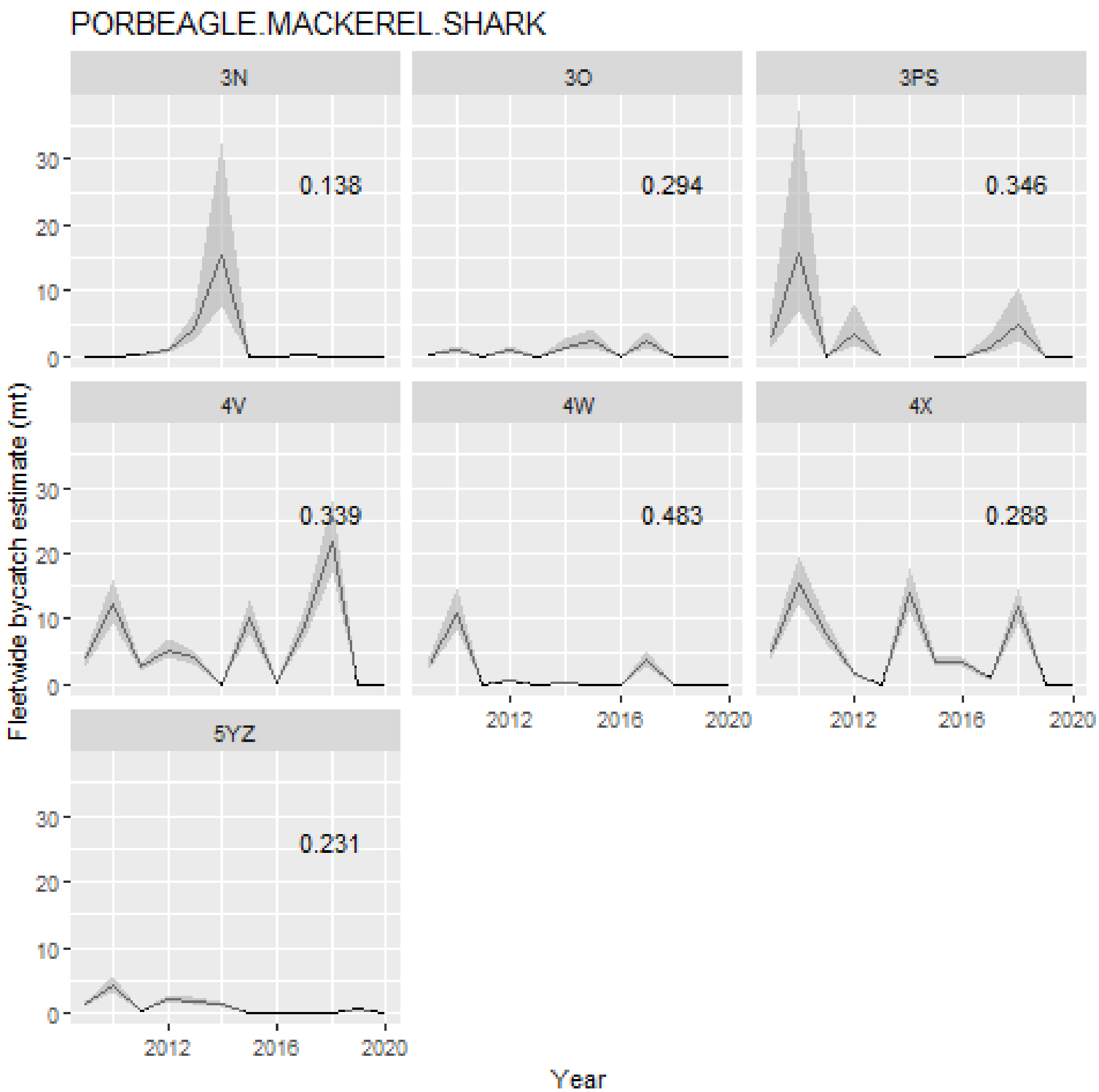

Figure A16. Porbeagle Shark (Mackerel Shark) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Porbeagle Shark catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

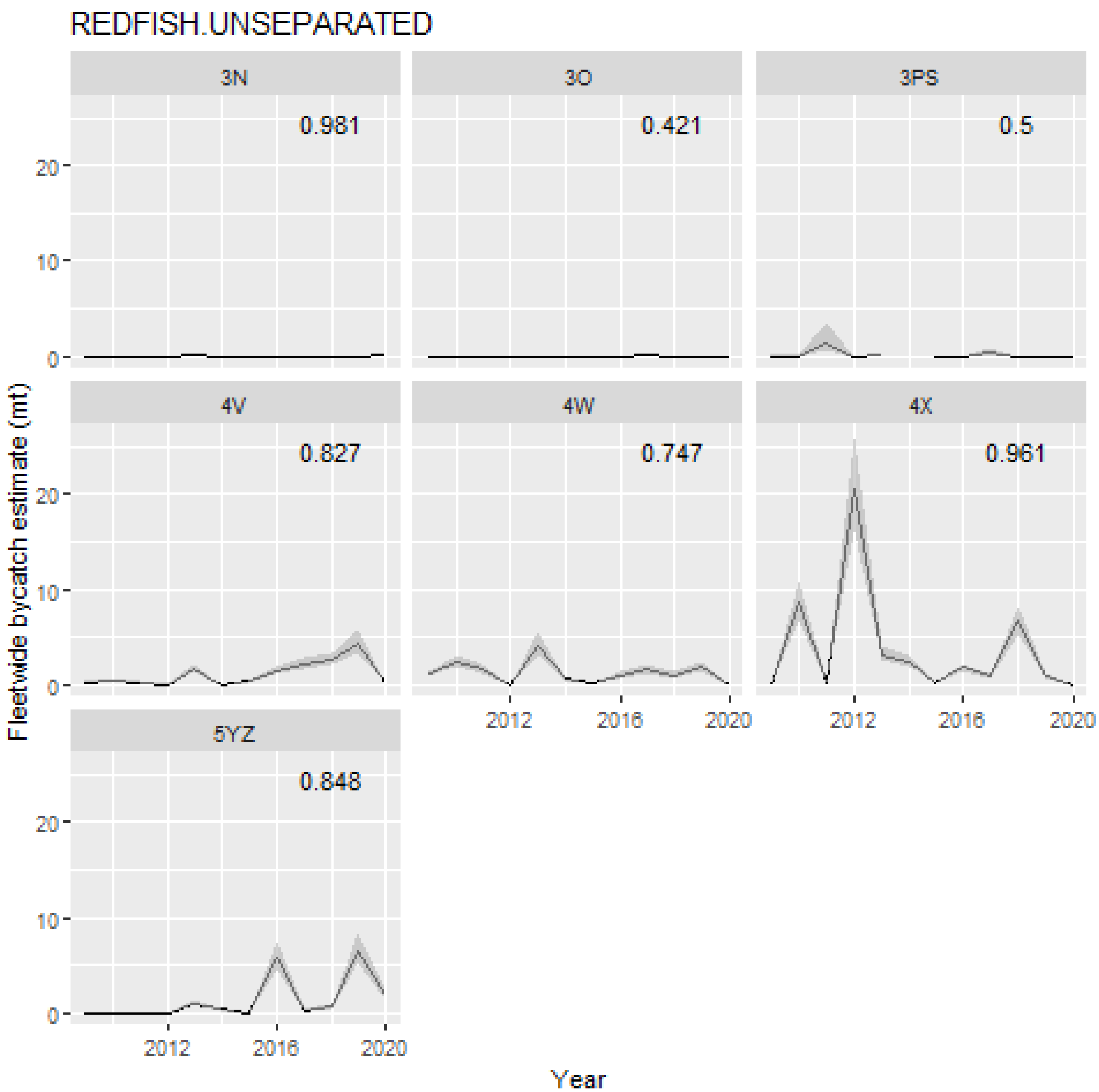

Figure A17. Redfish (not separated by species) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Redfish catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

