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Newfoundland and Labrador Region

Status of the *Anarhichas lupus*, *A. minor*, and *A. denticulatus* in the Canadian Atlantic and Arctic Regions

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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 the latest assessment on the status of Northern Wolffish, Atlantic Wolffish, and Spotted Wolffish stocks that inhabit the Canadian Atlantic and Arctic Regions. There was a noticeable increase in the indices of stock size since the mid–2000s in Newfoundland and Labrador (NL) Region, as well Atlantic Wolffish and Spotted Wolffish in the Quebec Region, but only Spotted Wolffish in Northwest Atlantic Fisheries Organization (NAFO) Divisions (Div.) 2J3K continued to experience some level of recovery in most recent periods, including a northward expansion in range into Div. 2H during the last decade. However, since the last assessment in 2014, population status for all three wolffish species throughout Canadian Atlantic and Arctic waters remains largely unchanged and has shown little recovery.

Most wolffish interactions with commercial fisheries occurred in the areas where the stocks are centered, primarily along the slopes of the continental shelf and deep channels, and to a lesser extent over the southern Grand Bank and the remaining portions of the study area. Mobile fleets were responsible for the majority of wolffish removals in NL and Maritimes Regions prior to 2003, as well in the Arctic Region (2000–21), whereas fixed gear fleets accounted for most wolffish removals in the Quebec and Gulf Regions.

INTRODUCTION

The most recent Zonal Peer Review (ZPR) on the status of the three wolffish species inhabiting Canadian Atlantic and Arctic waters was conducted in 2014 (Collins et al. 2015). Since then, the most significant contributions to the status of these species have been the identification of critical habitats and the development of an action plan for the recovery of Northern Wolffish (*Anarhichas denticulatus*) and Spotted Wolffish (*A. minor*) (DFO 2020a). In addition, recent trends in abundance and distribution of Atlantic Wolffish (*A. lupus*) within Scotian Shelf waters (DFO 2022a) were found to have remained largely unchanged since the last assessment by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

The three species of wolffish that inhabit Canadian Atlantic and Arctic waters were added to Schedule 1 of Canada's *Species at Risk Act* (SARA) in 2003, with the status of Atlantic Wolffish being assessed as Special Concern, and those of Northern Wolffish and Spotted Wolffish being assessed as Threatened, due to major declines in abundance (>90%) and reductions in the area of occupancy over 2 to 3 generations. The SARA status of these species were re-assessed and confirmed by COSEWIC in 2012: there have been some increases in Spotted Wolffish abundance and area of occupancy over most of its Canadian range (COSEWIC 2012a); Northern Wolffish has experienced small increases in abundance and area occupied since about 2002 (COSEWIC 2012b); and, while continued declines in Atlantic Wolffish abundance have occurred in the southern Gulf of St. Lawrence (sGSL) and on the Scotian Shelf, there have been overall increases in this species' abundance and area of occupancy (COSEWIC 2012c). However, since the last assessment in 2014, population status for all three wolffish species throughout Canadian Atlantic and Arctic waters remains largely unchanged and has shown little recovery.

The objective of this document is to provide an updated assessment of Northern Wolffish, Atlantic Wolffish, and Spotted Wolffish through analyses of the most recent data on population status, life history, habitat use, and interactions with commercial fisheries. Updates from five Regions of Fisheries and Oceans Canada (DFO) are presented based on the following Divisions and Subdivisions: Newfoundland and Labrador (Div. 2GHJ3KLNO and Subdiv. 3Ps), Quebec (Div. 4RS + St. Lawrence Estuary), Gulf (Div. 4T), Maritimes (Div. 4VWX5Y, and Subdiv. 5Ze), and Arctic (Div. 0AB) (Figs. 1a-b).

SPECIES ECOLOGY AND BIOLOGY

Geographic Range and Designatable Unit (DU)

Wolffish (Genus *Anarhichas*) inhabit both sides of the North Atlantic Ocean. In Canadian Atlantic and Arctic waters, Northern Wolffish, Atlantic Wolffish, and Spotted Wolffish are found from the Davis Strait to the Maritimes Provinces; the distributions of the three species overlap to some extent across their geographic range (DFO 2020a). Tagging studies have indicated that the three species are largely sedentary, with most individuals being recaptured at scales of tens of kilometers or less from the release site, with only a few individuals being recaptured at scales of hundreds of kilometers within the study period (Templeman 1984, Riget and Messtorff 1988, Simpson et al. 2015). Moreover, COSEWIC considers each wolffish species in Canadian waters as a single population or Designatable Unit (DU).

Habitats

Wolffish are demersal fish species found over all bottom types, including hard bottom with complex relief; Atlantic Wolffish presence in soft sediments like sand and mud is infrequent, whereas the highest concentrations of Northern Wolffish and Spotted Wolffish are found over sand, shell hash, and coarse sand (Rountree 2002, Kulka et al. 2004, DFO 2020a, DFO 2022a).

The three wolffish species occupy varying depths across their geographic ranges. In Canadian Atlantic and Arctic waters, Northern Wolffish inhabit depths of up to 1,500 m, and close to 1,000 m for Spotted Wolffish and Atlantic Wolffish. Atlantic Wolffish and Spotted Wolffish also inhabit nearshore waters seasonally (Kulka et al. 2004, DFO 2020a and references therein).

Wolffish thermal ranges vary between species and with geographic region. In NL waters, Northern Wolffish and Spotted Wolffish are more common at temperatures between 1.5 to 5ºC and Atlantic Wolffish between -1.5 to 4ºC (Kulka et al. 2004, DFO 2020a). Atlantic Wolffish in the Maritimes Region tolerates a wider range of temperatures, from -1 to 10ºC (DFO 2022a).

Trophic Interactions

Wolffish species are members of the demersal fish assemblage, occupying a broad range of ecological niches. The diet of Northern Wolffish in Canadian waters consists primarily of pelagic and benthic fish, and shellfish; crabs and echinoderms for Atlantic Wolffish; and shrimp and echinoderms for Spotted Wolffish (Simpson et al. 2013a). The preference for specific prey groups suggests that the three wolffish species exploit different trophic niches despite the overlap in distribution across their geographic range.

Natural predators of wolffish include Greenland Shark (*Somniosus microcephalus*), finfish species such as Whiting (*Merlangius merlangus*) and Grey Gurnard (*Eutrigla gurnardus*), and marine mammals like Harbor Porpoises (*Phocoena phocoena*) (Hislop et al. 1991, De Gee and Kikkert 1993, Leclerc et al. 2012, Andreasen et al. 2017).

Size and Age and Growth

The maximum reported length and age for Northern Wolffish are 180 cm and 14 years; 150 cm and 22 years for Atlantic Wolffish; and 180 cm and 21 years for Spotted Wolffish (Nelson and Ross 1992, O’Dea and Haedrich 2001a, 2001b, Simpson et al. 2013b).

Reproduction and Maturity

Reproduction of wolffish species occurs through internal fertilization. The eggs are relatively large and have a prolonged incubation period. Fecundity is relatively low, ranging between approximately 2,400 and 35,000 eggs per individual female (Barsukov 1959, Templeman 1986a, 1986b, Simpson et al. 2013b). All species reach maturity by age 5 or 6, but the length-at-maturity differs among species, 54 cm for Northern Wolffish, 60 cm for Atlantic Wolffish, and 75–80 cm for Spotted Wolffish.

METHODS

RESEARCH VESSEL SURVEYS

Newfoundland and Labrador

Estimates of abundance, biomass, distribution, size composition, growth, maturity, and indices of physiological condition were obtained from the DFO annual multispecies stratified random research vessel (RV) surveys in NAFO Div. 3LNO and Subdiv. 3Ps in spring (1971–2021), and Div. 2GHJ3KLNO in fall (1977–2021). Data analysis took into consideration the various Ecosystem Production Units within the Newfoundland and Labrador (NL) continental shelves

(Pepin et al. 2014) and was conducted for each of the following bioregions: Div. 2GH, Div. 2J3K, Div. 3LNO, and Subdiv. 3Ps.

Various RVs and fishing trawls have been employed over the extent of these surveys (Yankee 41.5 bottom trawl for spring surveys until 1982; Engel 145 Hi-lift for fall surveys in 1977–94 and spring surveys in 1983–95; and Campelen 1800 shrimp trawl for fall of 1995 and spring 1996 to present), and additional survey strata were included in the 1980s, along with changes to portions of the original stratification scheme. Of note, only Div. 2H has been surveyed on a regular basis (since 1996), thus the information presented for the bioregion Div. 2GH are for the most part indicative of the trends and patterns observed in Div. 2H. Likewise, survey coverage in Div. 3L started in 1981, and both Div. 3N and 3O in 1990; therefore, the information presented for the bioregion Div. 3LNO prior to 1990 is indicative of the trends and patterns observed in Div. 3L only. Detailed information on changes in survey design, fishing trawls, and spatial coverage can be found in McCallum and Walsh (1996) and most recently in Rideout et al. (2022).

Except for the surveys conducted in the Gulf of St. Lawrence and Estuary (Benoît 2006, Bourdages et al. 2007), and the Scotian Shelf (Hugues Benoît, pers. comm.), no conversion factors were estimated for wolffish between the different fishing trawls employed in these surveys. For this reason, survey data from different trawls are not directly comparable, and thus constitute independent time series.

Northern Gulf of St. Lawrence and Estuary

The status of wolffish species in the northern Gulf of St. Lawrence (nGSL) and the St. Lawrence estuary (Div. 4RS+Estuary) was primarily assessed based on the DFO multispecies bottom trawl RV survey conducted annually in August from 1990 to 2021. As in the previous version of this assessment (Collins et al. 2015), data collected by the MV Gadus Atlantica (gear: Engel 145 otter trawl; 1978–94) and MV Lady Hammond (gear: Western IIA trawl; 1984–90) were not analyzed as these did not cover the same survey area as the more recent series (e.g., creation of new strata in 1990) and also lacked appropriate conversion factors for wolffish. However, unlike the previous report, the present analysis did not include data from the mobile Sentinel Fishery survey program in Québec for 1995–2021; the reasons include close similarity of inputs with the DFO RV survey, and the greater risk of species misidentification for wolffish and other non-commercial species.

The DFO multispecies bottom trawl RV survey in the nGSL has been conducted by the CCGS Alfred Needler (gear: URI 81'/114' shrimp trawl) from 1990 to 2005 and by the CCGS Teleost (gear: Campelen 1800 shrimp trawl) from 2004 to 2022. Given known differences in survey catchability between the Alfred Needler and Teleost, and the impact of such differences on most biological indices, catch numbers and weights were adjusted to the Teleost-Campelen equivalent for each tow based on a comparative fishing protocol applied in 2004 and 2005 (Bourdages et al. 2007). In instances where the number and identity of strata covered by the survey deviated from the original 43 strata retained for analysis, the values for missing combinations of stratum and year were predicted from log-transformed linear models on either mean numbers or kilograms per tow, using three-year sliding windows. These adjustments were intended to ensure that abundance indices in that region were fully comparable and representative of the underlying population dynamics over the 1990–2021 period.

Southern Gulf of St. Lawrence

In Div. 4T, the multispecies southern Gulf September RV survey provides data concerning the estimated abundance, biomass, distribution, size composition, and indices of physiological condition of more than 70 marine and diadromous fish species annually since 1971. As in comparable bottom trawl surveys conducted by DFO in other NAFO Divisions, this survey uses a stratified random design, with the number of fishing stations in each stratum being proportional to the area of the stratum (a minimum of three fishing stations are sampled per stratum). Since 1971, different research vessels and fishing gear have been employed. From 1971 to 1985, fishing was carried out with the E.E. Prince using the Yankee-36 trawl, followed by the Lady Hammond (1985–91), the Alfred Needler (1992–2005), and the Teleost (2004–21) which were all equipped with a Western IIA trawl.

Maritimes

The Maritimes Region ecosystem summer RV survey has been conducted annually since 1970. The survey follows a stratified random sampling design for sampling fish and invertebrates using a bottom otter trawl. Survey data are the primary source for monitoring trends in species distribution, abundance, and biological condition within the Region. Sampling is conducted in Div. 4VWX, Subdiv. 5Yb, and the Canadian portion of Div. 5Z, however only areas of the Scotian Shelf (Div. 4VWX; Strata 440–495) are consistently sampled. From 1970–81, the survey was conducted by the A.T. Cameron using a Yankee 36 trawl. In 1982, the vessel was replaced by the Lady Hammond using the Western IIA as the new standard trawl, along with some changes in data collection protocols. No conversion factors are available for wolffish to account for these changes; however, it was suggested based on unpublished data that wolffish species did not require any (H. Benoît, pers. comm.). The survey has been conducted primarily by the Alfred Needler since 1983, and the Teleost in its place if mechanical issues occurred. In 2018, sampling was incomplete due to mechanical issues. In 2021 a comparative fishing survey was expected to be conducted by the Alfred Needler and the Jacques Cartier to investigate catchability between the Western IIA and the new NEST trawl. Due to mechanical issues, the Needler did not conduct any surveys in this period; exploratory sampling took place instead on the Jacques Cartier.

The Georges Bank winter RV survey has been conducted annually since 1987 following a stratified random sampling design. These surveys are the primary data source for monitoring trends in species distribution, abundance, and biological condition on Georges Bank (Div. 5Z), and typically occur in February/March. The Alfred Needler has been the primary survey vessel, using a Western IIA trawl, with its sister ship the Wilfred Templeman being used in 1993 and 2004. A comparative survey was completed in 2005 and 2006 between the Alfred Needler and the Teleost to estimate catchability between vessels, and due to mechanical issues with the Needler, the Teleost conducted the survey in 2016, 2017, 2020, and 2021. The survey was incomplete in 2022. The survey concentrates on the Canadian side of the bank (Subdiv. 5Zc) with additional sets on the USA side of Canada’s Exclusive Economic Zone (EEZ) that cover the remainder of the bank, and some trips doing sets on the Western Scotian Shelf (Div. 4X). Due to inconsistency of sampling coverage, abundance and biomass indices are only calculated for Divisions 5Z1-5Z4. Additional data for the Maritimes Region are available from industry surveys (DFO 2022a). These include the Atlantic Halibut longline survey in Div. 4VWX, the Sentinel longline survey in Div. 4VsW, the Snow Crab trawl survey in Div. 4VWX, and the Individual Transferable Quota (ITQ) survey in Div. 4X, which has been replaced by the Inshore Lobster Trawl survey (ILTS) since 2013. Although these surveys do not provide consistent and sufficient sampling of wolffish to allow for estimates of population trends, the data can be used to supplement information gained by the RV surveys, particularly in shallow (<50 m) near-shore strata that cannot be accessed by the summer RV survey.

Arctic

Baffin Bay and Davis Strait

Since 1999, multispecies stratified random bottom trawl surveys have been conducted by DFO's Arctic Region to assess stocks of Greenland Halibut (*Reinhardtius hippoglossoides*) in Div. 0A0B. Surveys were conducted in the fall aboard the Greenland Institute of Natural Resources RV Pâmiut using an Alfredo III trawl (mesh size of 140 mm and a 30 mm mesh liner in the codend) from 400 m to 1,500 m depth. Detailed descriptions of the survey methods can be found in Treble (2018).

The northern portion of Div. 0A (N-0A, north of 72˚N) is surveyed less frequently than the southern portion of Div. 0A (S-0A); therefore, each Division has separate stratification schemes. Surveys in N-0A took place in 2004, 2010, and 2012, while surveys in S-0A took place in 1999, 2001, every second year from 2004–14, and annually from 2015–17. Surveys in Div. 0B took place in 2000, 2001, 2011, and annually from 2013–16. In 2019 the FV Helga Maria surveyed Div. 0A, but the data are not included in this document. The RV Tarajoq (Greenland Institute of Natural Resources – replacement for RV Pâmiut) surveyed Div. 0AB in 2022.

Davis Strait and Ungava Bay

Since 2005, multispecies stratified random bottom trawl surveys have been conducted by DFO's Arctic Region to assess stocks of Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*P. montagui*) in Shrimp Fishing Areas (SFAs) 0–3 (Fig. 1b). Detailed descriptions of the survey methods can be found in Siferd (2015) and DFO (2019).

In SFAs 0 and 1, survey data were collected from the Pâmiut using a Cosmos 2000 shrimp trawl (20 mm codend mesh) from 200–800 m depth. Surveys were conducted in SFA 0 in 2006 and 2008, and in SFA 1 every second year from 2006–12.

In SFAs 2 and 3, surveys have been conducted by the Northern Shrimp Research Foundation (NSRF), with a survey plan developed by DFO Arctic Region. Surveys were conducted from 100–750 m depth using different vessel platforms: FV Cape Ballard (2005–11), FV Kinguk (2014), FV Katsheshuk *II* (2015), and FV Aqviq (2012, 2013, 2016–18).

The Resolution Island Survey Area (RISA) is sampled separately from SFA 2, although the two areas are aggregated together for assessments of *P. borealis* and *P. montagui*. A standard Campelen 1800 shrimp trawl (12.7 mm codend mesh) was used in 2005–07 in RISA and 2005–08 in SFA 2. However, high incidences of tear ups led to modifications in trawl design including increased footgear size and additional floatation on the fishing line and lower belly seams (Siferd and Legge 2014). The modified Campelen 1800 shrimp trawl has been used since 2008 in RISA and 2009 in SFA 2. Additional sampling of RISA occurred in 2007 from the Pâmiut using a Cosmos 2000 shrimp trawl. SFA 3 was sampled every second year between 2007 and 2013 using a Cosmos shrimp trawl but switched over to annual sampling using the modified Campelen trawl in 2014. Conversion factors between vessel and gear types have not been established.

Data and analysis of the three wolffish species are presented separately for each assessment area with more than four years of survey data. Differences between survey methods and gear preclude combining data sources into a single comparable time series.

BIOLOGICAL SAMPLING AND ANALYSES

Total length (cm) and whole weight (kg) were recorded for each wolffish specimen captured during a DFO RV survey tow. Other information recorded during each tow included fishing location (latitude and longitude), fishing depth, and water temperature at depth. In addition, during the spring and fall surveys conducted in 2001–03 in the NL Region, a total of 1,460 wolffish specimens were frozen aboard the vessels and subsequently transported and processed at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's. Collected data included total length, whole weight, sex, maturity stage, stomach and gonad weight, and otoliths which were used to derive a putative age. Several morphometric and meristics measurements were also recorded (details in Simpson et al. 2013c). This dataset was then used to estimate age-length relationships, as well as maturity stages in relation to wolffish age and size.

Age-length keys were used to estimate initial values for the growth parameters L_{inf} (asymptotic length), t_0 (theoretical age at which length equals 0), and K (Brody growth coefficient). The Ford-Walford plot method (Walford 1946) was employed to estimate the starting values for growth parameters, which were then used to fit nonlinear regression models. Three growth models (von Bertalanffy [VBL], Gompertz, Logistic) were specified to describe the age-length relationship of wolffish. The growth models were fitted using the NLIN procedure in Statistical Analysis System (SAS) software v.9.4 (SAS Institute 2010). The Marquardt iterative procedure was used to reduce the residuals and improve the goodness of fit. The best-fitting model was chosen based on achieving the convergence criterion (i.e., lowest residual sum of squares), and a graphic analysis of the observed and estimated curves.

Maturity stage determination of female wolffish followed the approach proposed by Gunnarsson et al. (2008) and Gunnarsson et al. (2016). Only two classes for maturity stage were considered in this analysis: immature and mature. Maturity ogives were calculated using maturity parameters estimated from the Logistic Regression procedure in SAS, from which the median length (L_{50}) and age (A_{50}) at maturity could be determined.

Length and weight data of unsexed wolffish were used to calculate the Fulton's K Condition Factor as follows:

$$K_{i,j} = \frac{w_{i,j}}{l_{i,j}^{n}} x\ 100$$

where $w_{i,j}$ is whole weight (in grams) and $l_{i,j}$ is total length (in centimeters) of wolffish i in year j. The coefficient n denotes the slope of the log-transformed linear regression relationship between weight and length. Isometric growth would occur when $n = 3$; whereas $n > 3$ indicates a positive allometric growth, and vice-versa. The Gonado-Somatic Index (GSI) and the Stomach Fullness Index (FI) were also estimated for both male and female wolffish using the detailed 2001–03 dataset:

$$GSI = \frac{m_{i,j}}{w_{i,j}}$$

and

$$FI = \frac{t_{i,j}}{w_{i,j}}$$

where $m_{i,j}$ is gonad weight (in grams) and $t_{i,j}$ is stomach weight (in grams) of wolffish i in year j.

INDICES OF STOCK SIZE AND DISTRIBUTION

Newfoundland and Labrador

Indices of abundance, biomass, and distribution of wolffish were obtained from depth stratified random surveys covering the various bioregions. Catch rates (no. fish/tow; kg/tow) were standardized with regard to tow time (15 minutes) and speed (3 knots). Estimates of trawlable biomass and abundance were calculated by extrapolating catch rate to the total number of trawlable units in each survey stratum, and scaled by stratum area. However, as indicated previously, not all strata were surveyed in a particular year, notably in spring during the 1970s (Yankee time series) and 1980s (Engel time series) in Div. 3LNO and Subdiv. 3Ps, as well in fall during the 1980s in Div. 3NO, and no predictions were made for missing combinations of stratum and year. Accordingly, survey estimates of stock size in those periods and bioregions are likely underestimated, and therefore should be interpreted with caution.

For each wolffish species, time series (e.g., Engel 1971–94, Campelen 1995–2021), season (spring, fall), and bioregion (Div. 2GH, 2J3K, 3LNO, Subdiv. 3Ps), the distribution of catch rate in relation to fishing depth and water temperature was calculated as the cumulative distribution of raw data (no./tow; kg/tow) to the cumulative distribution of fishing depth and temperature bins. The length frequency of RV catch (raw data) was also estimated for each species, time series, season, and bioregion.

Geo-referenced catch rates from RV surveys were used to infer the range of wolffish distribution within the study area, in terms of presence or absence in successful tows. In addition, the expanding symbol plot map series from Collins et al. (2015) was updated for each species of wolffish.

Northern Gulf of St. Lawrence and Estuary

Biological indices for the nGSL survey were estimated for Atlantic Wolffish and Spotted Wolffish over the full Teleost-Campelen corrected series (1990–2021). Except for the length frequency distributions, data for Northern Wolffish were excluded as their sample sizes were deemed too small for meaningful interpretation of values or temporal trends. Habitat associations were quantified from the stratified approach outlined by Perry and Smith (1994), using either depth (resolution: 1 m) or temperature (resolution: 0.1°C) as the independent variable and the Teleost-Campelen corrected catch numbers and weights per tow as dependent variables. Although individual length and weight records were sometimes only available for a portion (subsample) of the total capture for a given species and set, most survey years were represented in the length-weight relationship models and Fulton’s K Condition Factor analyses. All biological analyses incorporated the correction factor from the Alfred Needler to the Teleost (4.092, in number; see Table 9 in Bourdages et al. 2007).

Southern Gulf of St. Lawrence

The standardized catch rate of wolffish was calculated as the catch weight (kg) and number per 30-minute tow at a speed of 3.5 knots. Then, estimates of trawlable biomass and abundance were calculated by dividing the respective standardized catch rate by the trawl swept area, and by extrapolating the normalized catch rate to each stratum area. The summation of the estimated total catch of all strata provided an estimate of the trawlable biomass and approximate number of specimens for the surveyed area. No predictions were made for occasional missing combinations of stratum and year. The biomass and abundance estimates for the southern Gulf (for all the years of the September RV survey) should be interpreted with caution, given the low numbers of wolffish encountered in this region; between 1971–2021, a total of 667 Atlantic Wolffish, 25 Spotted Wolffish and 41 Northern Wolffish were measured during the southern Gulf RV survey.

Habitat associations for wolffish in Div. 4T were assessed by comparing cumulative abundance (weight and number of fish) to cumulative records of depth and temperature from the southern Gulf RV survey.

Maritimes

Biological indices were estimated for Northern Wolffish, Spotted Wolffish, and Atlantic Wolffish from 1970–2022 for Div. 4VWX, and from 1987–2021 for Div. 5Z. Summer RV survey data for 2018 and 2021 were excluded due to insufficient sampling. Standardized catch rate of wolffish was calculated as the catch weight (kg) and number per 30-minute tow at a speed of 3 knots. Estimates of trawlable biomass and abundance were calculated by extrapolating catch rate to the total number of trawlable units in a survey stratum, and scaled by stratum area. Similar scaling was used for stratified length frequencies. These estimates should be considered with care, particularly over the last ten years, given the low numbers of wolffish in recent survey catches. Detailed descriptions of the indices of wolffish abundance and biomass, as well as data from various other RV surveys are provided in Simon et al. (2012).

Habitat associations for Atlantic Wolffish on the Scotian Shelf and Georges Bank were estimated by comparing cumulative stratified estimates of abundance to cumulative stratified estimates of temperature and salinity from the summer RV survey. The variable of depth was not used as very few individual tows had recorded fishing depth between 1992 to 2016. Similarly, the period of 1982–95 was excluded from the length-weight analysis due to insufficient sampling of individual weights. No new data were available for Northern Wolffish and Spotted Wolffish since the last assessment for the Region (Simon et al. 2012).

Arctic

Baffin Bay, Davis Strait, and Ungava Bay (NAFO Div. 0A0B, SFA 0-3)

Standardized catch rates of wolffish from each individual tow were calculated as the number or kg per km^2 as there is no currently established idealized tow for either the annual multispecies survey (Div. 0A0B) or shrimp survey (SFA 0–3). The weighted average of the mean catch per depth stratum (including zero catch) was used to produce an annual mean number and weight per km^2 and area. Weights were assigned to each depth stratum based on the total area of the stratum. Modifications in stratification (e.g., adding or adjusting strata size) have been made to both the multispecies RV and shrimp surveys. As a result, an unbiased index of total abundance could not be estimated.

Cumulative plots of average catch and depth were produced using data aggregated across all years and 50 m depth bins to evaluate depth associations for all three species. In addition to associations with depth, the northernmost catch for each species by year is presented in Table 1. Due to logistics and limitations of fishing in ice, the multispecies survey of Div. 0AB did not have a consistent maximum latitude between years. The data presented represents the maximum observed latitude per year but is not necessarily indicative of each species' potential range.

COMMERCIAL FISHERIES

Removal information from commercial fisheries is generally available as either unspeciated or speciated landings from different sources. Unspeciated and speciated wolffish landings are available from the NAFO STATLANT-21A database (1960–2021), as reported by Canada and other NAFO-member countries; and unspeciated wolffish landings from the DFO Zonal Interchange File Format (ZIFF, 1985–2021) and the DFO Maritimes Fisheries Information System (MARFIS, 2002–21), both as reported by Canadian fishers. Speciated wolffish catch and discard data are available from the Canadian At-Sea Fisheries Observers Program (ASFO, 1985–2021), SARA logbooks from vessels greater than 35 ft in the NL Region (2008–19), and groundfish fisheries in the Maritimes Region (2006–22). The information recorded on SARA logbooks in the NL Region also include location of capture, gear used, date, wolffish length and weight, and condition upon release (i.e., live, dead, injured); the three wolffish species are not always coded separately in the Maritimes Region, and coding of Spotted Wolffish and Northern Wolffish can be unreliable. Data for the years 2019 through 2021 are considered preliminary.

Moreover, discards are rarely reported to NAFO or the DFO Statistics Branch (for ZIFF and MARFIS), and the most reliable source of data on discarding at sea comes from the ASFO Program. However, a simulation study suggested that ASFO coverage probably remains too low to accurately estimate wolffish bycatch in most Canadian Atlantic fisheries (Collins et al. 2015), which makes comparison between years and areas difficult given the variation in observer coverage among different fisheries.

RESULTS

RESEARCH VESSEL SURVEYS - STOCK SIZE AND DISTRIBUTION

Newfoundland and Labrador

The fall RV mean catch rates of Northern Wolffish were highest at the start of the Engel time series in Div. 2J3K when compared with other bioregions (Fig. 2a). The mean number per tow and mean weight per tow peaked at 5 fish/tow and 33 kg/tow in 1977 prior to declining abruptly to less than 1 fish/tow and between 1–3 kg/tow in 1989, then remained at these levels throughout the Campelen time series until 2021. Fall catch rates in Div. 3L (1981–89) reached values of up to 0.5 fish/tow and 4.5 kg/tow at the start of the time series and then declined to even further low values starting in 1989 (Fig. 2b). Even with the addition of fall RV surveys in Div. 3NO in 1990 the fall catch rates of Northern Wolffish remained low in this bioregion (both Engel and Campelen time series); whereas spring catch rates in both Div. 3LNO and Subdiv. 3Ps varied without trend; in both cases catch rates remained below 1 fish/tow and 4.4 kg/tow in all years; in contrast catch rates were very low in Div. 2H (<0.02 fish/tow, <0.02 kg/tow) until 2010, but increased during the last decade to up to 1 fish/tow and 6 kg/tow in 2013. The estimated fall abundance and biomass in Div. 2H peaked at 1.2 million fish and 7,300 t in 2013 (Fig. 3a). The estimated fall abundance and biomass in Div. 2J3K reached nearly 11 million individuals in 1978 and 74,000 t in 1980, but remained below 5 million fish and 22,000 t since then. Abundance and biomass indices in Div. 3LNO ranged mostly between 0.5–1 million fish and 2,500–11,000 t (all-time series, Fig. 3b). In Subdiv. 3Ps the spring abundance and biomass estimates peaked at 133,000 fish (1996) and 450 t (2019), but these values were generally much smaller (both Engel and Campelen time series).

Similarly to Northern Wolffish, the fall RV mean catch rates of Atlantic Wolffish were highest in Div. 2J3K peaking at 8.2 fish/tow and 7.3 kg/tow in 1978, then declining to minimum values by 1994 (0.2 fish/tow, 0.1 kg/tow), and remaining at levels of less than 4 fish/tow and 2 kg/tow through the Campelen time series until 2021 (Fig. 4a). Mean catch rates varied without trend in Div. 3LNO and Subdiv. 3Ps, while not surpassing 4.2 fish/tow and 3.9 kg/tow in any particular year (all-time series, Fig. 4b). Mean catch rates in Div. 2H also followed a similar trend as observed for Northern Wolffish, increasing during the last decade and reaching 15 fish/tow and 2.5 kg/tow in 2014 (Campelen time series). The RV survey stratified abundance and biomass estimates varied mostly between 7–10 million fish and 2,000 t in Div. 2H during the last decade. Abundance and biomass estimates peaked at 33 million fish and 30,000 t (1978) in Div. 2J3K, prior to indicating a near-collapse by 1994 (0.6 million, 440 t); abundance estimates increased by ten-fold once the Campelen trawl was introduced in 1995 (6.6 million wolffish), ranging between 10–30 million fish thereafter, whereas the increase in biomass ranged between 937–9,300 t during that same time period (Fig. 5a). Similar patterns were observed in the other bioregions. Abundance and biomass estimates in Div. 3LNO (spring and fall) varied without trend, ranging between 0.8–5.5 million fish and 1,200–20,000 t annually (Yankee and Engel time series, Fig. 5b). Estimated abundance was considerably higher after 1995–96 (2.6–27 million fish), whereas biomass ranged between 1,800–27,000 t. The lowest abundance and biomass estimates for Atlantic Wolffish were observed in Subdiv. 3Ps (0.1–5.9 million fish, 181–6,000 t) regardless of the time series.

The fall RV mean catch rates of Spotted Wolffish in Div. 2H increased by four to five-fold in 2020–21, reaching 3 fish/tow and 5.6 kg/tow; catch rates were highest at the start of the respective fall time series (Engel time series) in both Div. 2J3K (1.3 fish/tow, 5.8 kg/tow) and Div. 3L (1.3 fish/tow, 7 kg/tow), declined to the lowest levels by 1995 (0.03 fish/tow, 0.03 kg/tow), and subsequently increased in Div. 2J3K (Campelen time series) (Fig. 6a, while remaining at very low levels in Div. 3LNO (Fig. 6b). Catch rates in Div. 3LNO and Subdiv. 3Ps in spring varied without trend (all time series) at very low levels in most years. Abundance and biomass estimates in Div. 2H experienced a substantial increase from approximately 1 million fish and 1,300 t in 2011 to 4.2 million fish and 9,700 t in 2021, the highest values of the time series (Fig. 7a). Fall Abundance and biomass estimates in Div. 2J3K declined from nearly 4.3 million fish and 16,000 t in the late–1970s to 100,000 fish and 430 t in 1994 (Engel time series); the trend was reversed once the Campelen trawl time series began, peaking at 4.8 million fish (2014) and 16,000 t (2013); levels that have been maintained up to 2021. The fall abundance and biomass estimates in Div. 3L declined from almost 3 million fish and 18,000 t in 1981 to 1 million fish and 3,800 t in 1989, with the addition of surveys into Div. 3NO, the fall abundance and biomass in Div. 3LNO combined had declined to 160,000 fish and 790 t by 1994 (Fig. 7b). Abundance of Spotted Wolffish has since increased, however fall biomass has remained low, ranging between 290–3,900 t annually. Abundance and biomass estimates in Div. 3LNO (spring) reached nearly 5 million fish (2006) and 16,000 t (2007), but generally varied without trend at considerably lower levels (all-time series). As seen with the other two wolffish species, the lowest estimates of abundance and biomass were observed in Subdiv. 3Ps (4,800–64,000 fish, 1–158 t).

No seasonal variability in abundance and biomass estimates was observed for Northern Wolffish in Div. 3LNO. However, the fall abundance and the spring biomass of Atlantic Wolffish, as well the fall abundance of Spotted Wolffish tended to be higher, notably for the Campelen time series.

The geo-referenced distribution of RV survey catch rates in the NL Region show that Northern Wolffish are found throughout Div. 2H and 2J3K, particularly along the shelf edge and to a lesser extend over the continental shelf; in Div. 3LNO the distribution is concentrated on a very narrow band along the shelf edge, except over the shelf in the Bonavista Corridor, but Northern Wolffish are almost absent on the Grand Banks and in Subdiv. 3Ps (Fig. 8). The distribution of Atlantic Wolffish overlaps that of Northern Wolffish to a large extent in Div. 2H, 2J3K, and 3LNO; in addition, Atlantic Wolffish are found more frequently in inshore areas (Div. 3K), over the southern Grand Bank (Div. 3NO), and in Subdiv. 3Ps, except the Laurentian Channel (Fig. 9). The distribution of Spotted Wolffish is also very similar to that of Northern Wolffish (Fig. 10). In general, the three wolffish species continued to occupy the same areas of the continental shelf over the years, despite some inter-annual variability in indices of stock size during the last decade (Figs. 11a-d to Figs. 13a-d), however in the case of Atlantic Wolffish, an expansion of its distribution range was detected over the shelf in Div. 2J3K since 2013, while the opposite was observed for Spotted Wolffish during the period 2013–17.

The distribution of RV survey catch rates in relation to fishing depth shows that the majority of Northern Wolffish were caught between 250–450 m (Engel time series) and 300–500 m (Campelen time series) in all bioregions (Fig. 14). Atlantic Wolffish were caught in shallower water, mostly between 200–300 m in Div. 2H, 2J3K, and 3LNO, and between 100–200 m in

Subdiv. 3Ps; no marked differences in catch rates at depth were observed between trawls in Div. 2J3K, but when compared with the Engel trawl, Atlantic Wolffish were caught in larger proportions at depth by the Campelen trawl in Div. 3LNO in fall and Subdiv. 3Ps in spring, while the opposite occurred in Div. 3LNO in spring. Most Spotted Wolffish were caught between 200–400 m by both trawls in Div. 2H, 2J3K, and 3LNO, and between 100–300 m in Subdiv. 3Ps.

Most Northern Wolffish in Div. 2J3K and 3LNO were caught by the Engel trawl in water temperatures of 2–3°C, 1–4°C in Div. 2H, 2J3K, and 3LNO by Campelen trawl, and 4–5°C in Subdiv. 3Ps (both trawl series) (Fig. 15). Most Atlantic Wolffish were caught in waters of 1–3°C in Div. 2H, 2J3K, and 3LNO (both trawl series), but in Subdiv. 3Ps, Atlantic Wolffish were found over a broader range of temperatures (0–6°C). As observed with Northern Wolffish, Spotted Wolffish tended to be caught within a narrower range of water temperatures in Div. 2J3K and 3LNO by the Engel trawl (1–3°C), when compared to the Campelen trawl (0–4°C) in Div. 2J3K, 3LNO, and 2H, but in Subdiv. 3Ps most fish were caught in warmer waters (3–9°C).

No marked seasonal variability in catch rates in relation to depth was observed in the case of Northern Wolffish and Spotted Wolffish in Div. 3LNO, however a larger proportion of Atlantic Wolffish were caught at depth in spring than in fall. Likewise, no marked seasonal differences in catch rates were observed in relation to water temperature at fishing depth for Northern Wolffish and Atlantic Wolfish, but in the case of Spotted Wolffish, more fish tended to be caught in relatively colder waters in the fall.

Northern Gulf of St. Lawrence

Estimates of mean numbers and weights per tow in the nGSL and estuary did not deviate much from the results of the last assessment report (Collins et al. 2015). The most abundant of the three species in the region was Atlantic Wolffish, with average catch rates having stabilized at around 2 fish/tow and 0.750 kg/tow since 2013 (Fig. 16). The next most commonly observed species was Spotted Wolffish, with indices of stock size exhibiting some evidence of recovery between 2019 and 2021; however, catch rates rarely exceeded 0.1 fish/tow and 0.3 kg/tow. For the more sporadically observed Northern Wolffish in the nGSL, no additional capture has been reported since 2012; the total number of valid captures since 1990 thus remains at five.

Trends over time in the total abundance were largely coherent with the estimated mean numbers and weights per tow (Fig. 17). Specifically, the Teleost-Campelen corrected total abundances (in numbers) peaked at around 20 million fish for Atlantic Wolffish in 1997 (corresponding biomass: 3,501 t), 794,000 for Spotted Wolffish in 2004 (1,275 t), and 32,900 for Northern Wolffish in 2012 (49.6 t). While these extrapolated numbers may be informative to some degree, their interpretation must be made with caution given the wider confidence intervals associated with these years and the use of a predive model for missing combinations of year and stratum.

The presence-absence distribution maps for wolffish species in the summer nGSL survey were based on the Teleost-Campelen equivalent series over the years 1990–2021 exclusively. Non-zero observations for Northern Wolffish were very rare, suggesting that sightings of this species may only have been occasional in this portion of the Northwest Atlantic Ocean (Fig. 8). Atlantic Wolffish were commonly found along the west coast of Newfoundland, particularly in Subdiv. 4Rb, 4Rc, and 4Rd, but positive observations were also made along the coasts of Anticosti Island and off Quebec's North Shore in Div. 4S (Fig. 9). Similarly to Atlantic Wolffish, there were positive observations of Spotted Wolffish in Subdiv. 4Rb and 4Rd, as well as in more offshore locations in Div. 4S, but the latter species did not occur in Subdiv. 4Rc (Fig. 10). Wolffish species were mostly absent from sets conducted in the St. Lawrence estuary, suggesting that this portion of the nGSL survey did not contribute much to total abundance and biomass estimates.

Cumulative distribution functions for the nGSL and St. Lawrence estuary provided evidence that Atlantic Wolffish and Spotted Wolffish mostly occurred at depths between 100 and 300 m (Fig. 18) and at temperatures between 0 and 5°C (Fig. 19). These distributional patterns are consistent with the descriptions for the GSL and elsewhere in the Northwest Atlantic (e.g., Collins et al. 2015). Estimates for Spotted Wolffish covered a broader range of temperatures (up to 6.0°C) than for Atlantic Wolffish, but the difference between the two species should be interpreted with caution given the lower sample sizes for Spotted Wolffish. Northern Wolffish with available depth and temperature records have been captured at depths of 199 to 355 m and at temperatures of 4.1 to 5.8°C.

Southern Gulf of St. Lawrence

The catch rates of Northern Wolffish have always been low in Div. 4T (no specimens were collected for 39 of the annual survey editions between 1971–2022). The RV stratified mean number per tow peaked in 1986 at 0.08 fish/tow (Fig. 20). The stratified mean weight per tow peaked in 1986 at 0.06 kg/tow. The estimated stratified abundance and biomass of Northern Wolffish in Div. 4T reached approximately 138,000 individuals and 116 t in 1986 (however, that estimate is based on a total annual catch of seven specimens during the 1986 survey edition), and no Northern Wolffish were caught in the southern Gulf RV survey in the past 11 years (Fig. 21).

As for the Northern Wolffish, the catch rates of Atlantic Wolffish have always been relatively low in Div. 4T, when compared with other Regions. The RV stratified mean number per tow peaked in 1988 at 0.13 fish/tow (Fig. 20). The average stratified mean weight per tow peaked in 1988 at 0.3 kg/tow. The estimated stratified biomass of Atlantic Wolffish in Div. 4T peaked at 400t for approximately 240,000 individuals in 1988 but has remained low (between 2 and 50 t) for the past 10 years (Fig. 21).

For the Spotted Wolffish, the RV stratified mean number per tow peaked in 2009 at 0.015 fish/tow (Fig. 20). An earlier peak was also observed in 1986 at 0.013 fish/tow. The abundance of the Spotted Wolffish shows similar patterns to the Atlantic Wolffish. The average stratified mean weight per tow peaked in 1986 at 0.2 kg/tow. Like the Atlantic Wolffish, the estimated stratified biomass of Spotted Wolffish in Div. 4T also reached its maximum in 1988 at 439 t but the maximum estimated number of individuals reached its maximum in 2009 with 26,000 individuals (high levels of variance are explained by the low numbers of individuals caught). Overall, the estimated biomass has remained low (between 2 and 58 t) for the past 10 years (Fig. 21).

The geo-referenced distribution of RV survey catch rates (from all survey years) in Div. 4T indicated that Northern Wolffish are found mostly along the slopes of the Laurentian Channel, and were very rare over the shallow water areas of Div. 4T (Fig. 8), while Atlantic Wolffish are more widely distributed along the slope of the Laurentian Channel and in the near shore waters of Div. 4T (Fig. 9). Spotted Wolffish had a similar distribution as observed for Northern Wolffish (Fig. 10).

The cumulative proportion of RV survey catch in relation to fishing depth shows that the majority of Northern Wolffish were caught between 135–155 m (Fig. 22). However, only 41 catches of this species were recorded over all survey years, thus this data should be interpreted with caution. Atlantic Wolffish were found at similar depths, mostly between 100–175 m. Spotted Wolffish were also found in the same range (100–150 m) however only 25 catches of Spotted

Wolffish were recorded and the shape of the cumulative proportion curve for that species suggests that additional data from fish sampled at deeper sites could change these results.

All Northern Wolffish and Spotted Wolffish from Div. 4T were caught between 0–6ºC (Fig. 23), however given the current shape of the cumulative proportion curves (due to the limited dataset for these two species), it is not possible to identify a preferred range of temperature for Northern and Spotted Wolffish. The catches of Atlantic Wolffish show a clearer signal and indicate that most specimens were also caught between 0–6ºC.

Maritimes

Abundance of wolffish in the Maritimes Region has remained at low levels since the last assessment. Over the last decade, only Atlantic Wolffish continue to be caught in the RV survey. Northern Wolffish and Spotted Wolffish were nearly absent on the Scotian Shelf and the Bay of Fundy, except for a few observations in Div. 4VW; in contrast, Atlantic Wolffish were found throughout the Scotian Shelf and Bay of Fundy (Figs. 8–10).

Northern Wolffish and Spotted Wolffish had been caught in the northern end of the survey area (Subdiv. 4Vs and 4Vn) until the early–2000s (Figs. 24 and 25). Since 2008, only one Northern Wolffish and no Spotted Wolffish have been caught in the summer RV survey. These species are never caught by the winter survey on George's Bank. The general distribution of Atlantic Wolffish has remained consistent, with greater numbers occurring in Div. 4V and 4X, and fewer in Div. 4W (Fig. 26). Distribution in Div. 4X has become less evenly distributed, and more confined around Brown's Bank over the past 20 years.

Catches of Spotted Wolffish and Northern Wolffish on the Scotian Shelf have always been at low numbers (average number per tow of less than 0.03; Fig. 27). Since 2013, catches of Atlantic Wolffish have decreased overall (average catch of 0.22 fish/tow), especially in Div. 4W. Stratified biomass of Northern Wolffish peaked in 1981 at 1,421 t, and in 1991 at 622 t for Spotted Wolffish (Fig. 28). Atlantic Wolffish biomass on the Scotian Shelf peaked in 1975 at 11,338 t and was generally stable in the 1970s and 1980s, but has declined by 91% since that period. Abundance peaked in the late–1990s to early–2000s with high interannual variability, followed by rapid decline, and remains at low levels to present day.

Distribution of Atlantic Wolffish on Georges Bank is primarily concentrated in stratum 5Z2, with average catches of 0.01 fish/tow over the last decade (Fig. 29). Abundance was variable from 1987 to the early–2000s, with peaks of 156,000 and 171,000 in 1987 and 1996, respectively. Catches have been inconsistent, resulting in highly variable estimates of abundance at the start of the time series. Data collected after 2010 show a steep decline, with catches nearing zero in areas where fish were previously caught. Stratified biomass has been decreasing since the early–1990s and has remained consistently near zero since the late–2000s. This corresponds to a 99.9% decrease in biomass over the survey period, most of which occurred from 1987 to 2010. No Atlantic Wolffish were caught in 2009, 2010, 2013, 2015, 2017 and 2019.

Arctic

Northern Wolffish and Spotted Wolffish have been observed in catches from both the NAFO multispecies survey and NSRF shrimp survey (Figs. 30 and 31), while Atlantic Wolffish have not been observed in the NAFO survey to date (Fig. 32). All three species varied without trend across the time series, but Northern Wolfish were observed more frequently in the NAFO survey, while Spotted Wolffish were encountered in greater numbers in the NSRF survey. Differences in standardized catch per km^2 can likely be attributed to differences in the depth strata and gear used by the two surveys. The three wolffish species overlapped in Div. 0AB, but Atlantic Wolffish were encountered less frequently in Div. 0A, and in a more concentrated geographic area of Div. 0B than either Northern Wolffish or Spotted Wolffish (Figs. 8–10). Northern Wolffish were encountered in a wide range of depths (Fig. 33), but tended to be observed in deeper water when compared to Spotted Wolffish (Fig. 34). Atlantic Wolffish were captured most frequently in the shallow strata of the NSRF survey, which are not included in the NAFO survey (Fig. 35).

BIOLOGICAL CHARACTERISTICS OF RV SURVEY CATCH

Newfoundland and Labrador

The length frequency distribution of the RV survey catch shows that Northern Wolffish captured by the Campelen trawl in Div. 2H were mostly small fish (11–58 cm) at the start of the time series in 2004, but fish size increased almost every year, with the size range of catches varying between 50–95 cm since the mid–2010s; likewise, the size of individuals in most catches in Div. 2J3K ranged between 50–90 cm, but in the other bioregions, the size ranges were truncated, particularly in relation to the upper size-classes, 45–65 cm in Div. 3LNO and 40–60 cm in Subdiv. 3Ps (Fig. 36). The opposite was observed for Atlantic Wolfish, as most catch ranged between 10–35 cm in both Div. 2H and 2J3K, and 15–45 cm in Div. 3LNO, whereas the size range of catch in Subdiv. 3Ps tended to be more variable over time, with mostly small fish (10–20 cm) caught in some years and a broader range of sizes (15–45 cm) caught in other years. Spotted Wolffish had in most years the broadest range of sizes represented in RV survey catches,10–75 cm in Div. 2H, 2J3K, and 3LNO, and 15–55 cm in Subdiv. 3Ps.