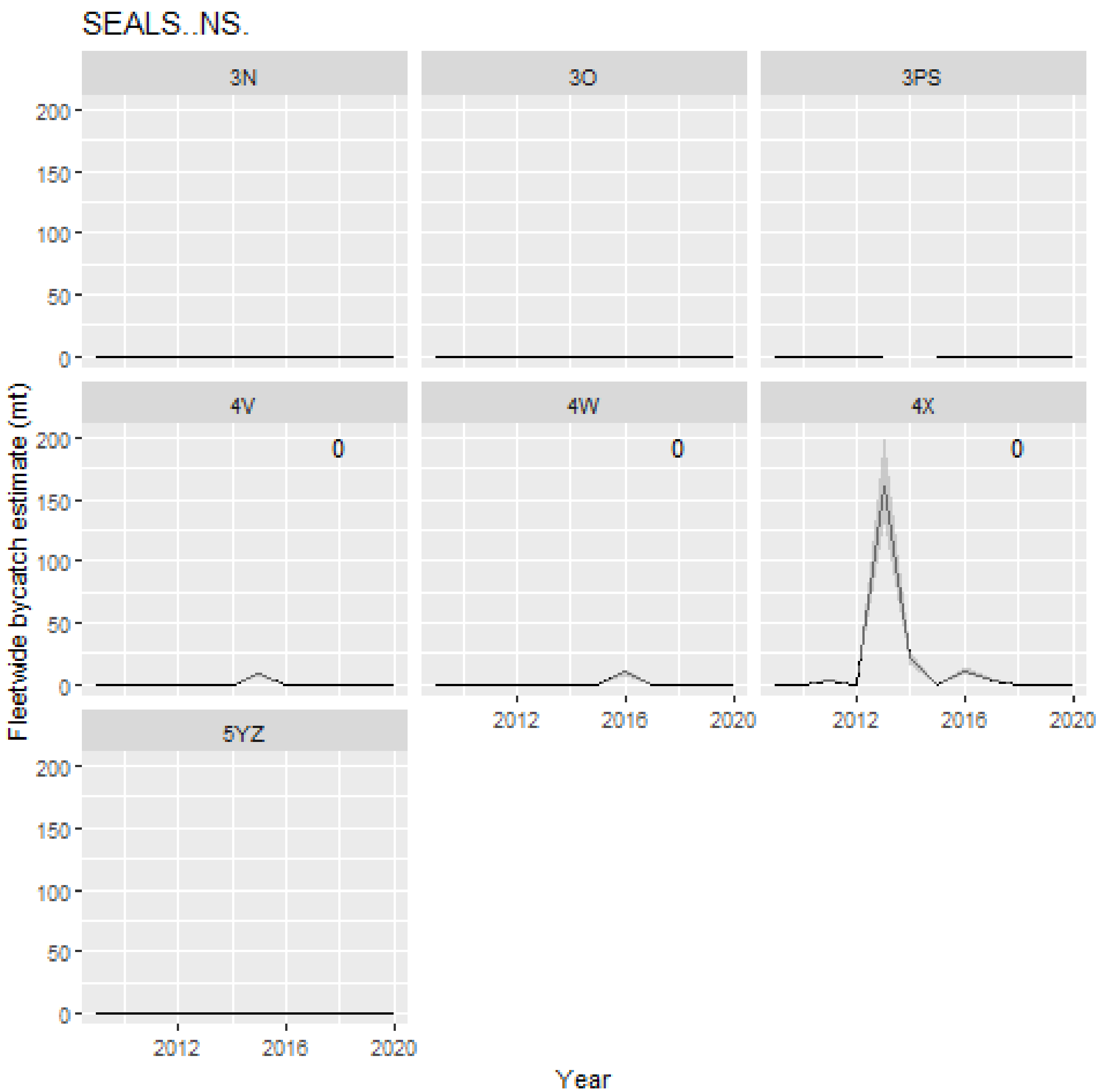

Figure A18. Seals (species non-specified (NS)) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Seals (NS) catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

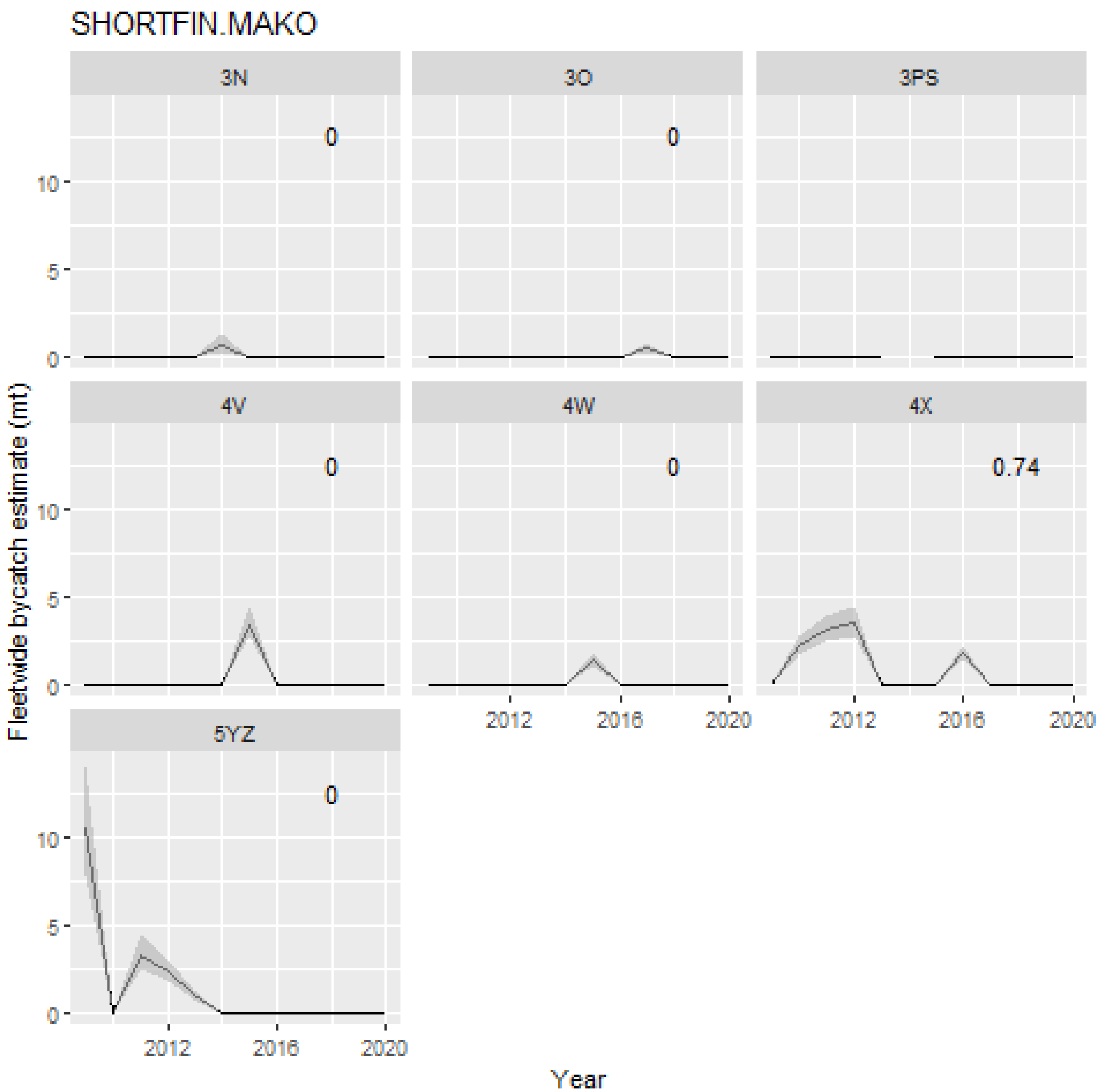

Figure A19. Shortfin Mako bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Shortfin Mako catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