Length and weight of the three wolffish species displayed a strong non-linear relationship in all bioregions (Fig. 37). Power models provided the best fit, explaining >94% of the variability in data, except for Atlantic Wolffish in Div. 2H (77%). In the case of Spotted Wolffish (all bioregions), Atlantic Wolffish in Div. 2J3K, 3LNO, and Subdiv. 3P, as well Northern Wolffish in Div. 3LNO, model coefficients ranged between 3.003–3.093 suggesting a slightly positive allometric growth; but for Northern Wolffish in Div. 2H, 2J3K, and Subdiv. 3Ps, and Atlantic Wolffish in Div. 2H, model coefficients were <3, suggesting negative allometric growth in these bioregions.

Mean length-at-age was not significantly different between male and female wolffish (all species, Fig. 38). The total length of age eight Northern Wolffish was on average 63 cm, but only 41 cm for both Atlantic Wolffish and Spotted Wolffish, whereas age 16 wolffish (all species) had a mean length around 80 cm, suggesting that Northern Wolffish have a higher growth rate at younger ages when compared to the other two species.

The VBL growth model provided the best predictive accuracy for the three species (Fig. 39). Model parameters L_{inf}, K, and t_0 for each species were in most cases comparable to those from the available literature and online databases (Table 2). According to the VBL model, the growth rate of age nine wolffish (all species) was 5 cm/year, and decreased gradually to 3 cm/year (Northern Wolffish and Atlantic Wolffish) and 4 cm/year (Spotted Wolffish) by age 18. The asymptotic (total) length of Northern Wolffish was 127 cm, 150 cm for Atlantic Wolffish, and 184 cm for Spotted Wolffish, whereas the maximum length observed from the RV survey catch was 132 cm, 131 cm, and 147 cm, respectively.

The maturity parameters for female wolffish estimated by the logistic model were significant in all cases (Table 3). The L_{50} and A_{50} for Northern Wolffish were 80.6 cm and 10.5 years, 50.7 cm and 10.4 years for Atlantic Wolffish, and 74 cm and 8 years for Spotted Wolffish (Fig. 40). In general, these estimates were consistent with the range of values found in published studies.

The mean Fulton's K Condition Factor of Northern Wolffish and Atlantic Wolffish were consistently higher in Div. 2H and 2J3K when compared to the other bioregions, and fluctuated without trend in all bioregions; whereas for Spotted Wolffish, Fulton's K also varied without trend, but mostly at similar levels in all bioregions (Fig. 41). These results suggest that Div. 2H and 2J3K contain suitable feeding habits for Northern Wolffish and Atlantic Wolffish, and that Spotted Wolffish has the largest plasticity in terms of habitat use, being able to maintain similar levels of physiological condition over the years and across bioregions.

The mean annual GSI (2001–03) for both male and female wolffish (all species) were similar, except for male and female Spotted Wolffish in 2001, which was near twice as high as values observed in 2002–03 (Fig. 42). GSI for both males and females increased during the spring and reached maximum values in June for Northern Wolffish and Atlantic Wolffish, and in December for Spotted Wolffish.

Similarly, no inter-annual variability in the FI was observed between male and female Atlantic Wolffish, and between male and female Spotted Wolffish, but the index for female Northern Wolffish in 2001 was more than twice as high as the values observed in 2002–03 (Fig. 43). No seasonal variability in FI was detected for male and female Northern Wolffish, but in the case of Atlantic Wolffish the index tended to increase in spring, and again in fall, as well increase in spring and decrease in fall for Spotted Wolffish.

Northern Gulf of St. Lawrence

Calculations of mean numbers and kilograms per tow were repeated on length-disaggregated data (i.e., totals per tow and one-cm length bin) to gain further insight into each species' size structure in the nGSL (Fig. 44). The most commonly observed length classes for Atlantic Wolffish were those between 15 and 25 cm, with individual data points ranging from 5 to 89 cm. Observations on Spotted Wolffish were more uniformly distributed between the lengths shorter and greater than 50 cm and also covered a broader range of values overall (8–115 cm). For Northern Wolffish, the only record with an associated length and tow identification number was for a 48 cm individual captured in 2012.

Length-weight relationships for Atlantic Wolffish and Spotted Wolffish were explained by power functions with exponents of 3.21 and 3.0, respectively (Fig. 45). The associated Fulton's K Condition Factor varied without trend over the entire 1990–2021 period, between 0.660 and 0.940 for Atlantic Wolffish and between 0.816 and 1.346 for Spotted Wolffish (Fig. 46). Note that the values for Spotted Wolffish excluded 5 unrealistic combinations of length and weight.

Southern Gulf of St. Lawrence

The length frequency distribution of the RV survey catch for Div. 4T shows that average size for Northern Wolffish was around 38 cm in length, however this result should be interpreted with caution as only data for 41 specimens were available for this analysis (Fig. 47). The average size for Atlantic Wolffish was 37 cm, with most specimens between 25–50 cm (n = 676). The maximum size recorded for that species was 102 cm in 2011. The average size for Spotted Wolffish was larger than for the two previous species, at 67 cm. However, like for Northern Wolffish, limited length data were recorded for Spotted Wolffish (n = 25), which might not be representative of the species in Div. 4T.

Length and weight of the three wolffish species displayed a non-linear relationship (Fig. 48). Power models provided the best fit. For Atlantic Wolffish, the species with the most observations (n = 676), the power model explained >95% of the variability in the data. The R^2 was similar in models for Northern Wolffish (0.93) and Spotted Wolffish (0.94). Model coefficients were 3.08 for Atlantic Wolffish, 3.11 for Northern Wolffish, and 3.19 for Spotted Wolffish, suggesting slightly positive allometric growth for these species in Div. 4T.

The mean annual Fulton's K Condition Factor was calculated for the three wolffish species (Fig. 49). When all specimens from all years were considered for the analysis, the mean Fulton's K Condition Factor was 0.90 for Northern Wolffish (n = 41), 0.96 for Spotted Wolffish (n = 25), and a global mean around 0.85 for Atlantic Wolffish (n = 676). For Northern Wolffish and Spotted Wolffish, it is not possible to infer temporal variations of *Fulton's K* as the datasets have too few recordings. The variance between survey years could result from:

1. a misidentification of the wolffish species, which was not unusual at the beginning of the survey period (as detailed in unpublished logbooks compiling the data from that period),
2. the low abundance of specimens collected (<7 per year between 1971–85), or
3. increased temporal variability in wolffish habitat conditions.

Maritimes

Data on fishing depth per tow for the summer RV survey are sparse, however Northern Wolffish and Spotted Wolffish were generally caught between 100–200 m in northeastern Nova Scotia, whereas Atlantic Wolffish were also caught in shallower near-shore areas and on banks. In recent years, small numbers of Atlantic Wolffish have also been caught by the ITQ/ ILTS survey in shallow (<50 meters) waters off southwest Nova Scotia that are not sampled by the summer RV survey. In past surveys, most Northern Wolffish and Spotted Wolffish were caught in water temperatures of 3–5°C and 2–8°C, respectively (Simon et al. 2012). Atlantic Wolffish were mostly caught in water temperatures of 2–6°C on the Scotian Shelf and 4–5°C on Georges Bank, with salinity ranges of 32.5–33.5 ppt and 32.6–33.1 ppt, respectively (Fig. 50).

The survey predominantly catches Atlantic Wolffish smaller than 60 cm (Fig. 51). There is a trend towards decreasing size in recent years: the average length between 2012–22 was 28 cm, compared to 42 cm from 1992 to 2002, and 45 cm from 1982 to 1992 (Fig. 52). The length-weight relationship for Atlantic Wolffish can be explained using a power model with the coefficient of 3.05 (Fig. 53).

Arctic

Biological information for wolffish from the NAFO multispecies and NSRF shrimp survey is limited to length of individual fish (Fig. 54). Weight is aggregated by species within each tow, which precludes an analysis of body condition. Of the three species, Northern Wolffish were the largest in both the multispecies (70 cm; n = 247) and NSRF shrimp (75 cm; n = 309) surveys. Spotted Wolffish observed were smaller than Northern Wolffish in both surveys but were slightly larger in the multispecies survey (57 cm; n = 38) versus the shrimp survey (47 cm; n = 783). Atlantic Wolffish were not encountered in the multispecies survey and had the smallest average length of the three species (26 cm; n = 252).

COMMERCIAL FISHERIES REMOVALS

Newfoundland and Labrador

According to NAFO STATLANT-21A database, landings of unspeciated wolffish increased from 835 t in 1960 to a peak of 6,660 t in 1975, and then gradually declining thereafter with landings of 30 t or less during the period 2013–21 (Fig. 55). Removals occurred mostly in Div. 3LNO, except during the period 1972–75, when most removals took place in Div. 2J3K; removals in any given year from Subdiv. 3Ps and Div. 2GH never exceeded 850 t and 385 t, respectively. In general, less than 30 t of Northern Wolffish and Spotted Wolffish were reported in any one year, whereas up to 350 t of Atlantic Wolffish have been reported in the NAFO STATLANT-21A; the majority of the reported landings were from Div. 3LNO.

The reported unspeciated wolffish landings from the ZIFF database ranged mostly between 150–416 t prior to 2003, dropping by ten-fold or more thereafter once the SARA listing of wolffish species came into effect and mandatory discard rules were enacted (Fig. 56). Initially most landings were from Div. 3LNO, but shifted to Subdiv. 3Ps since 1995. In Div. 2GH and 2J3K the reported annual landings were very low (<30 t) throughout the time series. Wolffish were caught by mobile gear (otter trawl) during the late–1980s and fixed gear (gillnet) during the 1990s in Div. 2GH; in Div. 2J3K most wolffish were caught by mobile fishing gear during the period 1985–90, notably by otter trawls, but since then fixed gears, including gillnet, pot, and longline were responsible for most reported wolffish landings (Fig. 57). Most reported landings in Div. 3LNO were from mobile gears in all years, with otter trawl being the main gear used, in contrast with Subdiv. 3Ps, which were predominantly from fixed gears, including longline and pots. In recent years the reported bycatch of wolffish has been predominantly from Subdiv. 3Ps gillnet and longline fisheries targeting Atlantic cod (*Gadus morhua*), and historically other fisheries targeting species such as Yellowtail Flounder (*Limanda ferruginea*) and Greenland Halibut (*Reinhardtius hippoglossoides*) have contributed to wolffish bycatch in NL waters (Collins et al. 2015).

The ASFO data show that reported landings of Northern Wolffish occurred mostly in Div. 2J3K, catch typically ranged between 150–300 t annually during the period 1985–92, except in 1987 (530 t), but dropped to less than 50 t from 1993 onwards (Fig. 58). However, comparison between years and areas using the ASFO catch data is difficult given the variation in observer coverage levels between different fisheries. Catch of Atlantic Wolffish occurred in Div. 3LNO in all years, ranging between 55–240 t during the period 2001–06, but otherwise catches were less than 40 t annually, except in 1989 (75 t). Spotted Wolffish catches occurred in both Div. 2J3K and 3LNO during most years, ranging between 55–190 t until 1992, and to less than 20 t thereafter. Northern Wolffish were caught by mobile gear in all bioregions, for example the Greenland Halibut trawl fishery, and in the Snow Crab (*Chionoecetes opilio*) pot fishery in Div. 3K (Collins et at. 2015). Northern Wolffish were also caught in gillnet and longline fisheries targeting Atlantic cod in Subdiv. 3Ps and Div. 2GH in 1985 (longline) (Fig. 59). Mobile gears also reported landings of Atlantic Wolffish and Spotted Wolffish in Div. 2GH (shrimp trawl), 2J3K (otter trawl, shrimp trawl), and 3LNO and Subdiv. 3Ps (otter trawl) (Figs. 60 and 61). Atlantic Wolffish were also reported in Subdiv. 3Ps longline and gillnet fisheries. Atlantic Wolffish were caught by the Northern Shrimp trawl fishery in Div. 2GH, the Yellowtail Flounder trawl fishery in Div. 3N, and the Snow Crab pot fishery in Div. 3KL, whereas Spotted Wolffish were caught in the Northern Shrimp trawl fishery in Div. 2GH, by the Greenland Halibut trawl fishery Div. 3KL, and more recently by the Snow Crab pot fishery in Div. 3KL (Collins et al. 2015).

The spatial distribution of the reported catch from the ASFO database indicate that Northern Wolffish interactions with commercial fleets (both mobile and fixed gear) occurred along the continental shelf slope and deep channels across the shelf (Hawke Channel, Cartwright Saddle) in Div. 2J3K, and over the Southeast Shoal (mobile gear only) and Southwest Slope of the Grand Bank in Div. 3LNO (Fig. 62). For Atlantic Wolffish, interactions with commercial fleets deploying mobile gear occurred on the Southeast Shoal, as well as along the edge of the Green Bank and Halibut Channel in Subdiv. 3Ps, and along the continental slope of the Northern Grand Bank, and Hawke Channel; interactions with fixed gear fleets occurred on the Burgeo Bank and along the southwest coast of Newfoundland in Subdiv. 3Ps (Fig. 63). Interactions between Spotted Wolffish and mobile gears occurred along the shelf edge of Northern Grand Bank and Bonavista Corridor in Div. 3LNO, and along the shelf edge and Hawke Channel in Div. 2J3K; interactions with fixed gears were for the most part centered in the Bonavista

Corridor (Fig. 64). As with all fishery-dependent data, the information on spatial distribution is more indicative of the distribution of fishing effort in relation to targeted species than the distribution of the bycatch species.

In the SARA logbooks, the majority of wolffish (all species) captured by mobile fishing gear in the NL Region were recorded as dead upon release (2008–19), whereas most wolffish were released alive by fixed fishing gears (Fig. 65).

Gulf of St. Lawrence

According to NAFO STATLANT 21-A database, total reported landings of wolffish in the Gulf of St. Lawrence (all gear combined) were largely dominated by unspeciated and Atlantic Wolffish from the west coast of Newfoundland (Fig. 66). For unspeciated wolffish, reported landings peaked at 742 t in 1983, declined to very low values (<10 t) until the early– to mid–1990s, and have remained at zero since 2011. Landing records for Atlantic Wolffish, available over the years 2004–18, attained a maximum of 18 t in 2010.

Trends in DFO's ZIFF landings exhibited similar patterns as those in NAFO's STATLANT 21-A (Fig. 67), with reported landings for unspeciated wolffish and Atlantic Wolffish attaining maximum values in the mid–1980s (>300 t) and in 2010 (>15 t), respectively. Most landings originated from Div. 4R, with a predominance of fisheries utilizing fixed gear (e.g., traps, gillnets) as opposed to mobile gear (e.g., trawls, seines).

Data from the ASFO program were extracted and interpreted for the nGSL and sGSL separately. In both regions, the total reported catches of wolffish are only applicable to the fishing trips having observers onboard; the numbers and representativity of such trips are unknown for wolffish. The raw observations were not extrapolated to fishing trips without observers.

Records of unspeciated wolffish in the nGSL were negligible (<2 t) and restricted to a small number of years prior to 2000 (Fig. 68). Catches of Atlantic Wolffish and Spotted Wolffish peaked in the late–1980s and in the mid– to late–2000s. For Northern Wolffish, there were records in the late–1980s and observations remained relatively rare (<0.1 t) thereafter. Most wolffish records originated from mobile gear fisheries, including bottom trawl fisheries targeting Atlantic cod and redfish, and longline fisheries for Atlantic Halibut and Atlantic cod. Overall, the spatial distribution of ASFO records in the nGSL was reflective of the distribution of the wolffish species in the RV survey indices and the commercial fisheries landings in that region (e.g., dominance of Div. 4R over 4S), though we note that the sample sizes employed to infer these patterns were small (Figs. 62–64).

The reported catch of Northern Wolffish from the ASFO database in the sGSL was very low from 1989 to 2013 (<1,000 kg, and 15 of those years <100 kg). Starting in 2013, Northern Wolffish catch increased and peaked at 6,300 kg in 2015, before slowly decreasing to the current level around 1,000 kg (Fig. 69). For Spotted Wolffish, the reported catch was also generally low (<1,000 kg), although the reported catch peaked in 1989 (7,045 kg), 2008 (3,327 kg) and 2014 (2,800 kg). For the Atlantic Wolffish, the reported catch also peaked in 2008, at 5,200 kg, but varied between 200 kg and 2,000 kg for most of the years. For this species the minimum reported catch was observed in most recent years with only 20 kg reported in 2020. In Div. 4T, Northern Wolffish were caught mainly by mobile gear (mostly by bottom trawl, but also by Danish seine); sporadic catches of Northern Wolffish with fixed gear (longline) also occurred (Fig. 70). Similarly, most Spotted Wolffish were also caught using bottom trawl and longline. A few significant catches of Spotted Wolffish with Scottish seines (mobile gear) were also recorded. Atlantic Wolffish were mostly caught using bottom trawl between 1990–2000, after which they were mostly caught by longlines between 2000–16. In the most recent years, the reported catch of wolffish was caught by a mix of fixed gears (longlines and gill nets).

Very few interactions between Northern Wolffish and both mobile and fixed gears occurred in the sGSL, mostly in nearshore areas along the Gaspe Peninsula and Cape Breton in Div. 4T (Fig. 62). Interactions between Atlantic Wolffish and Spotted Wolffish with commercial fleets (both mobile and fixed gear) occurred mainly along the slope of the Laurentian Channel, and nearshore areas along the Gaspe Peninsula and Cape Breton (Figs. 63 and 64).

Maritimes

Domestic landings of wolffish (also reported as catfish) reported in the MARFIS database are presented beginning in the year 2001 (Fig. 71). Historical catches are available from Simon et al. (2012). Landings in Div. 4VW and Div. 5ZY have declined since the early–1980s and have remained at low levels of 3 to 11 t since 2008. Landings in Div. 4X peaked in 2002 at about 150 t and declined thereafter, with an average of 10 t over the past decade. Mobile gear accounted for the largest proportion of landed wolffish, followed by bottom longline. Landings by both gear types have declined to only a few tons in recent years.

Landings from the ZIFF database dropped from an average of 10 t to below 5 t in the early–1990s, with most of the catch coming from otter trawl fisheries (Fig. 72).

Similar to reported commercial landings, the number of at sea observations of Atlantic Wolffish during domestic commercial fishing activities have decreased since 2000, with an average estimated weight of 1.56 t per year over the last decade (Fig. 73). Catches of Northern Wolffish briefly increased in the early–2000s but have remained below 3 t over the last ten years, whereas catches of Spotted Wolffish have remained below 3 t annually throughout the time series. Longlines are the primary source of wolffish bycatch reported by fisheries observers in the recent decade, accounting for 27 to 80% of the total annual catch. These data do not account for the total landings or effort of a fishery (for example, proportion of trips observed compared to total fishing trips undertaken). The percentage of observed wolffish caught and discarded has been around 39% of the total annual catch since 2001 (Fig. 74). Wolffish are consistently caught in groundfish (includes Atlantic cod, Pollock, Haddock, and Silver Hake), redfish and Atlantic Halibut fisheries, as well as invertebrate fisheries such as shrimp, scallop, and lobster.

ASFO data are the only source of discard information for wolffish in the Maritimes Region, because there are no requirements to record discards in fishing or SARA logbooks, and fisheries for invertebrates (e.g., scallop, lobster) are not required to retain bycatch. Wolffish (primarily Atlantic Wolffish) are discarded as bycatch in the inshore and offshore scallop, Jonah Crab, and American Lobster fisheries (Gavaris et al. 2010, Sameoto and Glass 2012, Pezzack et al. 2014). They have also been observed discarded in the groundfish bottom longline and otter trawl fisheries (Gavaris et al. 2010, Clark et al. 2015). Interactions between Northern Wolffish and both mobile and fixed gears occurred mostly in the southern area of the Scotian Shelf in Div. 4X, and the northern slope of Georges Bank in Subdiv. 5Ze, however, low levels of catch were reported (Fig. 62). In the case of Atlantic Wolffish, most interactions with both fleets also occurred in the same areas as observed for Northern Wolffish, as well as in the Bay of Fundy (Fig. 63). Few ASFO records are available for Spotted Wolffish (Fig. 64).

In addition, wolffish are also caught during joint DFO-fishing industry surveys such as the Atlantic Halibut and sentinel longline surveys and the Snow Crab trawl survey in Div. 4VWX (Fig. 75). These data show that wolffish are encountered during commercial fishing operations, and that landings data are by themselves not an accurate reflection of the impact of fishing activities on the population. The contribution of discarded fish to estimates of fishing mortality is an important source of uncertainty.

Table 4 shows interactions between fisheries and three species of wolffish as recorded in SARA logbooks. These logbooks were implemented in 2005, but only recently have been digitized and entered into an accessible database. As expected, Atlantic Wolffish form only a small proportion of the records, since fisheries are not required to record them. The proportion of records of Northern Wolffish and Spotted Wolffish are surprising, particularly the observations of these species in relatively shallow, coastal fisheries targeting Sea Scallop and lobster (Table 5). Northern Wolffish and Spotted Wolffish are more northern, deeper dwelling species that are uncommon on the Scotian Shelf (Scott and Scott 1988, Simon et al. 2012), therefore those records may be misidentified Atlantic Wolffish. Going forward, quality control of the data from SARA logbooks would enhance their value; for example, some verification that trips recording thousands of kilograms of Northern Wolffish are not transcription errors or misidentifications.

Arctic

NAFO's STATLANT 21-A database reported only eight records of unspeciated wolffish catch, with the most recent report from 1993. A small number of individuals were observed in the DFO-NL ZIFF database, but no associated weights were recorded. ASFO data were available from vessels fishing in Div. 0AB; primarily mobile gear fisheries targeting Greenland Halibut and *Pandalus* shrimp. For commercial fisheries in Div. 0AB, ASFO data are reported at the home port of the vessel and therefore the data are split across multiple databases. Reported catch prior to 2000 was not available for all databases.

Of the three species, recorded catch of Northern Wolffish was consistently the highest by both weight and frequency, peaking at just under 100 t in 2019 (Fig. 76). Total recorded catch and frequency of encounters have been increasing for Northern Wolffish across the time series, but interpretation of the data should be considered with caution as the data are not scaled to observer coverage or contributions from different target fisheries. Additionally, there may be issues of misidentification or recording errors in the data. There have been several instances of very large catches (>2 t) of Northern Wolffish reported from depths around 1,000–1,200 m. For both Spotted and Atlantic Wolffish, total reported catches remained low across the time series, with less than 3 t reported for most years, but there was a spike in reported landings for both species from 2009–13.

DISCUSSION

The analysis of RV survey catch data indicate that the majority of the Northern Wolffish and Spotted Wolffish populations are centered in Div. 2J3K, with Atlantic Wolffish centered in Div. 2J3K and 3LNO. These bioregions include the broadest range of sizes, and the largest proportion of adults and spawner components of the respective populations for the entire study area. The findings suggest that these bioregions contain optimal habitats for wolffish populations (e.g., spawning and feeding habitats), and the remaining areas comprise marginal habitats where immature and smaller size components of the populations predominate.

There were noticeable increases in stock size (all species) since the mid–2000s when compared to the 1990s in NL Region. The average fall abundance index of Northern Wolffish in Div. 2J3K was 0.67 million fish/year during the late–1990s (1997–99), declined to 0.57 million fish/year in 2000–04, prior to more than doubling in 2005–09 to 1.5 million fish/year, and again in 2010–21 to 2.95 million fish/year. The average fall abundance index of Spotted Wolffish during the same periods in Div. 2J3K were approximately 1 million fish/year (1997–99), 1.7 million fish/year (2000–04), 3.1 million fish/year in 2005–09, and 3.6 million fish/year in

2010–21. The average fall abundance index of Atlantic Wolffish in Div. 2J3K declined from 14.1 million fish/year (1997–99) to 12.6 million fish/year (2000–04), prior to stabilizing around 18.5 million fish/year from 2005 onwards, whereas in Div. 3LNO the average fall abundance ranged from 7.4 million fish/year (1997–99) to 10.4 million fish/year (2000–04), than near doubling to 20.1 million fish/year during the period 2005–09, prior to declining to 11.3 million fish/year in the last decade. These findings are consistent with the results from previous studies (COSEWIC 2012a, COSEWIC 2012b, COSEWIC 2012c, Collins et al. 2015, DFO 2015).

The trends in abundance indices show that only Spotted Wolffish in Div. 2J3K continued to sustain some level of recovery in most recent years (including a northward expansion into Div. 2H during the last decade), as well the broader range of sizes, whereas for the other two species, stock size tended to stabilize over time after an initial increase (NL, Quebec), or decline (Maritimes, Gulf), and no improvement in fish size was observed (i.e., truncated size-classes).

Despite their broad geographic distribution, the three wolffish species have well defined habitat requirements, living within relatively narrow thermal and depth boundaries in the bioregions where the majority of the wolffish stocks are found. Between 5% and 95% of the Northern Wolffish captured during the fall RV surveys in Div. 2J3K were found in water temperatures ranging from -0.1 to 4.0°C (Engel time series) and 1.7 to 4.4°C (Campelen time series); -0.6 to 3.7°C (Engel) and 0.9 to 4.1°C (Campelen) in the case of Spotted Wolffish; and -0.1 to 3.5°C (Engel) and 1.4 to 4.0°C (Campelen) in the case of Atlantic Wolffish (the same range of values were observed in Div. 3LNO during both spring and fall). Likewise, between 5% and 95% of the Northern Wolffish were captured in Div. 2J3K at depths ranging from 174 to 692 m (Engel) and 214 to 1,108 m (Campelen); 148–464 m (Engel) and 199–432 m (Campelen) for Spotted Wolffish; 200–345 m (Engel) and 204–332 m (Campelen) for Atlantic Wolffish. In Div. 3LNO Atlantic Wolffish were mostly caught at depths ranging from 52 to 331 m in spring, and 67 to 345 m in fall (both fishing gears).

The physiological condition of Northern Wolffish and Atlantic Wolffish, as indicated by the mean Fulton's K Condition Factor, was consistently higher in Div. 2J3K (and 2H) when compared to Div. 3LNO and Subdiv. 3Ps. Snow Crab and Northern Shrimp are important components of the diet of both wolffish species, in addition to redfish and American Plaice (*Hippoglossoides platessoides*) in the case of Northern Wolffish (Simpson et al. 2013a). Historically, shellfish has been the dominant functional group in Div. 2J3K, whereas the groundfish community is the main functional group in Div. 3LNO and Subdiv. 3Ps (Koen-Alonso and Cuff 2018). The latter functional group has experienced increased levels of biological productivity in the last decade in Div. 3LNO, as well as in Div. 2J3K (Wheeland et al. 2019, DFO 2020b, DFO 2022b). These findings support the view that Div. 2J3K contain important feeding habitats for both Northern Wolffish and Atlantic Wolffish stocks, as well Div. 3LNO in the case of Atlantic Wolffish. Snow Crab and Northern Shrimp are also important components of Spotted Wolffish diet, in addition to Capelin (*Mallotus villosus*), and echinoderms like Brittlestar (*Ophiuroidea*), Sand Dollar (*Clypeasteroida*), and Sea Urchin (*Echinoidea*). In this case no differences in Fulton's K Condition Factor were detected among bioregions, suggesting that Spotted Wolffish has a higher level of plasticity in terms of diet, being able to compensate the reduced availability of certain prey taxa with others that might be more widely available. In fact, this trait is hypothesized to be one of the main reasons why Spotted Wolffish is the only wolffish species able to sustain some level of recovery in NL waters in recent years.

As expected, most reported wolffish interactions with commercial fisheries occurred in the bioregions where the stocks are centered, primarily along the slopes of the continental shelf and deep channels, and to a lesser extent over the southern Grand Bank and the remaining portions of the study area. Mobile fleets were responsible for the majority of wolffish removals in NL, and Maritimes Regions prior to 2003, as well the Arctic Region (2000–21), whereas fixed gear fleets accounted for most wolffish removals in the Quebec and Gulf Regions. The majority of wolffish (all species) captured by mobile gear in the NL Region were recorded as dead upon release in the SARA logbooks (2008–19), whereas the opposite was observed in the case of fixed gears.

THREATS

Change to thermal habitats is likely one of the most significant threats to wolffish species at the continental shelf scale. Such a threat can impact wolffish both directly and indirectly (Bluemel et al. 2022, Perry 2022). As shown in this study and previous studies (Simpson et al. 2013b, DFO 2020a, DFO 2022a), the three wolffish species have narrow thermal tolerances. Warmer than normal water temperatures were observed near the seafloor across all bioregions of the NL shelves in the last several years; positive anomalies were observed in 9 of 12 years during the period 2010–21, with 2011 being the warmest year on record (+1.8 standard deviation [SD]), followed by 2021 (+1.4 SD) (Cyr et al. 2022). The shelf waters over most of the Grand Banks are forecasted to continue to warm, as the effects of climate change intensify (Han et al. 2015, Han et al. 2018, Le Corre et al. 2021), hence a reasonable expectation for the coming decades is that essential habitats will become more or less available to wolffish species, as a function of species-specific thermal tolerances.

Moreover, ocean warming has already enabled hundreds of marine species to move to higher latitudes and deeper waters (Poloczanska et al. 2013, Poloczanska et al. 2016, Pinsky et al. 2020), including in the NL Region (Koen-Alonso et al. 2018, Morley et al. 2018). The impacts of the expansion in range boundaries and colonization of wolffish habitat by warmer water marine species are not known, but should be considered as potential threats to recovery (e.g., competition, predation). For example, species that are able to colonize new habitats tend to be ecological generalists with higher levels of plasticity in habitat and diet selection, such as omnivores, instead of piscivores or benthivores (Sunday et al. 2015), or species that can live across depths and substrates (Grieve et al. 2016). The same reasoning would potentially apply to the establishment of aquatic invasive species across wolffish habitat.

Other potential threats such as seismic activities, oil and gas drills, aquaculture siting, and pollution have the potential to negatively impact benthic habitats (e.g., habitat degradation, mortality of prey species) occupied by wolffish. However, the three wolffish species are widespread in Canadian Atlantic and Arctic waters, tend to be found in low densities, have low mobility, and a generally solitary lifestyle. Hence, the anticipated impacts to these species and habitats will likely be low and limited to the surrounding areas subjected to those threats. Otherwise, if significant evidence of local populations can be established, then the potential for spatial erosion of those populations should be assessed.

SOURCES OF UNCERTAINTY

Wolffish landings and discards by commercial fisheries are rarely identified to species when reported by domestic and foreign fleets in Canadian waters. The Canadian ASFO Program constitutes the sole source of total catch data by species, including discards at sea. However, in many fisheries, annual observer coverage is typically too low or not sufficiently representative to accurately estimate wolffish bycatch.

Although Canada’s SARA requires mandatory release of Northern Wolffish and Spotted Wolffish caught in Canadian waters as a conservation measure, the percentages of post-release mortality are unknown in different fisheries (i.e., a “live” release does not necessarily result in post-release survival).

Currently no stock assessment models for wolffish species inhabiting Canadian Atlantic and Arctic waters are available due to limited information/data on life history traits (e.g., growth rate, age at maturity, recruitment, and mortality). In addition, the lack of information on RV survey trawl catchability and survey gear conversion factors in regions outside the nGSL and Scotian Shelf limits the temporal extent of the existing survey data.

There is limited knowledge about aspects of habitat associations not covered in the present study, including breeding and nursery areas.

The increases in stock size observed since the mid–2000s coincided with the period when wolffish species became protected under the SARA legislation. However, there were concurrent shifts in oceanographic conditions and functional groups in the bioregions inhabited by wolffish (Rose 2004, Buren et al. 2014, Pedersen et al. 2017, Koen-Alonso and Cuff 2018, Cyr et al. 2022). Hence it is unclear if the trends in wolffish abundance during the last two decades were driven mainly by a reduction in fishing mortality, changes in environmental conditions or community structure, or the result of compounded multifactorial effects.

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TABLES

Table 1. Maximum latitude which each of the three wolffish species were observed each year. Note the difference in maximum latitude fished between years.

Year	Maximum Latitude Fished	Maximum Latitude Northern Wolffish	Maximum Latitude Spotted Wolffish	Maximum Latitude Atlantic Wolffish
1999	71.36	67.58	68.09	-
2000	66.19	64.97	61.80	-
2001	71.38	67.57	67.88	-
2004	75.18	-	-	-
2005	66.20	64.46	65.29	64.81
2006	72.29	68.02	68.42	64.95
2007	66.27	64.59	64.83	64.10
2008	71.52	67.85	68.51	68.12
2009	66.23	63.83	64.88	63.32
2010	75.53	67.75	68.44	68.04
2011	66.25	66.04	65.67	64.06
2012	75.58	74.12	71.30	68.09
2013	66.22	66.11	65.09	63.06
2014	72.57	72.07	65.50	64.93
2015	72.50	71.25	69.29	64.33
2016	72.56	69.21	65.22	64.75
2017	70.78	65.29	65.31	62.41
2018	66.21	65.79	65.09	65.37
2019	72.53	72.08	71.42	64.19
2020	66.19	64.72	65.16	65.16
2021	66.06	64.76	65.64	64.78

Table 2. Parameter estimates of the von Bertalanffy growth function (VBL) for female wolffish in Newfoundland and Labrador waters (NAFO Div. 2J3KLNOPs).

Species	Model					L_{inf}	K	t_0	References
	Function	DF	RSS	F Value	Pr > F	(cm)			
Northern Wolffish	VBL	88	3,870.4	4,834.06	<0.0001	127	0.061	-1.276	Fishbase.org (L_{inf}=150 cm, K=0.098, t_0=-2.94)
Atlantic Wolffish	VBL	518	27,910.2	8,789.96	< 0.0001	150	0.044	0.632	Fishbase.org (L_{inf}=158 cm, K=0.043, t_0=-0.39, -0.43) Nelson and Ross 1992 (L_{inf}=162 cm, K=0.04, t_0=-0.43)
Spotted Wolffish	VBL	416	25,164.4	40,431.1	<0.0001	184	0.037	-0.4	Fishbase.org (L_{inf}=181 cm, K=0.061) Gunnarsson et al. 2008 (L_{inf}=106 cm, K=0.043, t_0=0.486)

Table 3. Estimates of age and length at 50% maturity of the Logistic Regression function (Logit) for female wolffish in Newfoundland and Labrador waters (NAFO Div. 2J3KLNOPs).

Species	Function	n	Parameter	Estimate	SE	Pr > ChiSq	References
Northern Wolffish	Logit	20	Intercept	-15.7320	7.8437	0.0449	COSEWIC 2012 (L_{50} = 75.2 cm, A_{50} = 5.8 y.o.) Simpson et al. 2011 (A_{50} = 5 to 6 y.o.)
			Length	0.1953	0.0921	0.0339	
			L_{50} (cm)	80.6	-	-	
		20	Intercept	-6.6937	3.2178	0.0375	
			Age	0.6594	0.3418	0.05	
			A_{50} (Years)	10.5	-	-	
Atlantic Wolffish	Logit	473	Intercept	-6.1581	0.5511	<0.0001	Templeman 1986a (L_{50} = 51.4 to 68.2 cm) McRuer et al. 2000 (L_{50} = 55 cm. A_{50} = 10 y.o.) McBride et al. 2022 (L_{50} = 53 cm, A_{50} = 6.7 y.o.)
			Length	0.1226	0.0123	<0.0001	
			L_{50} (cm)	50.7	-	-	
		452	Intercept	-5.3869	0.4937	<0.0001	
			Age	0.5205	0.0534	<0.0001	
			A_{50} (Years)	10.4	-	-	
Spotted Wolffish	Logit	94	Intercept	-6.0785	1.2485	<0.0001	Gunnarsson et al. 2008 (L_{50}=82.7 cm, A_{50}=9.1 y.o.) Templeman 1986b (L_{50}= 81 to 86 cm) Simpson et al. 2011 (A_{50} = 5 to 6 y.o.)
			Length	0.0822	0.0177	<0.0001	
			L_{50} (cm)	74.0	-	-	
		90	Intercept	-10.0876	2.4879	<0.0001	
			Age	1.2763	0.3174	<0.0001	
			A_{50} (Years)	7.5	-	-	

Table 4. Interactions by wolffish species (kg) as recorded in SARA logbooks from fishing locations in Div. 4VWX (- indicates no data). Data for 2019–22 are preliminary.

Years	Northern Wolffish	Spotted Wolffish	Atlantic Wolffish	Unspecified Wolffish	Total (kg)
2006	2,457	113	214	-	2,784
2007	18,691*	400	105	24	19,220
2008	5,075	379	488	10	5,952
2009	2,152	826	24	-	3,002
2010	1,047	546	-	-	1,593
2011	667	506	40	9	1,222
2012	525	251	<1	350	1,127
2013	1,326	290	20	544	2,180
2014	1,246	337	14	<1	1,598
2015	402	400	16	5	823
2016	560	138	250	-	948
2017	352	176	-	-	528
2018	532	45	-	-	577
2019	788	250	-	-	1,038
2020	674	284	-	-	958
2021	584	73	-	-	657
2022	61	460	-	-	521
Total (kg)	37,139	5,474	1,172	943	44,728

*A single trip in 4VW recorded 13,000 kg

Table 5. Interactions by fishery with wolffish (kg) as recorded in SARA logbooks from fishing locations in Div. 4VWX (- indicates no data). Data for 2019–22 are preliminary.

Years	Snow Crab	Groundfish	Lobster	Sea Scallop	Tuna	Total (kg)
2006	-	1,637	-	-	-	1,637
2007	-	59,895*	-	-	227	60,122
2008	-	5,953	-	-	-	5,953
2009	-	9,529	-	-	-	9,529
2010	-	1,621	<1	-	-	1,622
2011	-	1,374	173	-	-	1,547
2012	-	1,116	33	-	-	1,149
2013	-	2,597	53	-	-	2,650
2014	<1	2,437	20	-	-	2,456
2015	-	1,663	18	3	-	1,684
2016	-	1,459	22	-	-	1,481
2017	26	1,615	95	<1	-	1,737
2018	-	634	102	20	-	756
2019	71	1,202	40	5	-	1,318
2020	16	8,224	103	20	-	8,363
2021	32	5,387	76	-	-	5,495
2022	-	431	23	2	300	756
Total (kg)	146	106,774	756	51	527	108,255

*A single trip recorded 13,000 kg

FIGURES

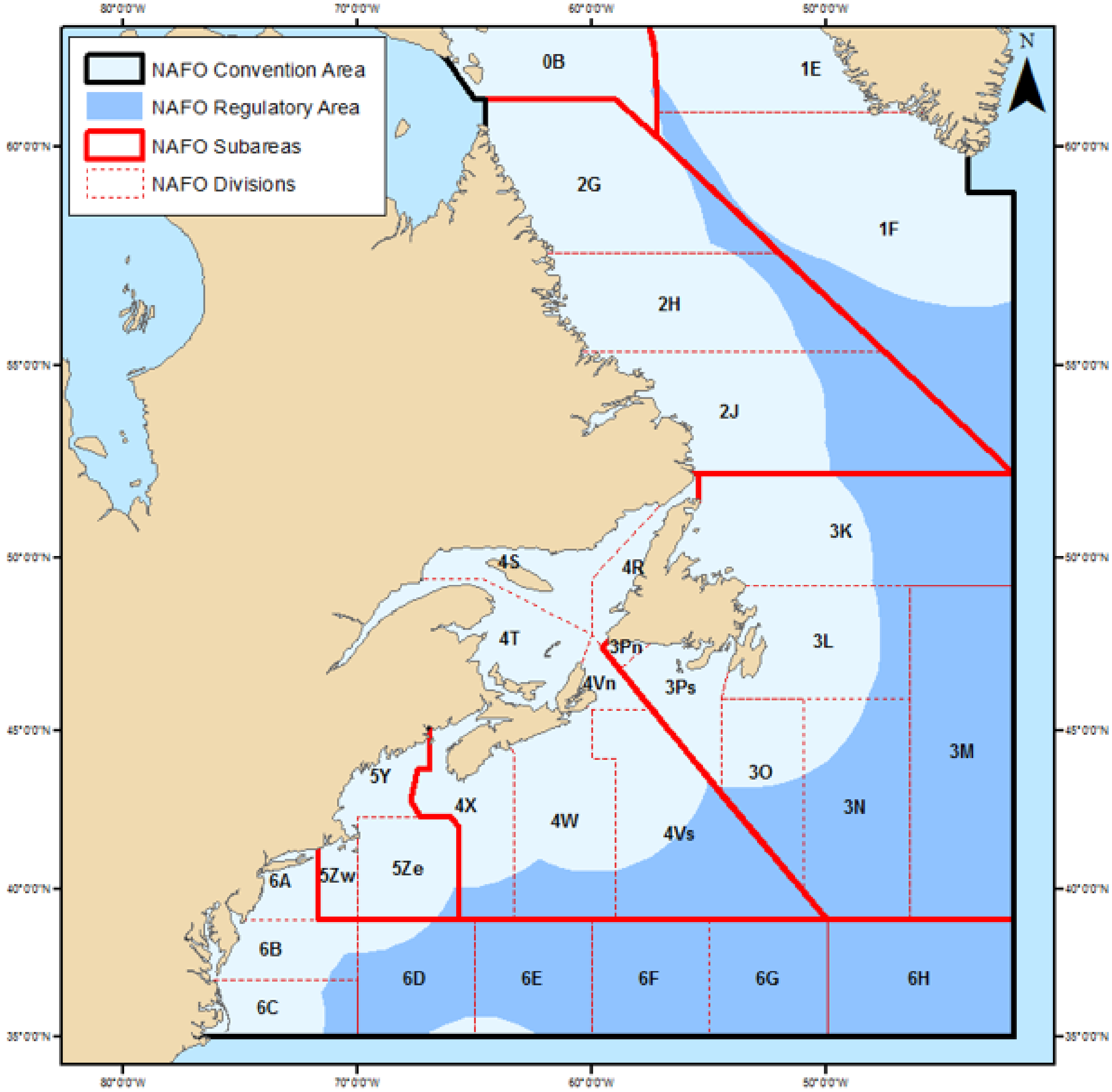


Figure 1a. Regulatory area map of the Northwest Atlantic Fisheries Organization (NAFO) and the Subareas and Divisions covered in this study: Newfoundland and Labrador (Div. 2GHJ3KLNO and Subdiv. 3Ps), Quebec (Div. 4RS + St. Lawrence Estuary), Gulf (Div. 4T), and Maritimes (Div. 4VWX5Y, and Subdiv. 5Ze).

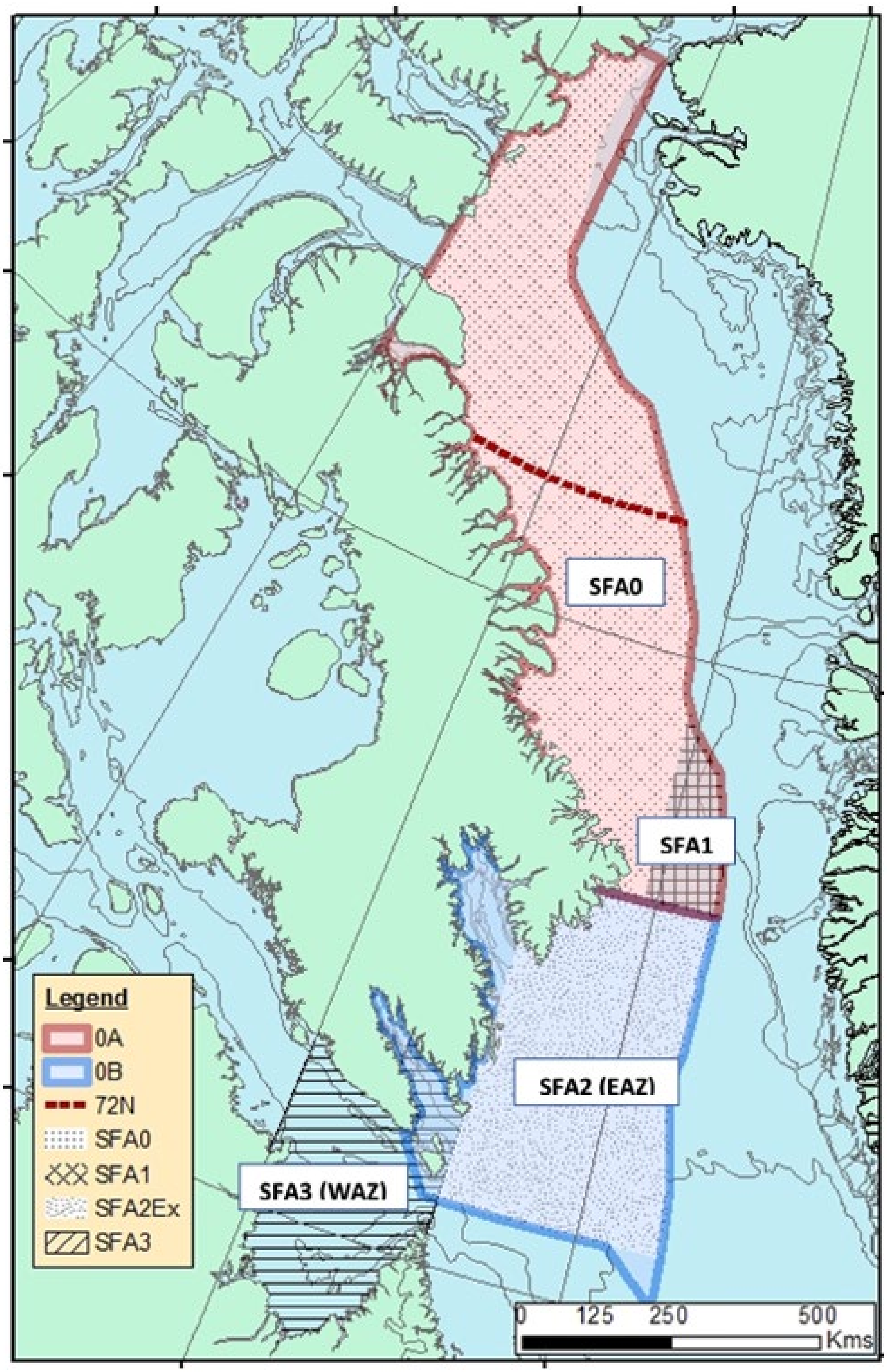


Figure 1b. Regulatory area map of the Northwest Atlantic Fisheries Organization (NAFO) and the Subareas and Divisions covered in this study: Arctic (Div. 0A0B).

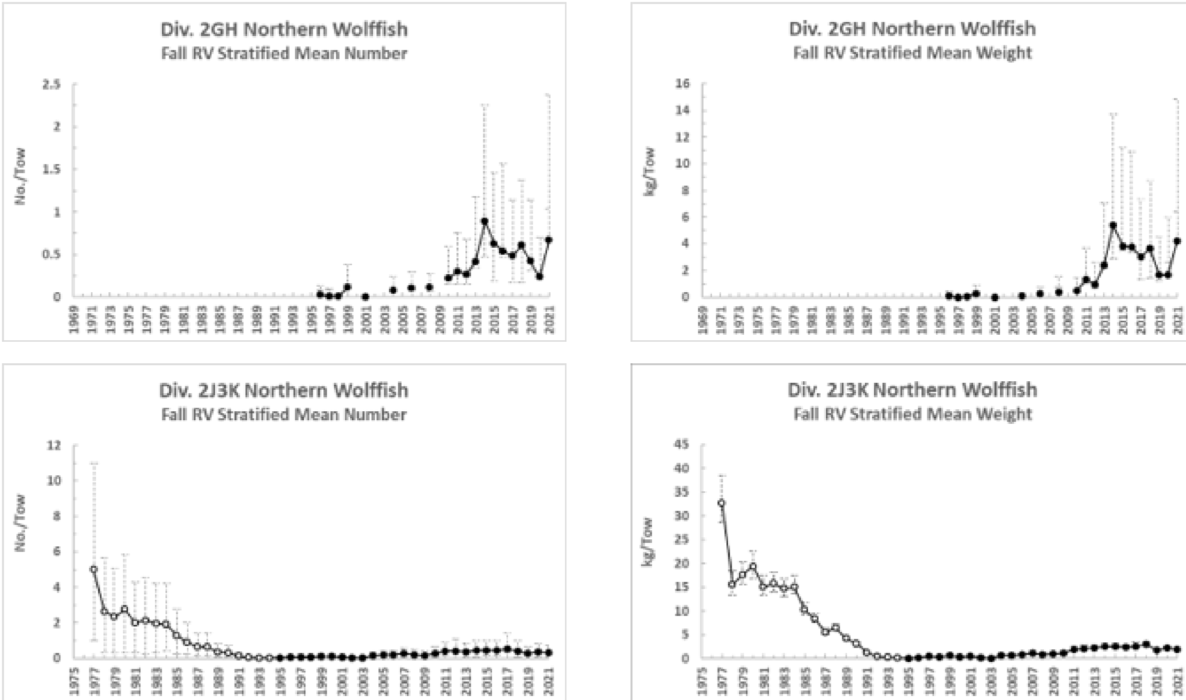


Figure 2a. Estimates of stratified mean catch rates of Northern Wolffish in Div. 2GH, and Div. 2J3K. Yankee (grey circle), Engel (open circle), and Campelen time series (black circle). T-bars = +/- 95% Confidence Intervals (CIs).