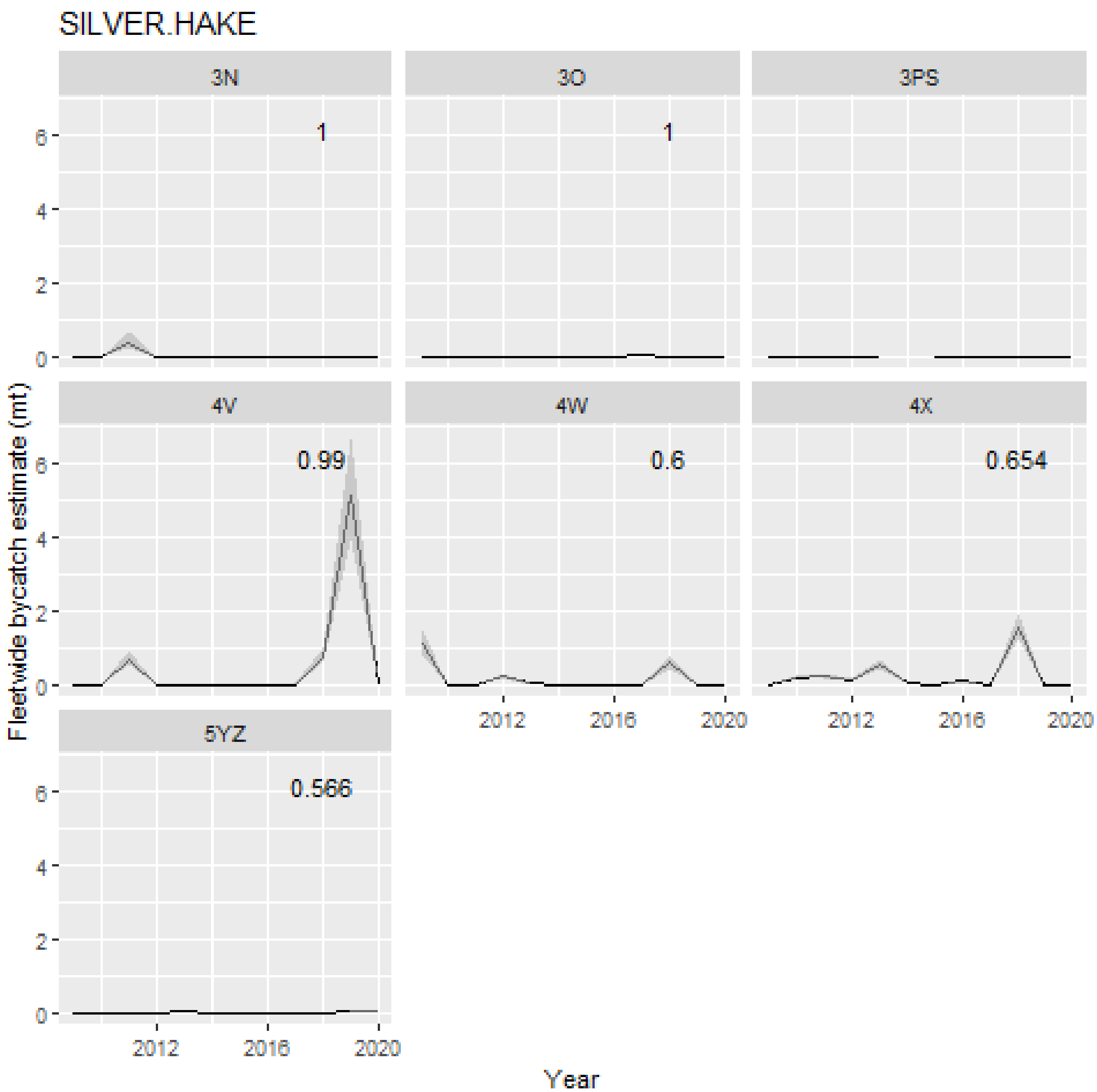

Figure A20. Silver Hake bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Silver Hake catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

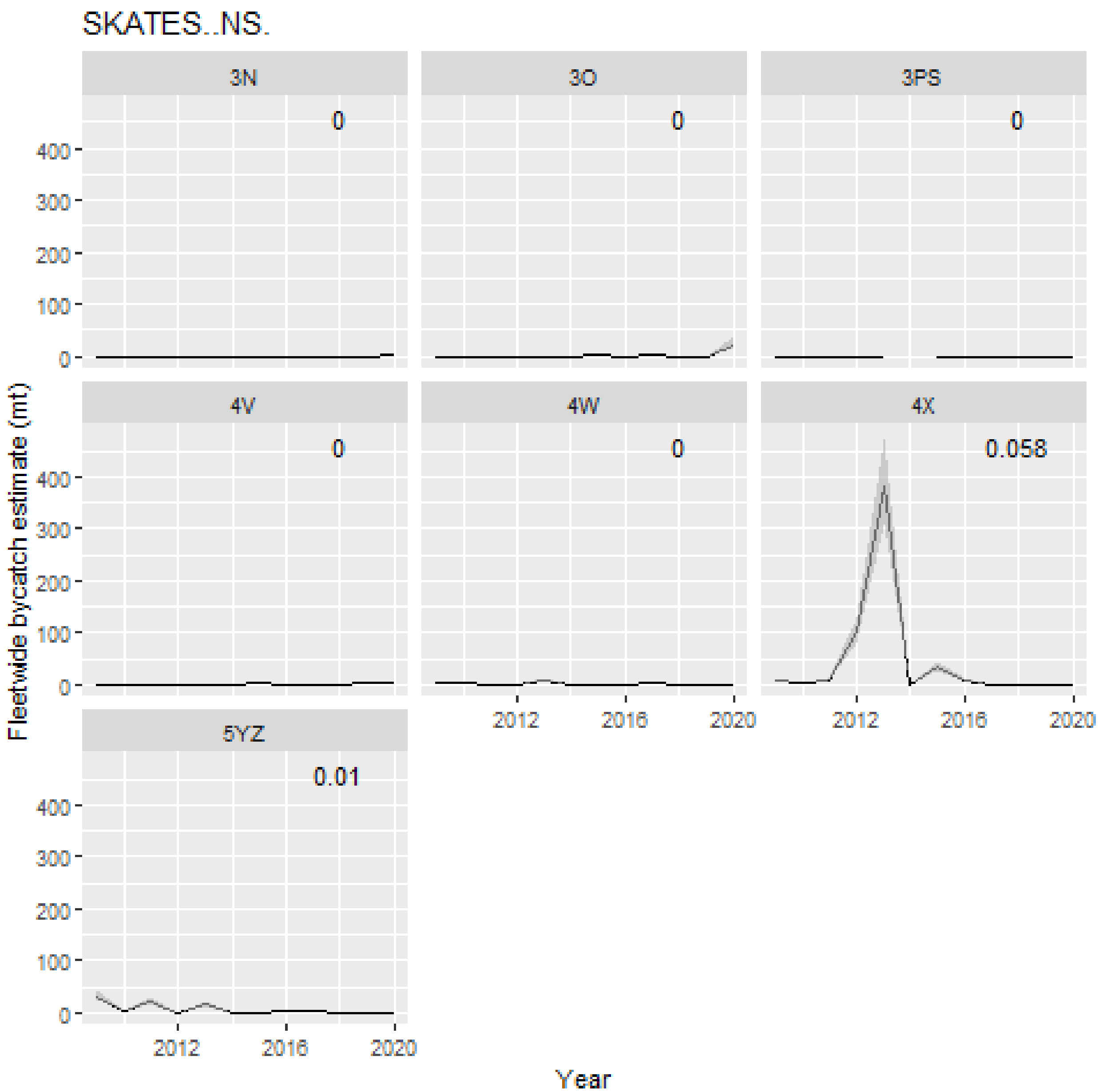

Figure A21. Skates (species non-specified (NS)) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Skates (NS) catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

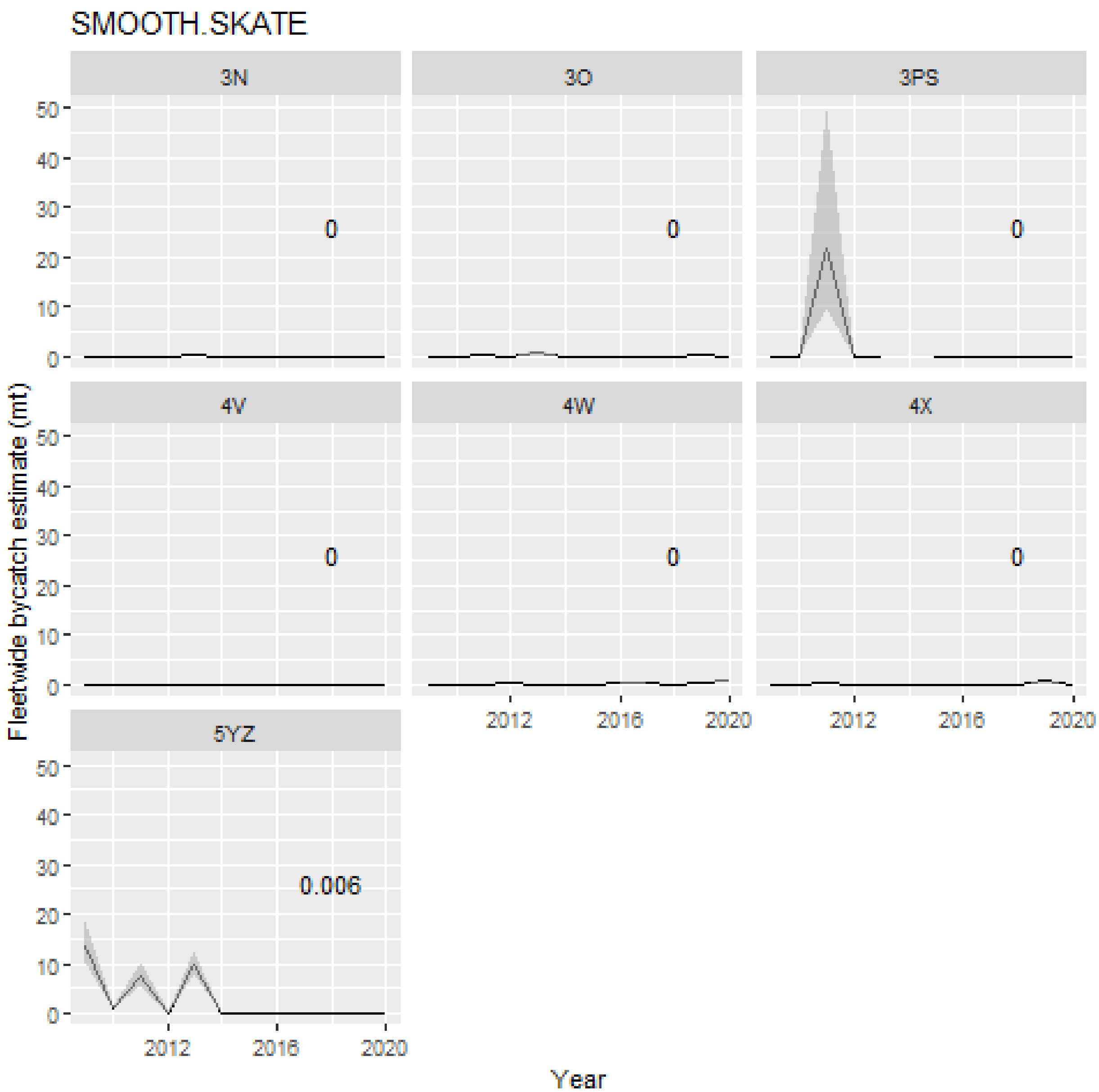

Figure A22. Smooth Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Smooth Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

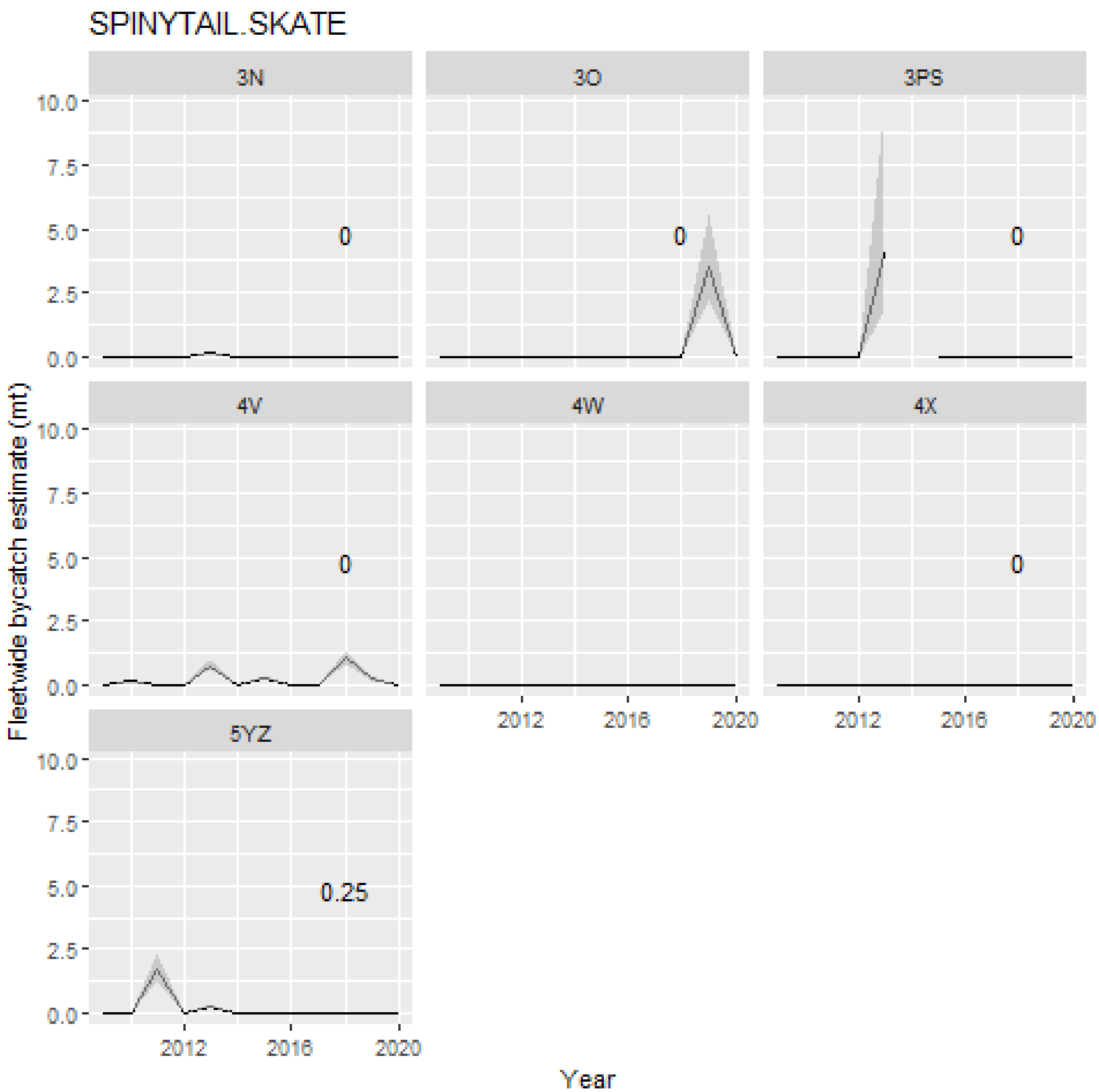

Figure A23. Spinytail Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Spinytail Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