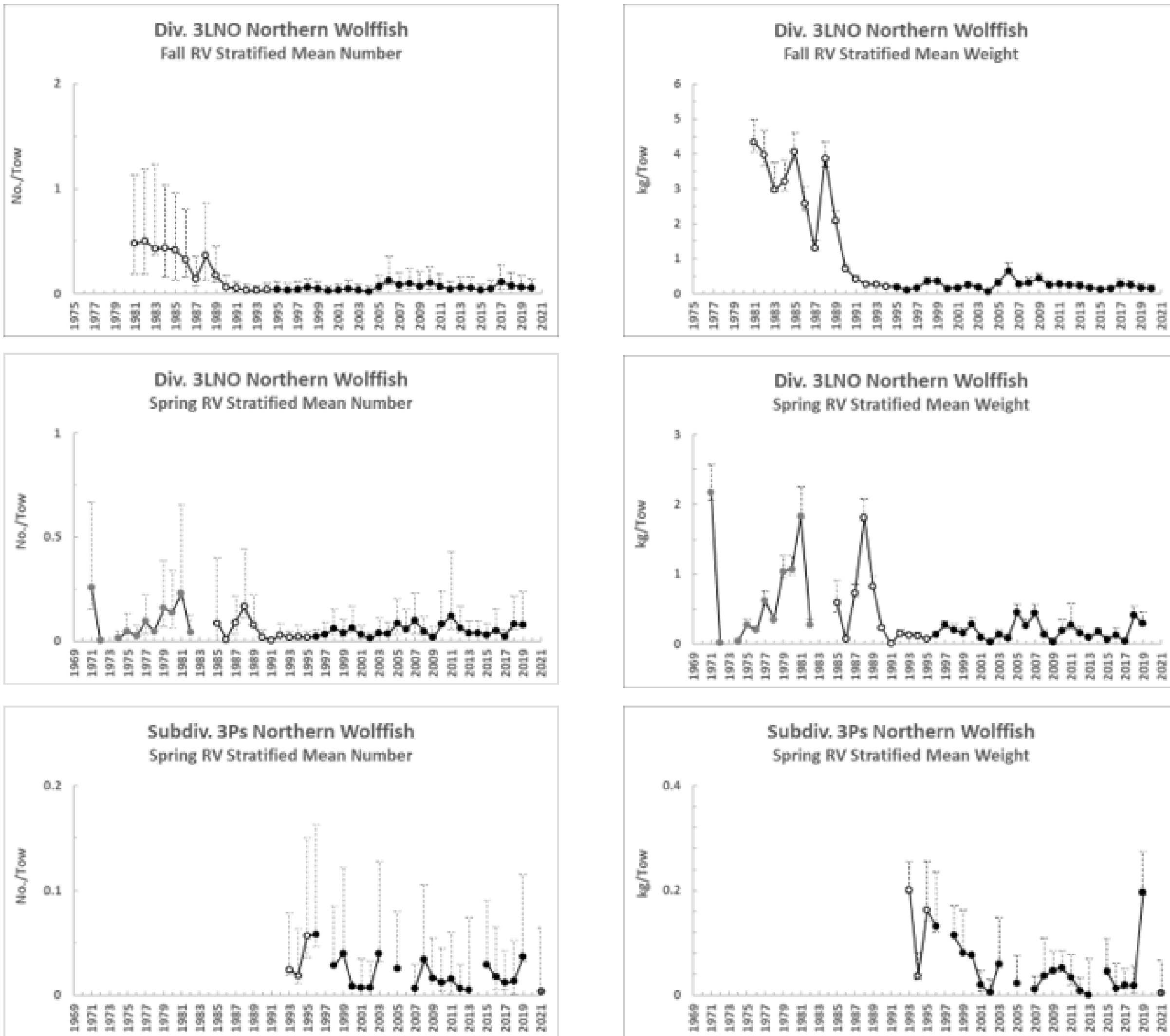


Figure 2b. Estimates of stratified mean catch rates of Northern Wolffish in Div. 3LNO, and Subdiv. 3Ps. Yankee (grey circle), Engel (open circle), and Campelen time series (black circle). T-bars = +/- 95% CIs.

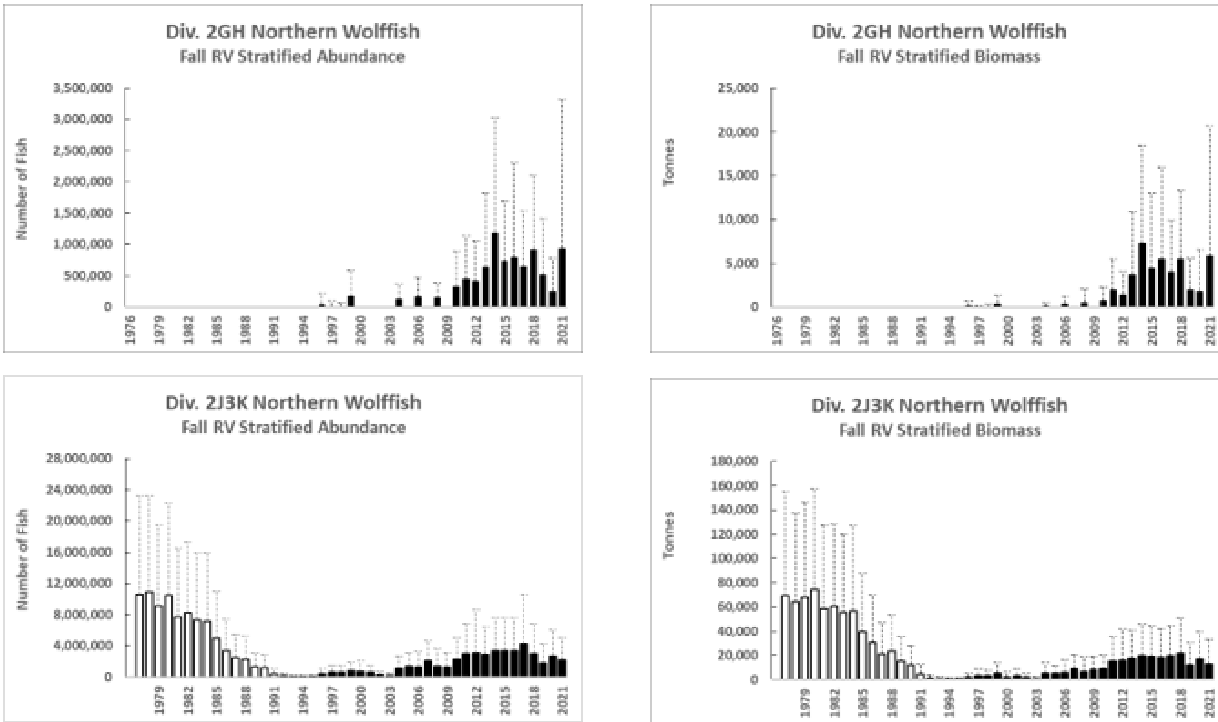


Figure 3a. Abundance and biomass estimates of Northern Wolffish in Div. 2GH, and Div. 2J3K. Yankee (grey bar), Engel (open bar), and Campelen time series (black bar). T-bars = + 95% CIs.

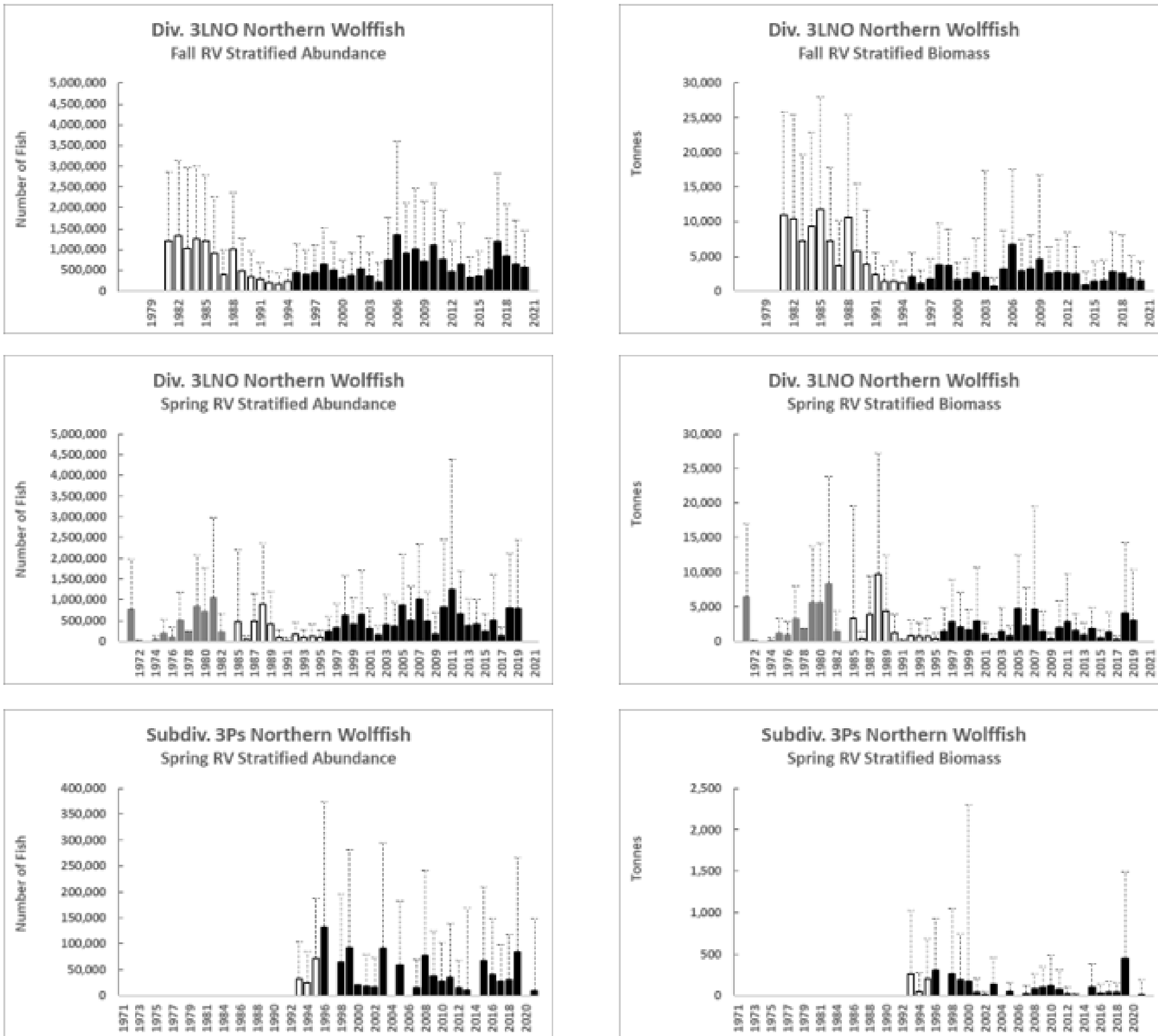


Figure 3b. Abundance and biomass estimates of Northern Wolffish in Div. 3LNO, and Subdiv. 3Ps. Yankee (grey bar), Engel (open bar), and Campelen time series (black bar). T-bars = + 95% CIs.

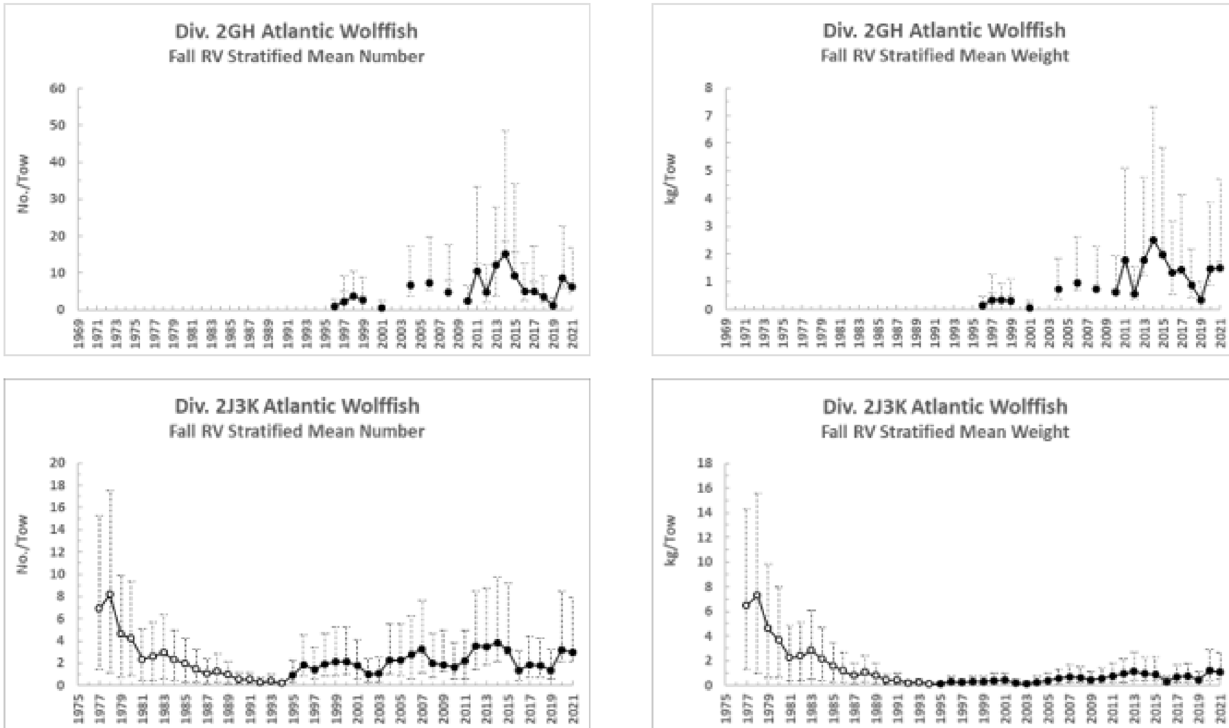


Figure 4a. Estimates of stratified mean catch rates of Atlantic Wolffish in Div. 2GH, and Div. 2J3K. Yankee (grey circle), Engel (open circle), and Campelen time series (black circle). T-bars = +/- 95% CIs.

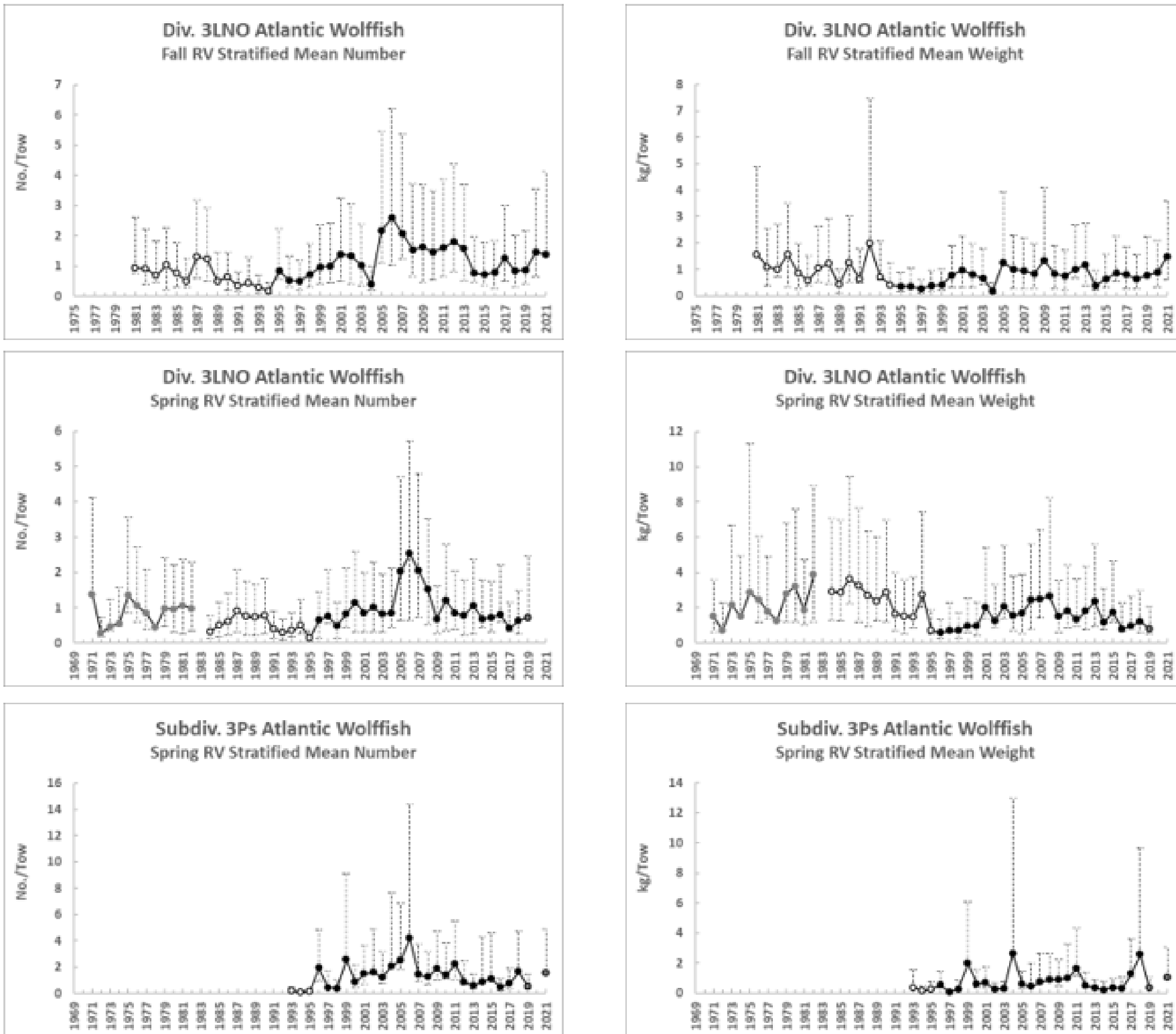


Figure 4b. Estimates of stratified mean catch rates of Atlantic Wolffish in Div. 3LNO, and Subdiv. 3Ps. Yankee (grey circle), Engel (open circle), and Campelen time series (black circle). T-bars = +/- 95% CIs.

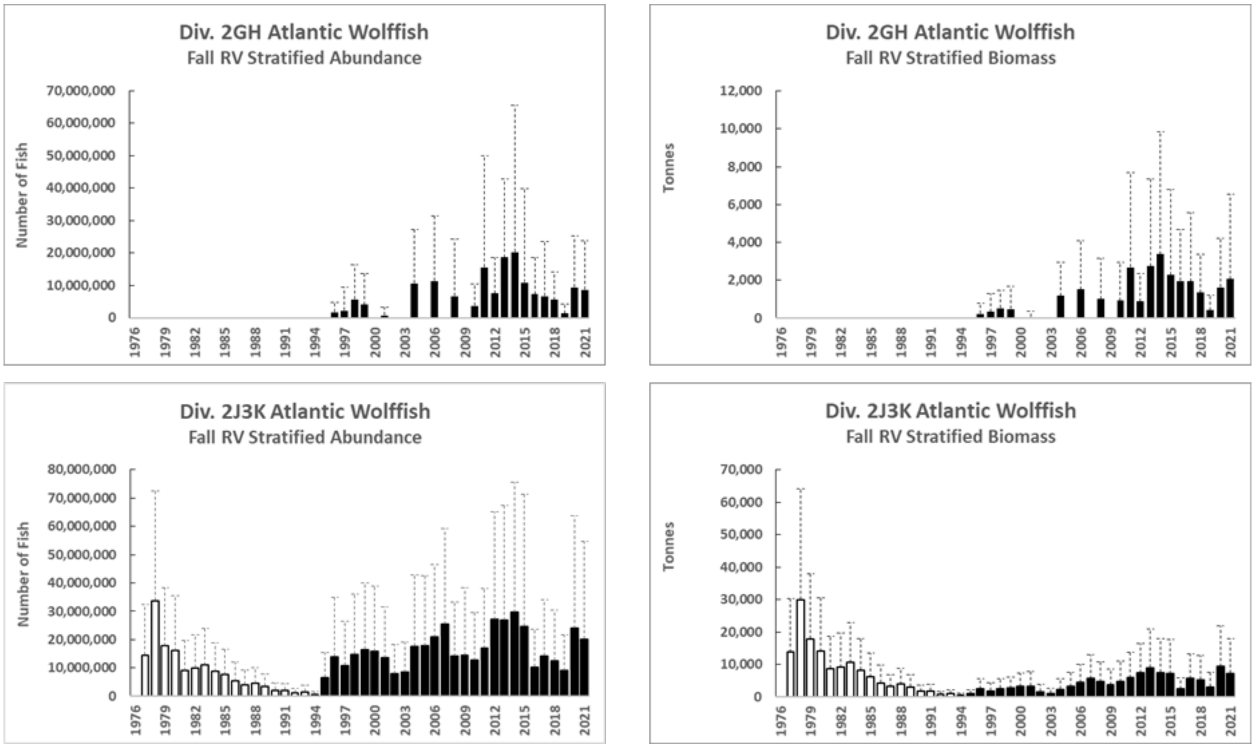


Figure 5a. Abundance and biomass estimates of Atlantic Wolffish in Div. 2GH, and Div. 2J3K. Yankee (grey bar), Engel (open bar), and Campelen time series (black bar). T-bars = + 95% CIs.

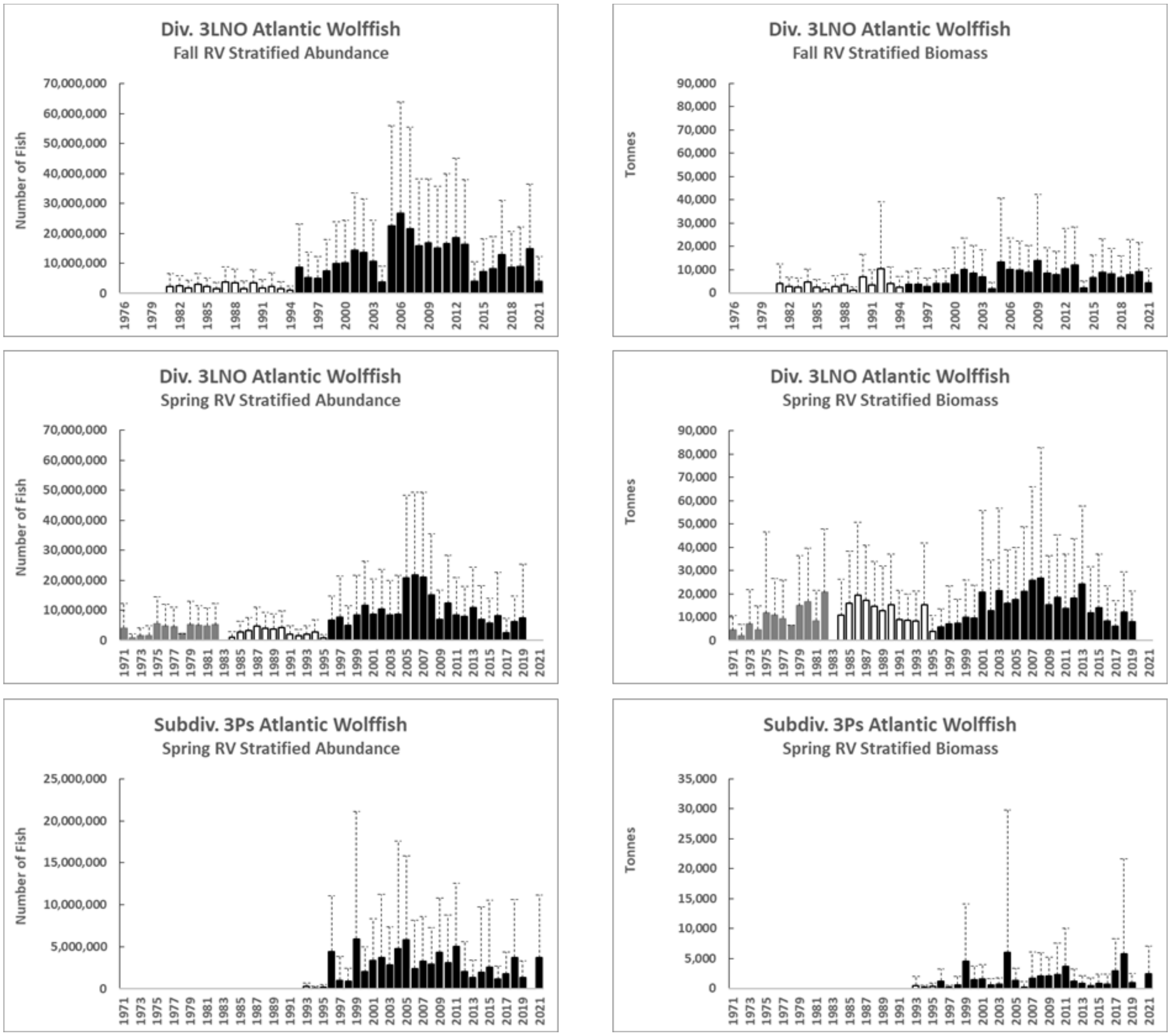


Figure 5b. Abundance and biomass estimates of Atlantic Wolffish in Div. 3LNO, and Subdiv. 3Ps. Yankee (grey bar), Engel (open bar), and Campelen time series (black bar). T-bars = + 95% CIs.

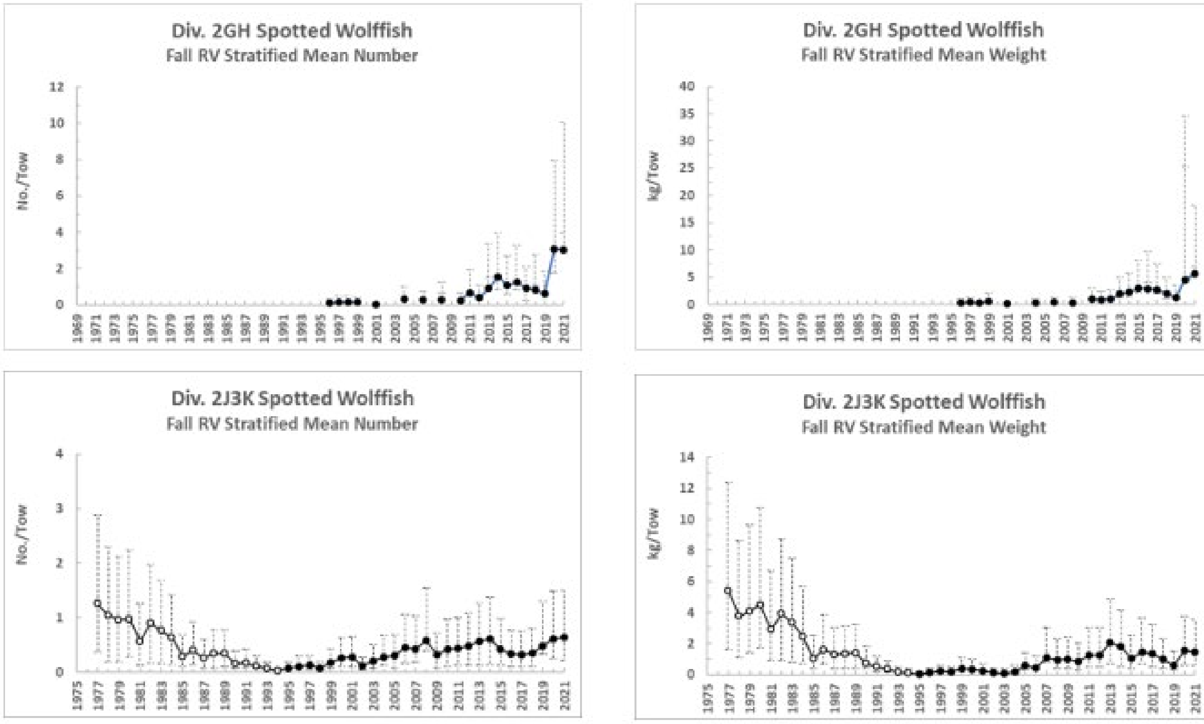


Figure 6a. Estimates of stratified mean catch rates of Spotted Wolffish in Div. 2GH, and Div. 2J3K. Yankee (grey circle), Engel (open circle), and Campelen time series (black circle). T-bars = +/- 95% CIs.

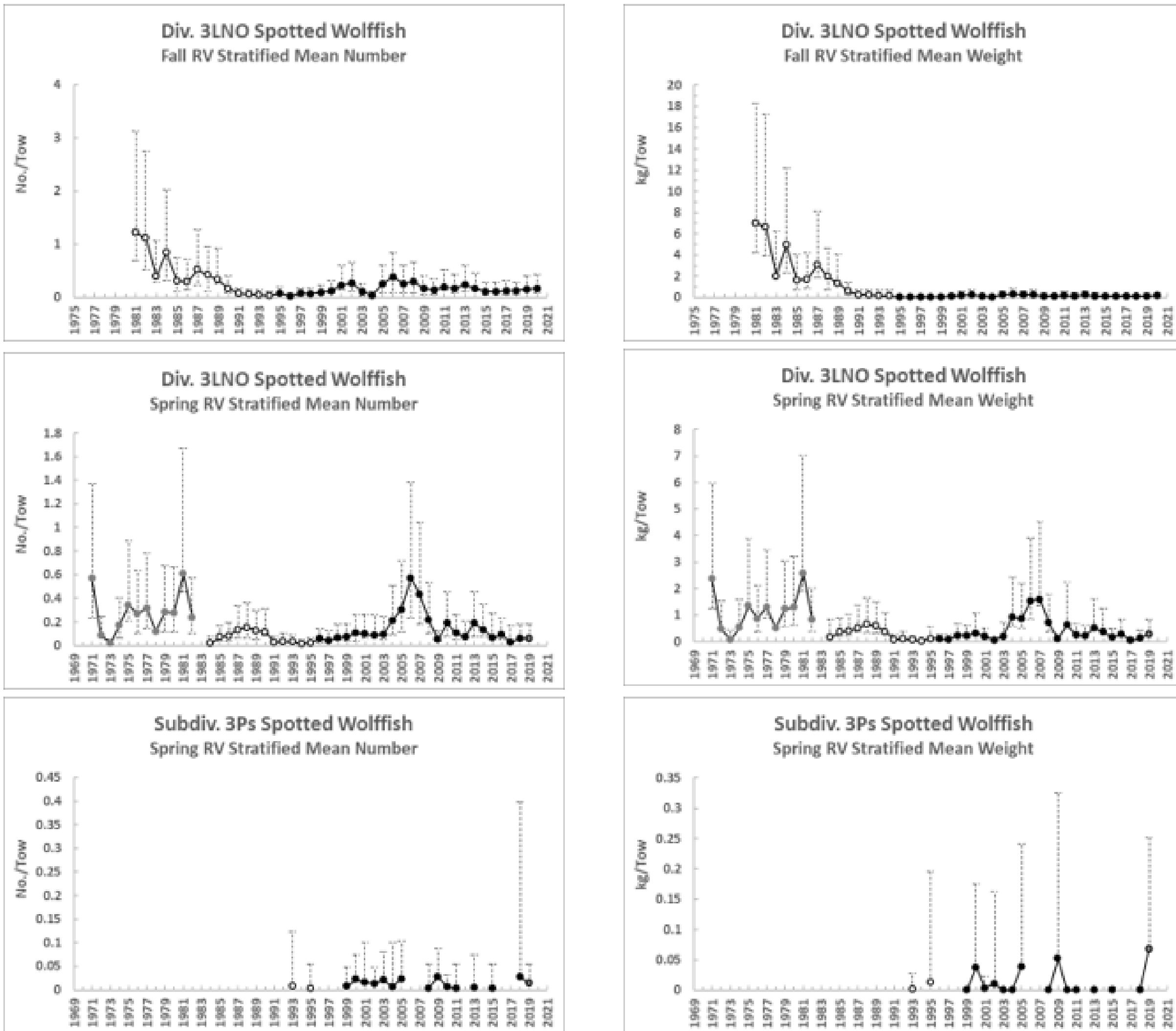


Figure 6b. Estimates of stratified mean catch rates of Spotted Wolffish in Div. 3LNO, and Subdiv. 3Ps. Yankee (grey circle), Engel (open circle), and Campelen time series (black circle). T-bars = +/- 95% CIs.

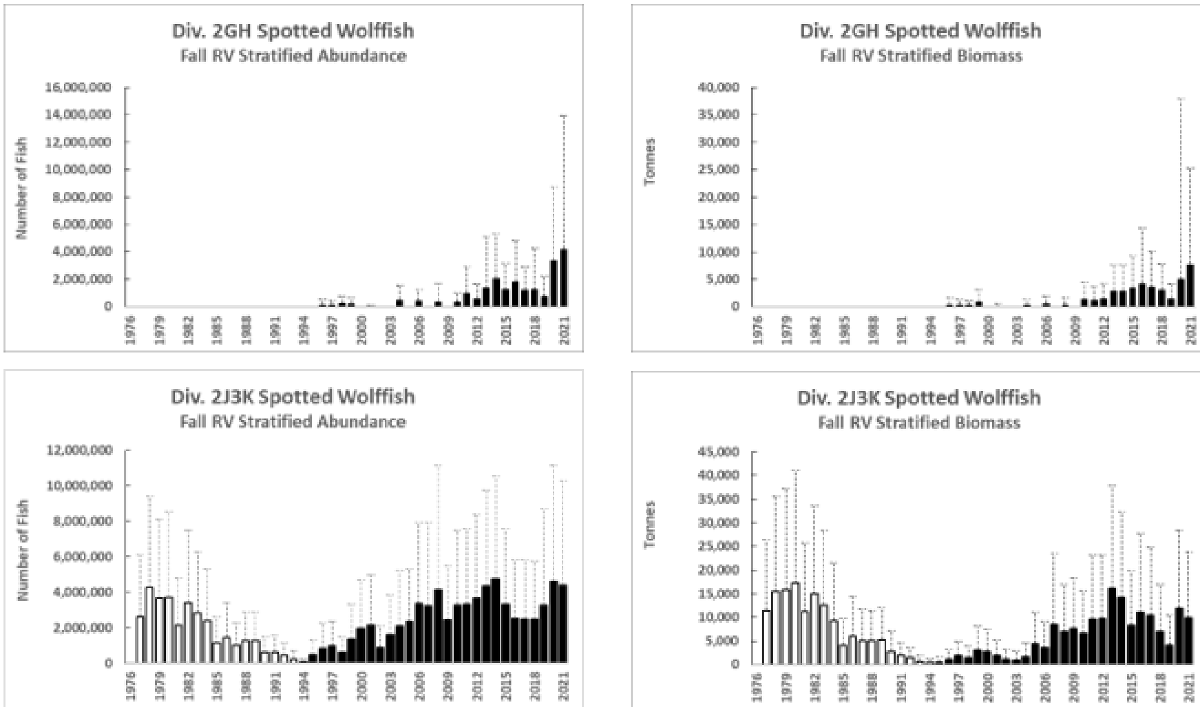


Figure 7a. Abundance and biomass estimates of Spotted Wolffish in Div. 2GH, and Div. 2J3K. Yankee (grey bar), Engel (open bar), and Campelen time series (black bar). T-bars = + 95% CIs.

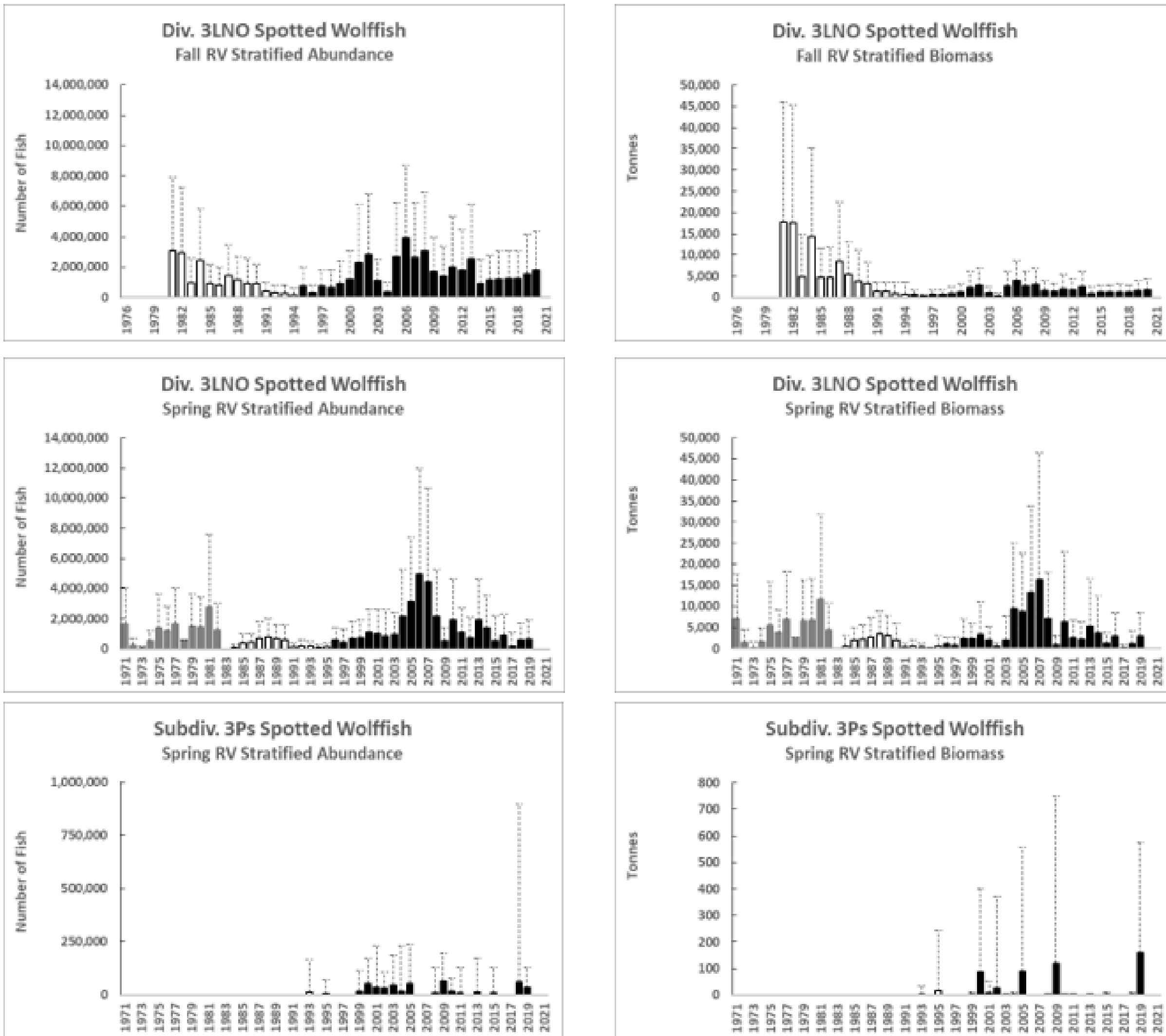


Figure 7b. Abundance and biomass estimates of Spotted Wolffish in Div. 3LNO, and Subdiv. 3Ps. Yankee (grey bar), Engel (open bar), and Campelen time series (black bar). T-bars = + 95% CIs.

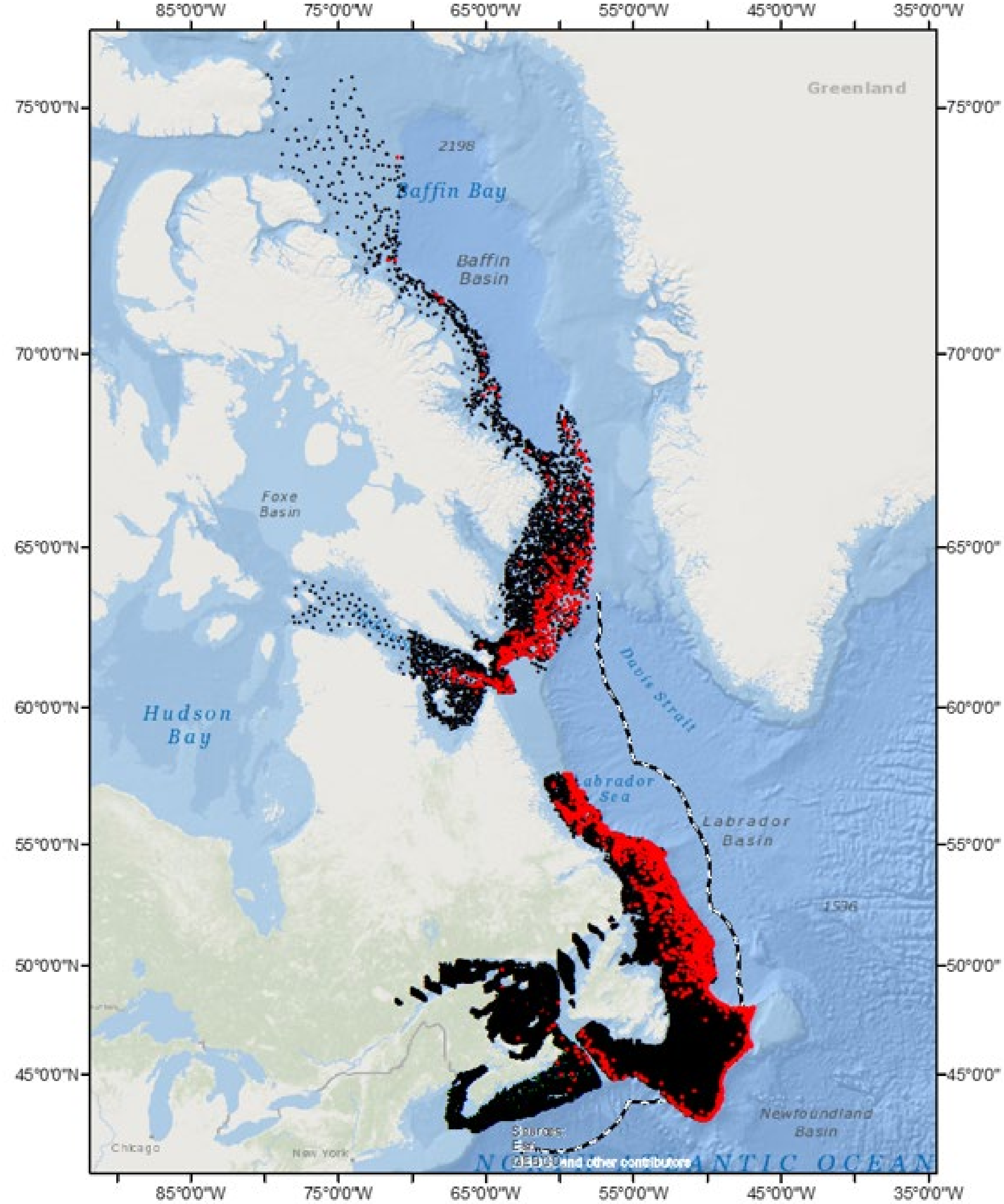


Figure 8. Range of Northern Wolffish distribution in Canadian Atlantic and Arctic waters. Red dot = species is present and black dot = absent in RV survey fishing tows (1971–2021).

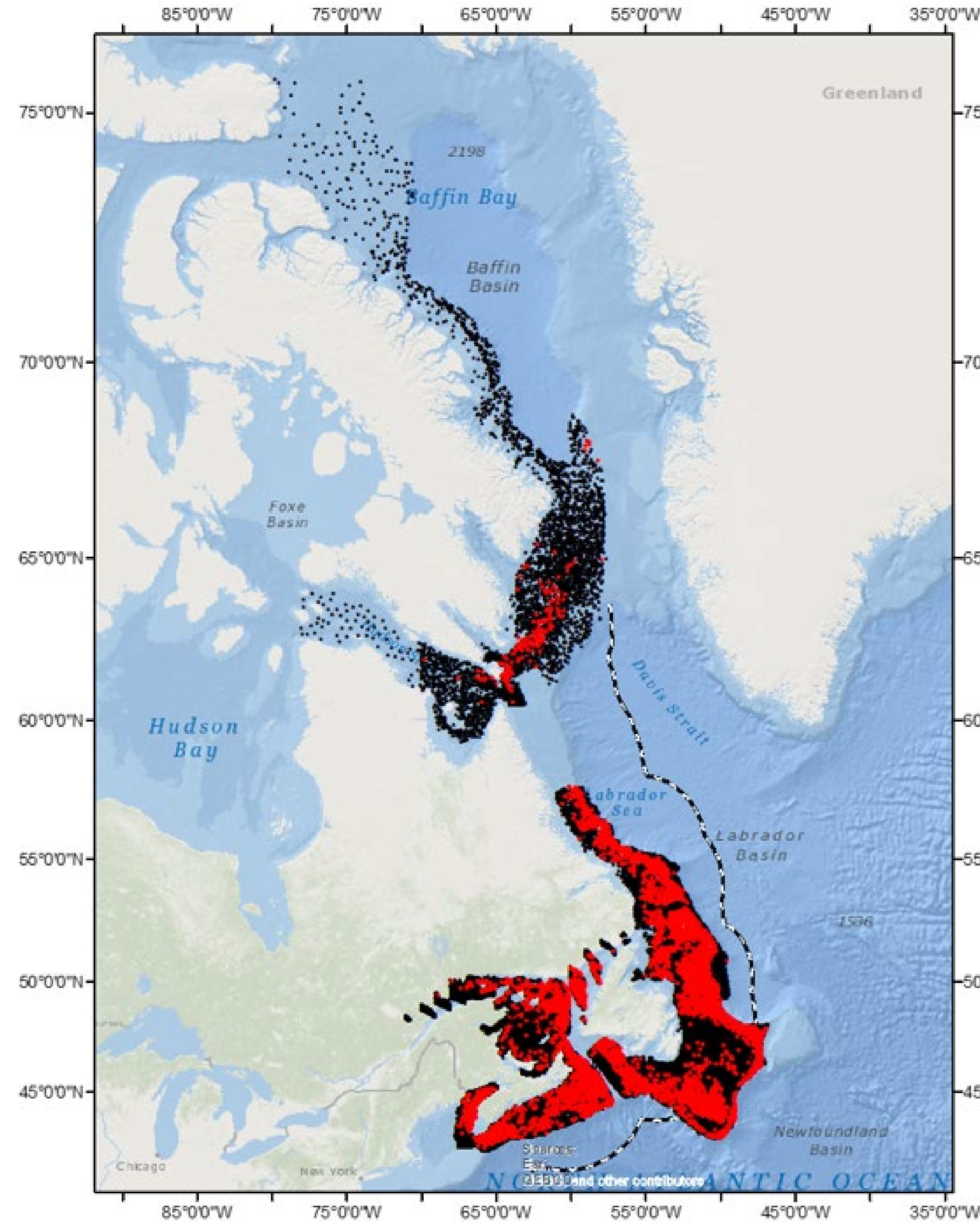


Figure 9. Range of Atlantic Wolffish distribution in Canadian Atlantic and Arctic waters. Red dot = species is present and black dot = absent in RV survey fishing tows (1971–2021).