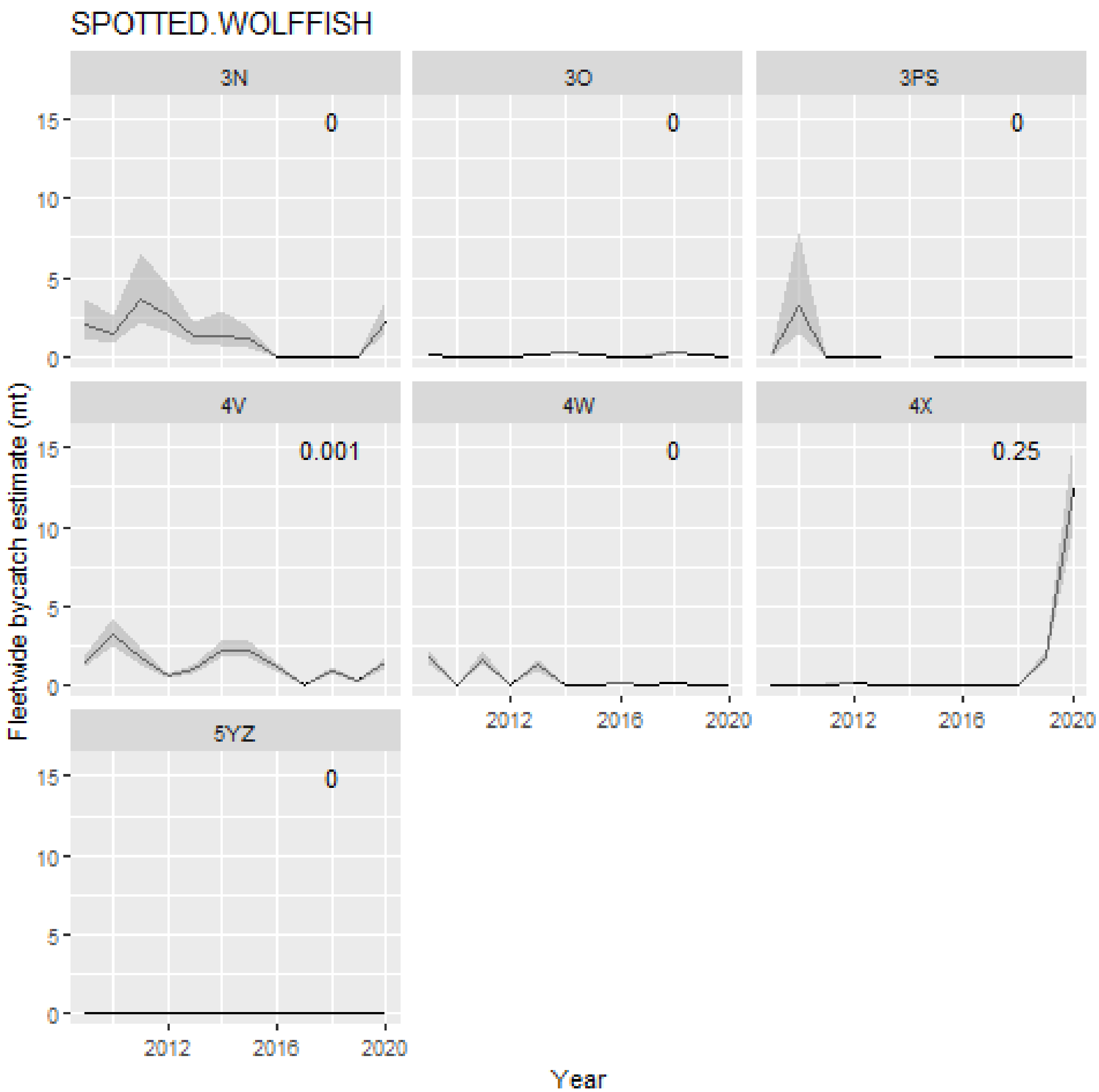

Figure A24. Spotted Wolffish bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Spotted Wolffish catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

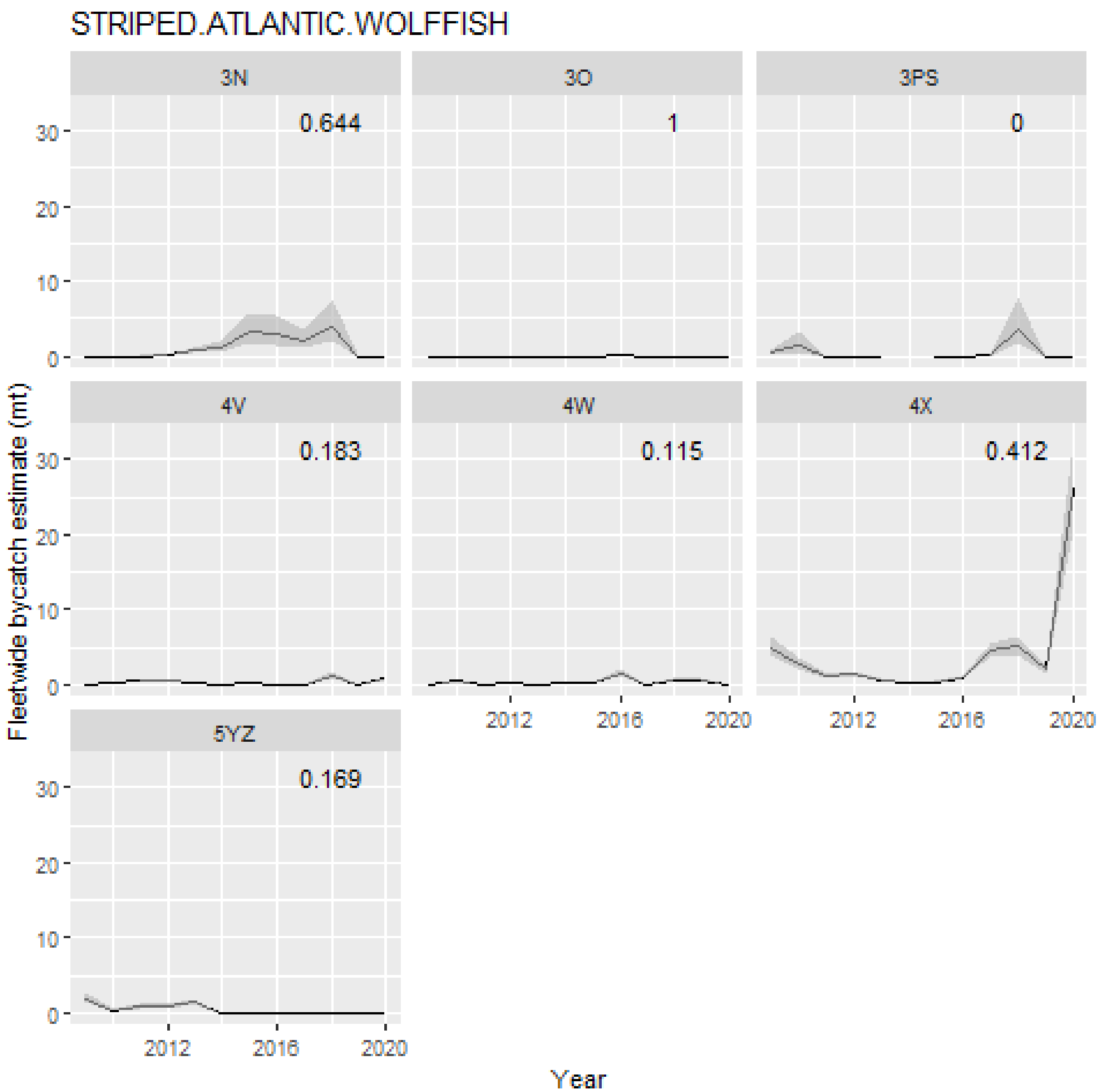

Figure A25. Striped Atlantic Wolffish bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Striped Atlantic Wolffish catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

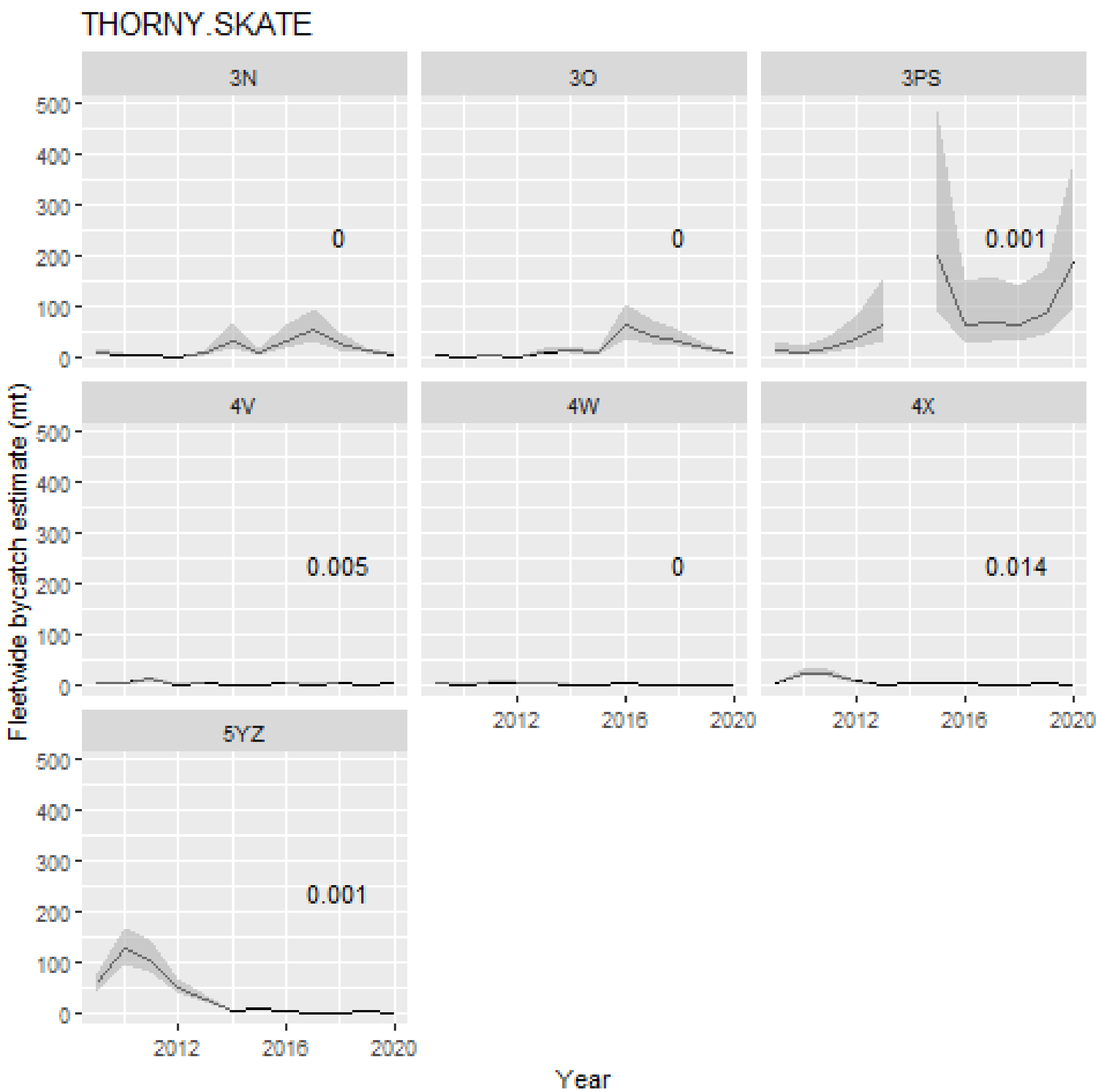

Figure A26. Thorny Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Thorny Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

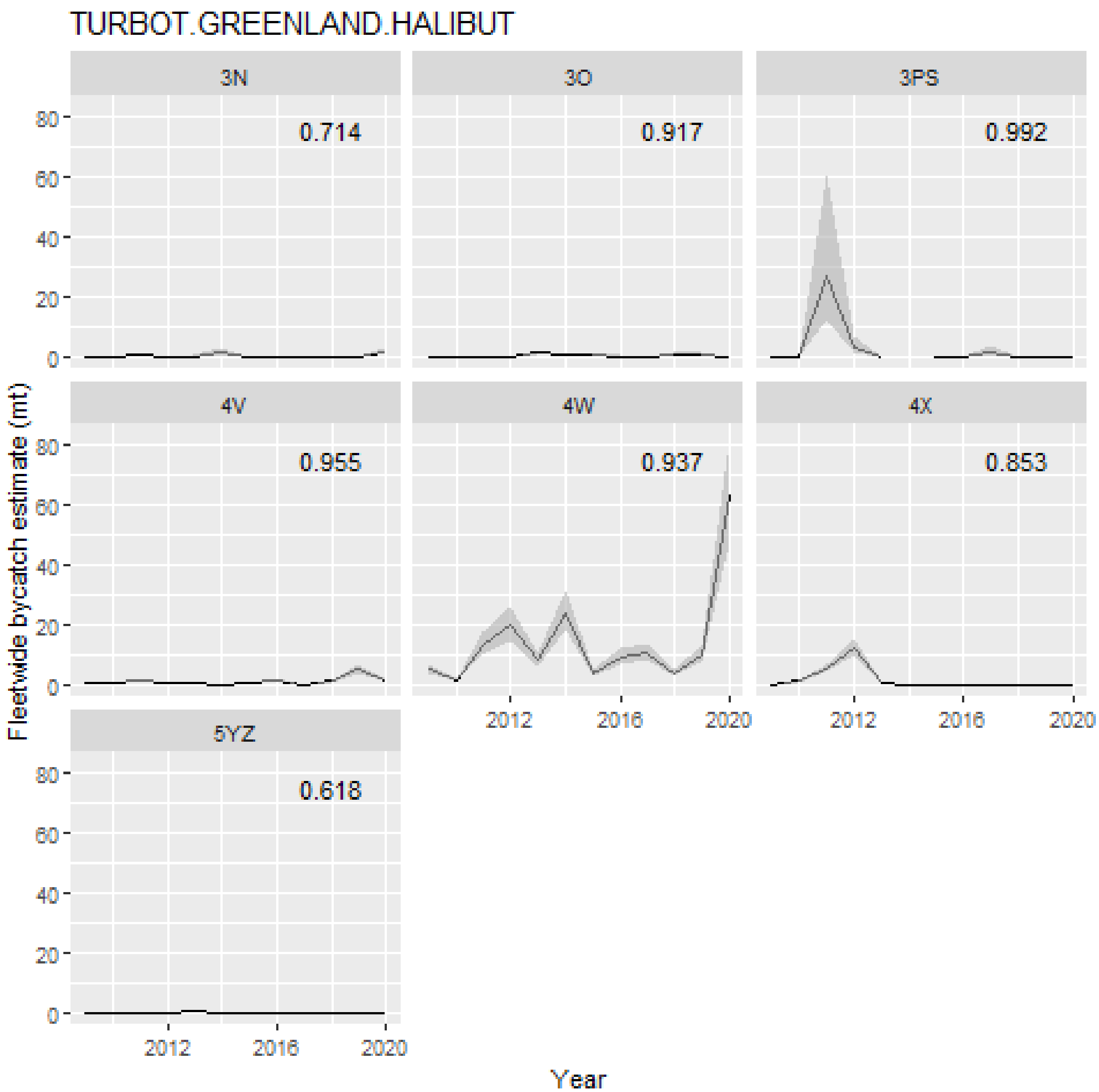

Figure A27. Turbot (Greenland Halibut) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Turbot catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