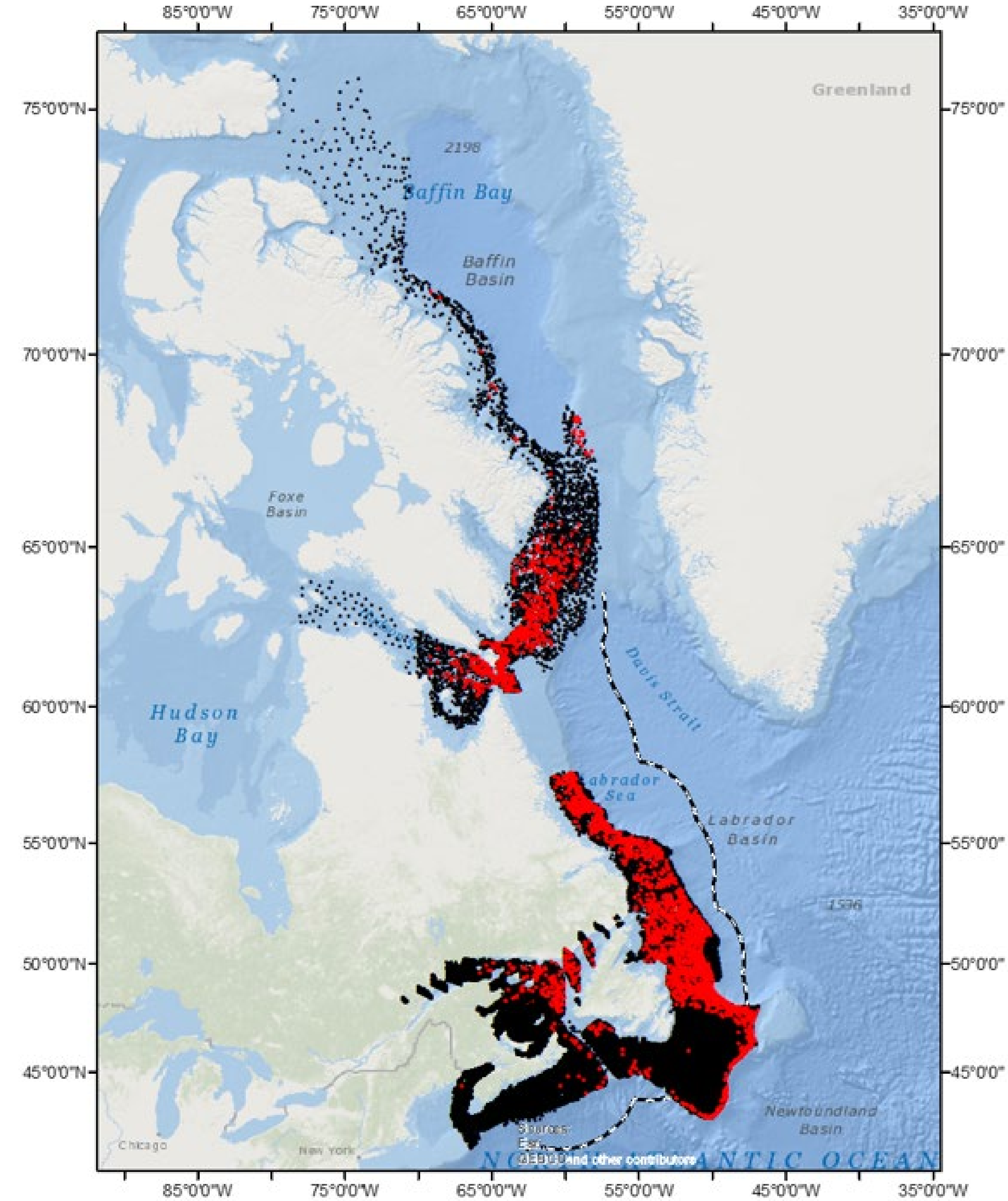


Figure 10. Range of Spotted Wolffish distribution in Canadian Atlantic and Arctic waters. Red dot = species is present and black dot = absent in RV survey fishing tows (1971–2021).

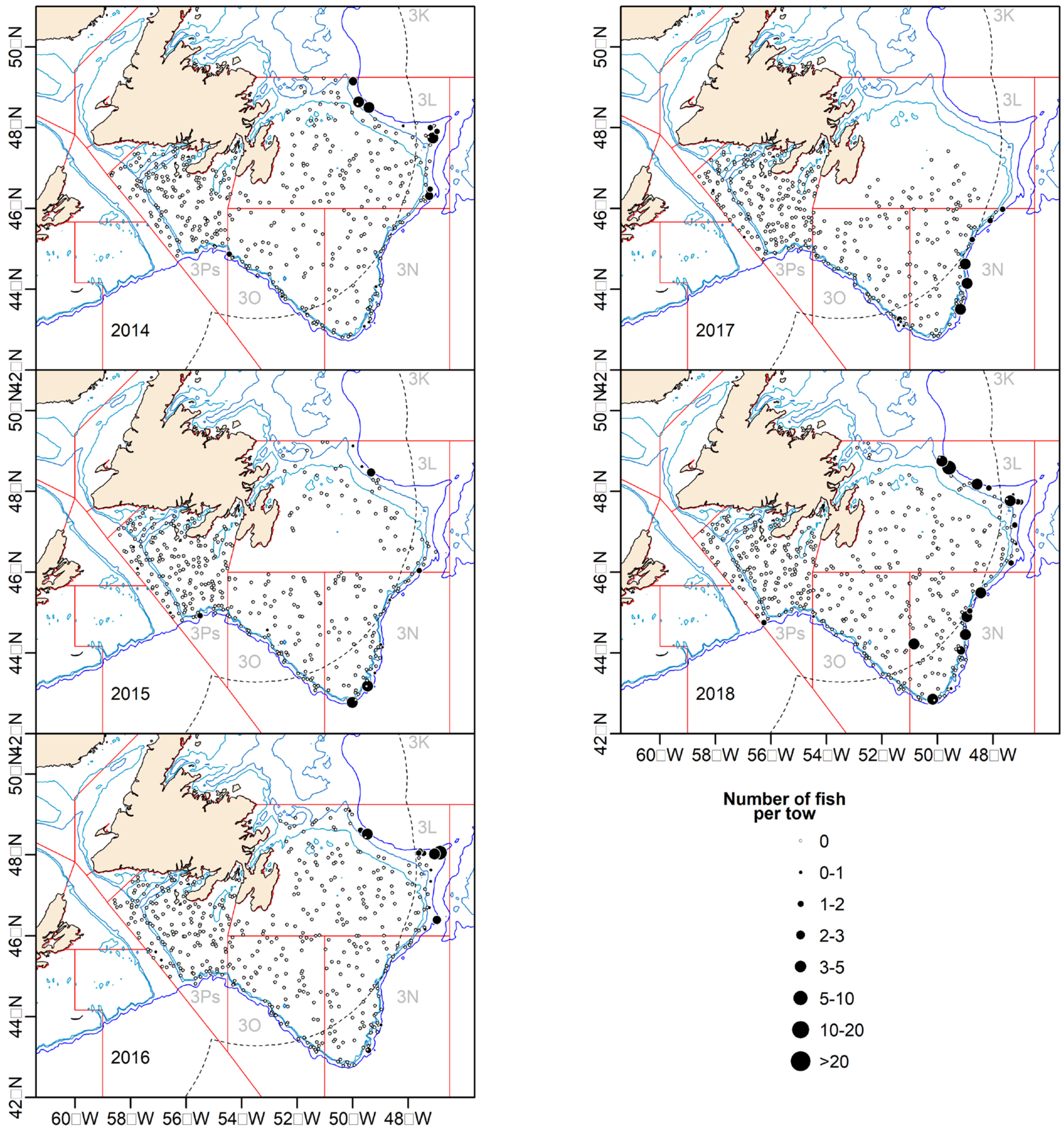


Figure 11a. Range of Northern Wolffish distribution in Newfoundland and Labrador waters from spring RV surveys (2014–18).

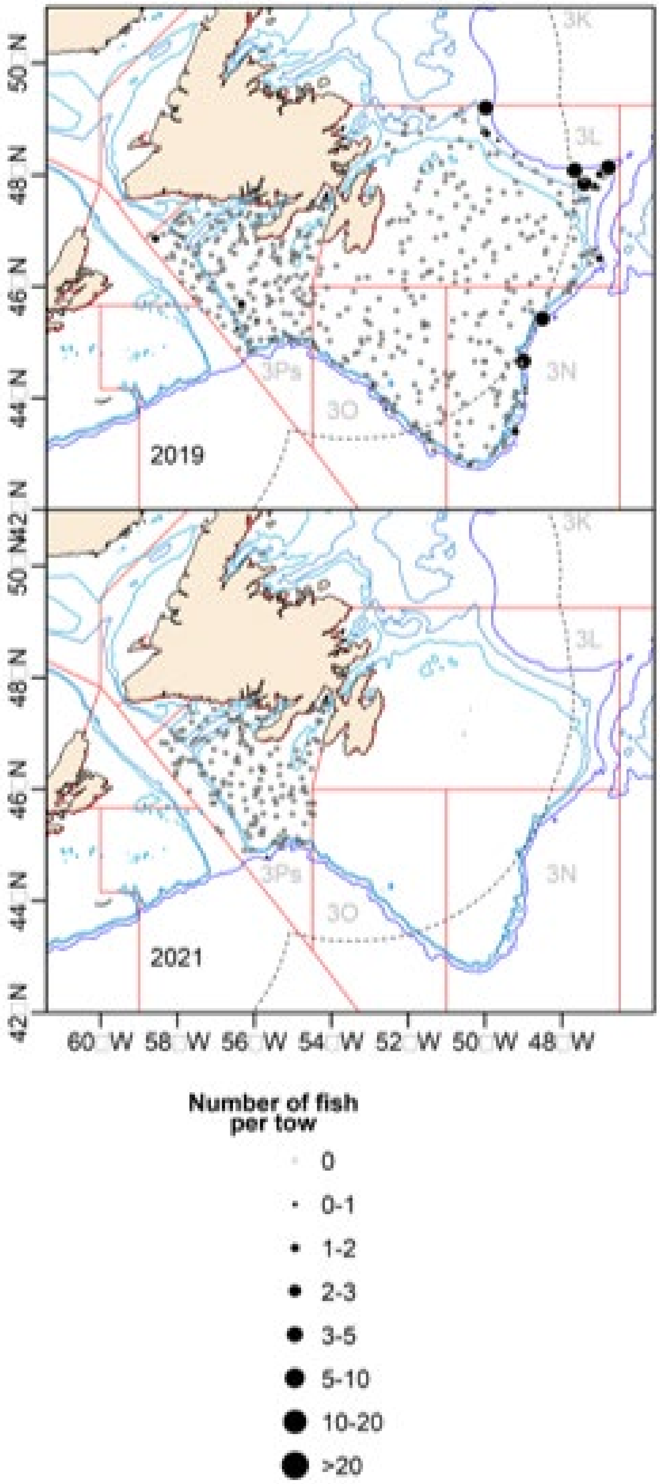


Figure 11b. Range of Northern Wolffish distribution in Newfoundland and Labrador waters from spring RV surveys (2019 and 2021).

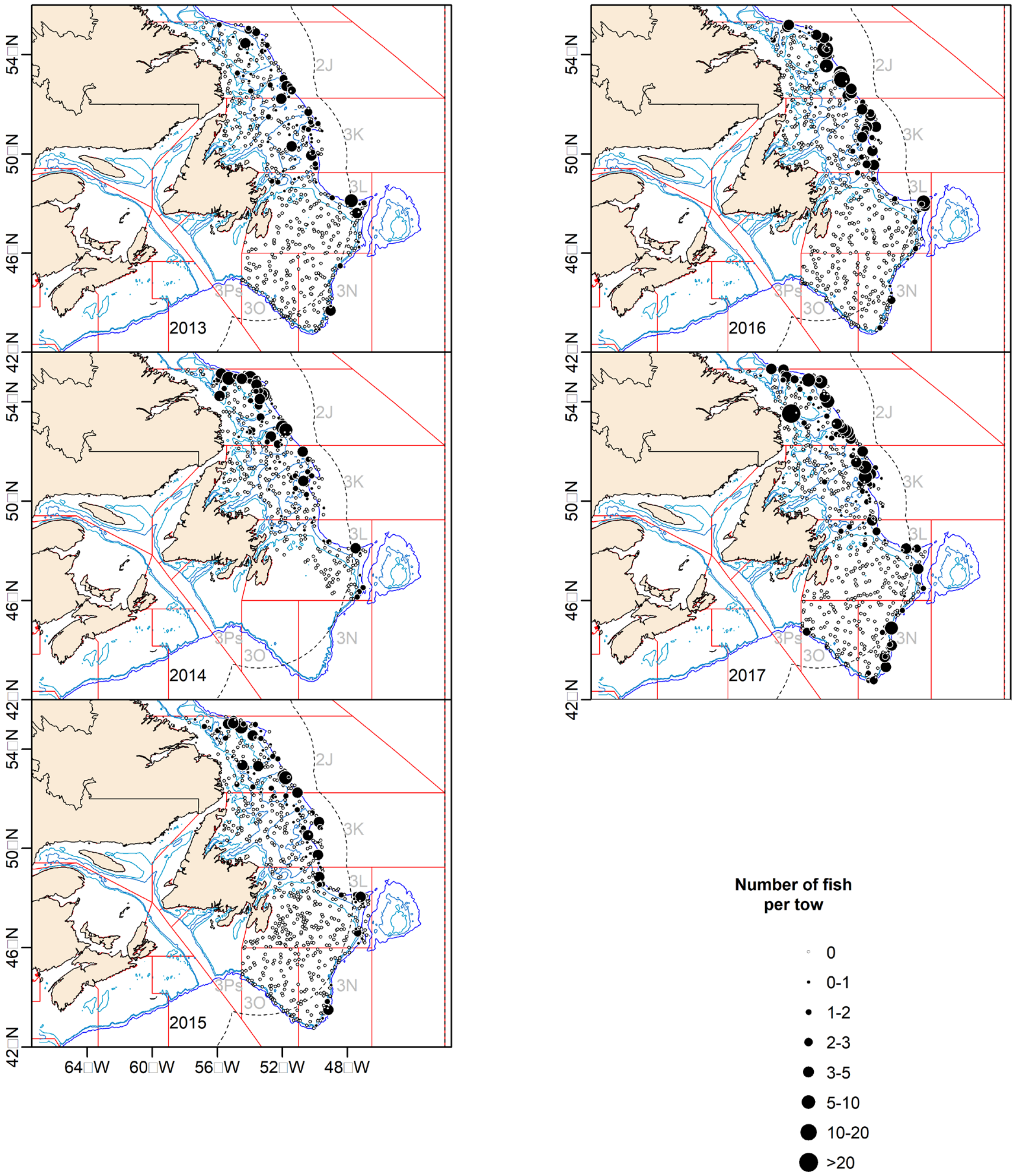


Figure 11c. Range of Northern Wolffish distribution in Newfoundland and Labrador waters from fall RV surveys (2013–17).

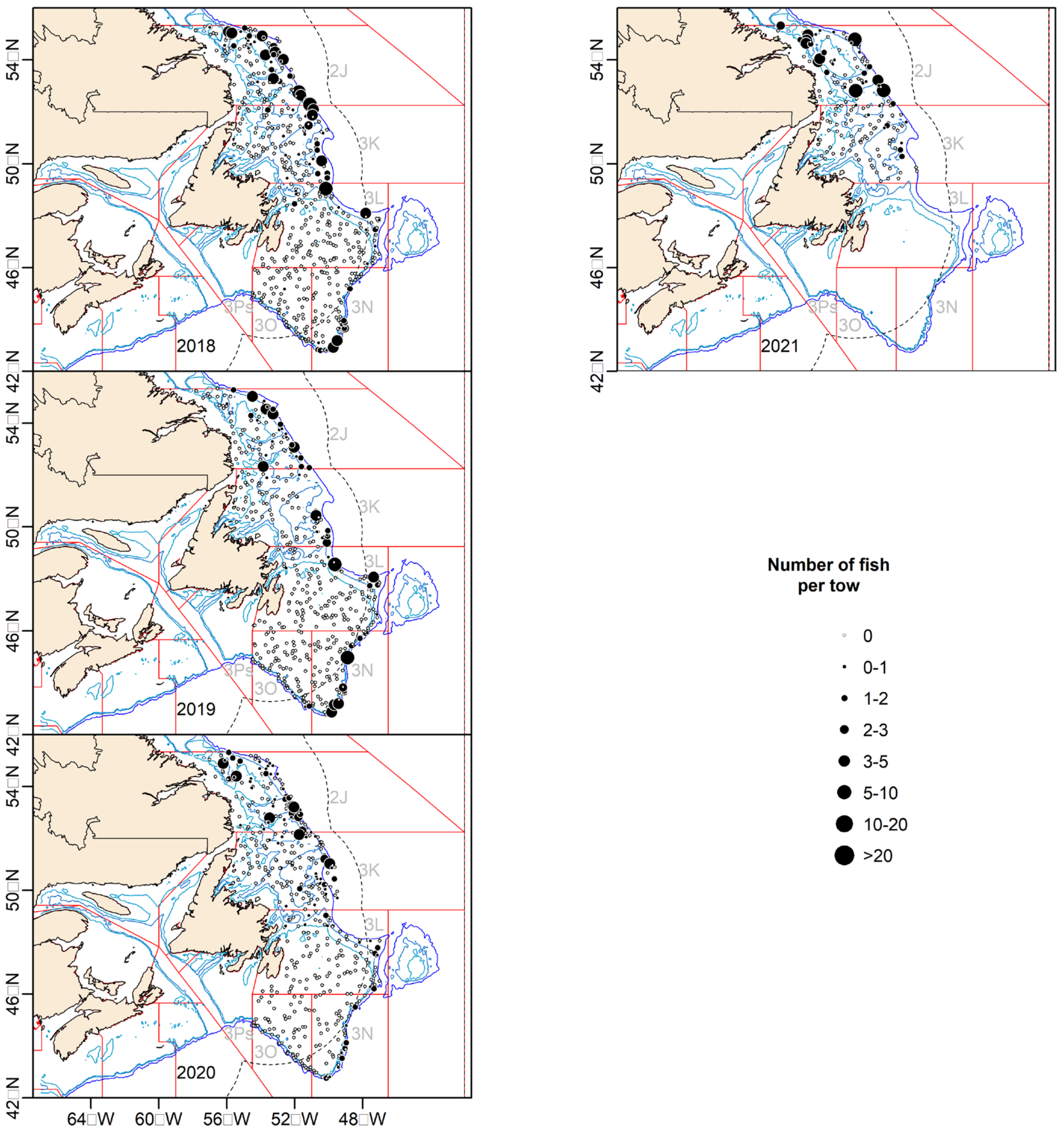


Figure 11d. Range of Northern Wolffish distribution in Newfoundland and Labrador waters from fall RV surveys (2018–21).

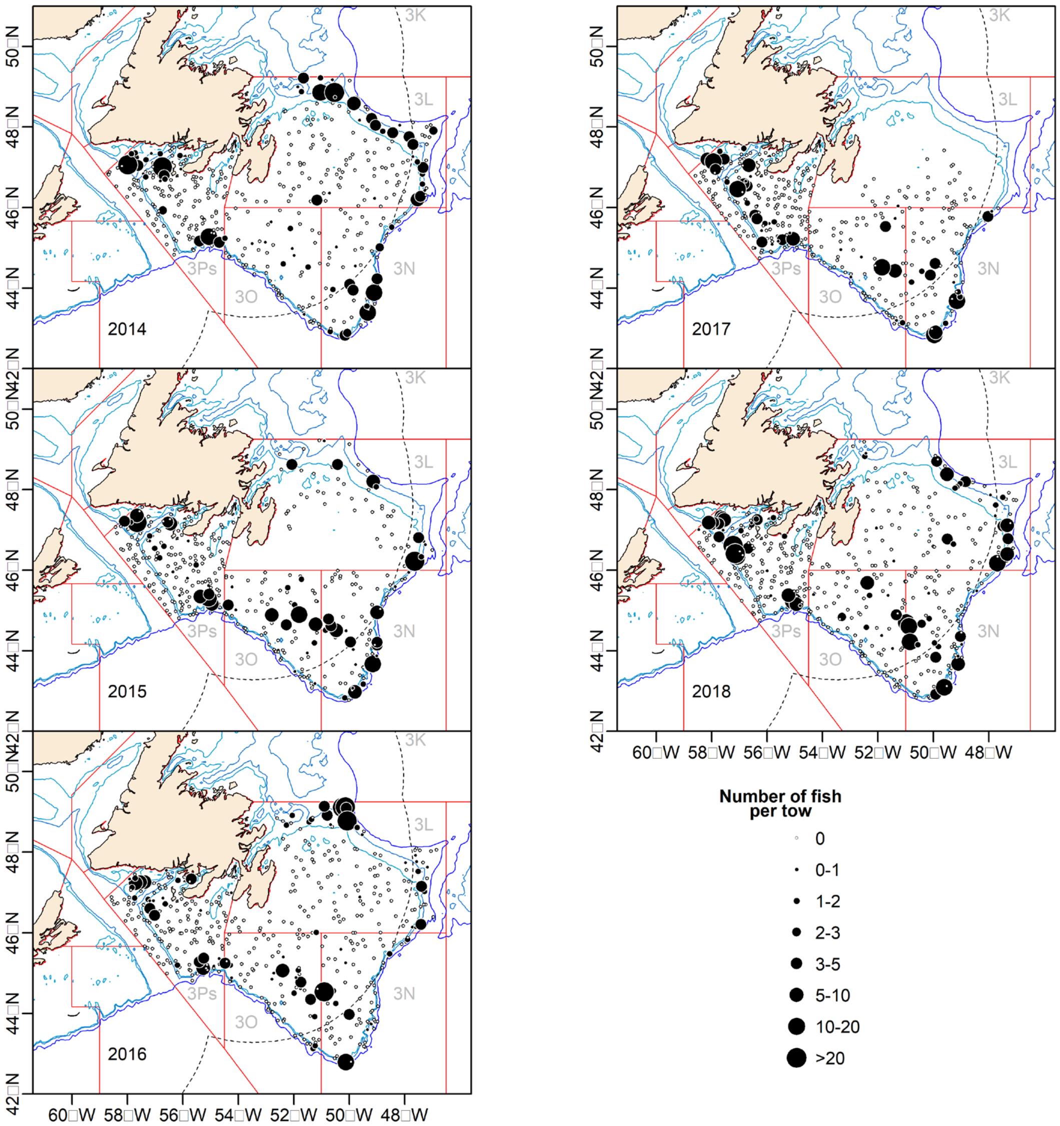


Figure 12a. Range of Atlantic Wolffish distribution in Newfoundland and Labrador waters from spring RV surveys (2014–18).

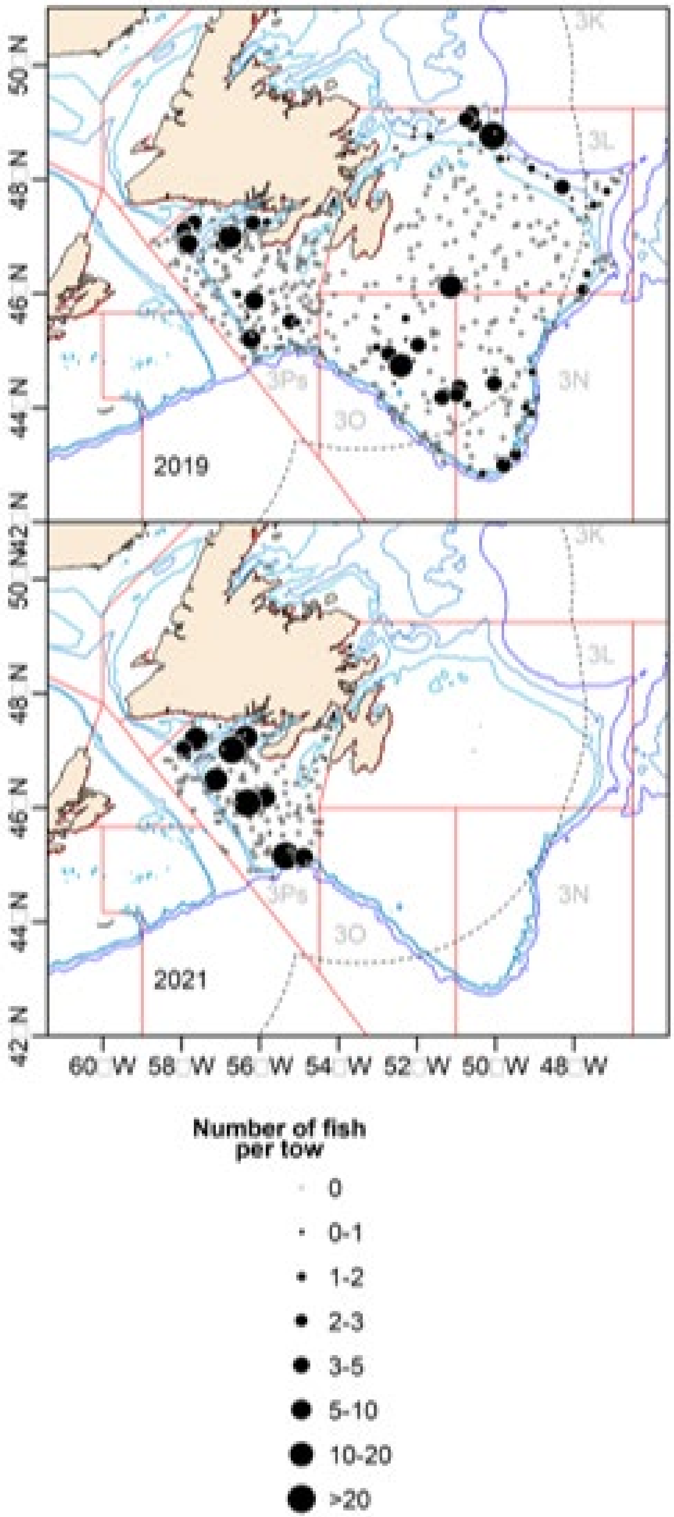


Figure 12b. Range of Atlantic Wolffish distribution in Newfoundland and Labrador waters from spring RV surveys (2019 and 2021).

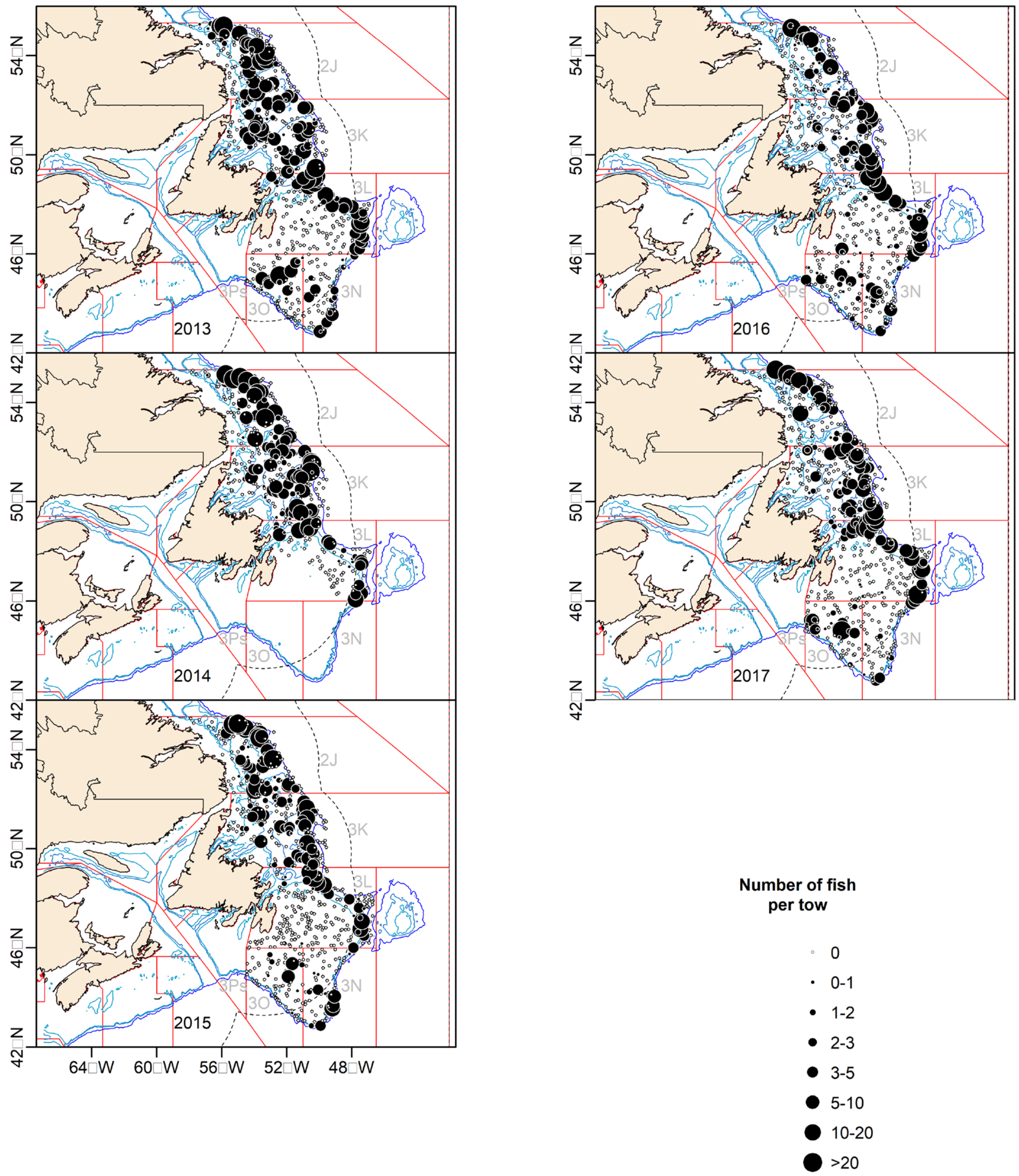


Figure 12c. Range of Atlantic Wolffish distribution in Newfoundland and Labrador waters from fall RV surveys (2013–17).

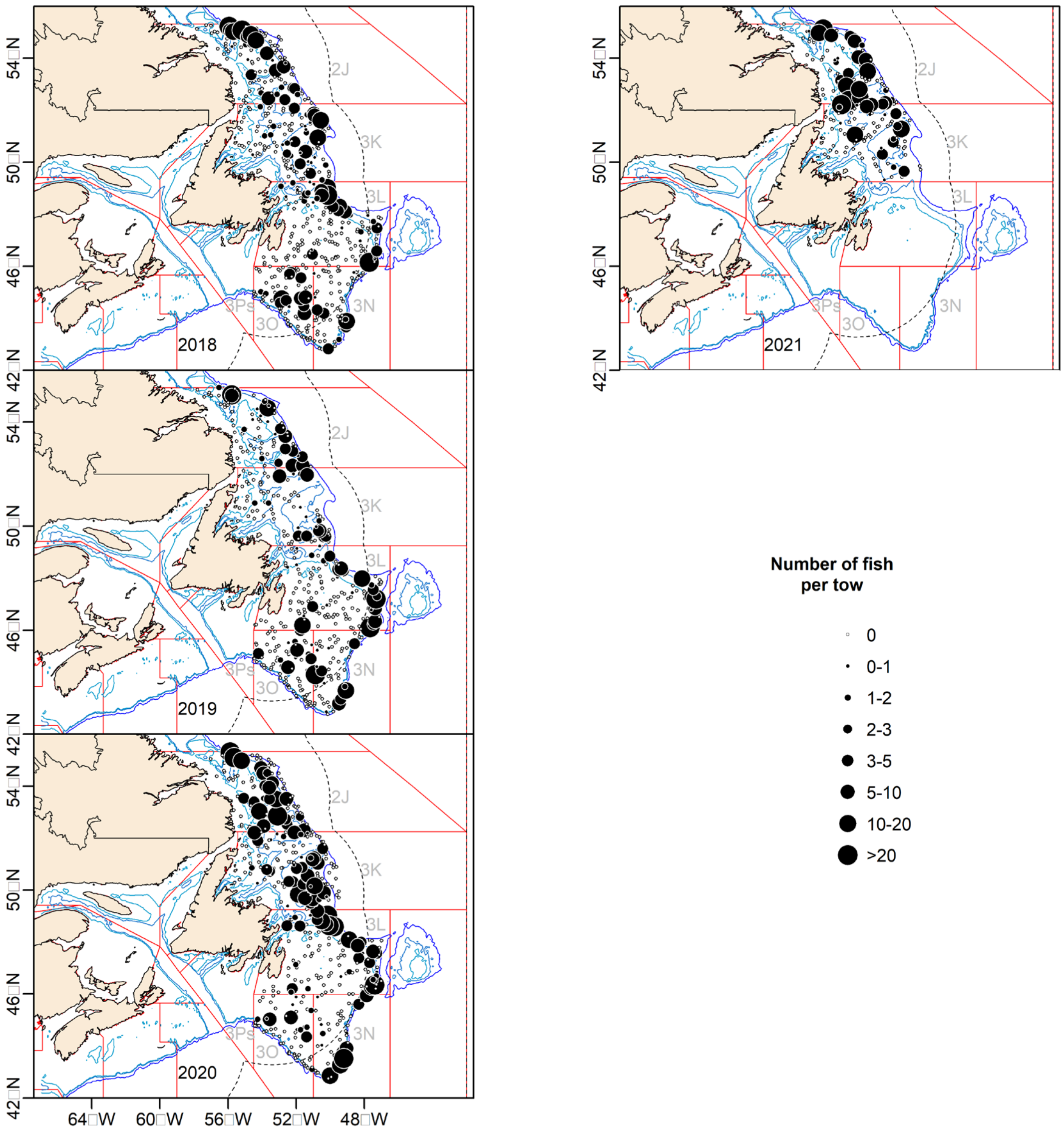


Figure 12d. Range of Atlantic Wolffish distribution in Newfoundland and Labrador waters from fall RV surveys (2018–21).

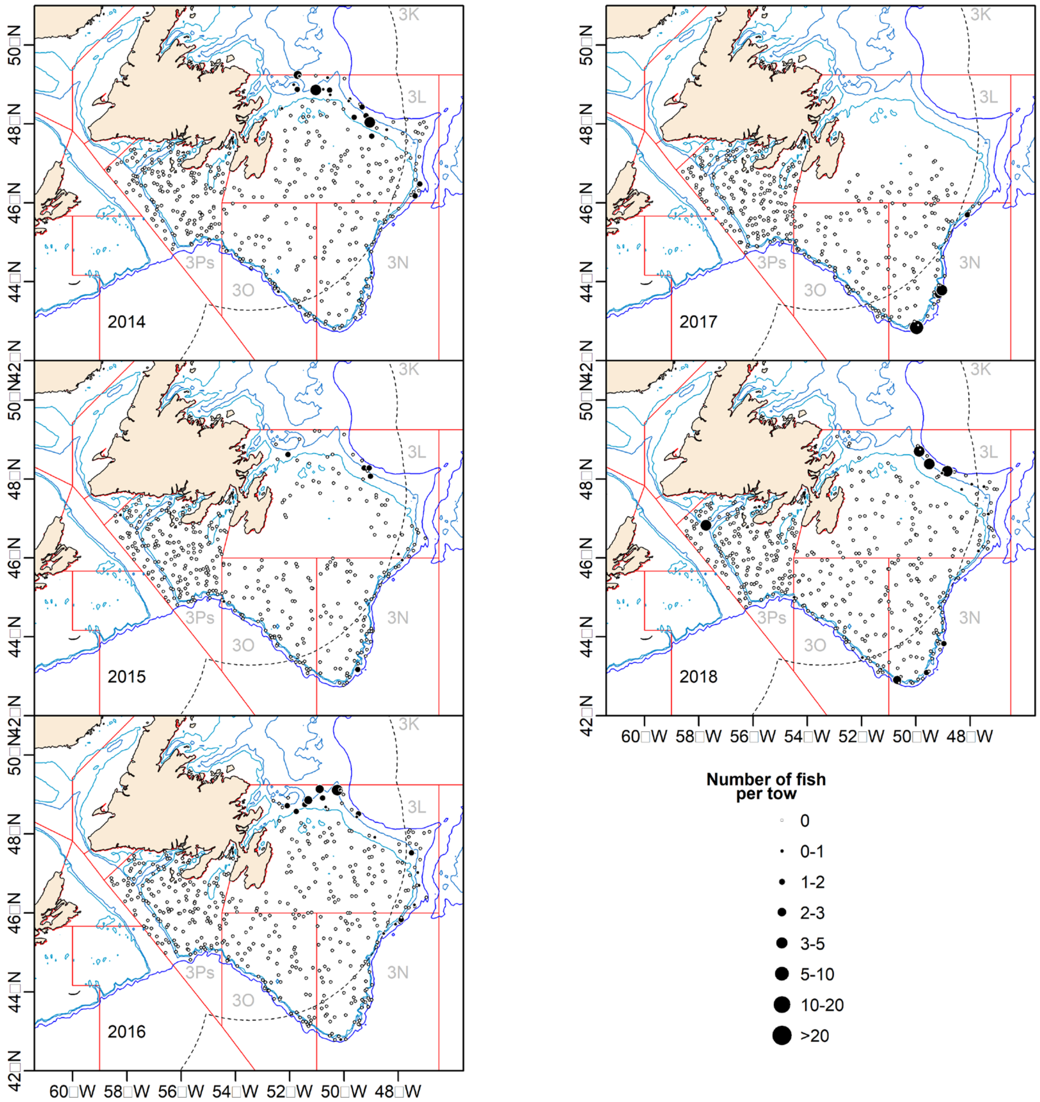


Figure 13a. Range of Spotted Wolffish distribution in Newfoundland and Labrador waters from spring RV surveys (2014–18).

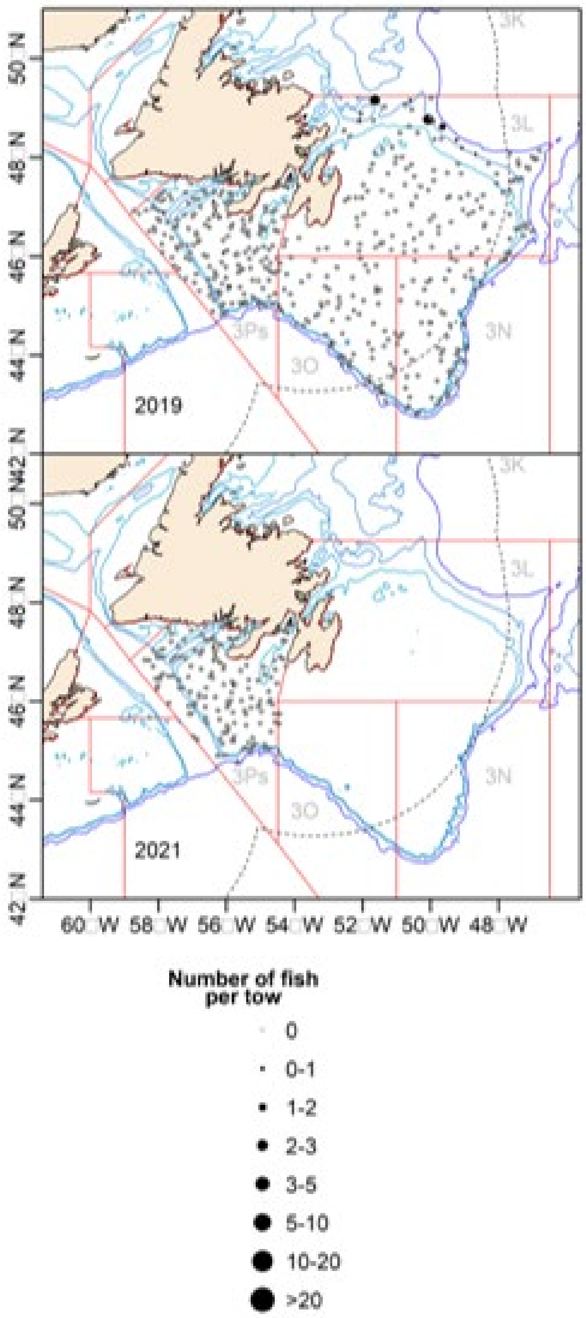


Figure 13b. Range of Spotted Wolffish distribution in Newfoundland and Labrador waters from spring RV surveys (2019 and 2021).

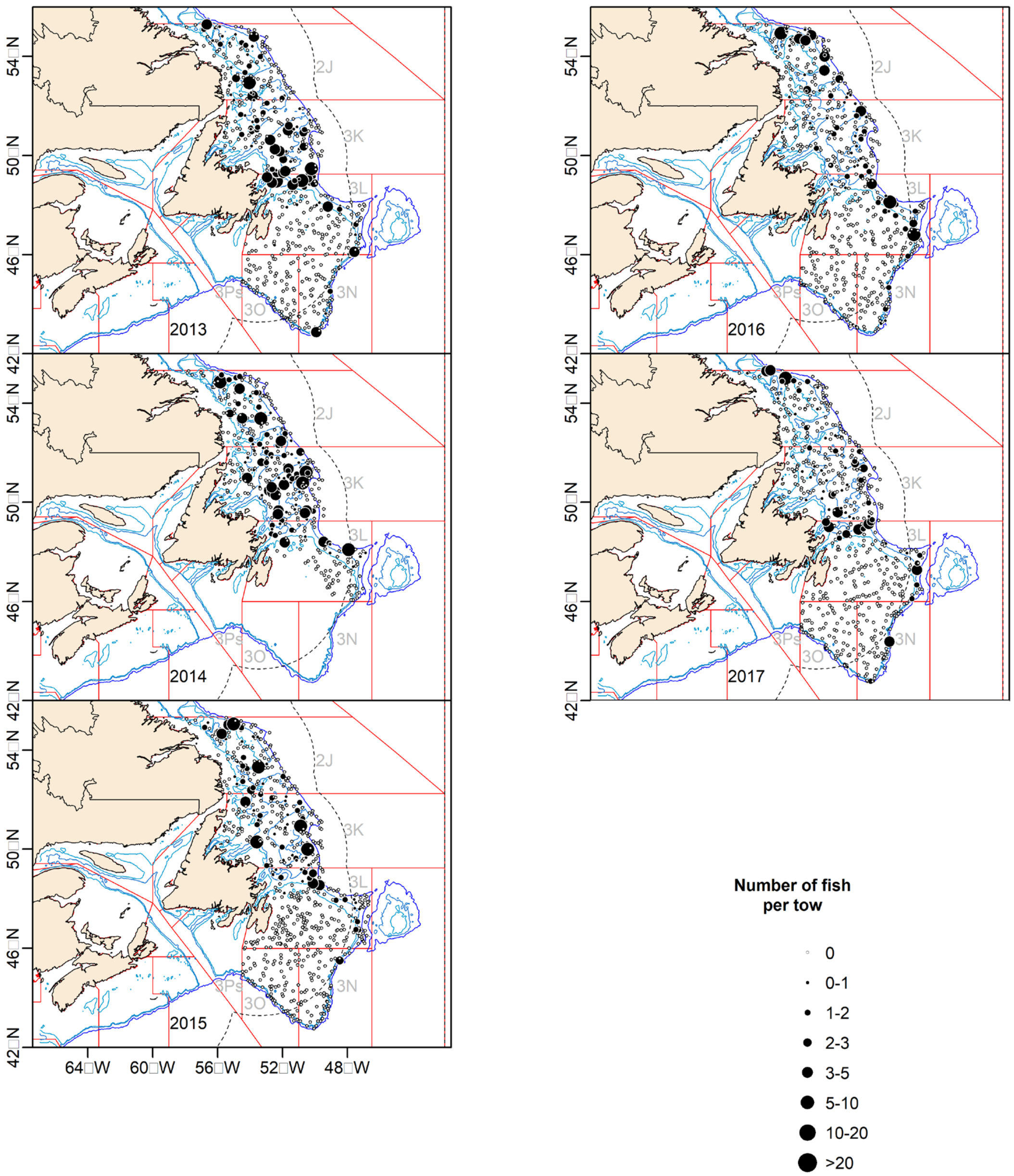


Figure 13c. Range of Spotted Wolffish distribution in Newfoundland and Labrador waters from fall RV surveys (2013–17).

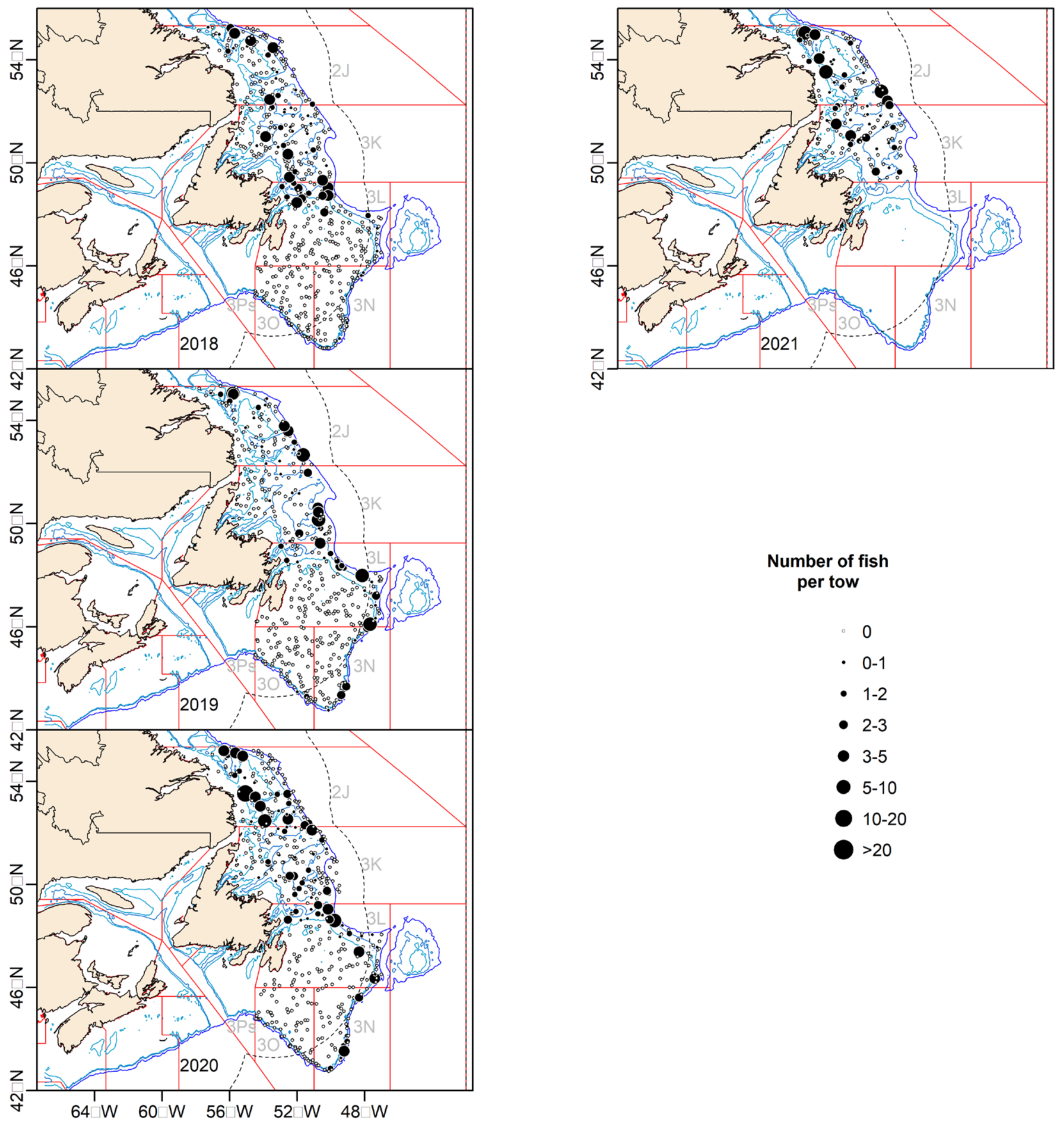


Figure 13d. Range of Spotted Wolffish distribution in Newfoundland and Labrador waters from fall RV surveys (2018–21).

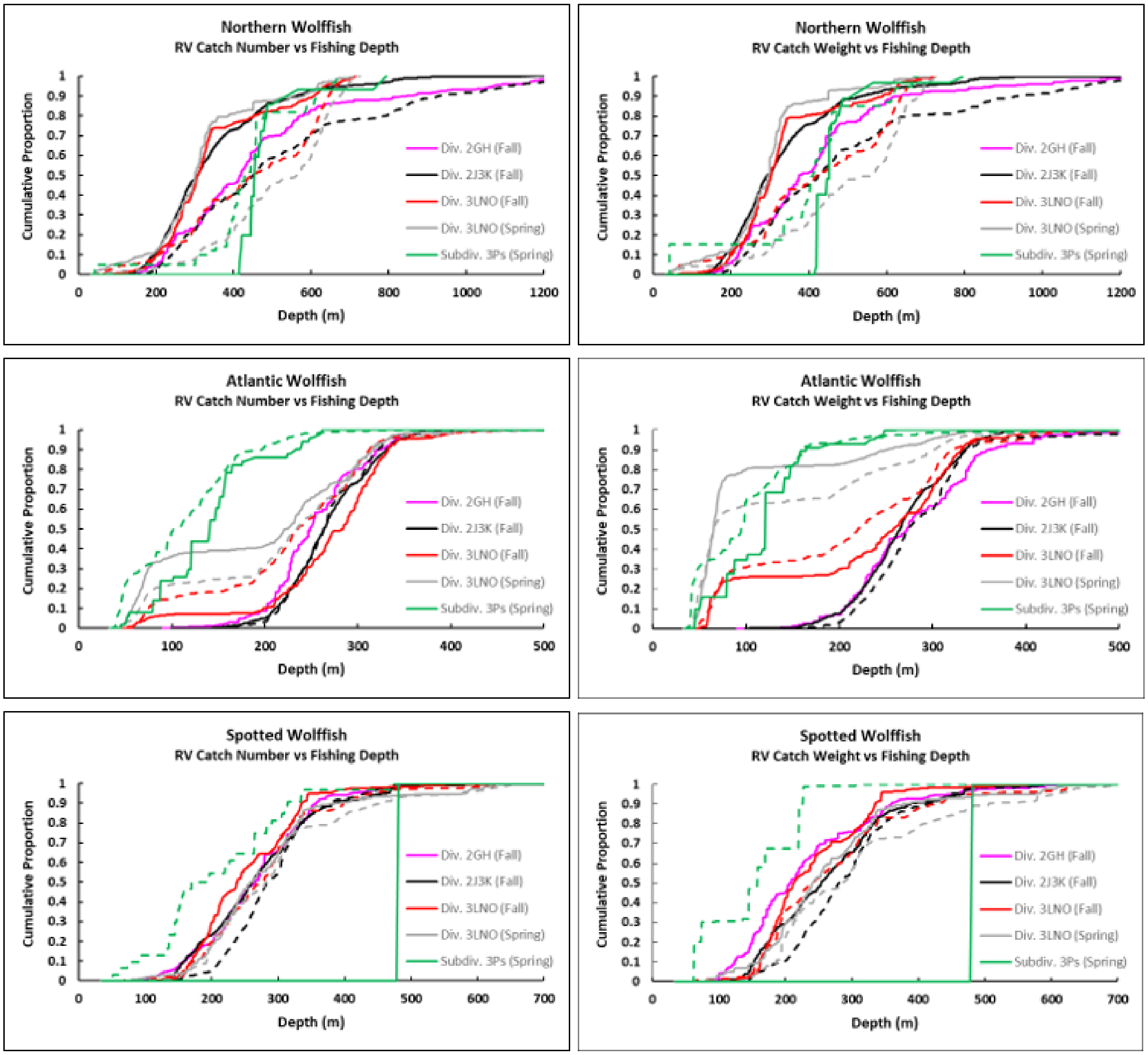


Figure 14. Cumulative distribution of RV survey catch rates of wolffish as a function of fishing depth for Div. 2GH, 2J3K, 3LNO, and Subdiv. 3Ps. Engel (dotted line), and Campelen time series (solid line).

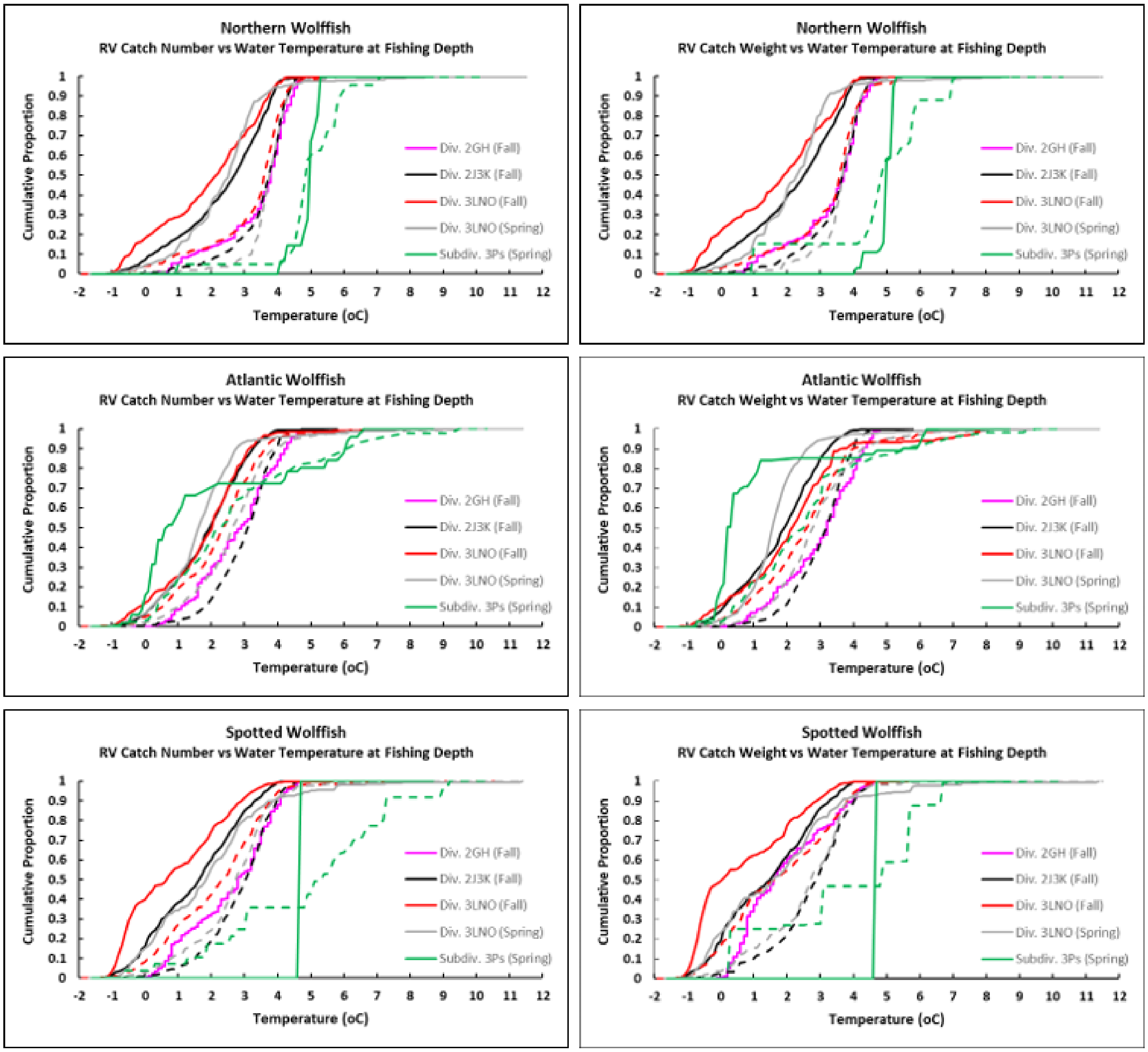


Figure 15. Cumulative distribution of RV catch rates of wolffish as a function of water temperature at fishing depth for Div. 2GH, 2J3K, 3LNO, and Subdiv. 3Ps. Engel (dotted line), and Campelen time series (solid line).

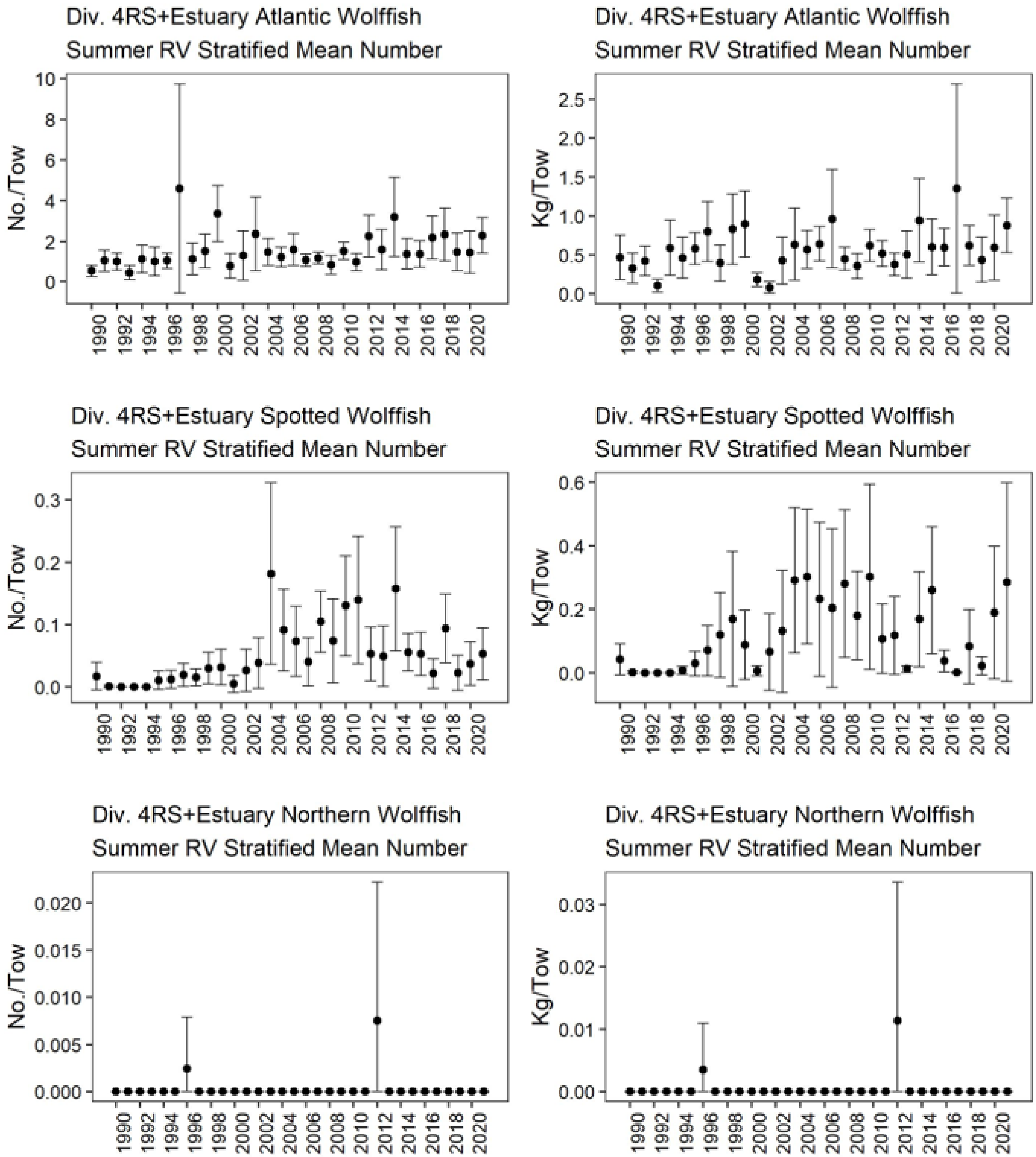


Figure 16. Estimates of stratified mean catch rates of Atlantic Wolffish, Spotted Wolffish, and Northern Wolffish in Div. 4RS and the St. Lawrence estuary and their 95% CIs (error bars). Catch numbers and weights from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen-equivalent for comparability.

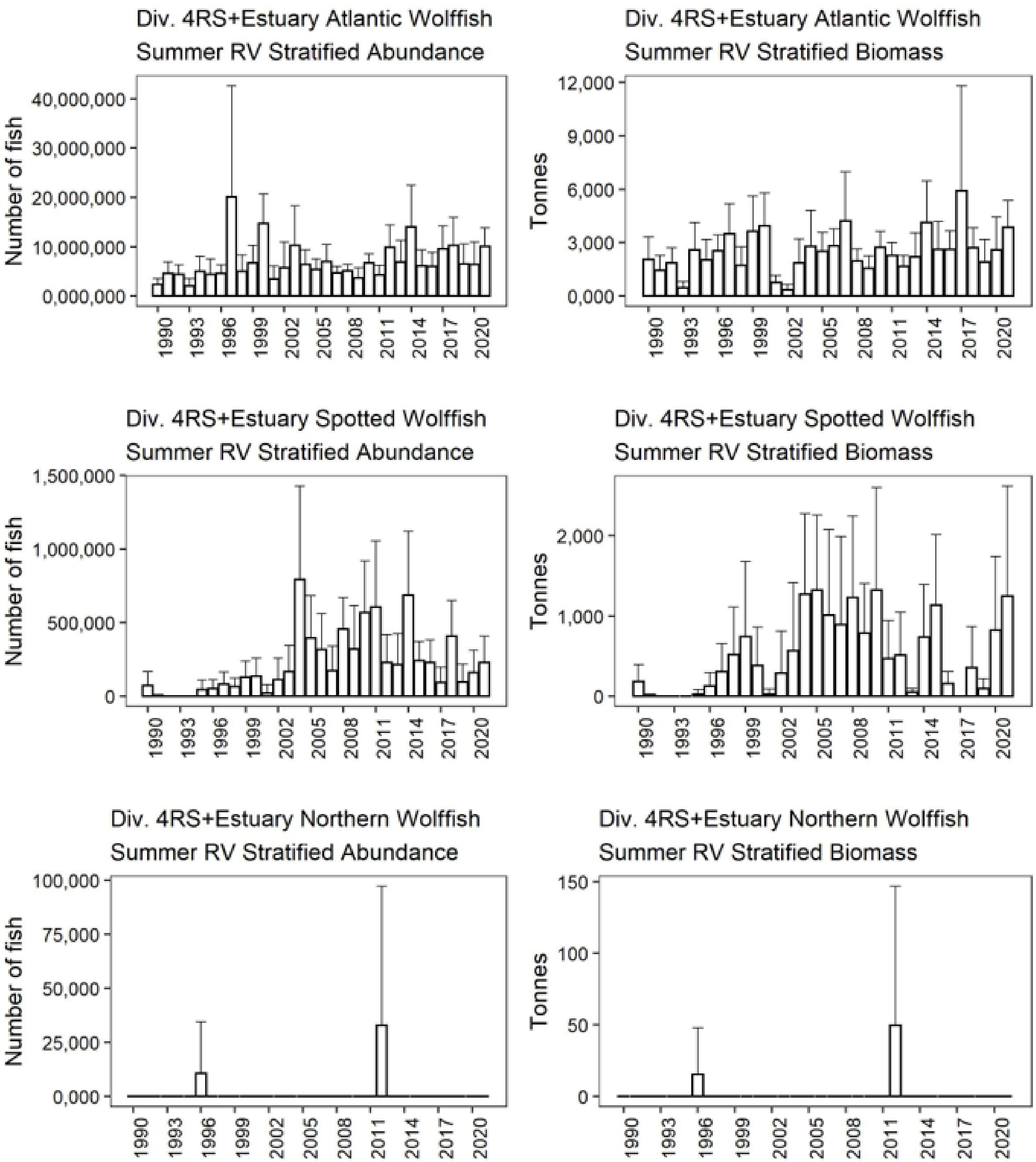


Figure 17. Estimates of total abundance and biomass of Atlantic Wolffish, Spotted Wolffish, and Northern Wolffish in Div. 4RS and the St. Lawrence estuary and their upper 95% CIs (error bars). Catch numbers and weights from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen equivalent for comparability.

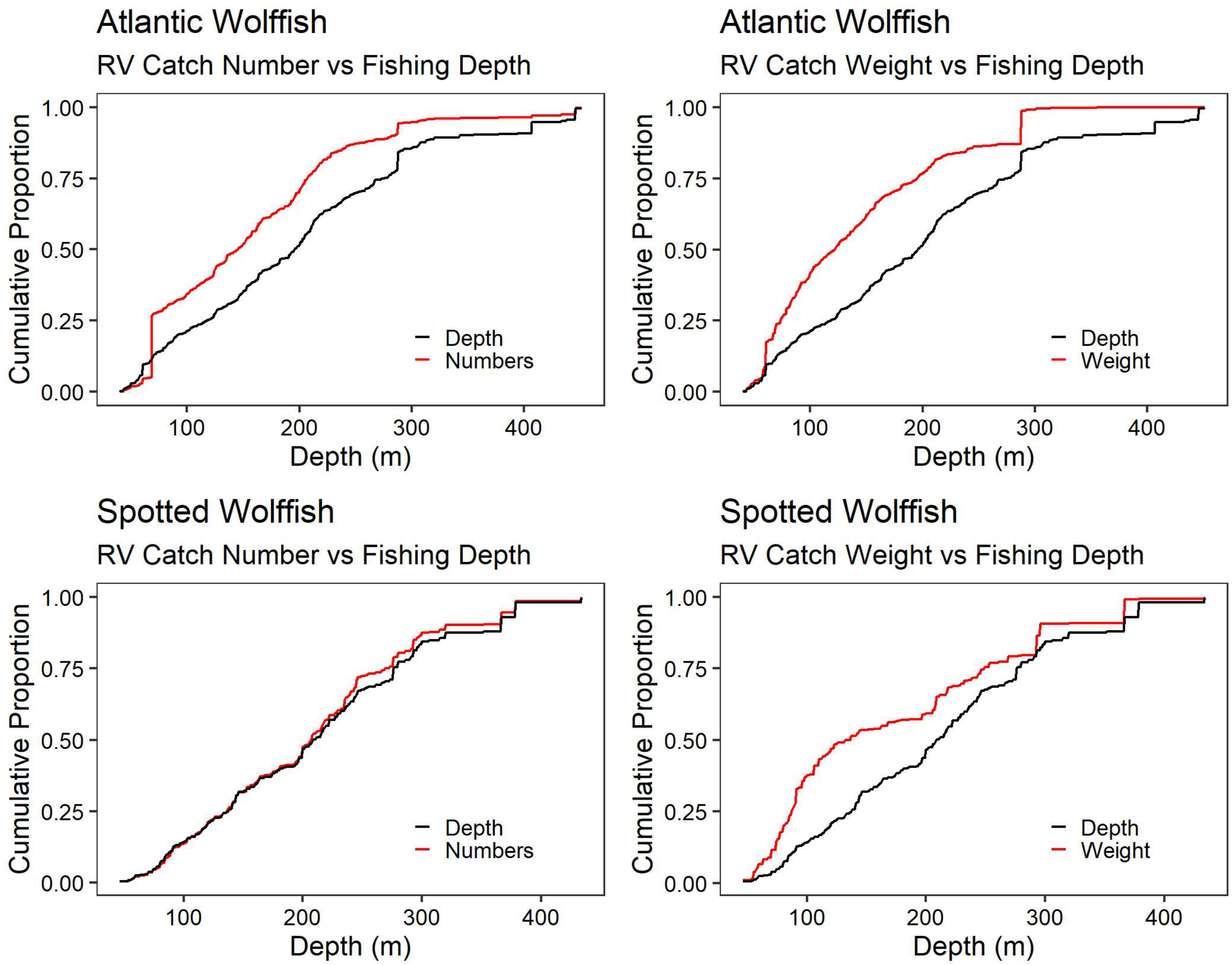


Figure 18. Cumulative distribution of stratified mean catch rates of Atlantic and Spotted Wolffish as a function of fishing depth for Div. 4RS and the St. Lawrence estuary. Catch numbers and weights from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen-equivalent for comparability.

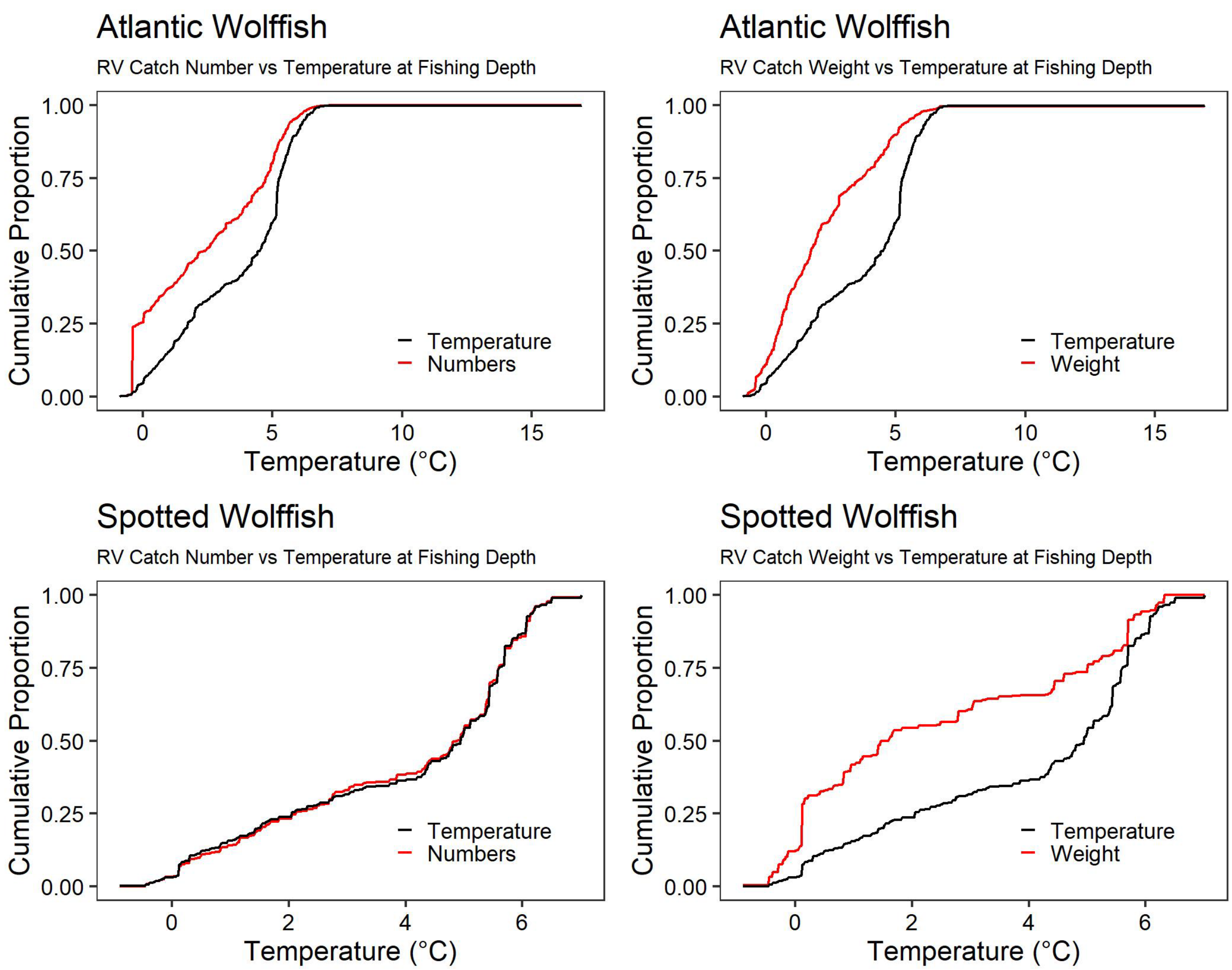


Figure 19. Cumulative distribution of stratified mean catch rates of wolffish as a function of temperature at fishing depth for Div. 4RS and the St. Lawrence estuary. Catch numbers and weights from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen-equivalent for comparability.

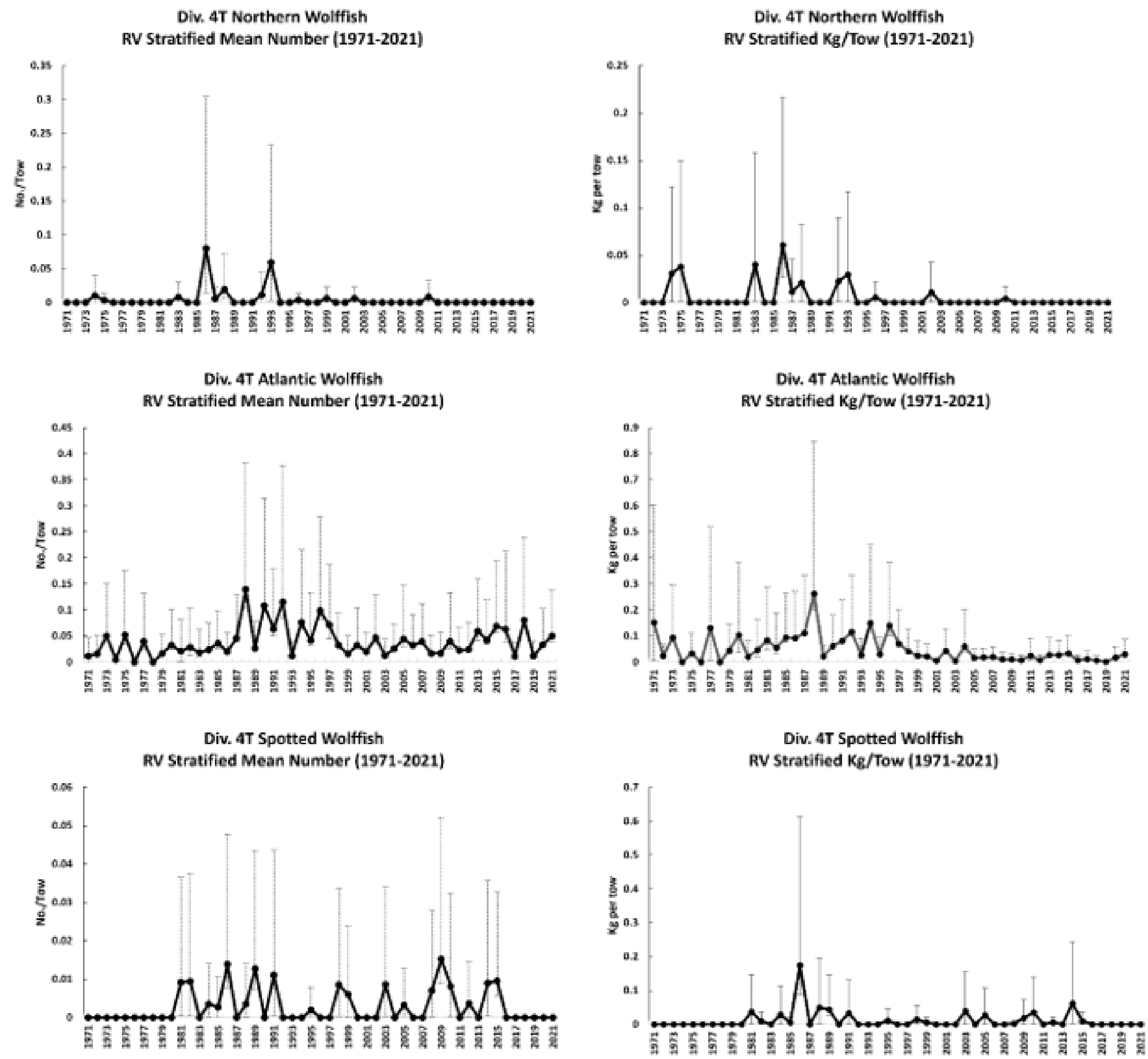


Figure 20. Estimates of stratified mean catch rates of Northern Wolffish, Atlantic Wolffish, and Spotted Wolffish in Div. 4T. T-bars = +/- 95% CIs.

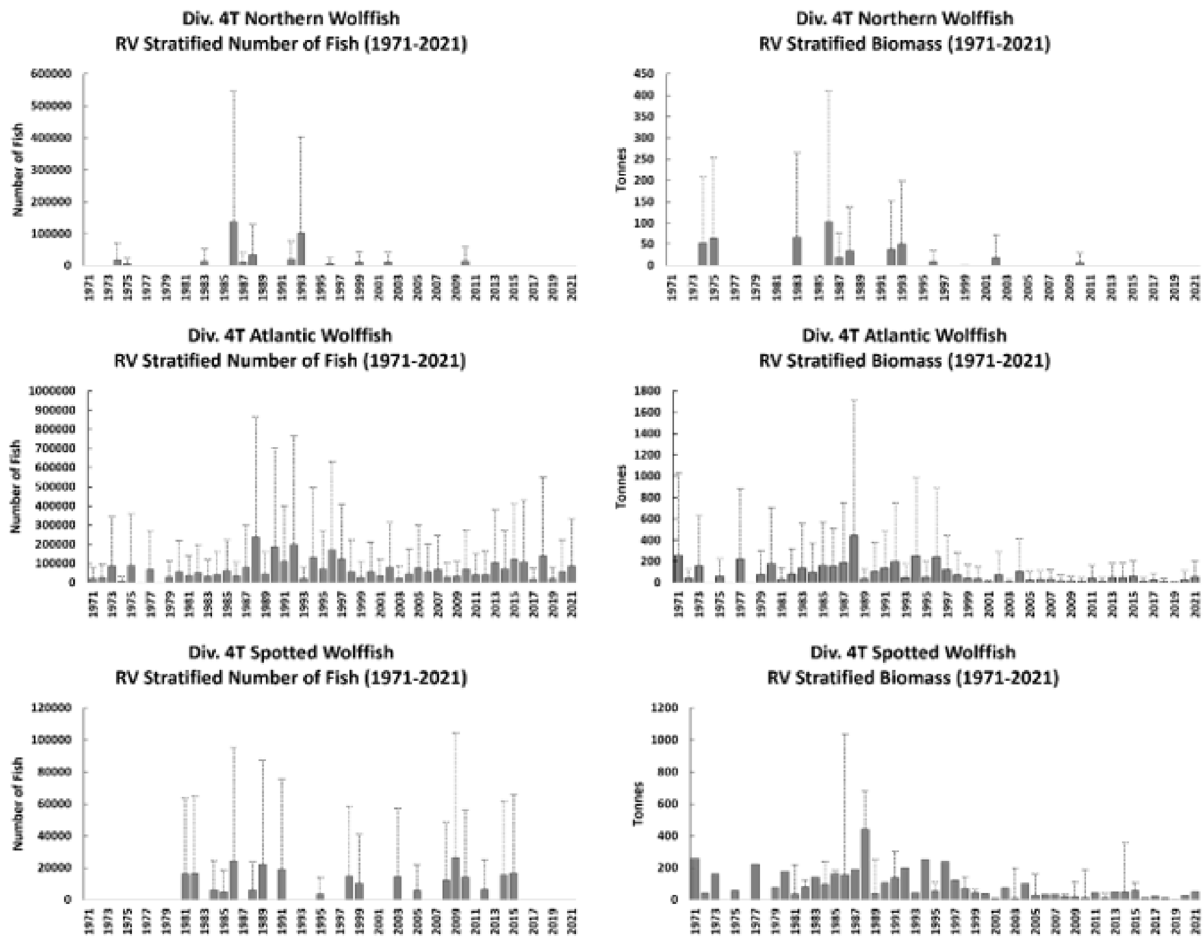


Figure 21. Abundance and biomass estimates of Northern Wolffish, Atlantic Wolffish, and Spotted Wolffish in Div. 4T. T-bars = + 95% CI.

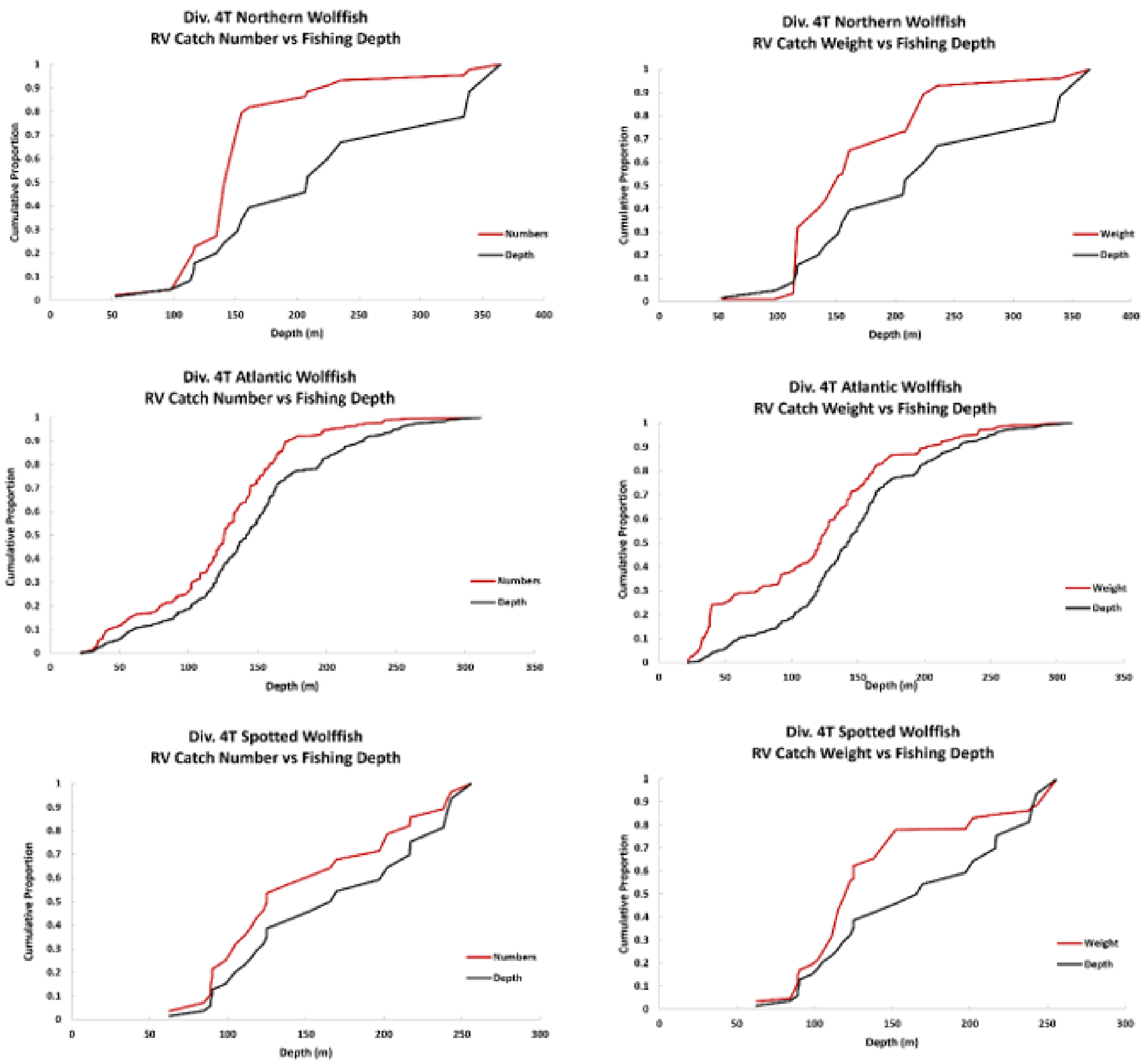


Figure 22. Cumulative distribution of stratified mean catch rates of wolffish as a function of fishing depth for Div. 4T.

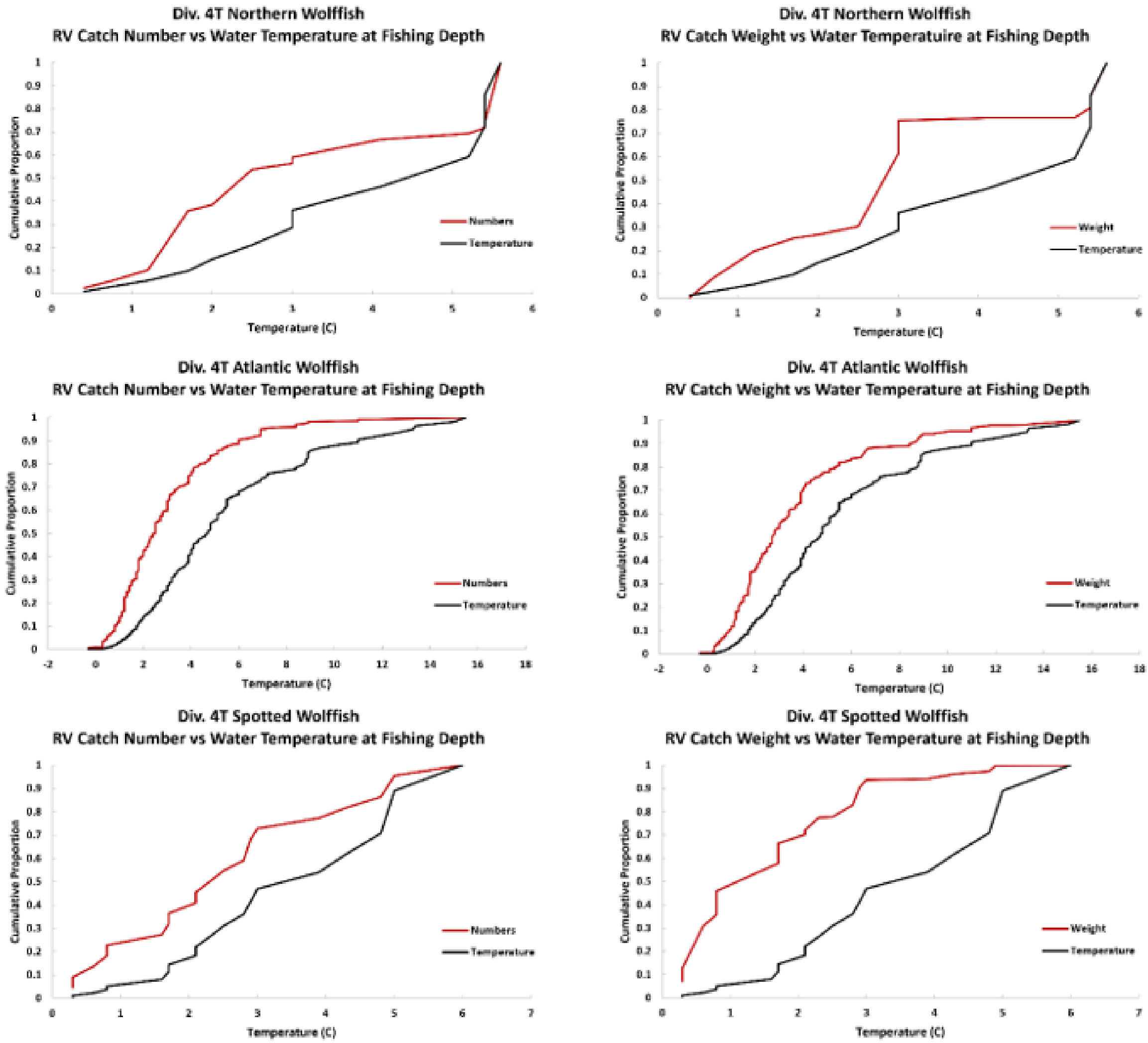


Figure 23. Cumulative distribution of stratified mean catch rates of wolffish as a function of water temperature at fishing depth for Div. 4T.

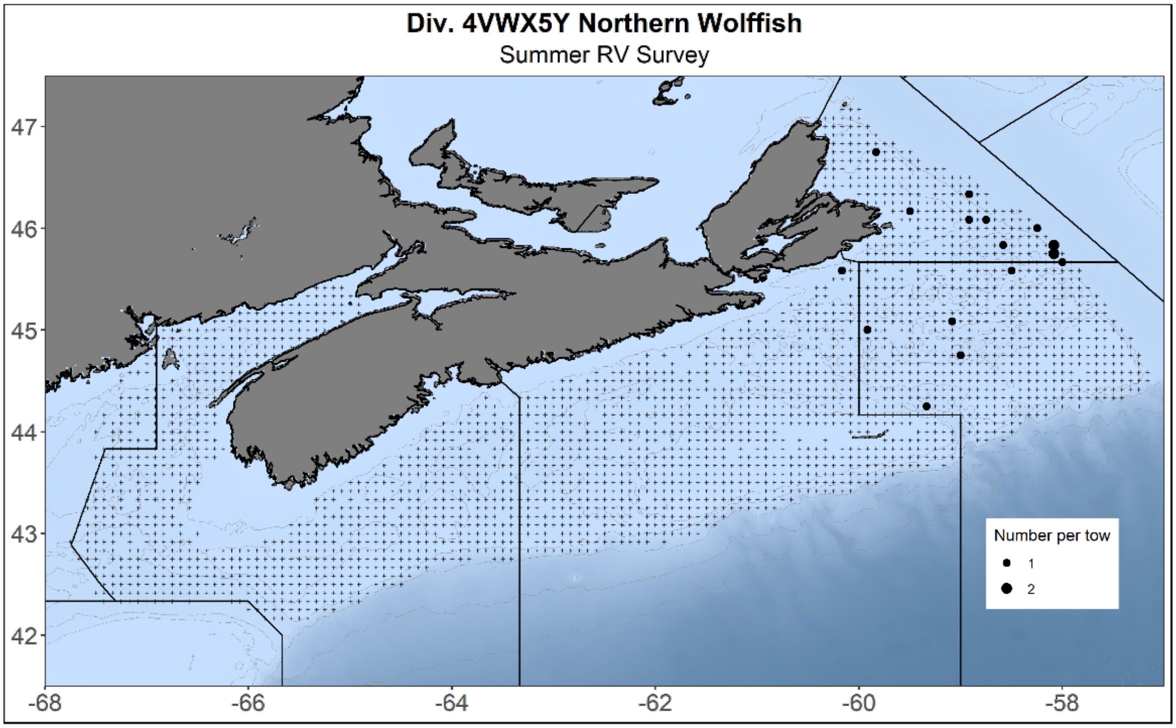


Figure 24. Distribution of catches of Northern Wolffish from the Maritimes Summer RV Survey in Div. 4VWX5Y, 1970–2020, 5 minutes square average aggregation. Zero catches represented by the cross (+) symbol.

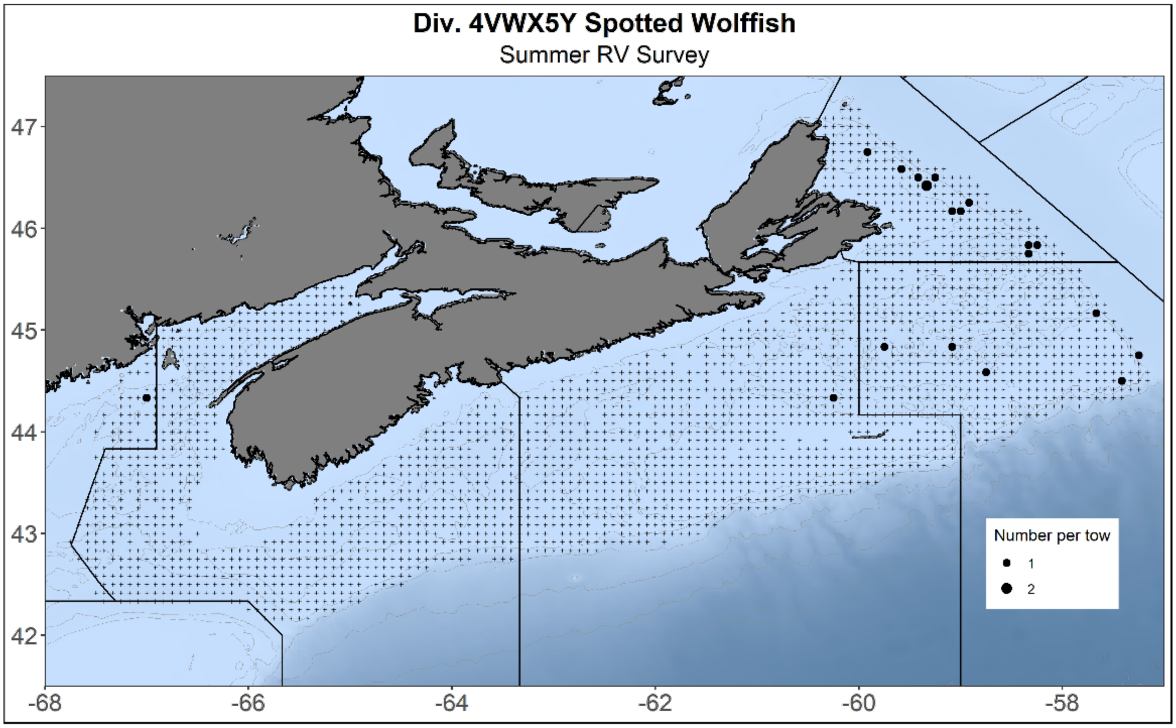


Figure 25. Distribution of catches of Spotted Wolffish from the Maritimes Summer RV Survey in Div. 4VWX5Y, 1970–2008, 5 minutes square average aggregation. Zero catches represented by the cross (+) symbol.

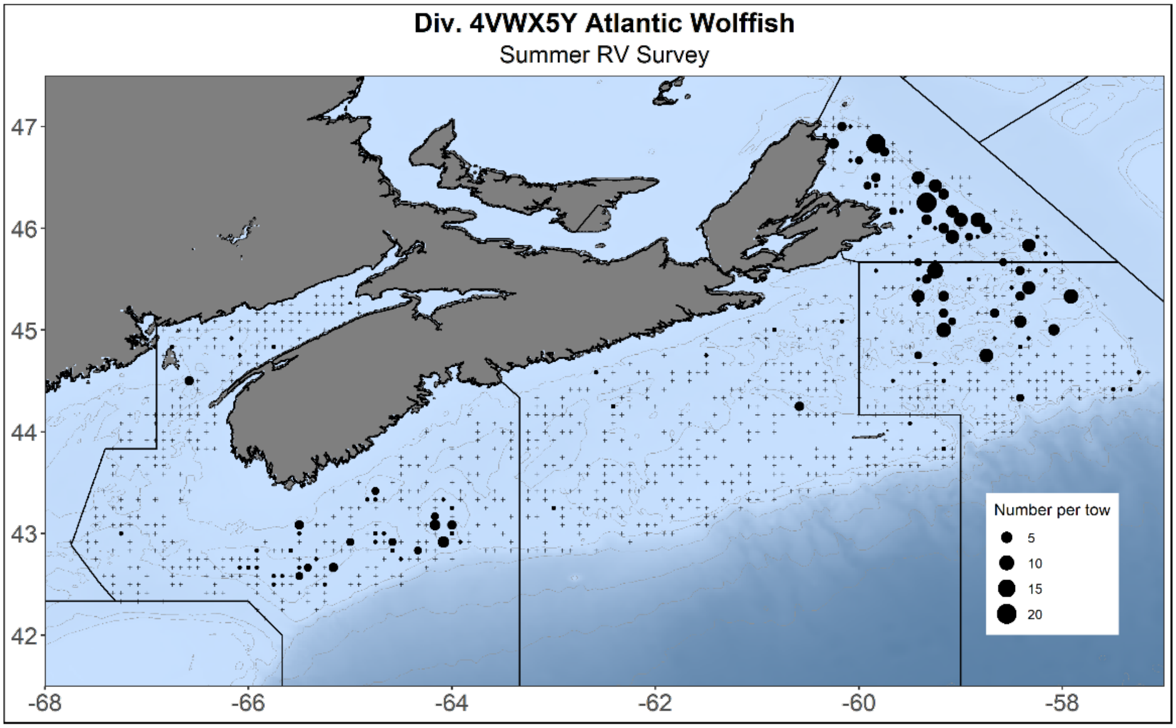


Figure 26. Distribution of recent catches of Atlantic Wolffish from the Maritimes Summer RV Survey in Div. 4VWX5Y, 2014–22, 5 minutes square average aggregation. Zero catches represented by the cross (+) symbol.