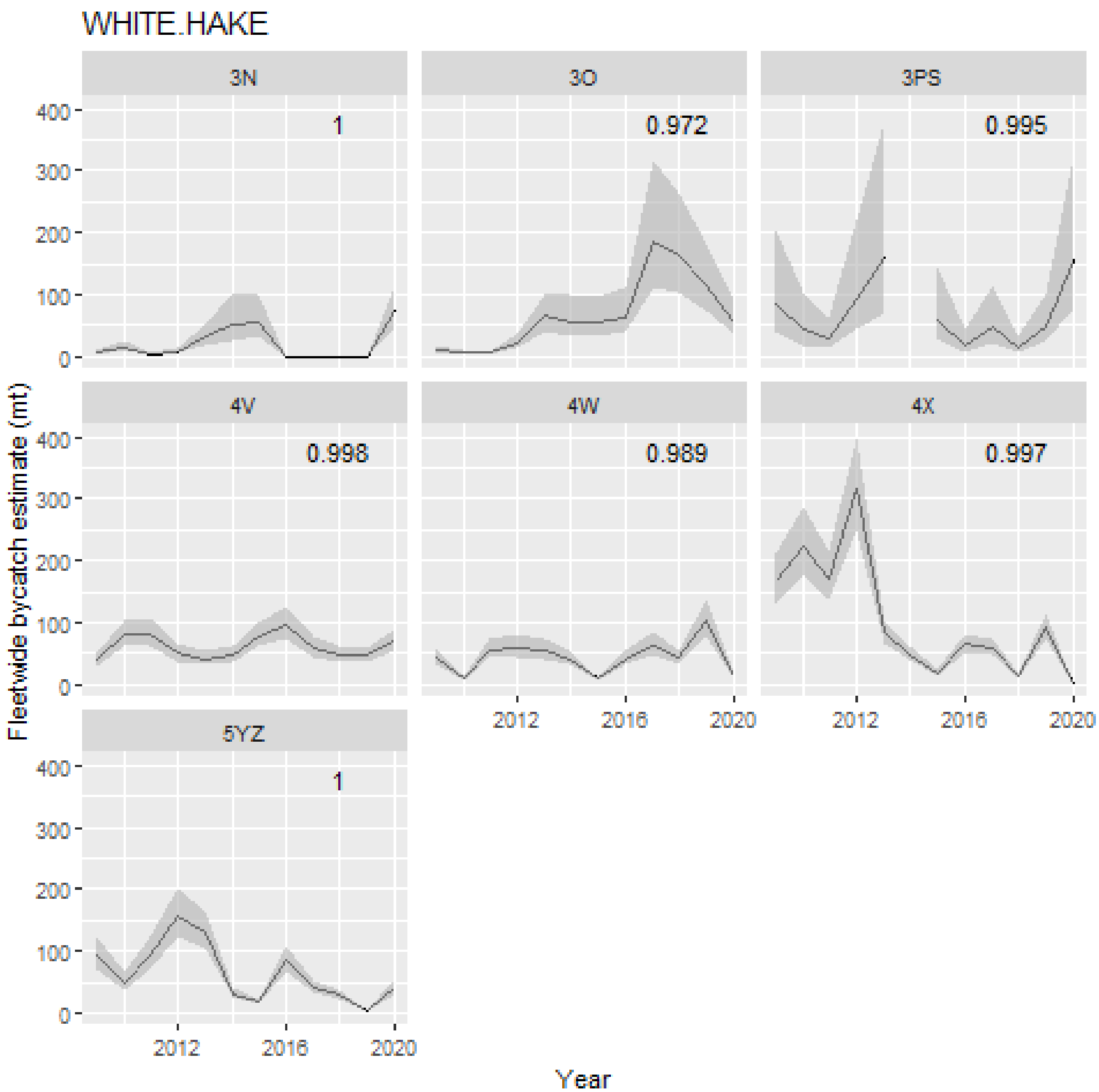

Figure A28. White Hake bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined White Hake catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

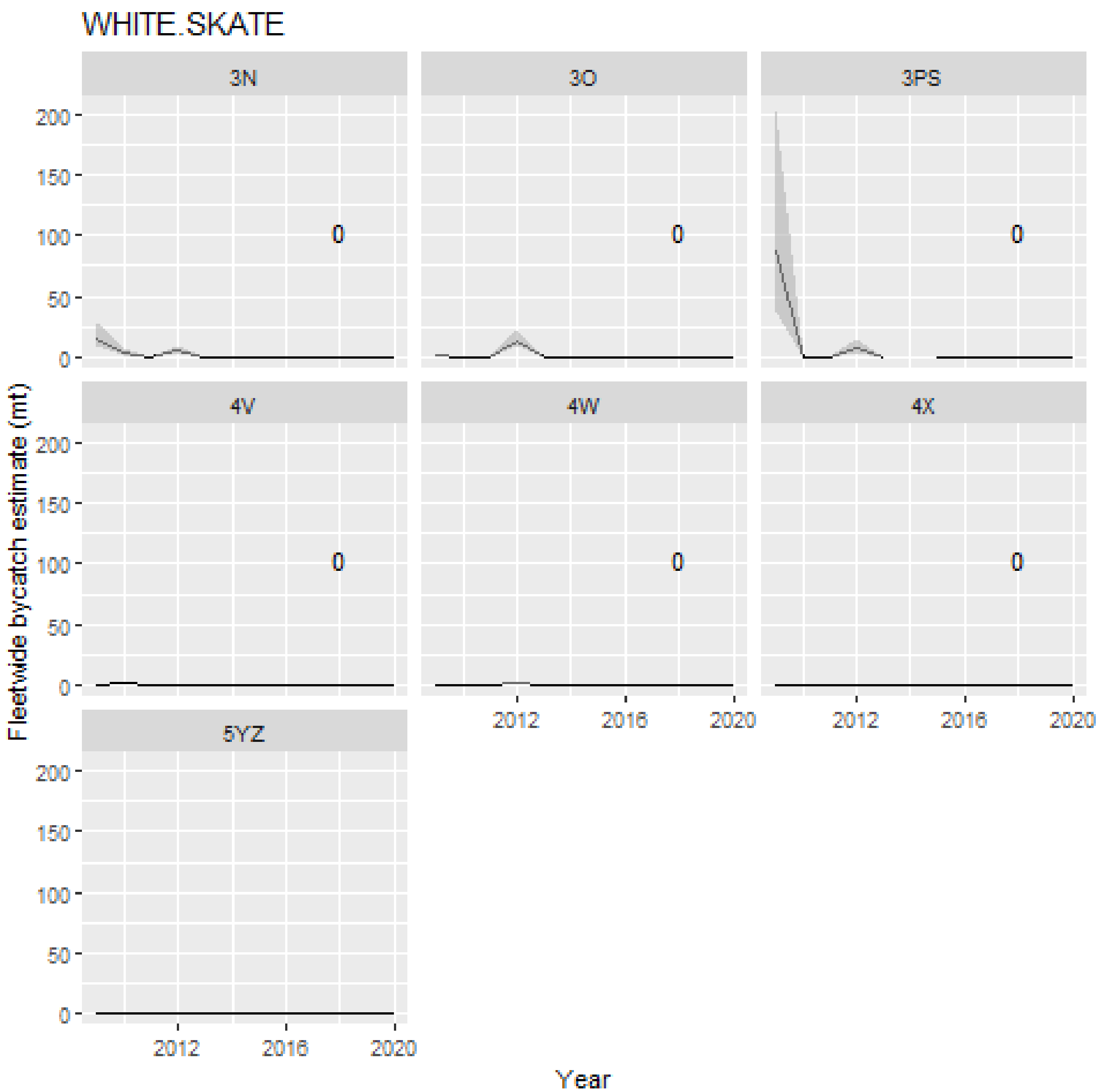

Figure A29. White Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined White Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