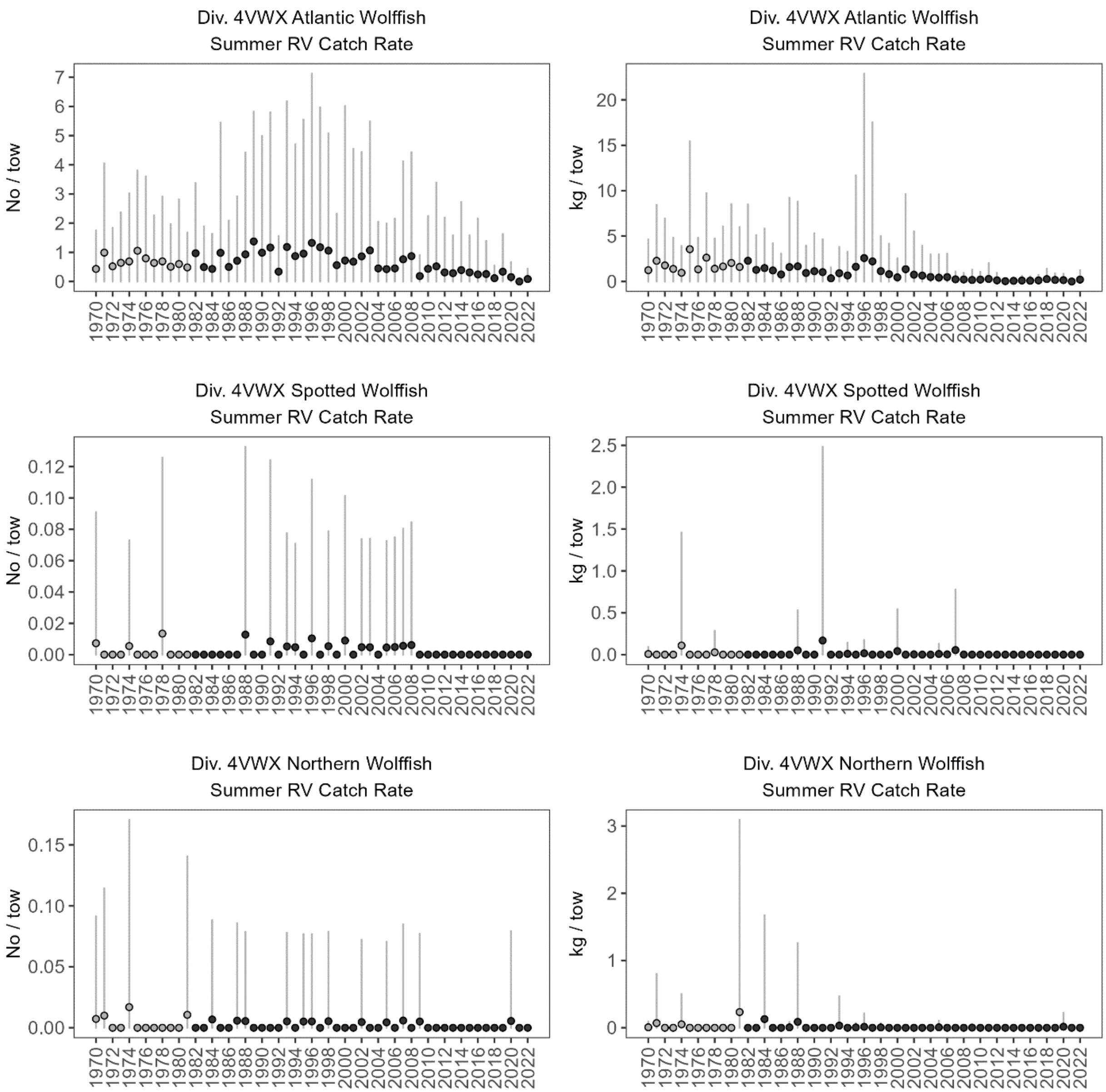


Figure 27. Standardized catch rate (mean number and weight per tow) of Atlantic Wolffish, Spotted Wolffish, and Northern Wolffish from the Maritimes Summer RV Survey in Div. 4VWX, 1970–2022. Survey trawl gear changed from Yankee 36 to Western IIA in 1982. T-bars = +/- 95% CIs.

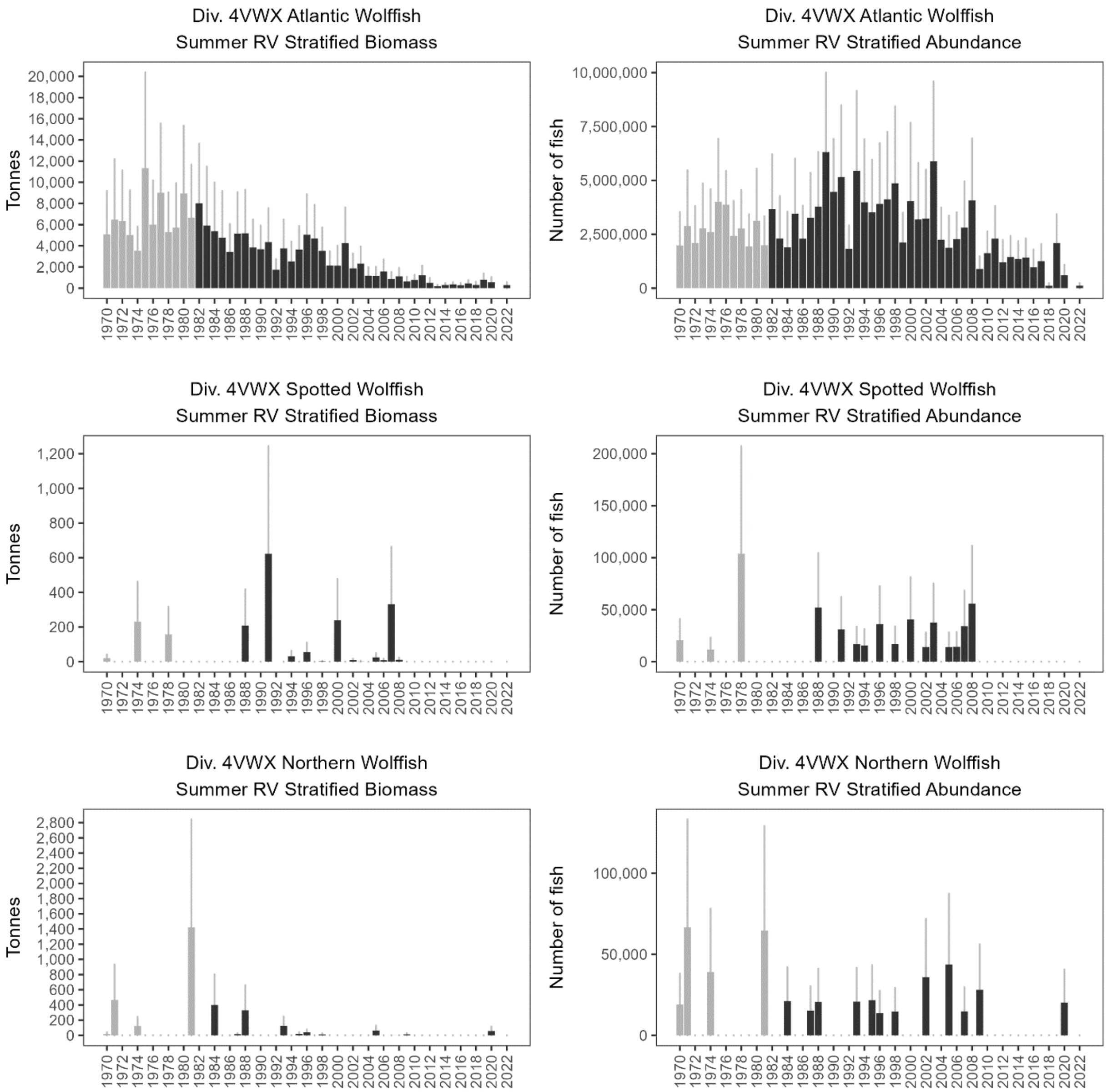


Figure 28. Stratified biomass and abundance of Atlantic Wolffish, Spotted Wolffish, and Northern Wolffish from the Maritimes Summer RV Survey in Div. 4VWX, 1970–2022. Survey trawl gear changed from Yankee 36 to Western IIA in 1982. T-bars = + 95% CI.

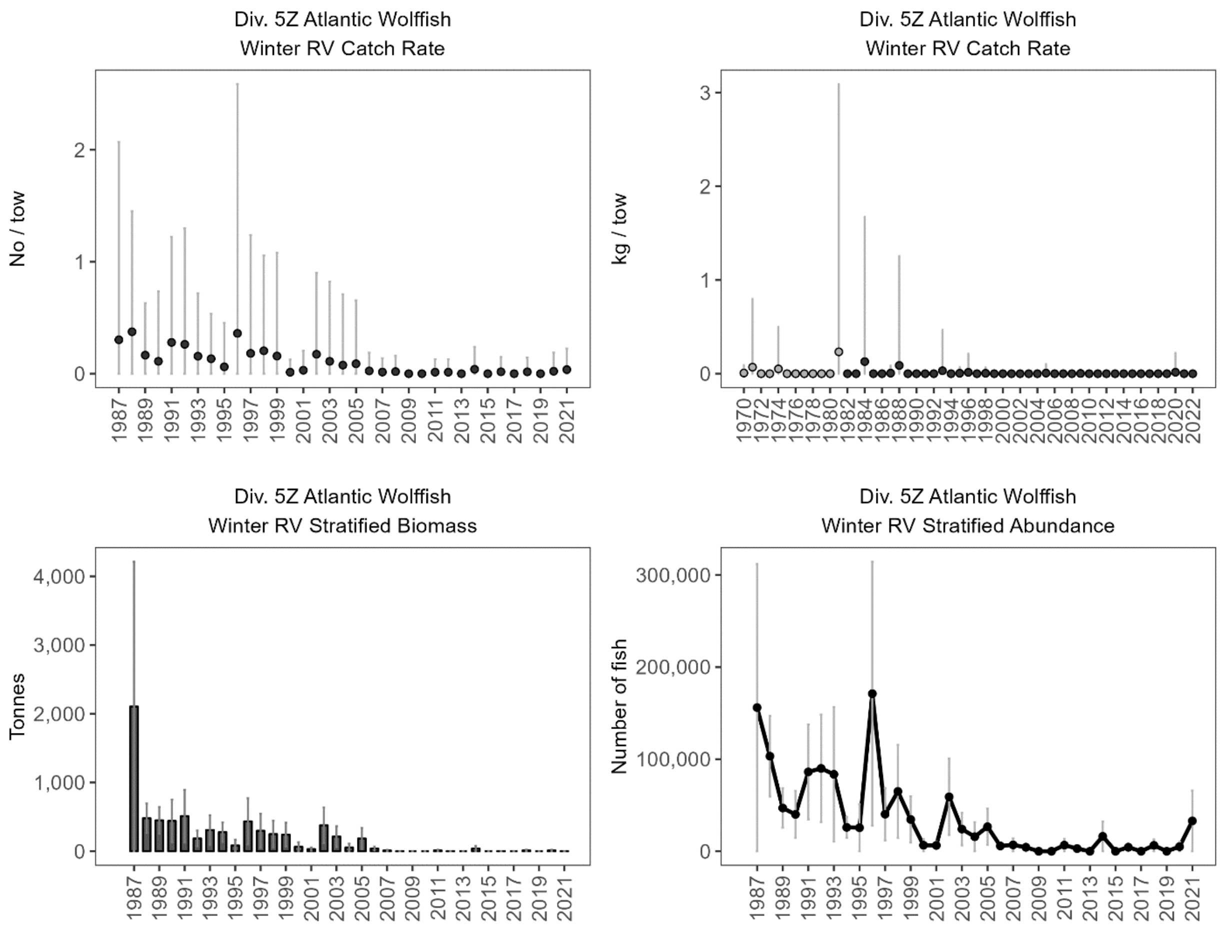


Figure 29. Standardized catch rate (mean number and weight per tow), stratified biomass, and stratified abundance of Atlantic Wolffish from the Maritimes Winter RV Survey in Strata 5Z1 to 5Z4 of Div. 5Z, 1987–2021. T-bars = +/- 95% CIs.

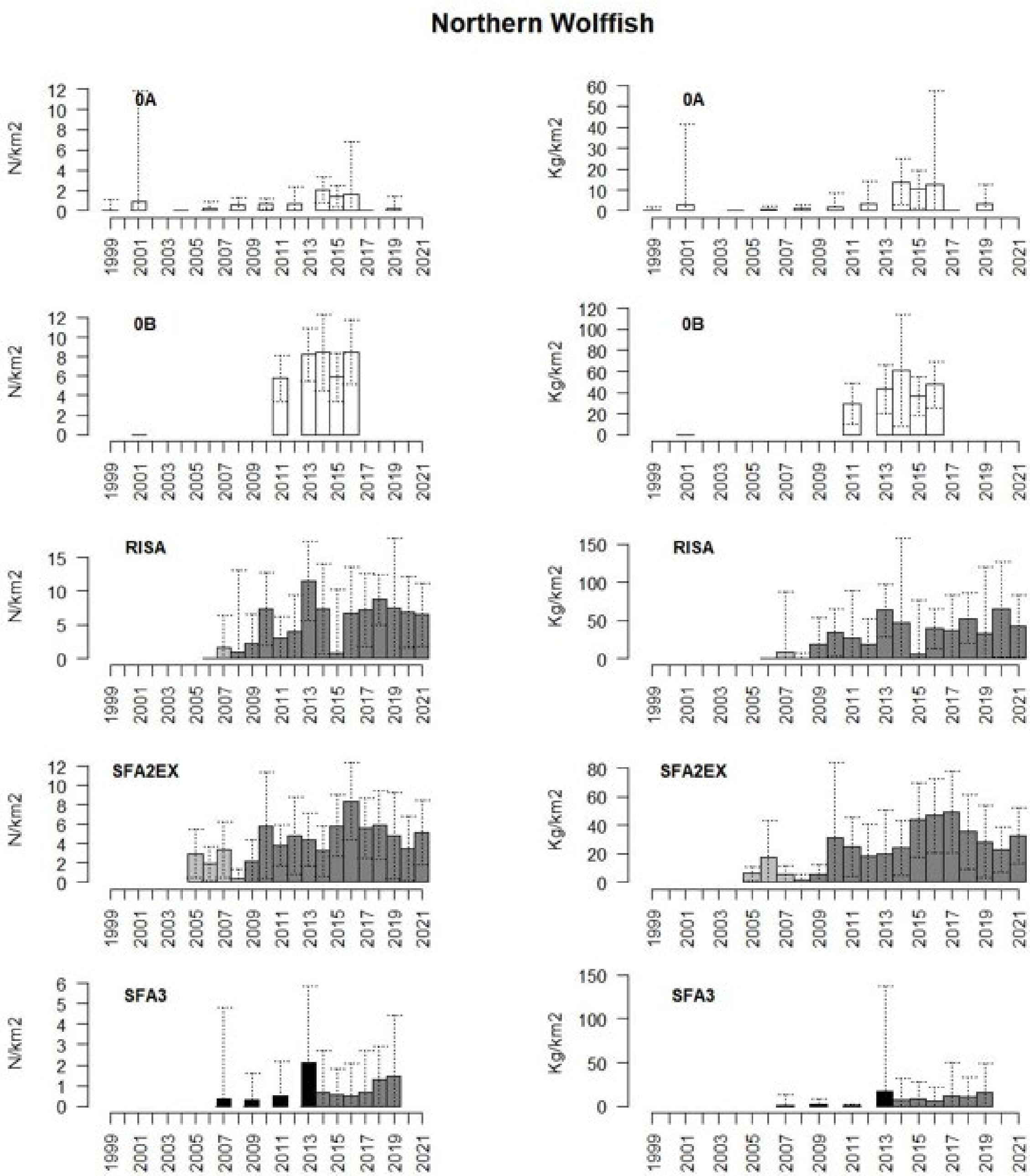


Figure 30. Standardized catch rates (number or kg per km²) for bycatch of Northern Wolffish in the multispecies survey (NAFO Div. 0A and 0B) and NSRF shrimp fishing (SFA 2, SFA 3 and RISA). The horizontal line indicates fishing occurred but there was no catch, blanks indicate now fishing occurred that year and area. Colour of bars denotes gear type: White = Alfredo; Light Grey = Standard Campelen; Dark Grey = Modified Campelen; Black = Cosmos. T-bars = +/- 95% CIs.

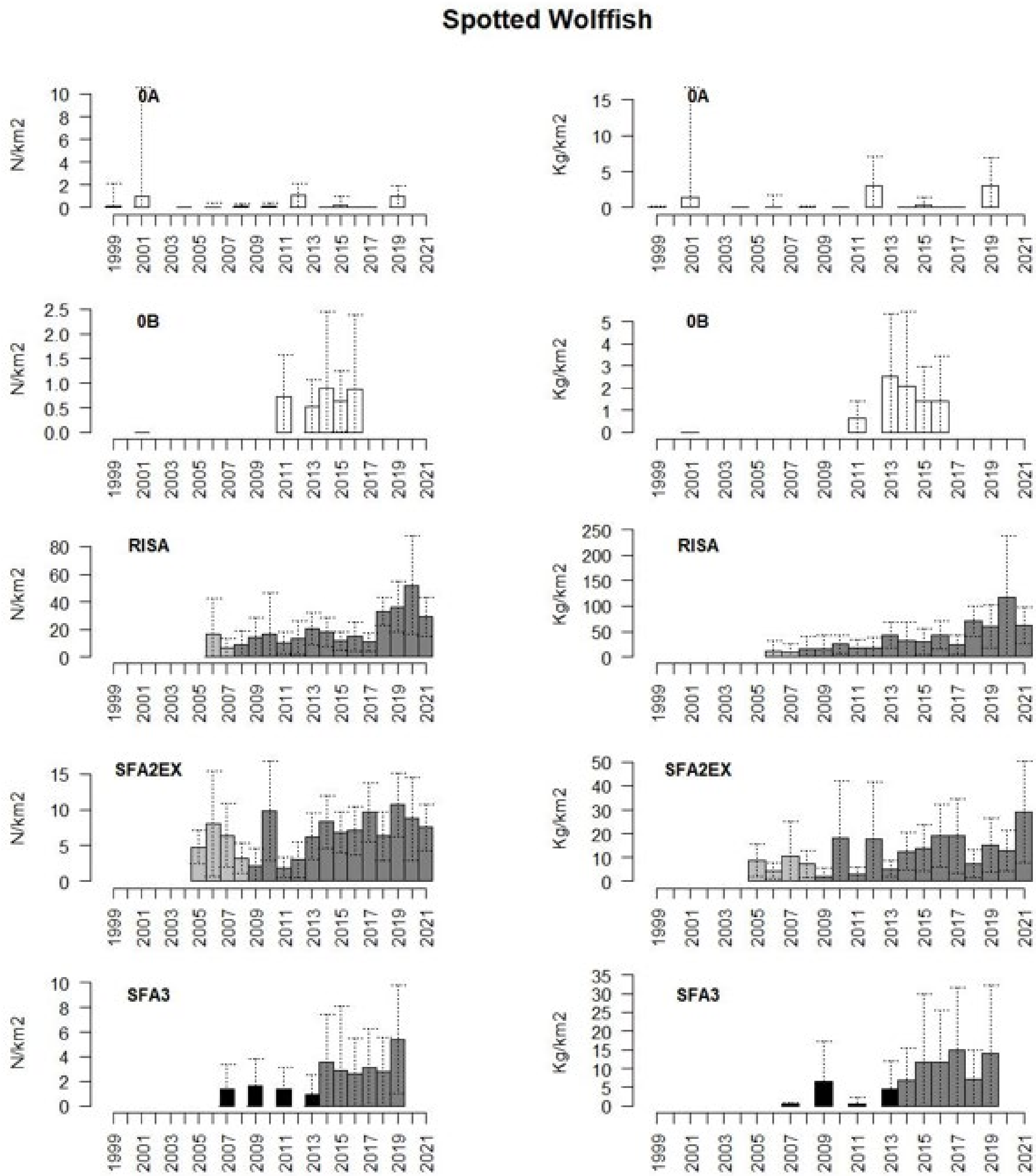


Figure 31. Standardized catch rates (number or kg per km²) for bycatch of Spotted Wolffish in the multispecies survey (NAFO Div. 0A and 0B) and NSRF shrimp fishing (SFA 2, SFA 3 and RISA). The horizontal line indicates fishing occurred but there was no catch, blanks indicate now fishing occurred that year and area. Colour of bars denotes gear type: White = Alfredo; Light Grey = Standard Campelen; Dark Grey = Modified Campelen; Black = Cosmos. T-bars = +/- 95% CIs.

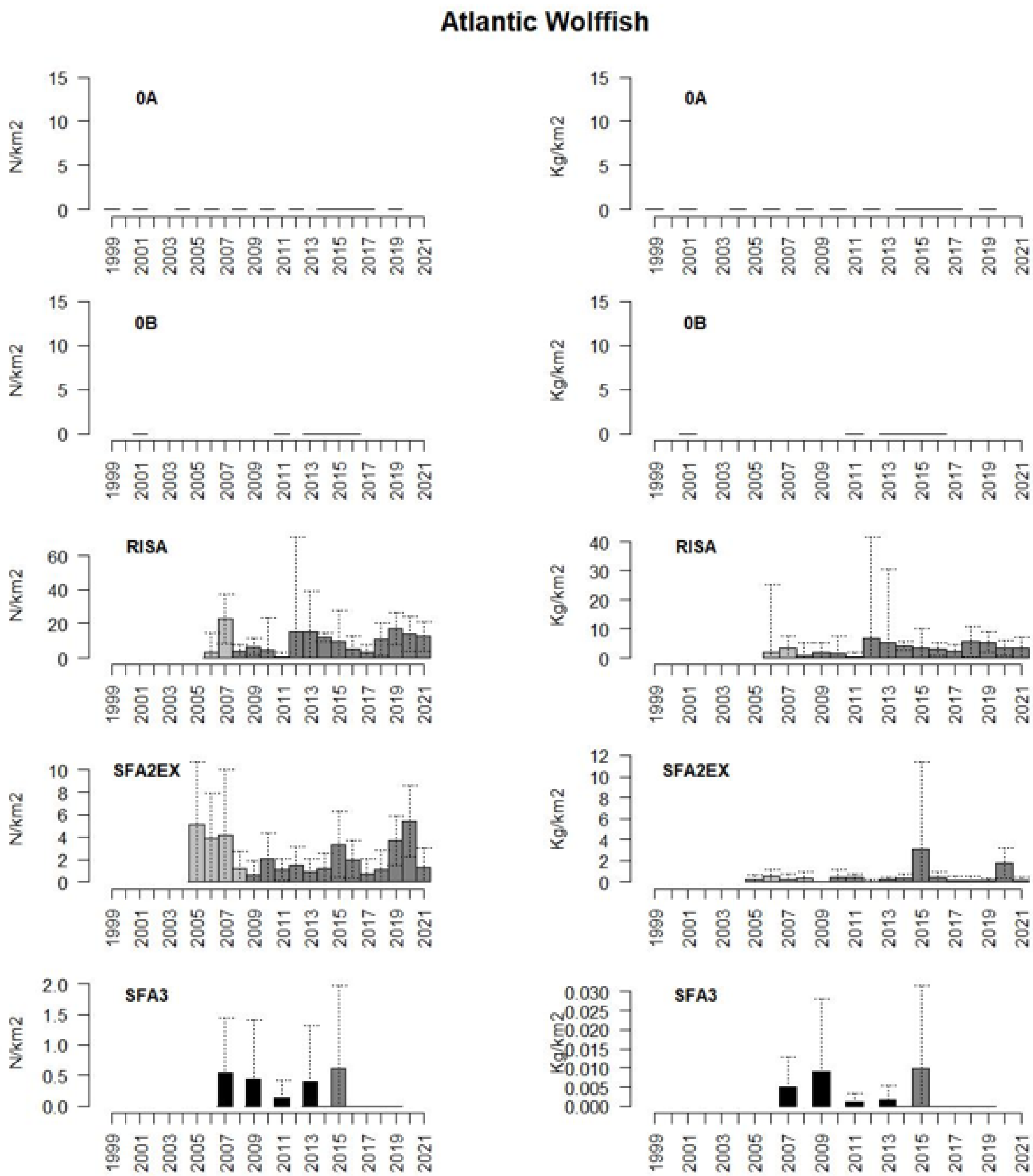


Figure 32. Standardized catch rates (number or kg per km²) for bycatch of Atlantic Wolffish in the multispecies survey (NAFO Div. 0A and 0B) and NSRF shrimp fishing (SFA 2, SFA 3 and RISA). The horizontal line indicates fishing occurred but there was no catch, blanks indicate now fishing occurred that year and area. Colour of bars denotes gear type: White = Alfredo; Light Grey = Standard Campelen; Dark Grey = Modified Campelen; Black = Cosmos. T-bars = +/- 95% CIs.

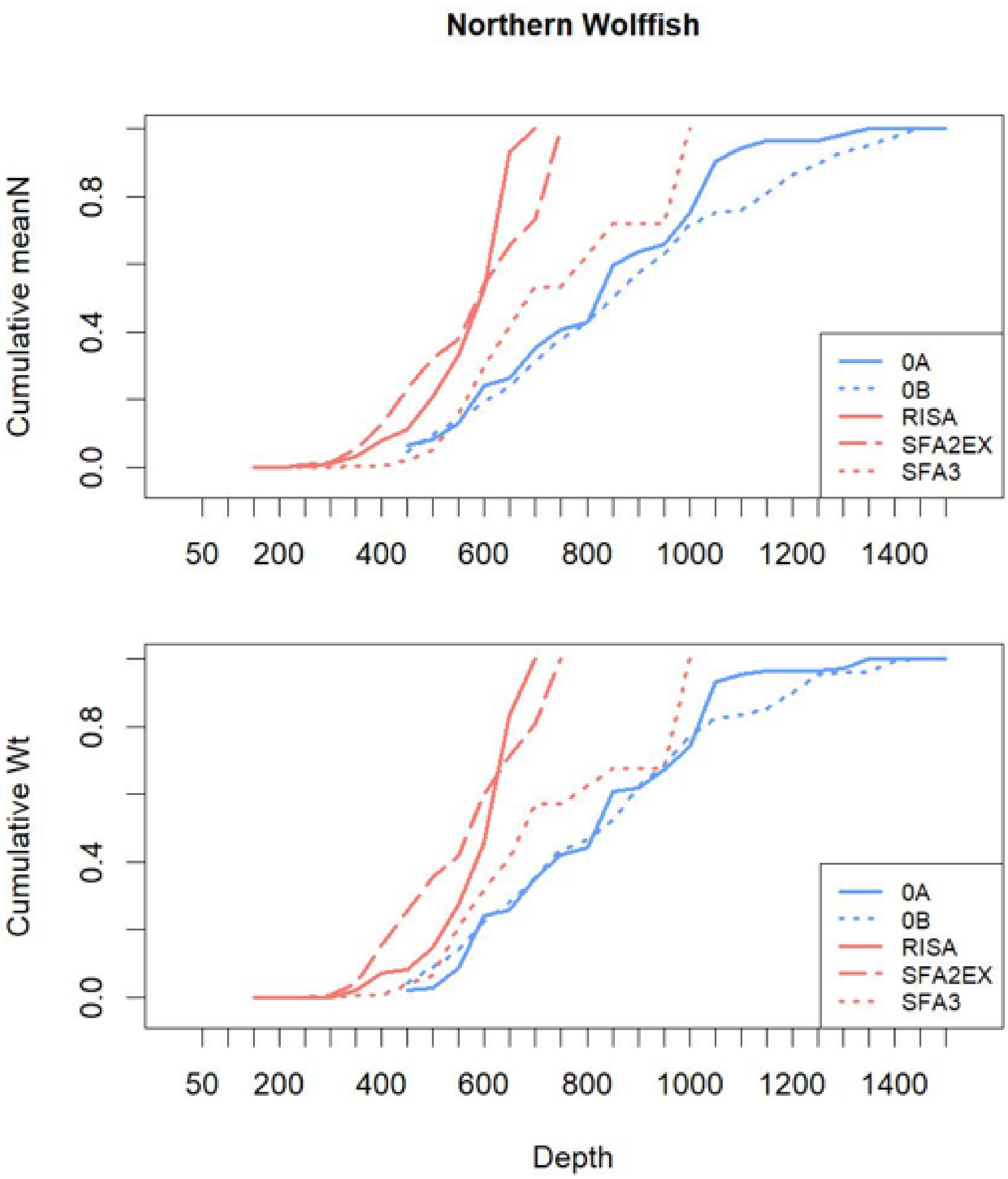


Figure 33. Cumulative catch by depth (50 m bins) for average number (top) and average weight in kg (bottom) per depth bin of Northern Wolffish. Red lines indicate the NSRF shrimp survey and blue lines the NAFO multispecies survey. The two surveys cover a different range of depths and use different gear (Alfredo trawl for NAFO, and Campelen or Cosmos for NSRF).

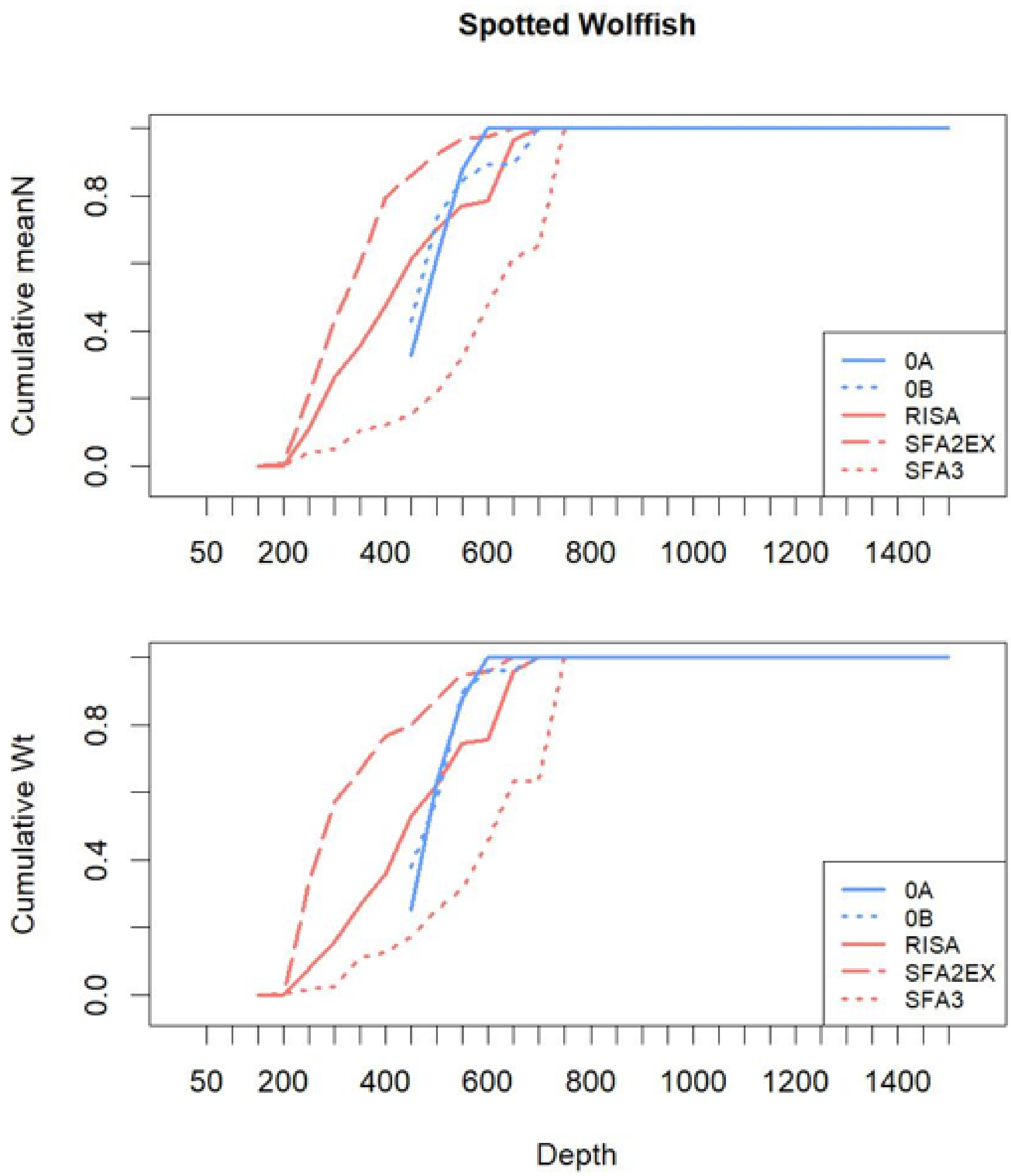


Figure 34. Cumulative catch by depth (50 m bins) for average number (top) and average weight in kg (bottom) per depth bin of Spotted Wolffish. Red lines indicate the NSRF shrimp survey and blue lines the NAFO multispecies survey. The two surveys cover a different range of depths and use different gear (Alfredo trawl for NAFO, and Campelen or Cosmos for NSRF).

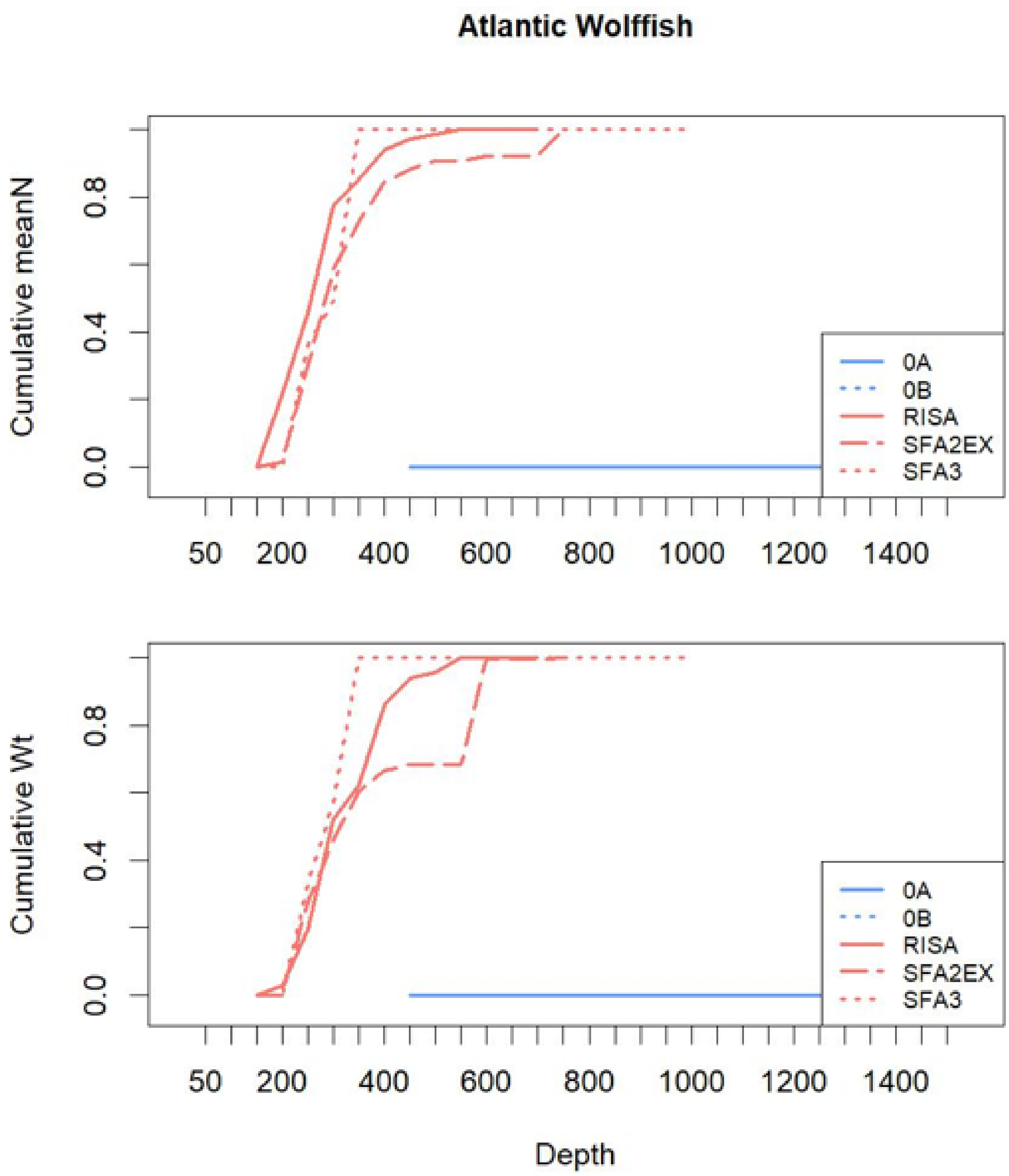


Figure 35. Cumulative catch by depth (50 m bins) for average number (top) and average weight in kg (bottom) per depth bin of Atlantic Wolffish. Red lines indicate the NSRF shrimp survey and blue lines the NAFO multispecies survey. The two surveys cover a different range of depths and use different gear (Alfredo trawl for NAFO, and Campelen or Cosmos for NSRF). No Atlantic Wolffish were captured in the NAFO multispecies survey.

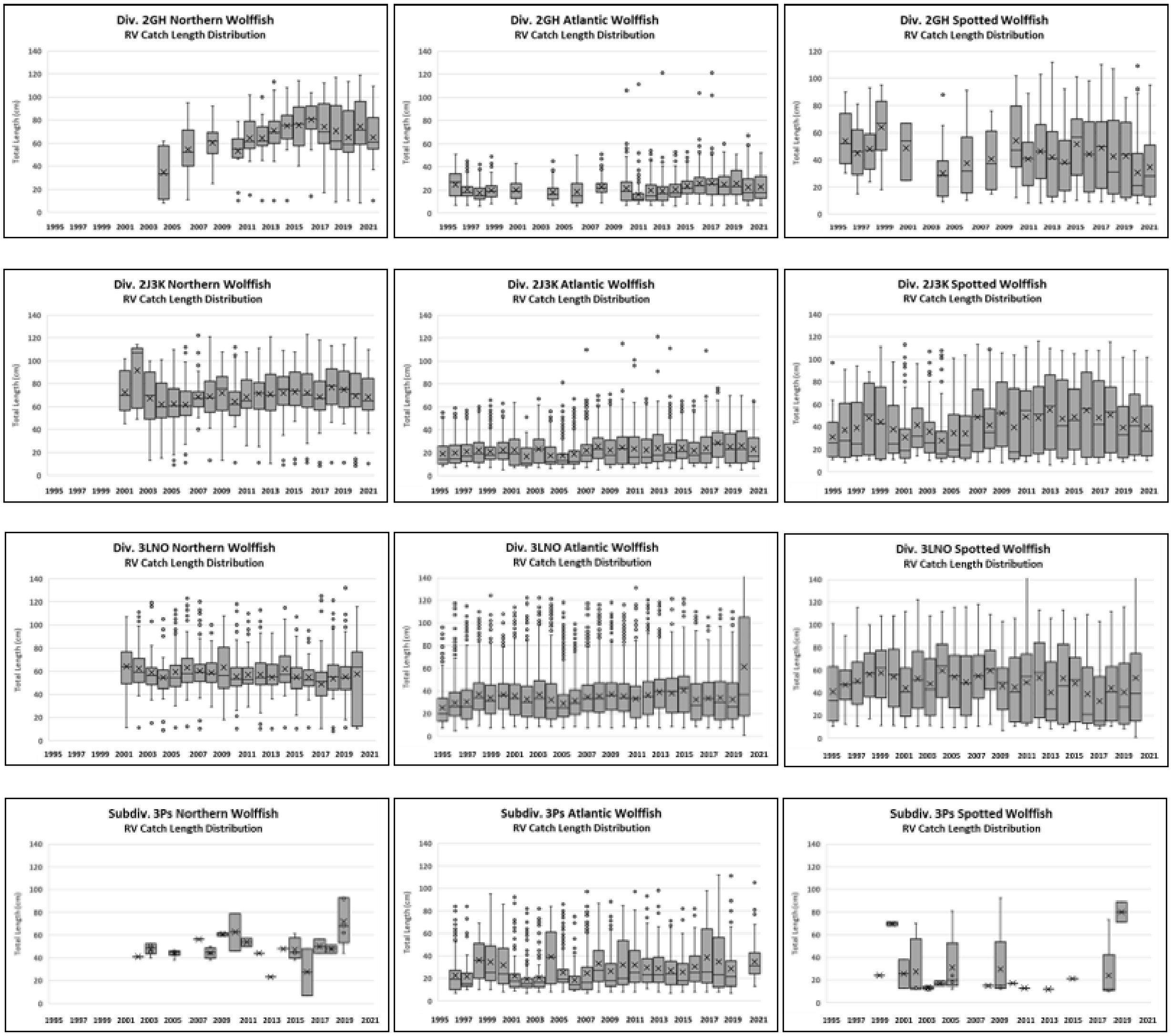


Figure 36. Length frequency distribution of wolffish from RV survey catch in the NL Region.

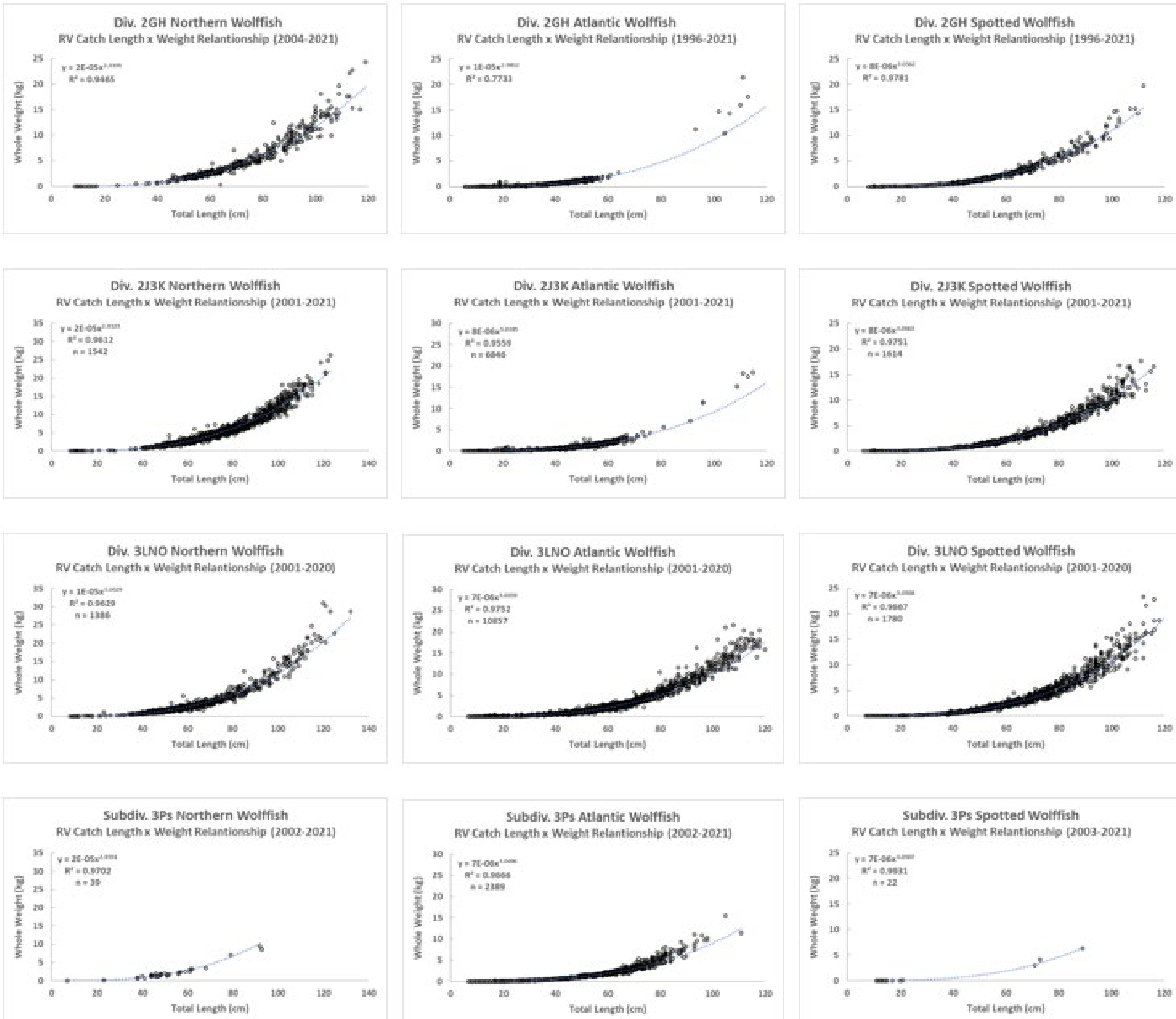


Figure 37. Length and weight relationship of wolffish from RV survey catch in the NL Region.

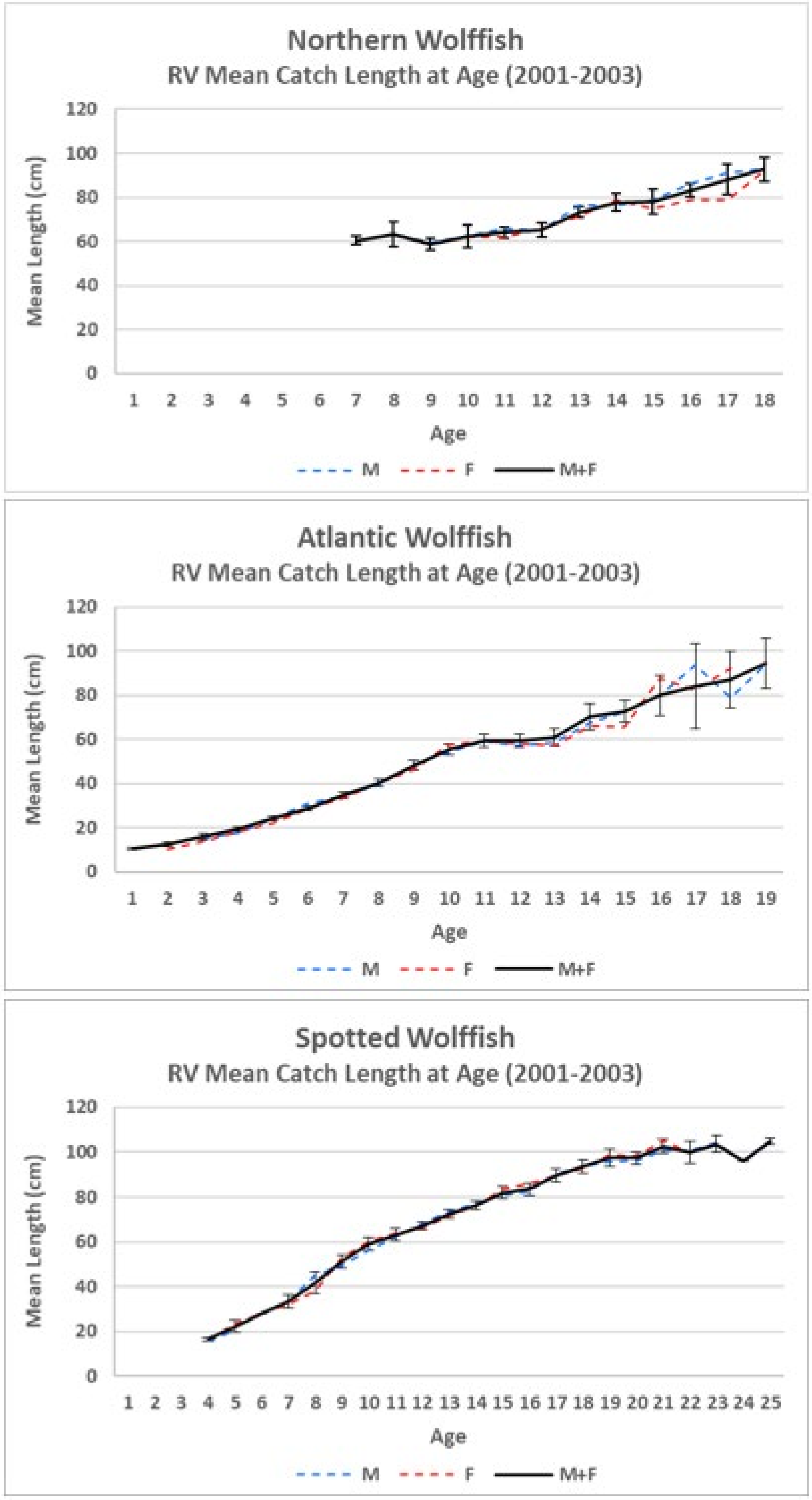


Figure 38. Mean length at age of wolffish from RV survey catch in the NL Region. M = male, F = female. T-bars = +/- 95% CIs.

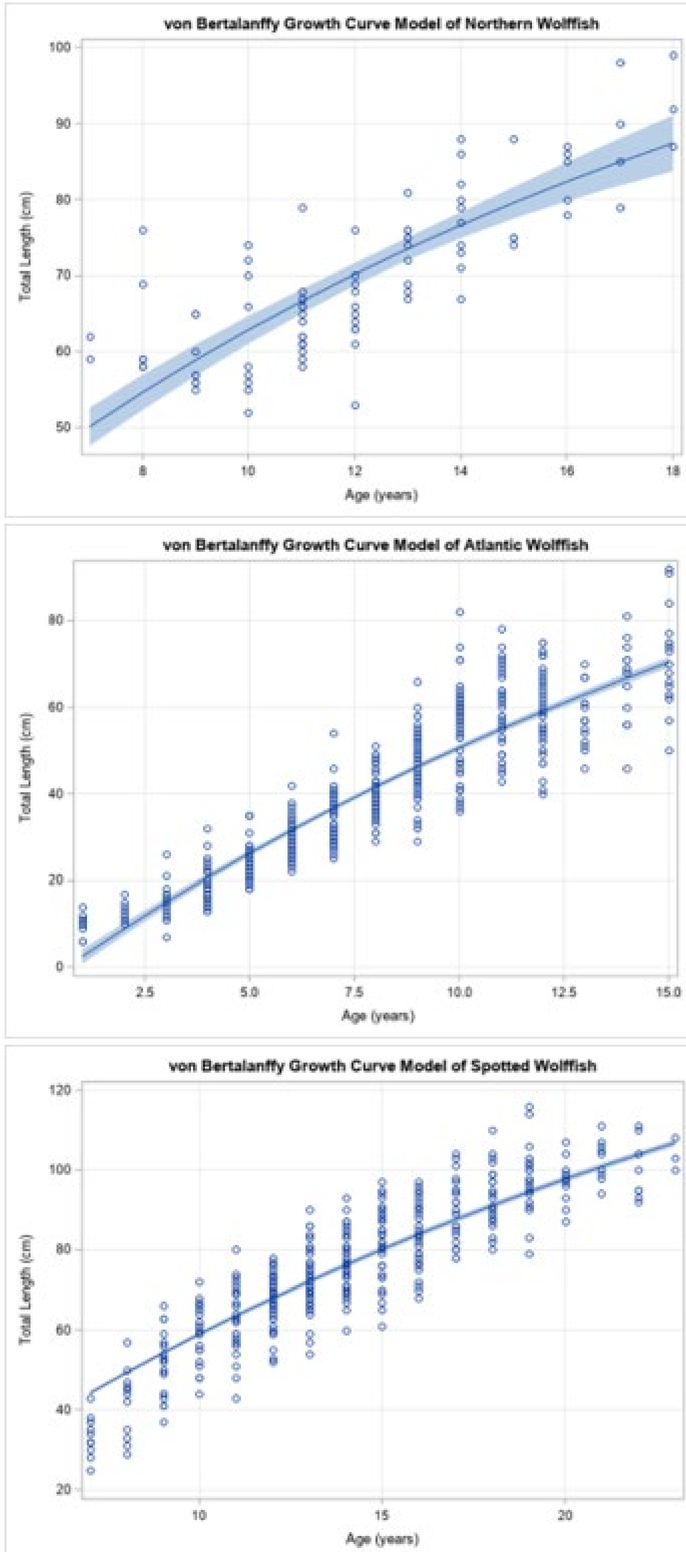


Figure 39. Observed (circle) and predicted (solid line) mean length at age of wolffish from RV survey catch in the NL Region (2001–03). The predicted curves were fitted using a VBL function.

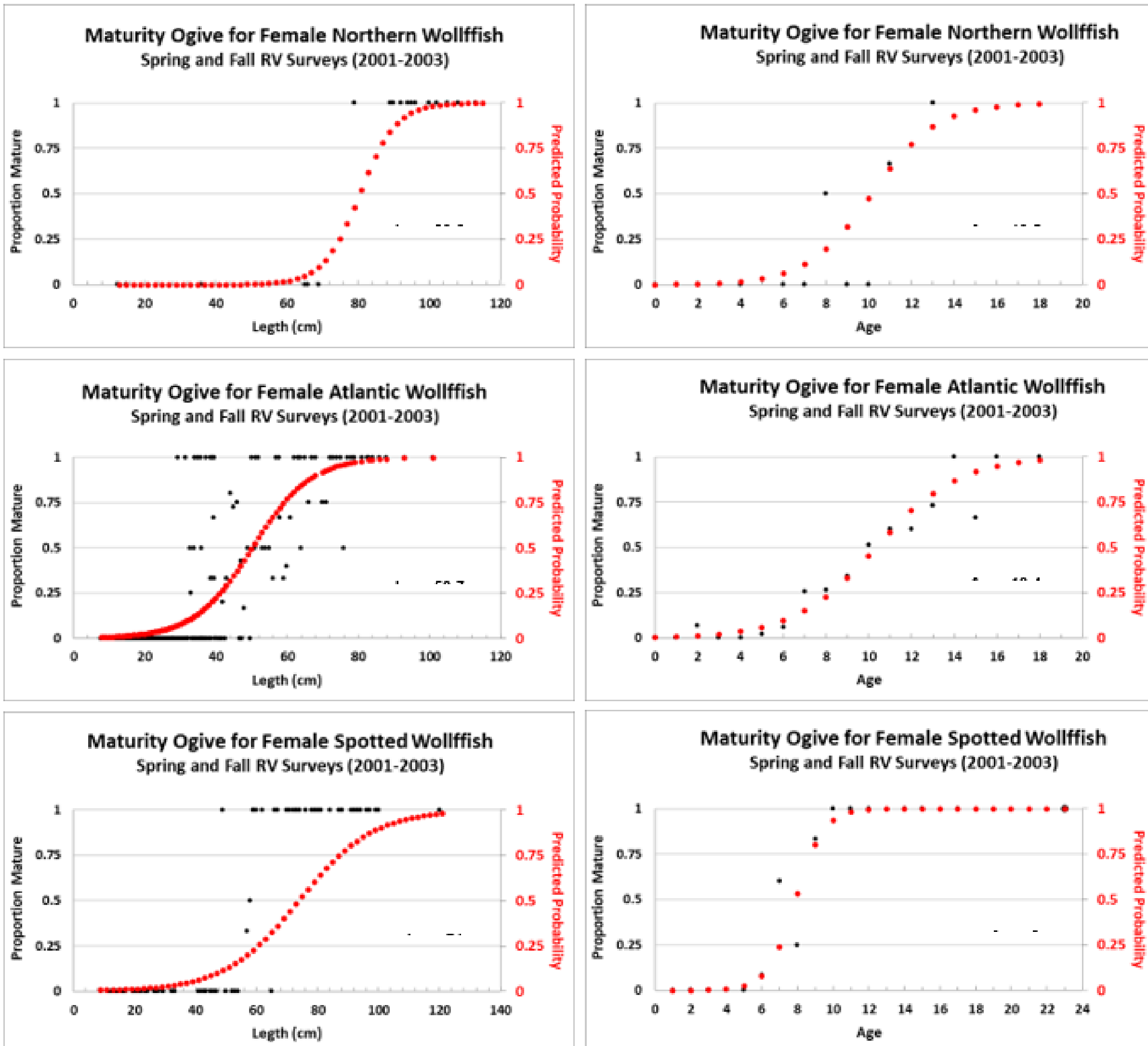


Figure 40. Proportion of mature female wolffish at length and at age from RV survey catch in the NL Region (2001–03). The predicted curves were fitted using a Logit function.

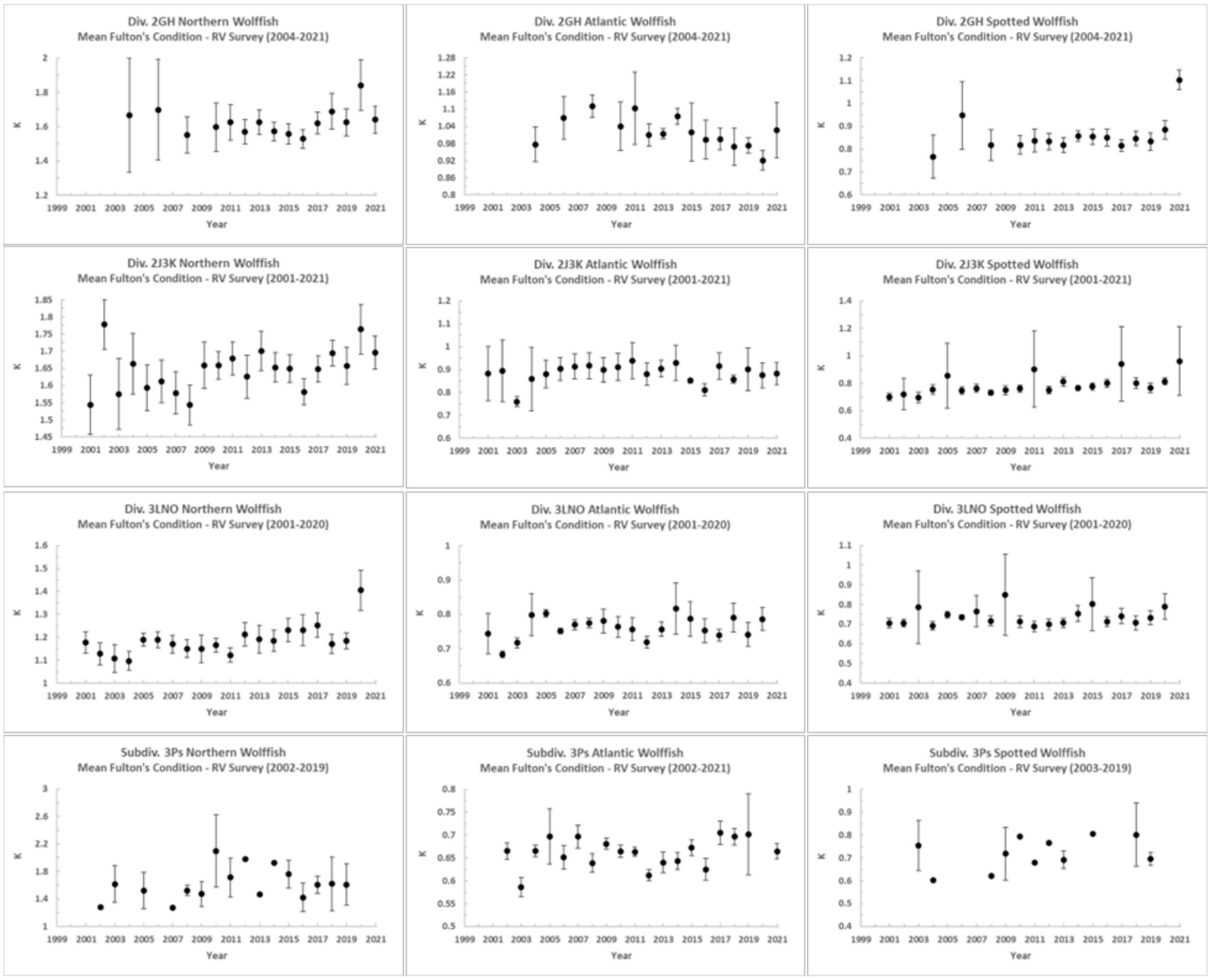


Figure 41. Mean Fulton's K Condition Factor of wolffish (both sexes) from RV survey catch in the NL Region. T-bars = +/- 95% CIs.

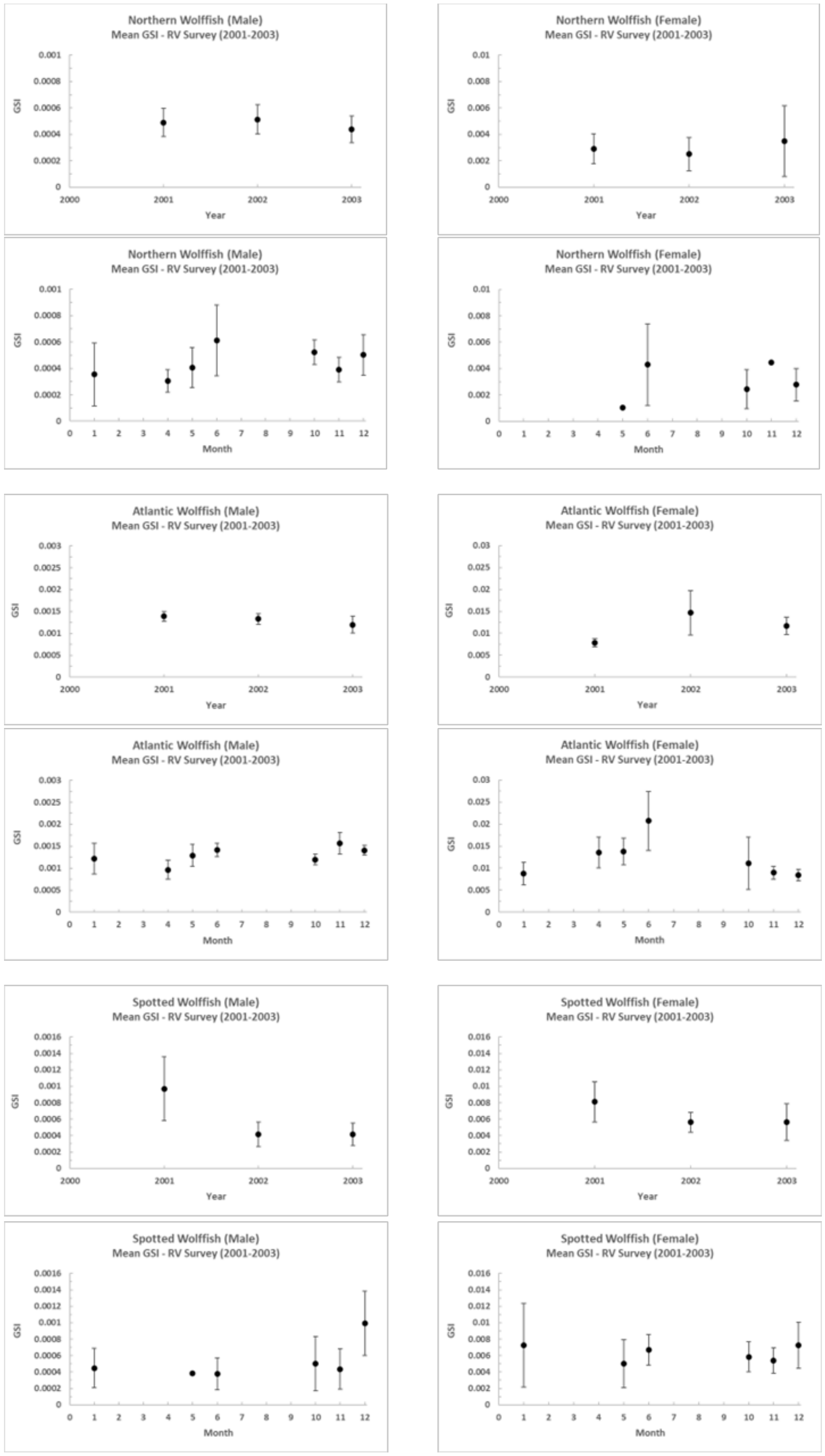


Figure 42. Mean Gonadosomatic Index (GSI) of male and female wolffish from RV survey catch in the NL Region (2001–03). T-bars = +/- 95% CIs.

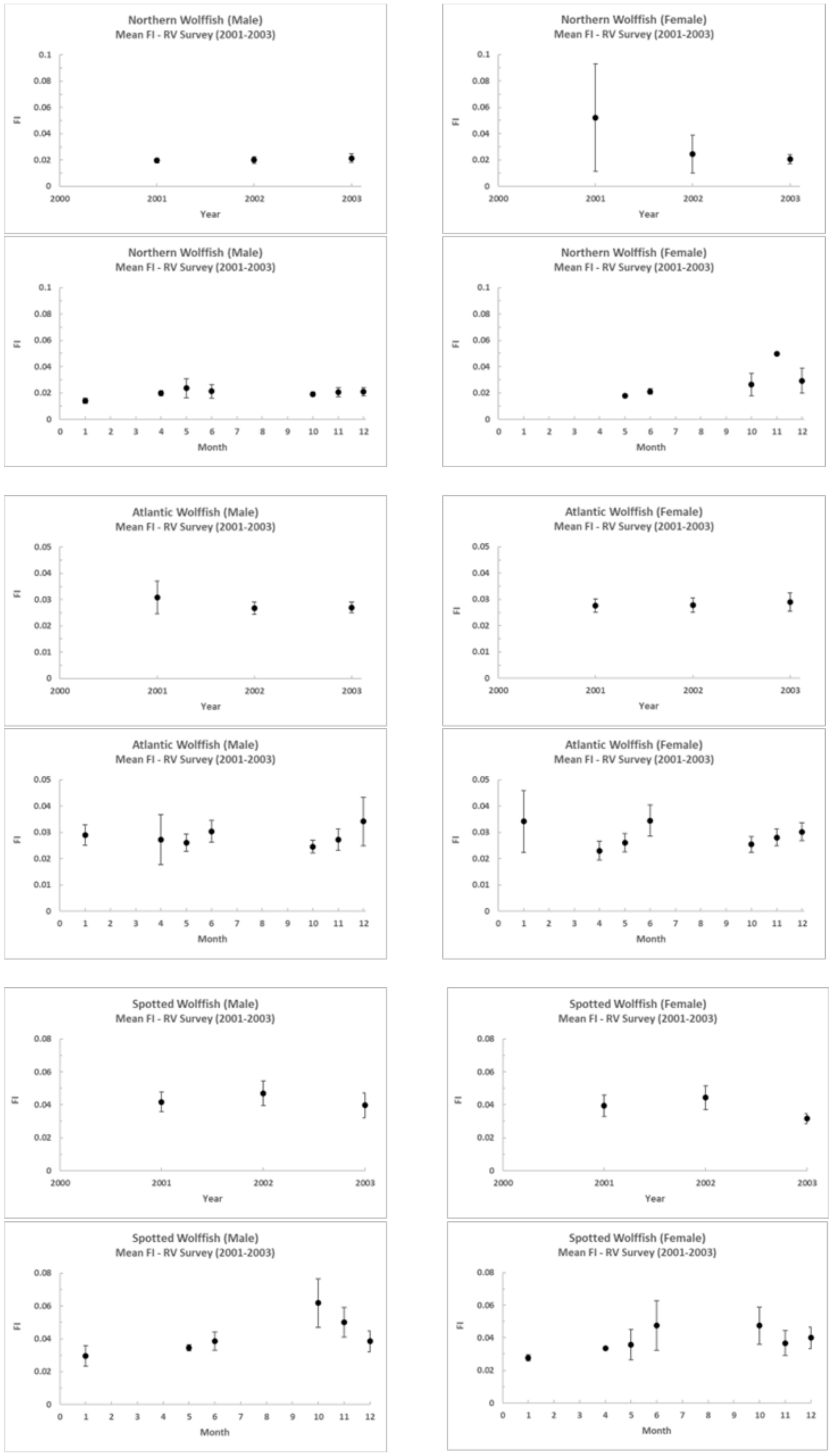


Figure 43. Mean Fullness Index (FI) of male and female wolffish from RV survey catch in the NL Region (2001–03). T-bars = +/- 95% CIs.

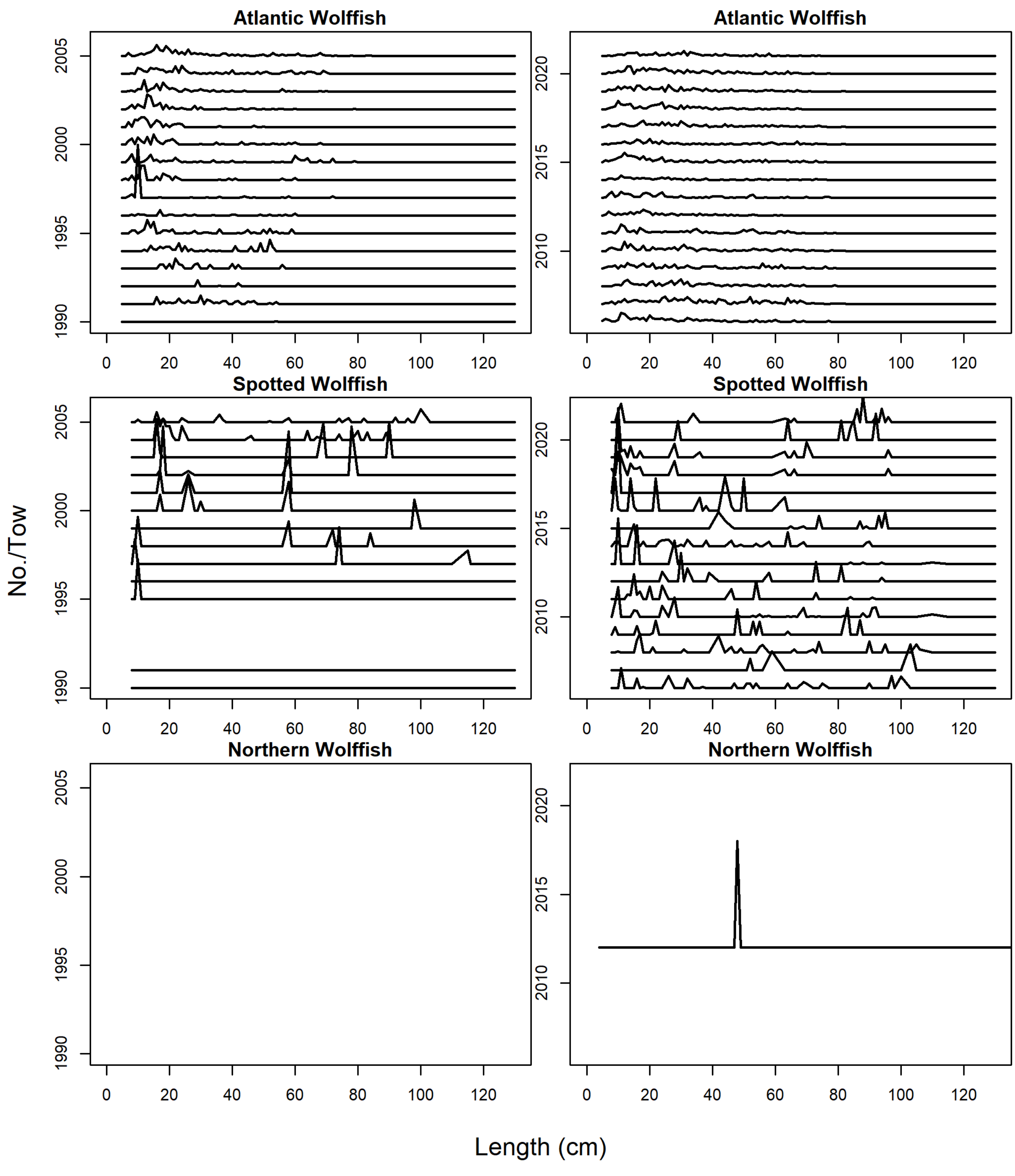


Figure 44. Length frequency distributions observed for Atlantic Wolffish, Spotted Wolffish, and Northern Wolffish with available tow and length records in Div. 4RS and the St. Lawrence estuary. Catch numbers and weights from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen-equivalent for comparability.

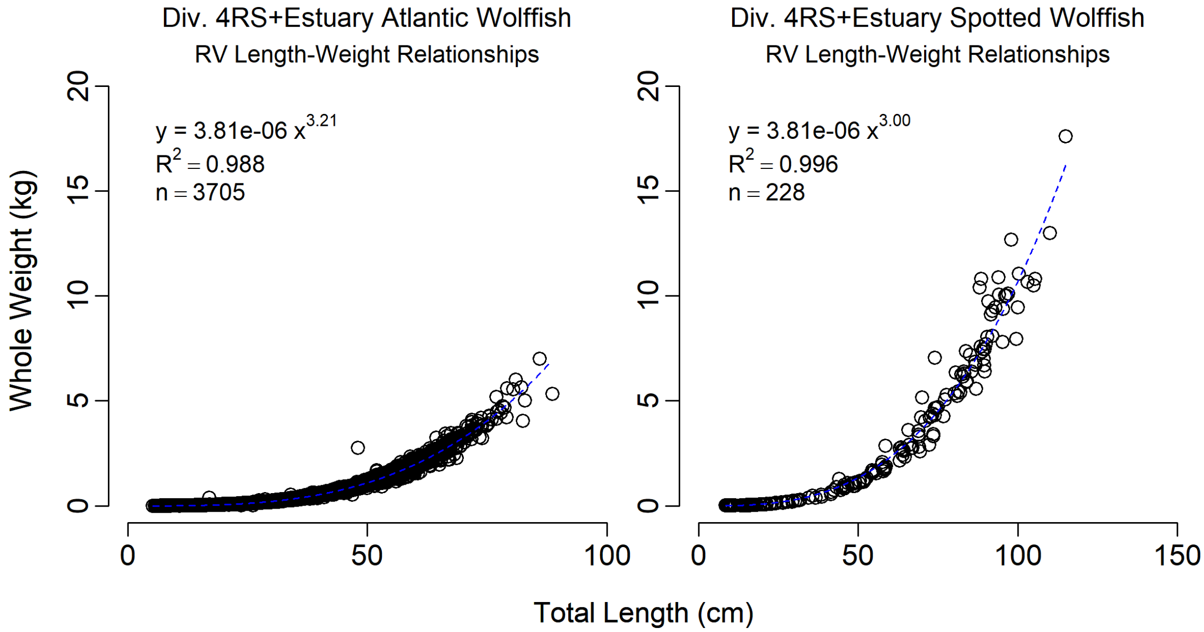


Figure 45. Length-weight relationships for Atlantic Wolffish and Spotted Wolffish in Div. 4RS and the St. Lawrence estuary. Observations from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen-equivalent for comparability.

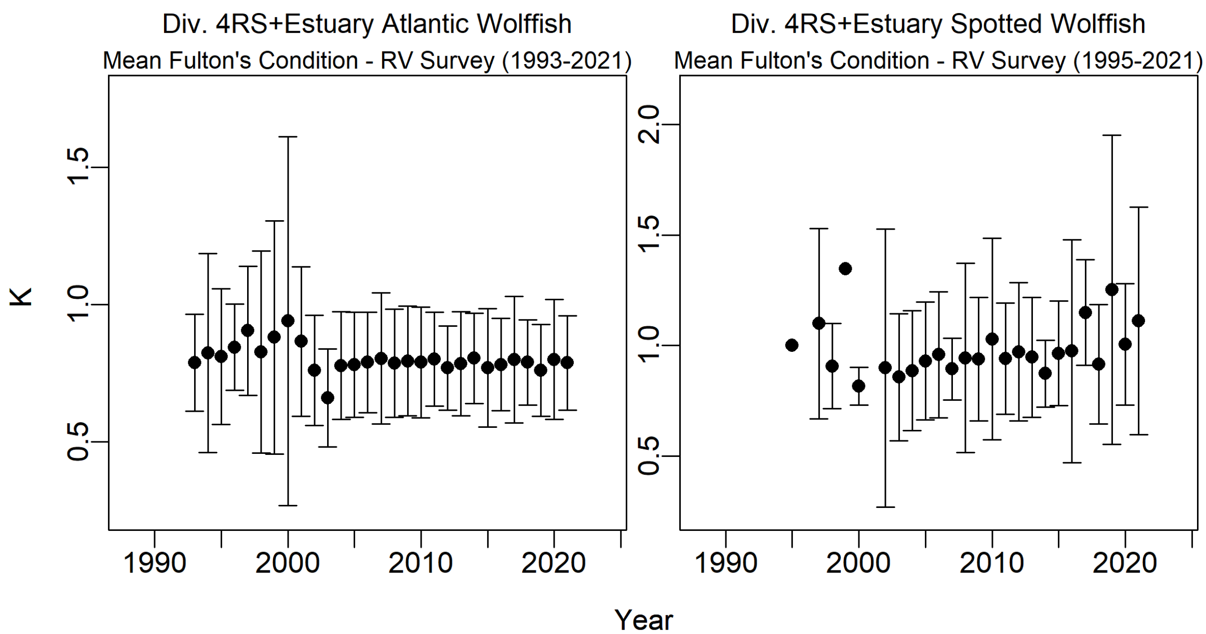


Figure 46. Trends in Fulton's K Condition Factor for Atlantic Wolffish and Spotted Wolffish in Div. 4RS and the St. Lawrence estuary over the period from 1990 to 2021. Observations from the CCGS Alfred Needler (1990–2003) were adjusted to the CCGS Teleost (2004–21) Campelen-equivalent for comparability.

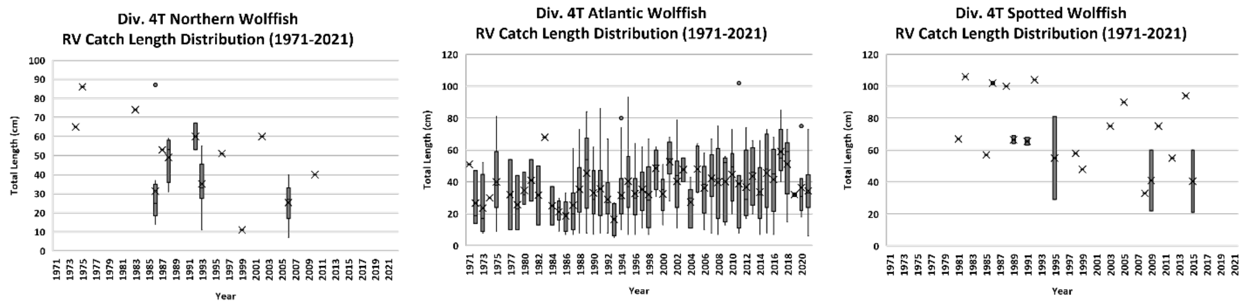


Figure 47. Length frequency distribution of wolffish from September RV survey catch for Div. 4T.

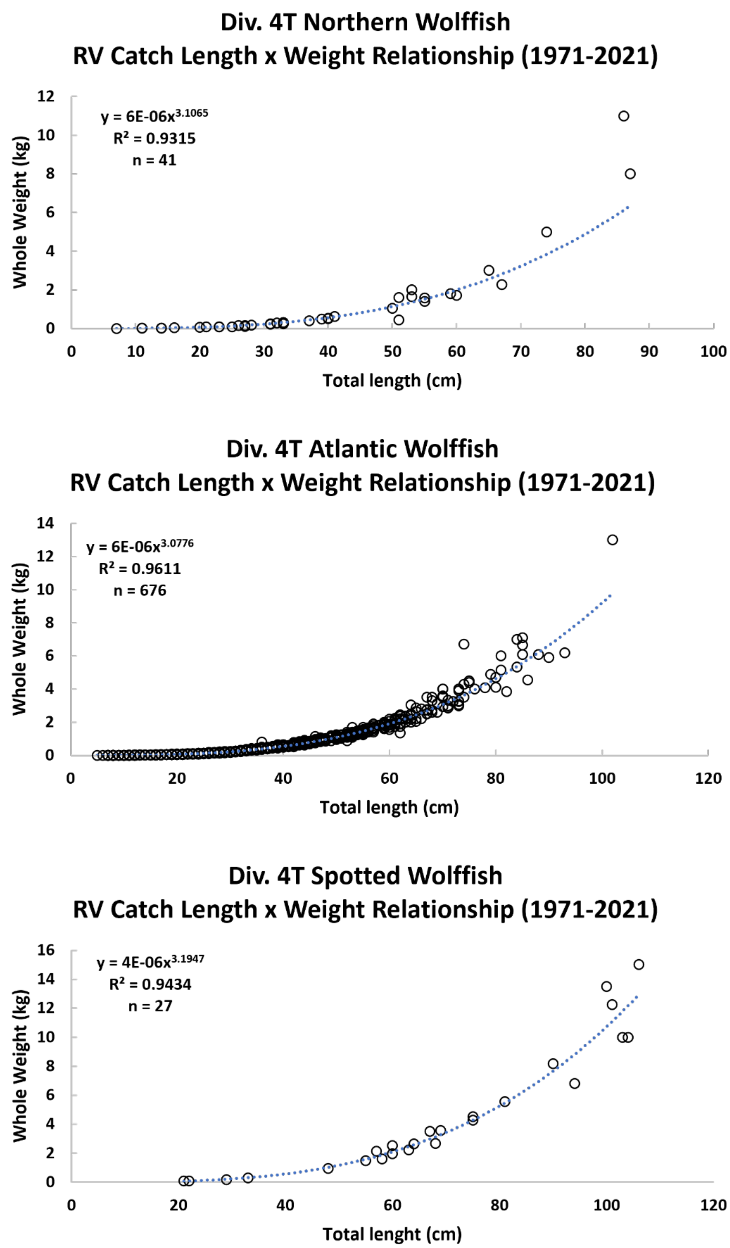
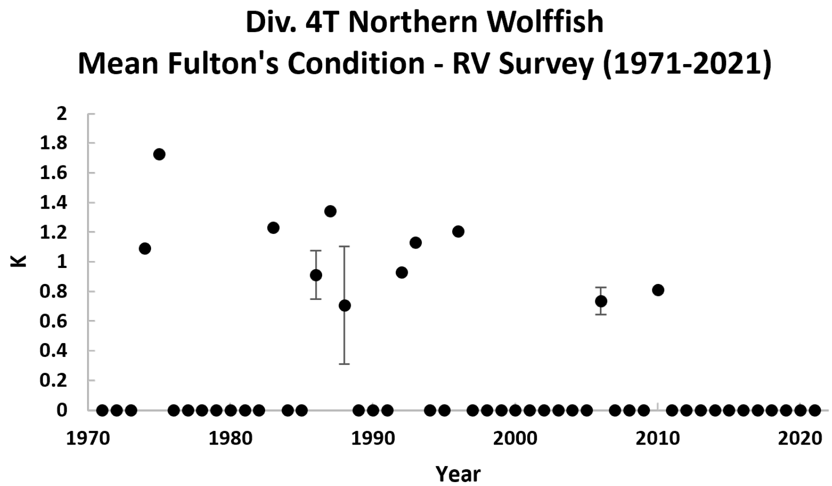
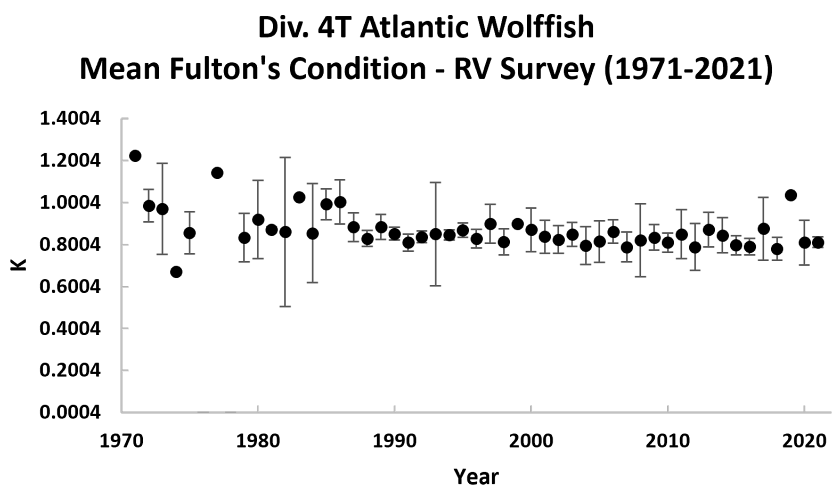


Figure 48. Length-weight relationship of wolffish from September RV survey catch for Div. 4T.





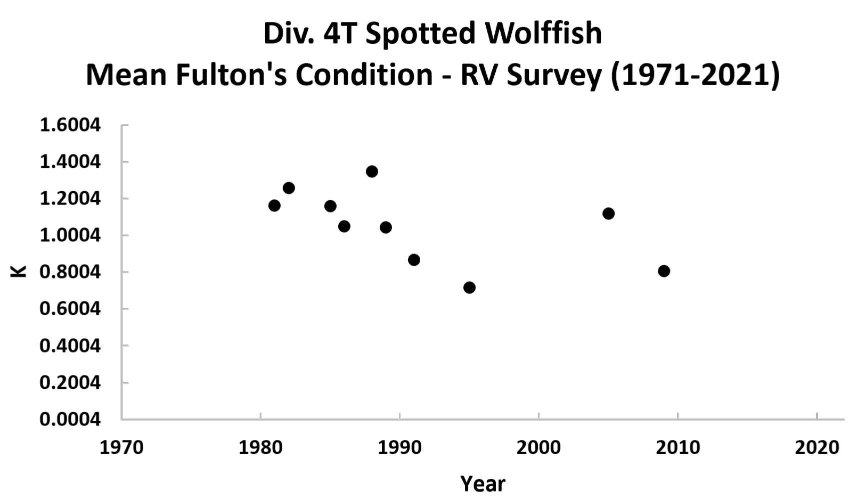


Figure 49. Mean annual Fulton's K Condition Factor of wolffish (both sexes) from September RV survey catch for Div. 4T. T-bars = +/- 95% CIs. Data points without T-bars are from years where less than three specimens were collected.

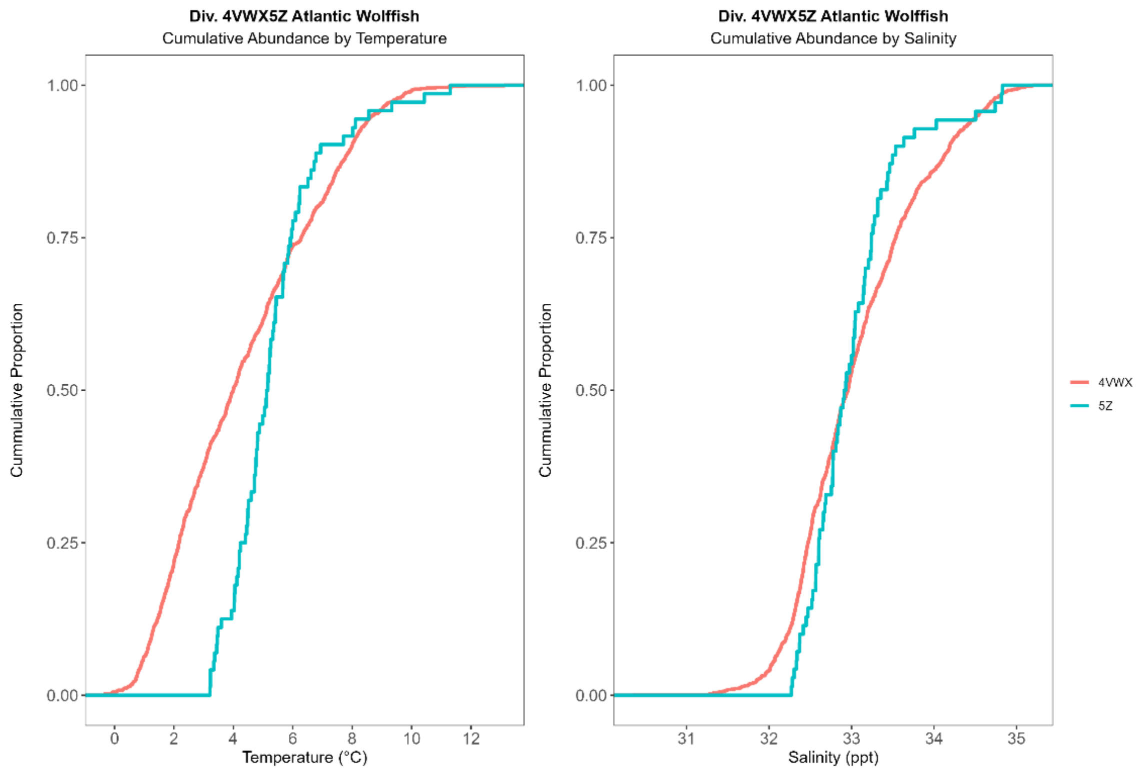


Figure 50. Cumulative stratified abundance of Atlantic Wolffish as a function of temperature and salinity from the Maritimes summer RV Surveys in Div. 4VWX and 5Z, 1982–2022.

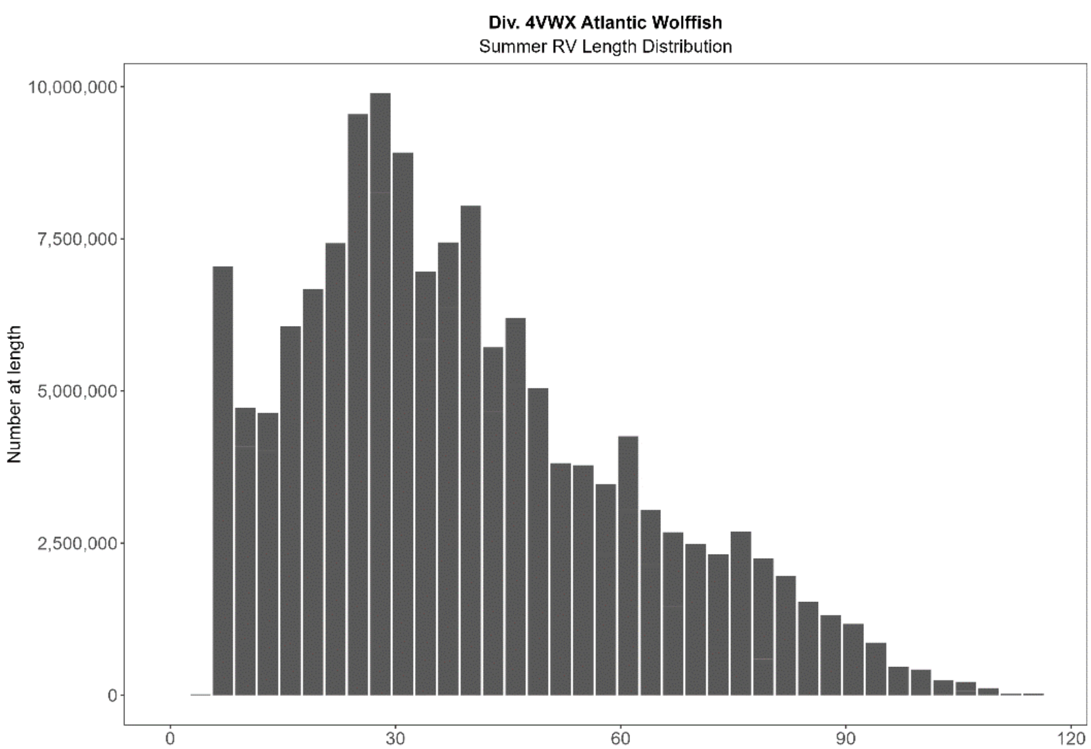


Figure 51. Stratified length frequency distribution of Atlantic Wolffish from the Maritimes summer RV survey in Div. 4VWX, 1982–2022.

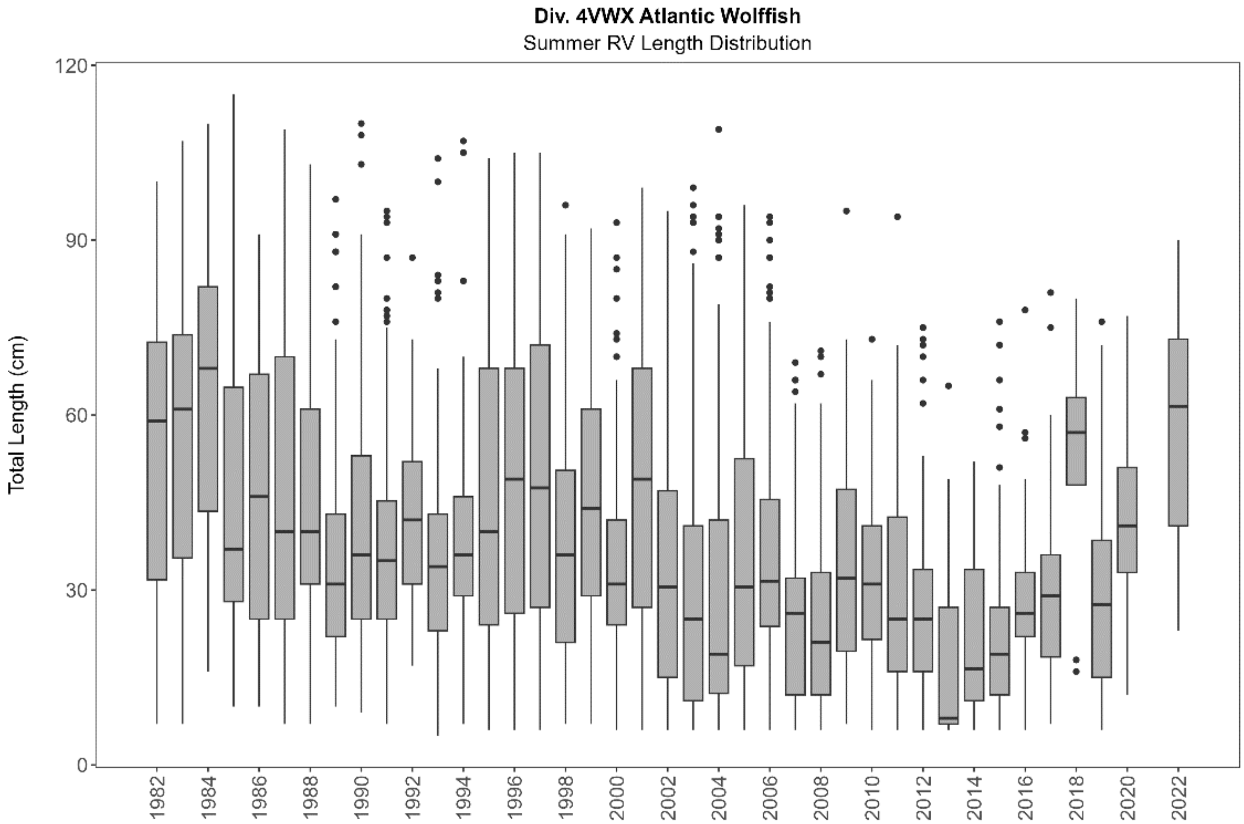


Figure 52. Raw length frequency distribution of Atlantic Wolffish from the Maritimes summer RV Survey in Div. 4VWX, 1982–2022.