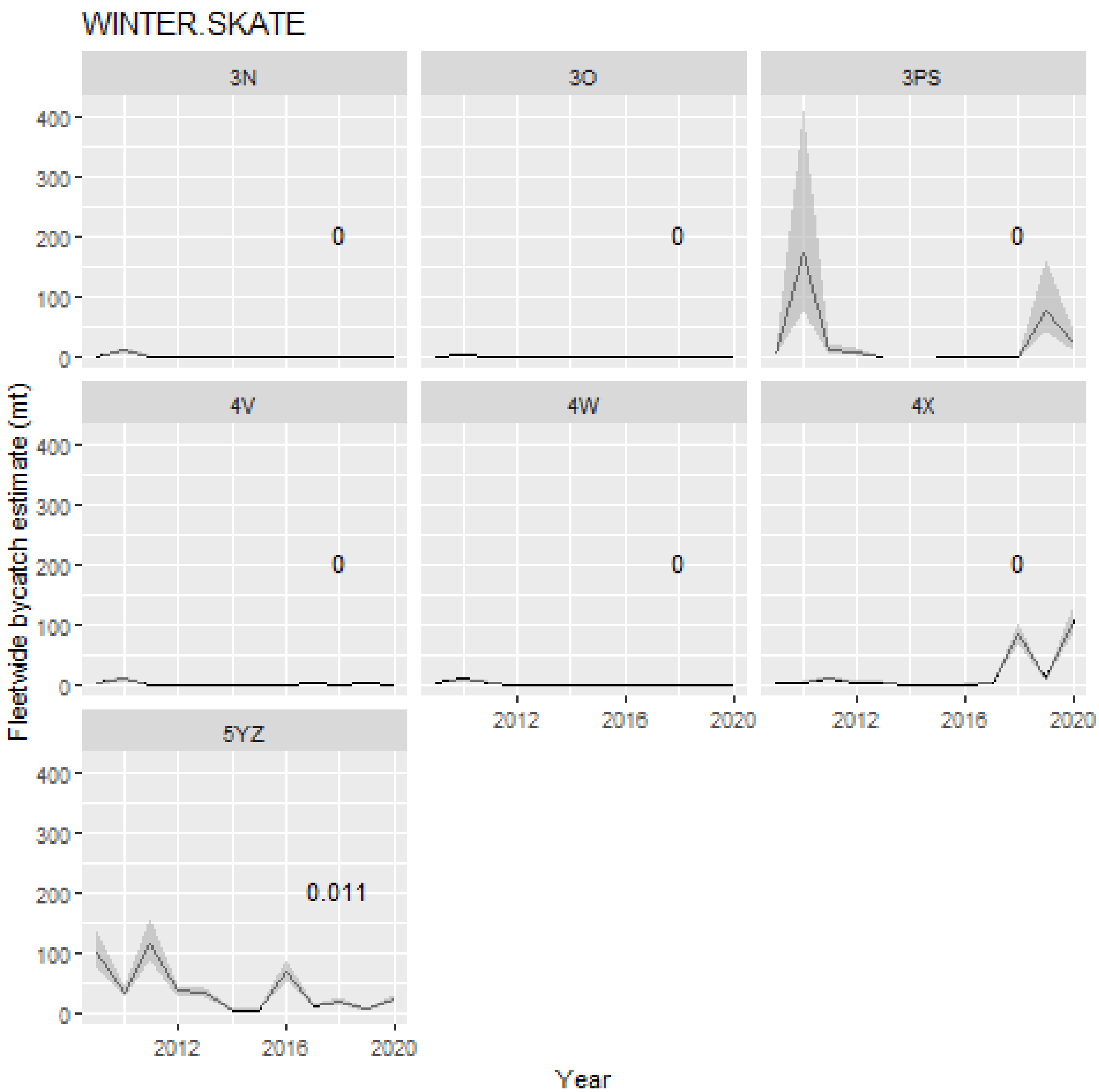

Figure A30. Winter Skate bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Winter Skate catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.

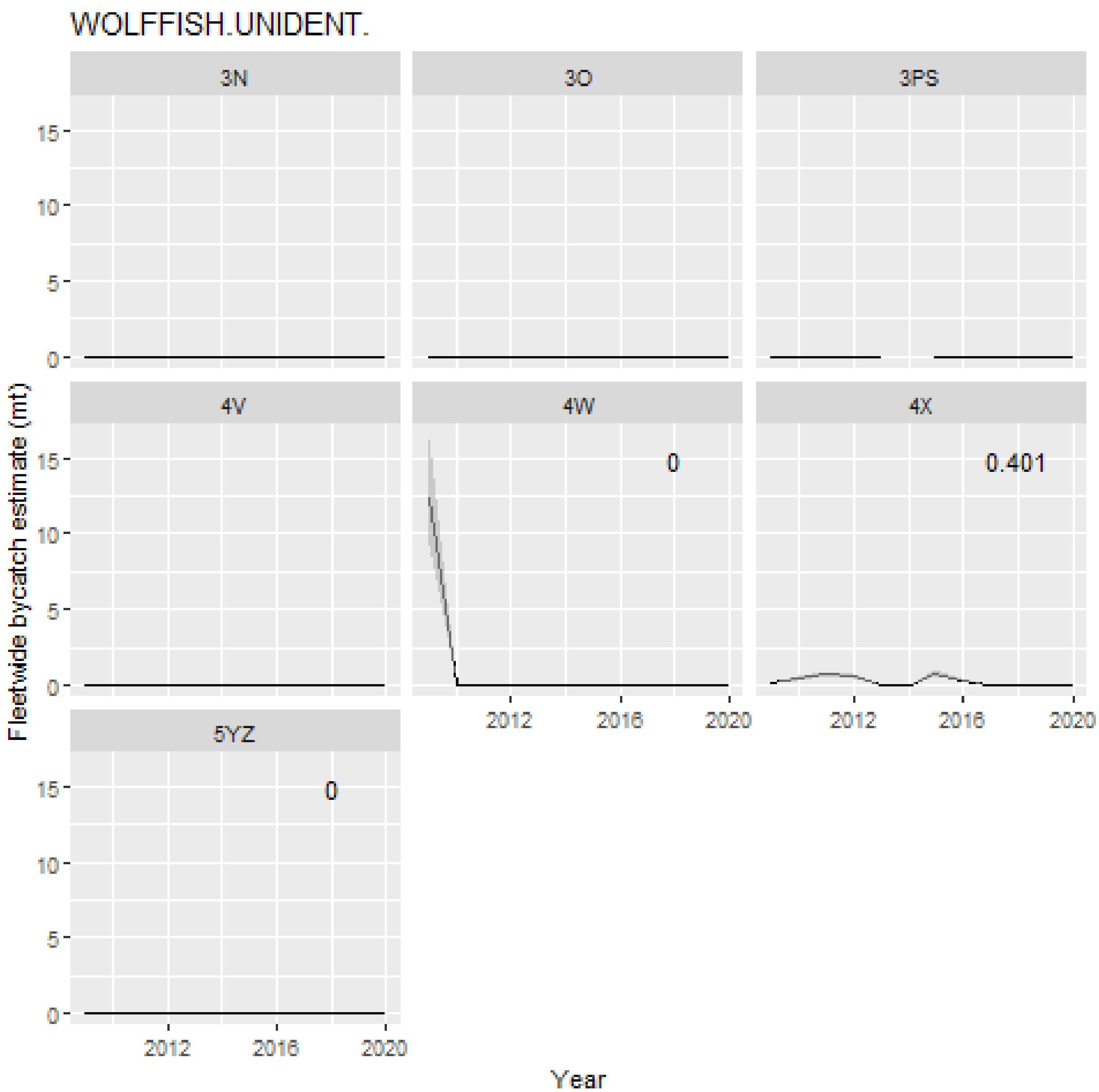

Figure A31. Wolffish (unidentified species) bycatch predictions (black lines) plus approximate 95% confidence intervals (grey shading) from 2009–2020 by Northwest Atlantic Fisheries Organization (NAFO) Division. The numeric value represents the mean proportion over time of the combined Wolffish catch (kept + discarded) that was retained and discarded by this fleet. Values close to zero indicate discarding, while values close to one show retention.