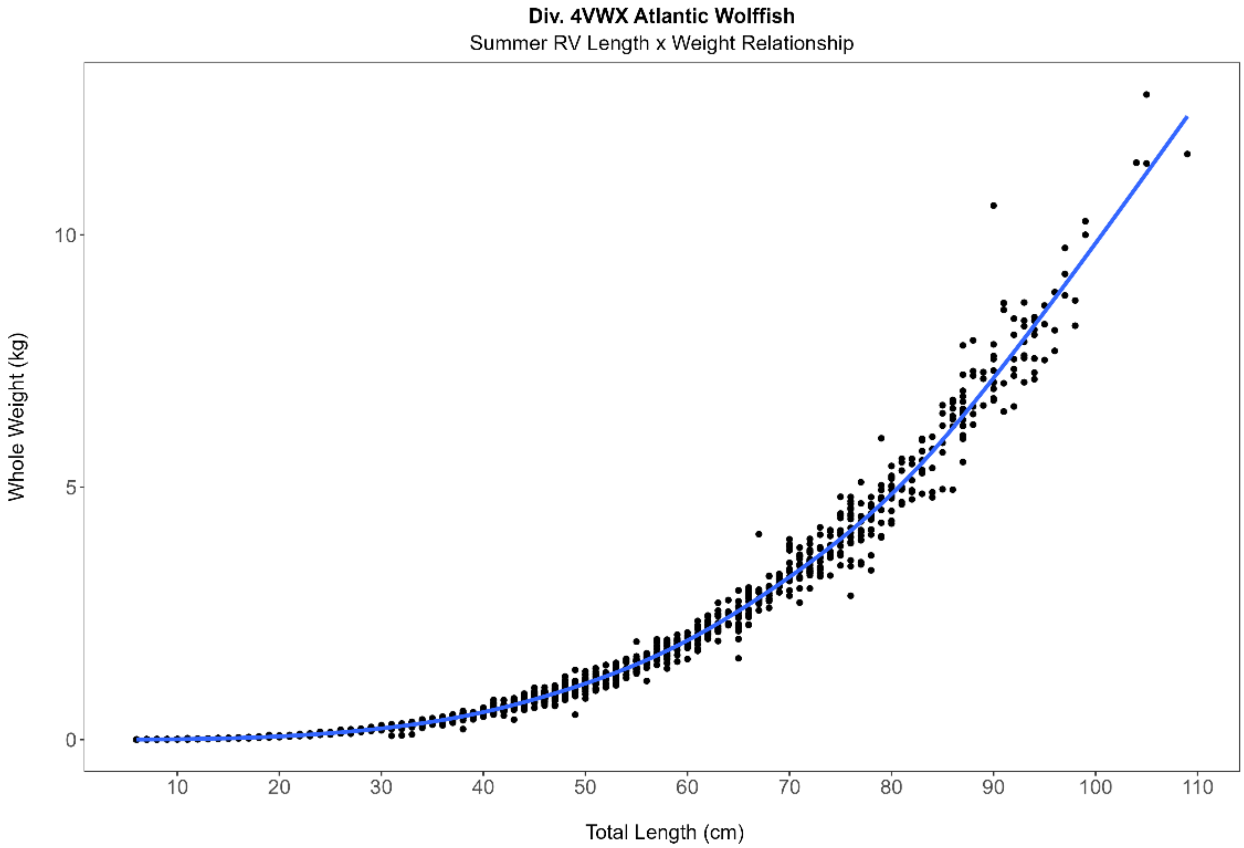


Figure 53. Length-weight relationship of Atlantic Wolffish from the Maritimes summer RV Survey in Div. 4VWX, 1995–2022. The fitted line (blue) is defined by the equation: $y = 7E\text{-}06x^{3.05}$ ($R^2 = 0.98$, n=2306).

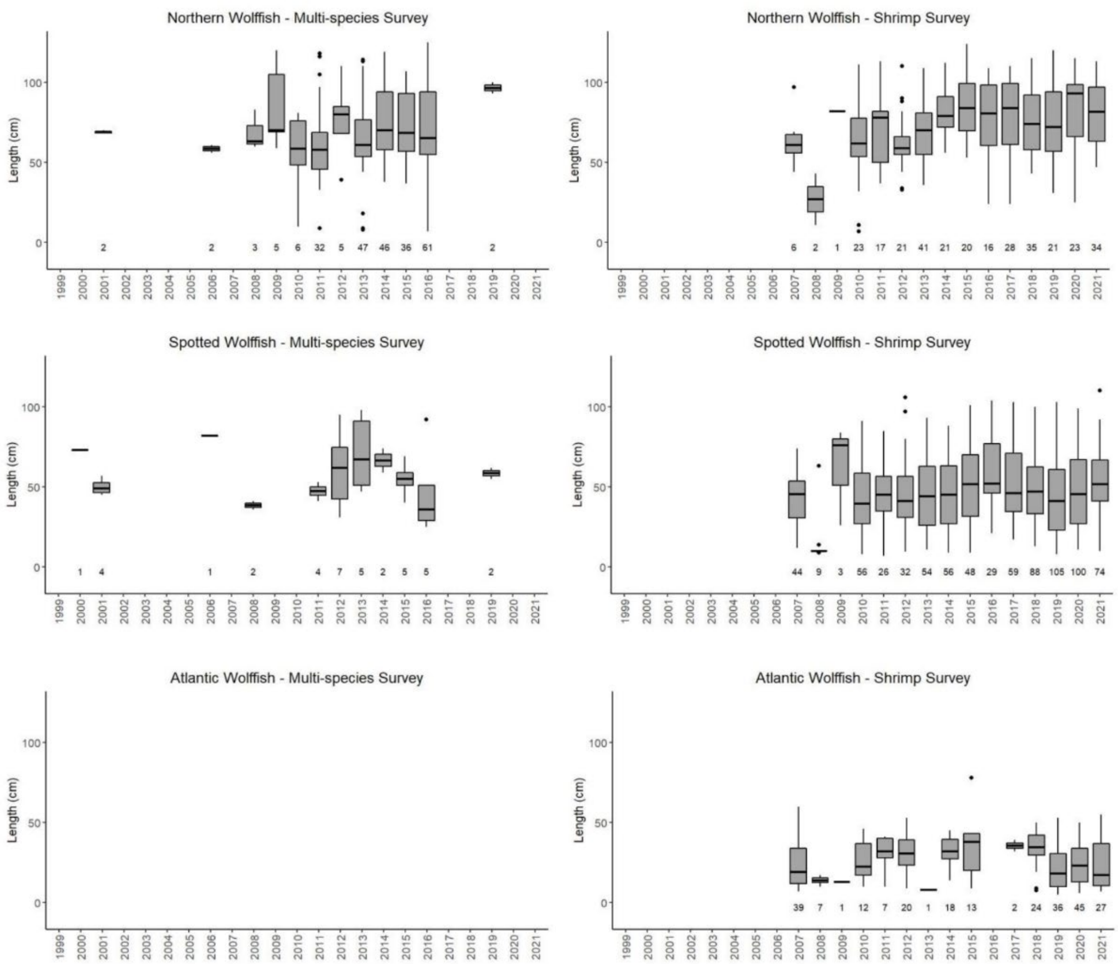


Figure 54. Length by year for Northern, Spotted, and Atlantic Wolffish caught in the multispecies NAFO and NSRF shrimp surveys. Areas are aggregated within each survey. The numbers below each box indicate the number of data points. No Atlantic Wolffish were caught in the NAFO multispecies survey.

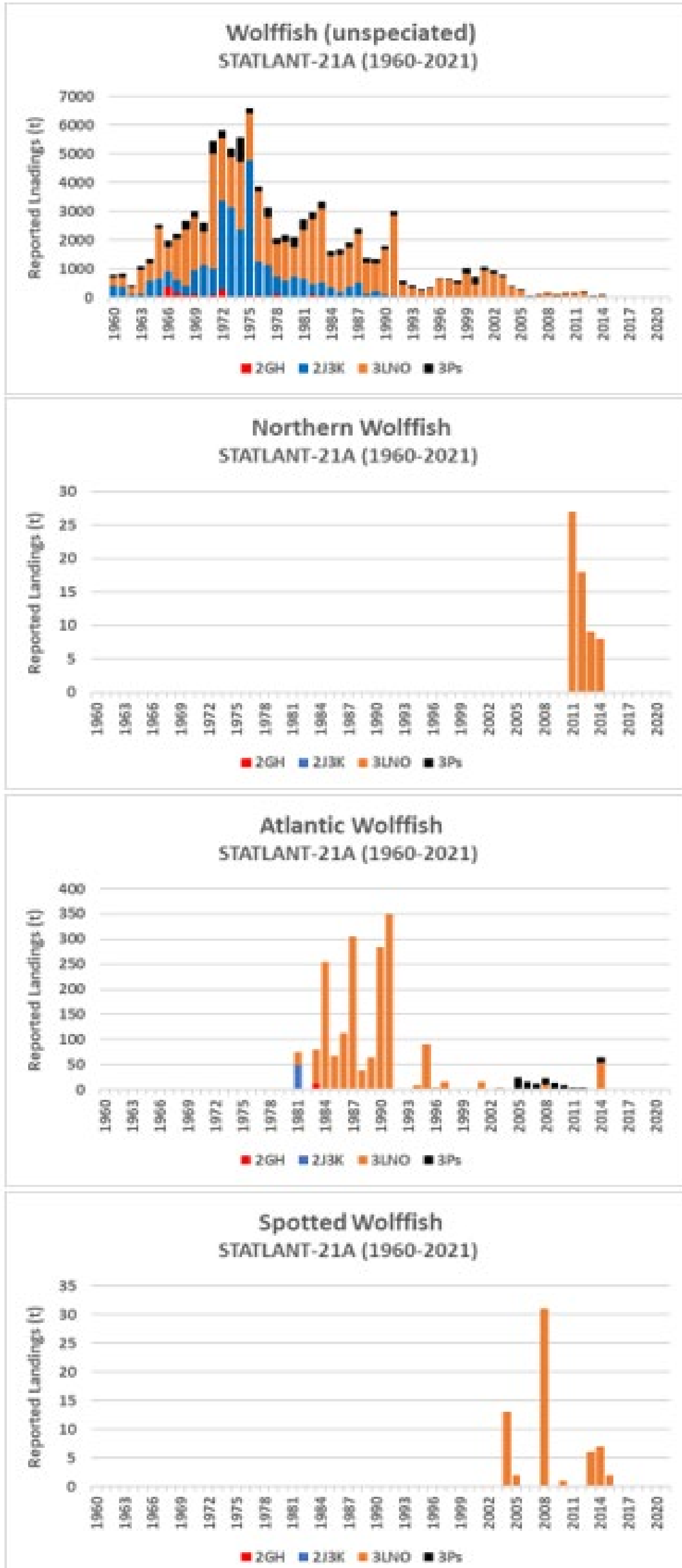


Figure 55. Reported landings of wolffish from NAFO STATLANT-21A database (1960–2021).

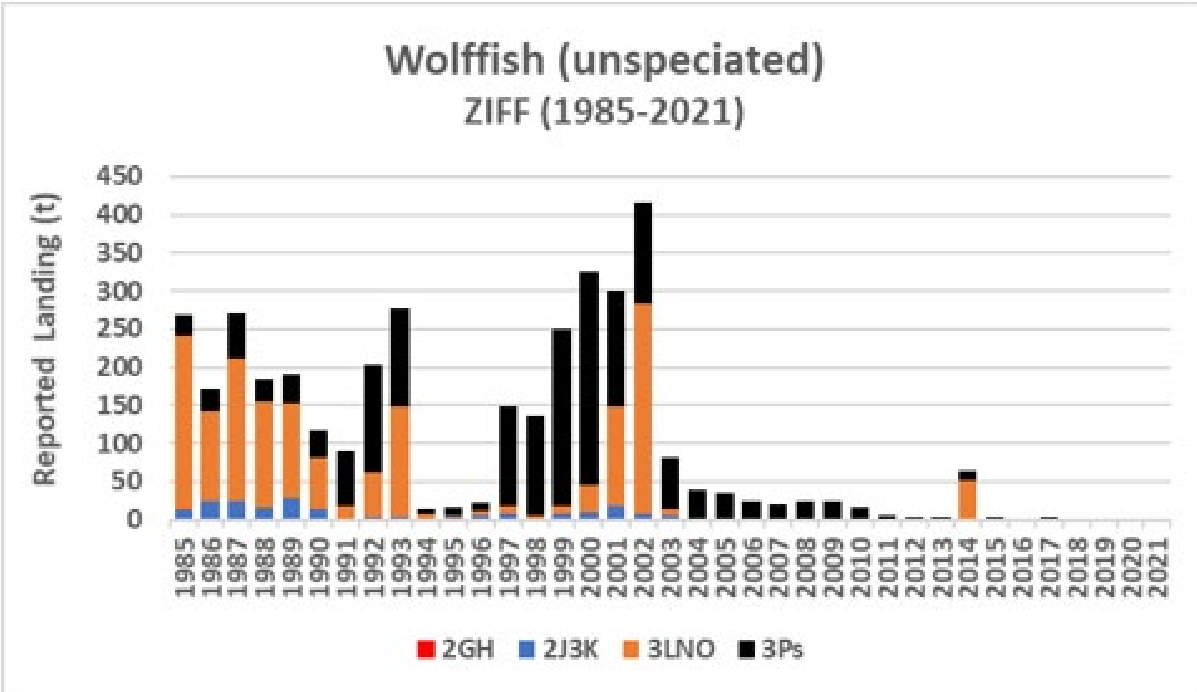


Figure 56. Reported landings of unspeciated wolffish from the NL Region ZIFF database (1985–2021).

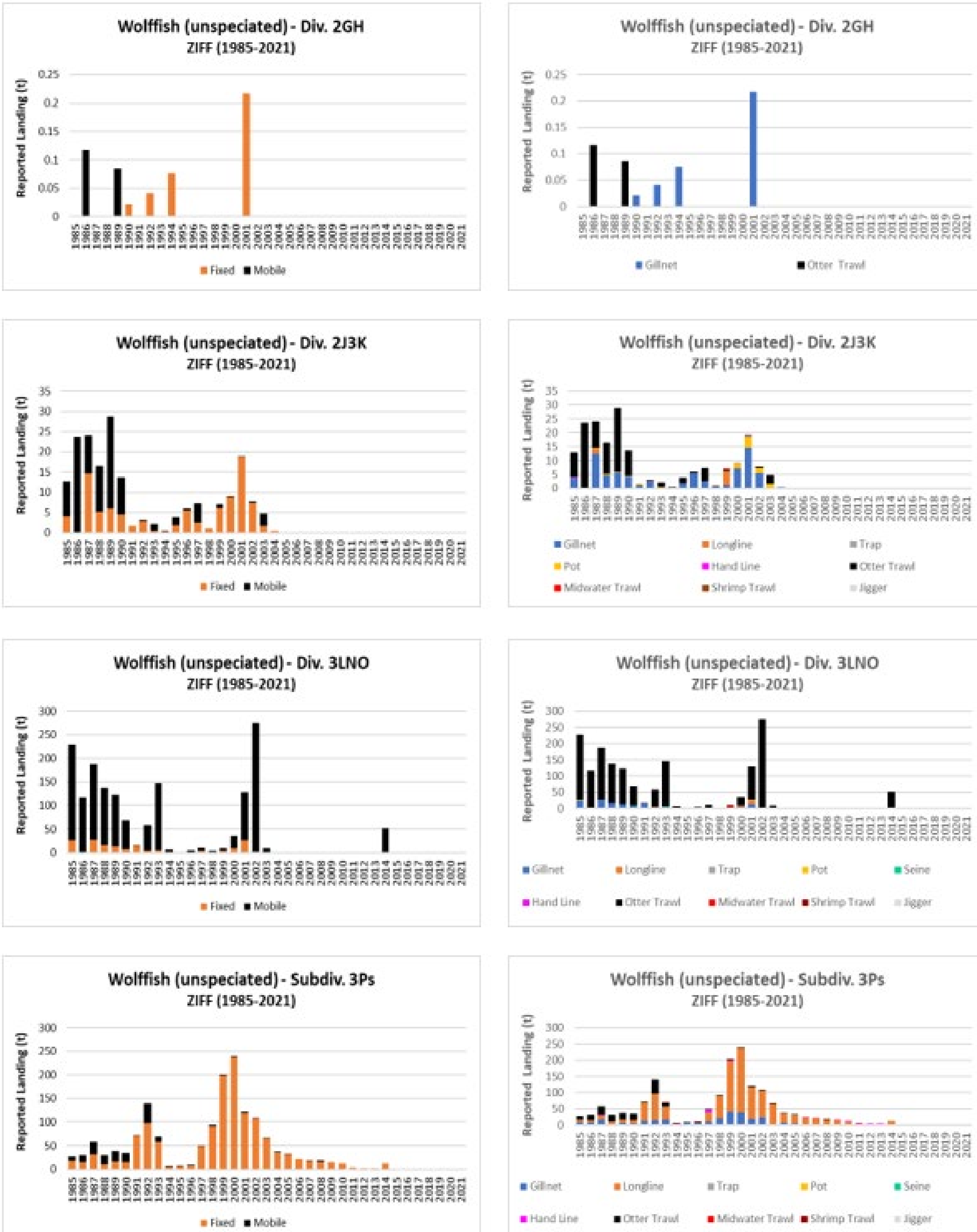


Figure 57. Reported landings of unspeciated wolffish from the ZIFF database (1985–2021) categorized by gear type.

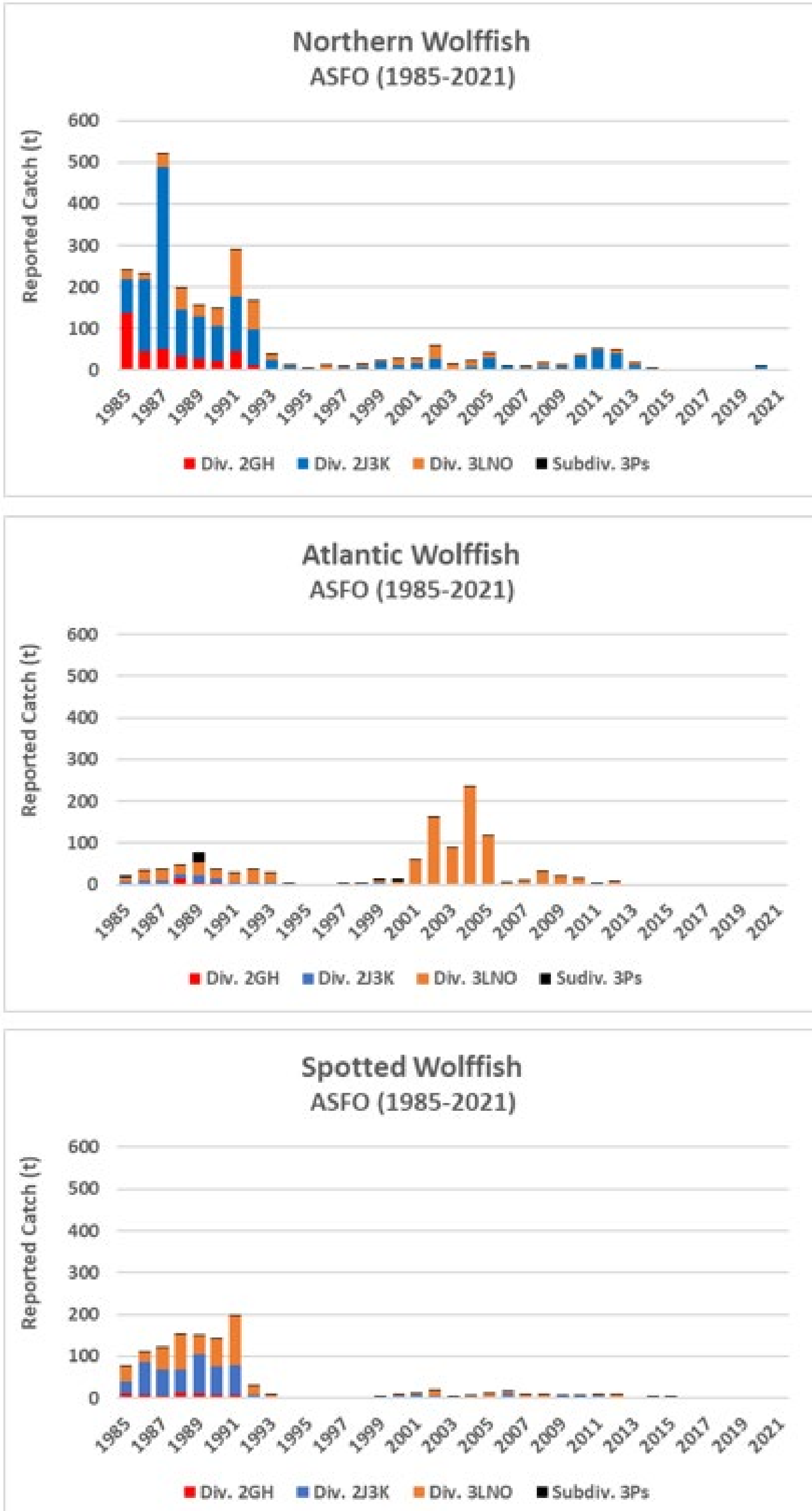


Figure 58. Reported catch of wolffish, by species, from the ASFO database (1985–2021). Data are not scaled by observer coverage.

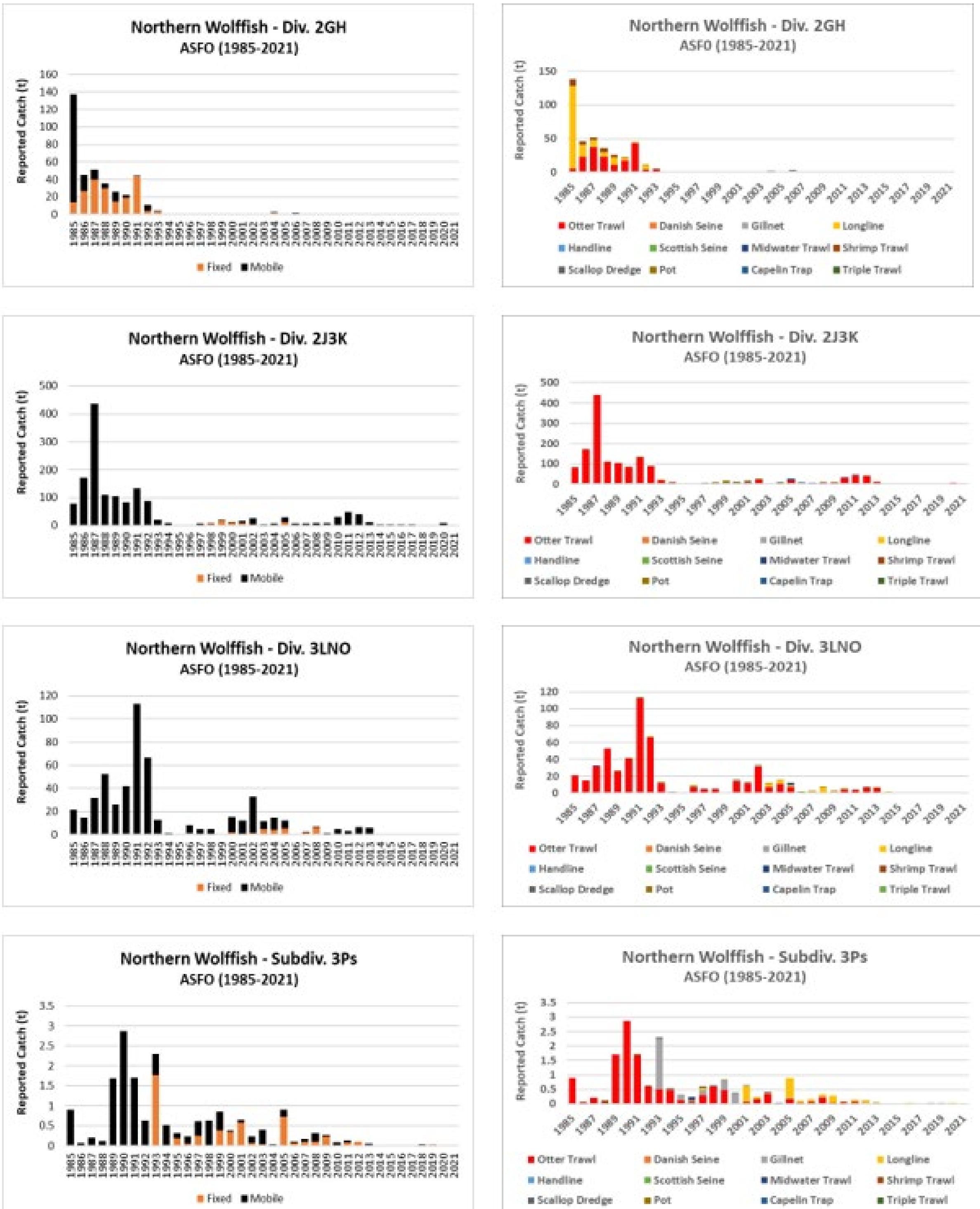


Figure 59. Reported catch of Northern Wolffish from the ASFO database (1985–2021) categorized by gear type. Data are not scaled by observer coverage.

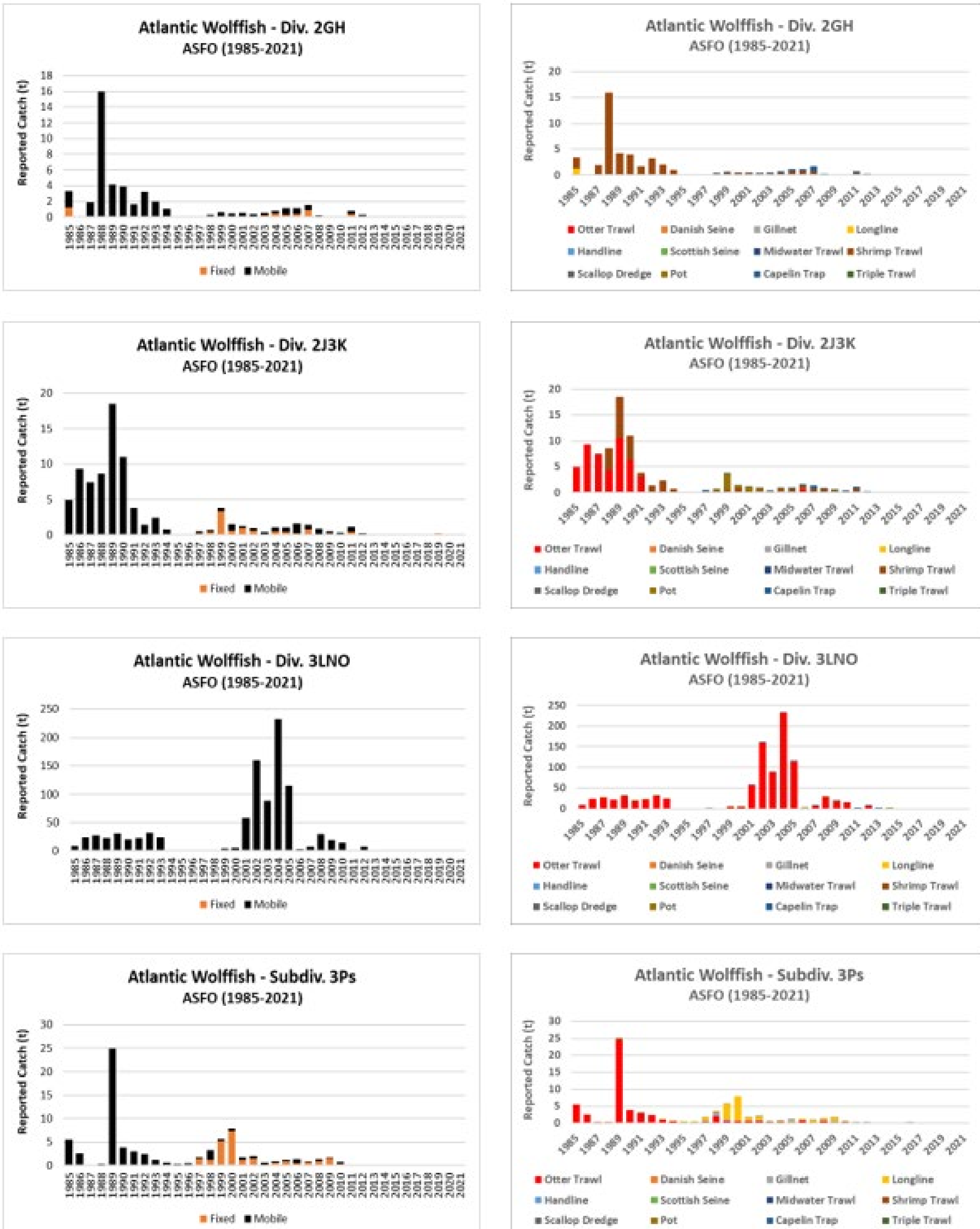


Figure 60. Reported catch of Atlantic Wolffish from the ASFO database (1985–2021) categorized by gear type. Data are not scaled by observer coverage.

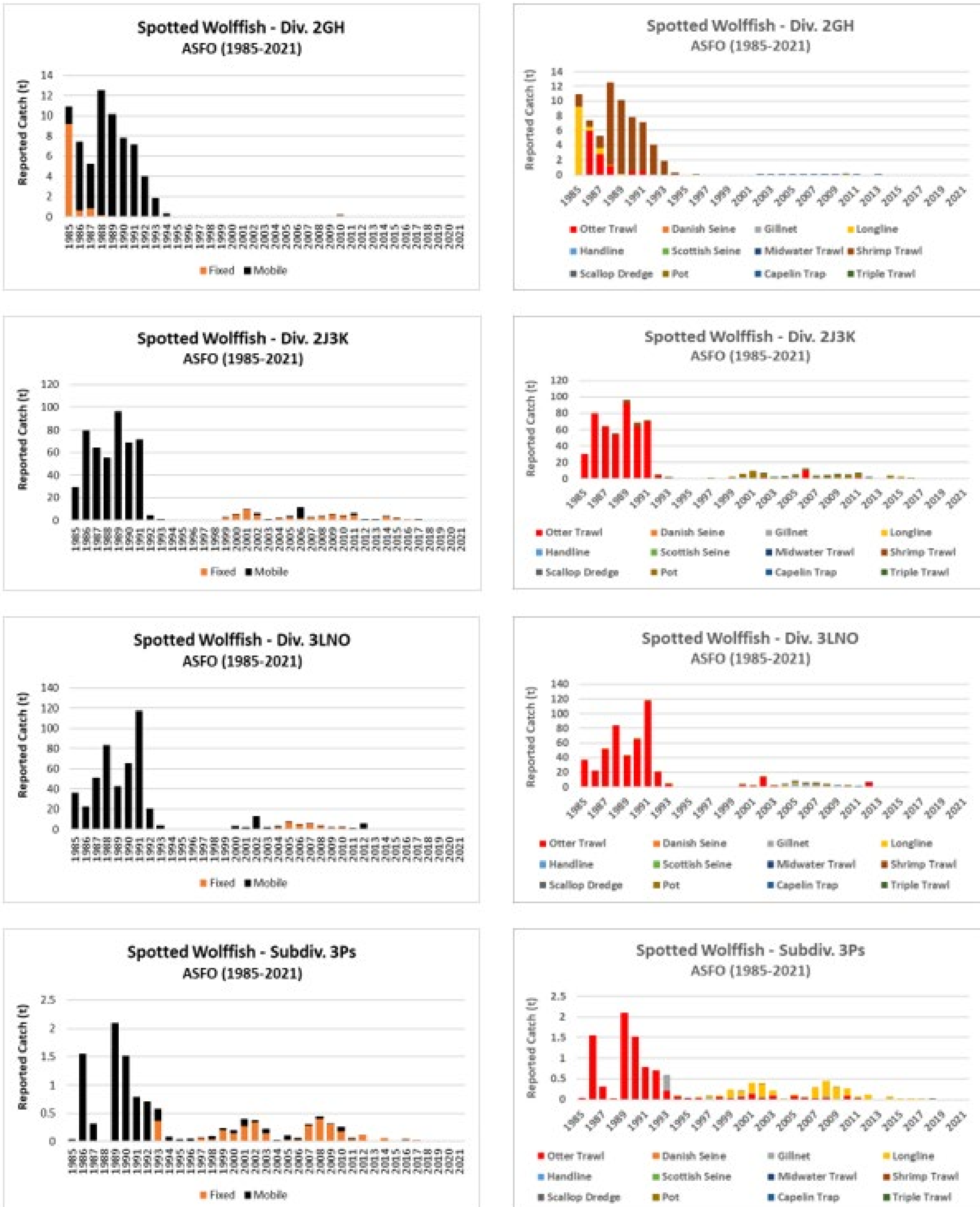


Figure 61. Reported catch of Spotted Wolffish from the ASFO database (1985–2021) categorized by gear type. Data are not scaled by observer coverage.

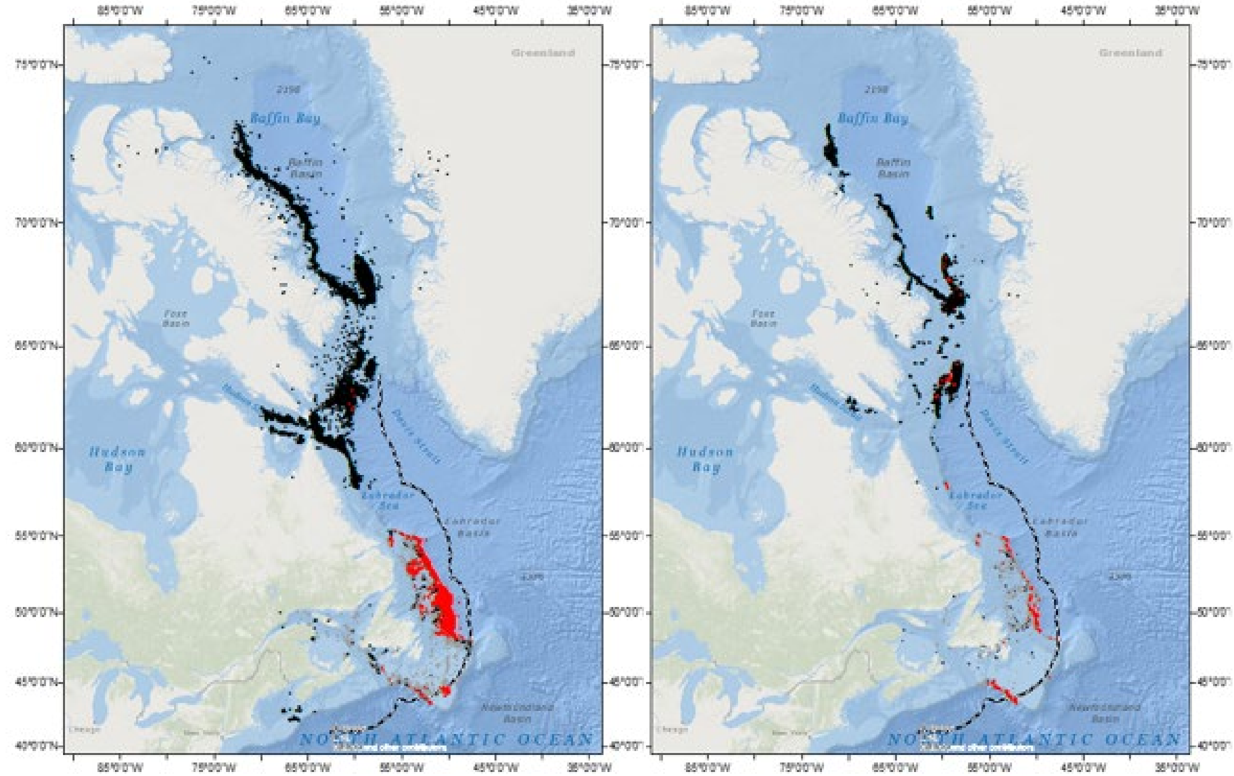


Figure 62. Distribution of catch (all fisheries) from the ASFO database (1985–2021) by mobile gears (left panel) and fixed gears (right panel) where Northern Wolffish were absent (black dots) or present (red dots).

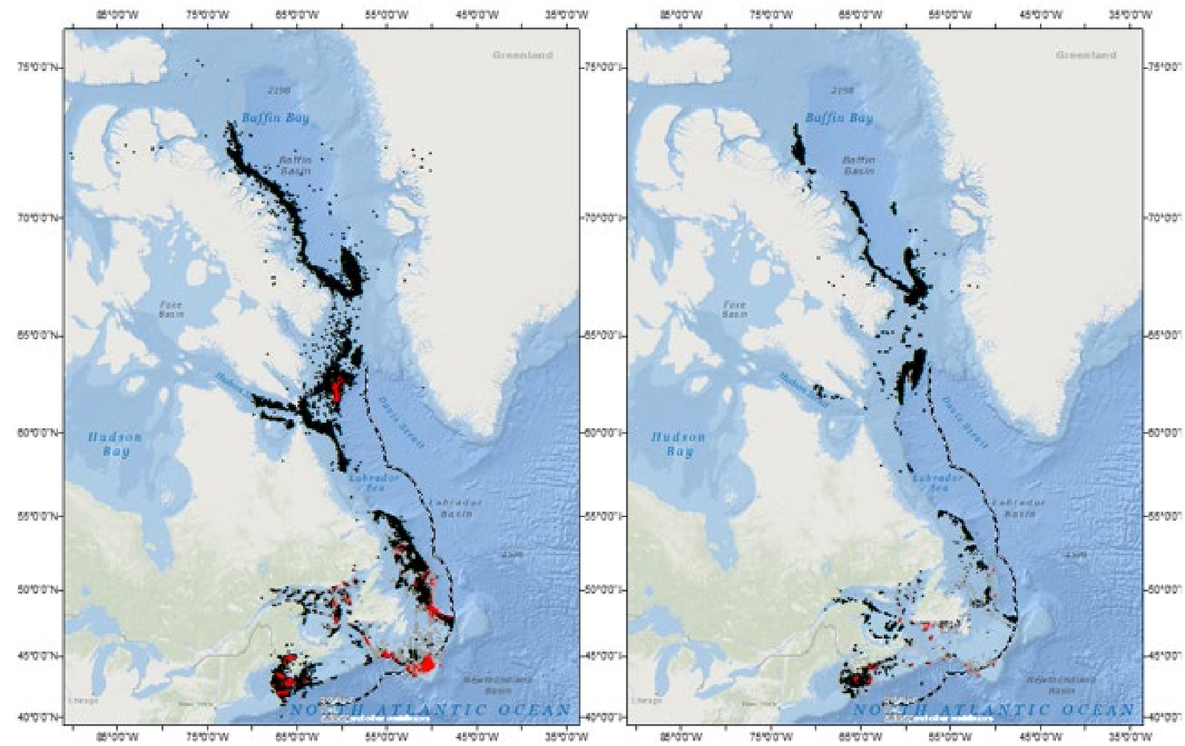


Figure 63. Distribution of catch (all fisheries) from the ASFO database (1985–2021) by mobile gears (left panel) and fixed gears (right panel) where Atlantic Wolffish were absent (black dots) or present (red dots).

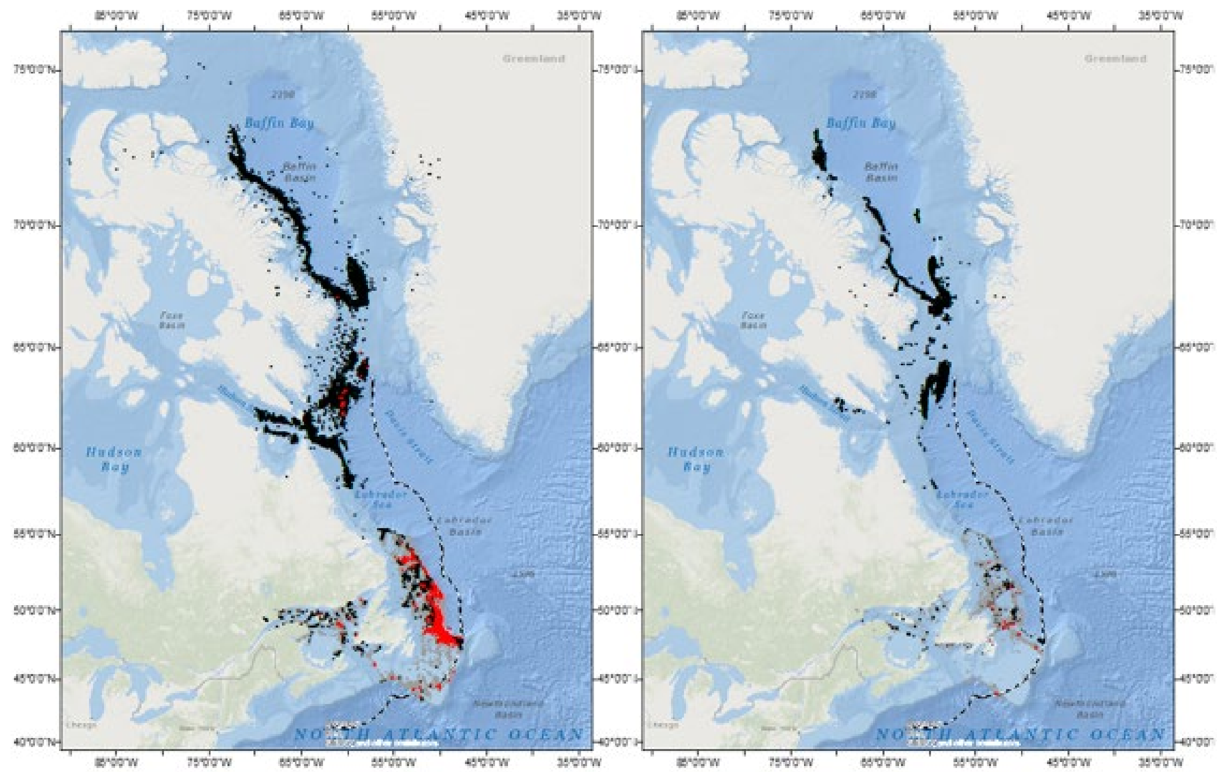


Figure 64. Distribution of catch (all fisheries) from the ASFO database (1985–2021) by mobile gears (left panel) and fixed gears (right panel) where Spotted Wolffish were absent (black dots) or present (red dots).

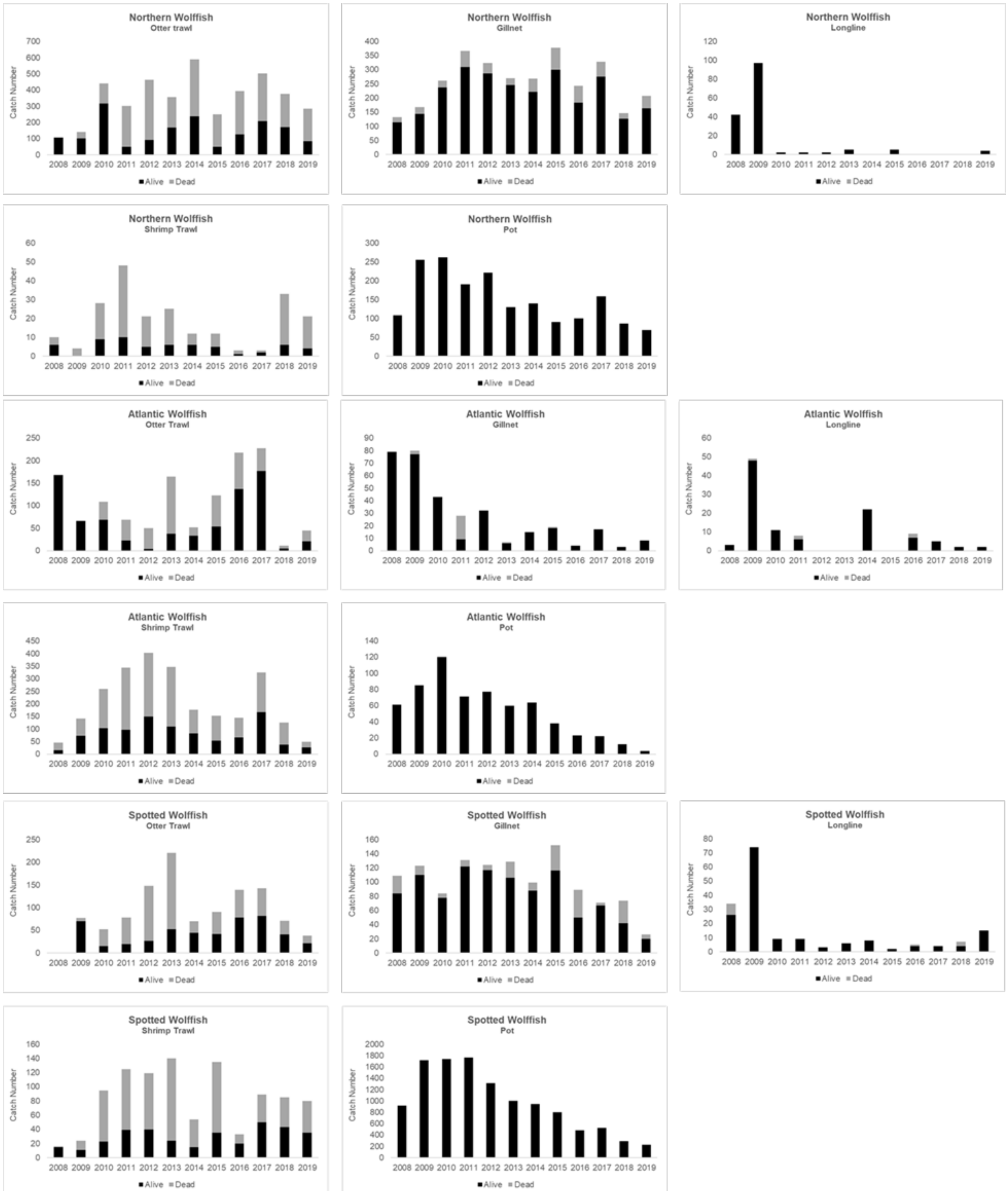


Figure 65. Reported catch and release of wolffish in the NL Region, by species and gear type, from the SARA logbooks (2008–19).

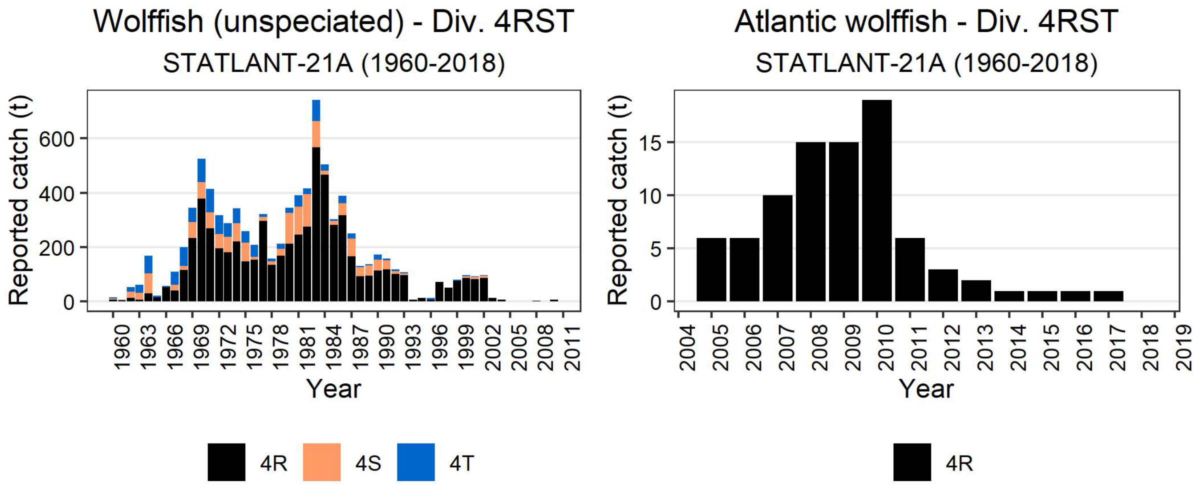


Figure 66. Reported catch of unspeciated wolffish and Atlantic Wolffish in the Gulf of St. Lawrence (Div. 4RST) from the NAFO STATLANT-21A database (1960–2018).

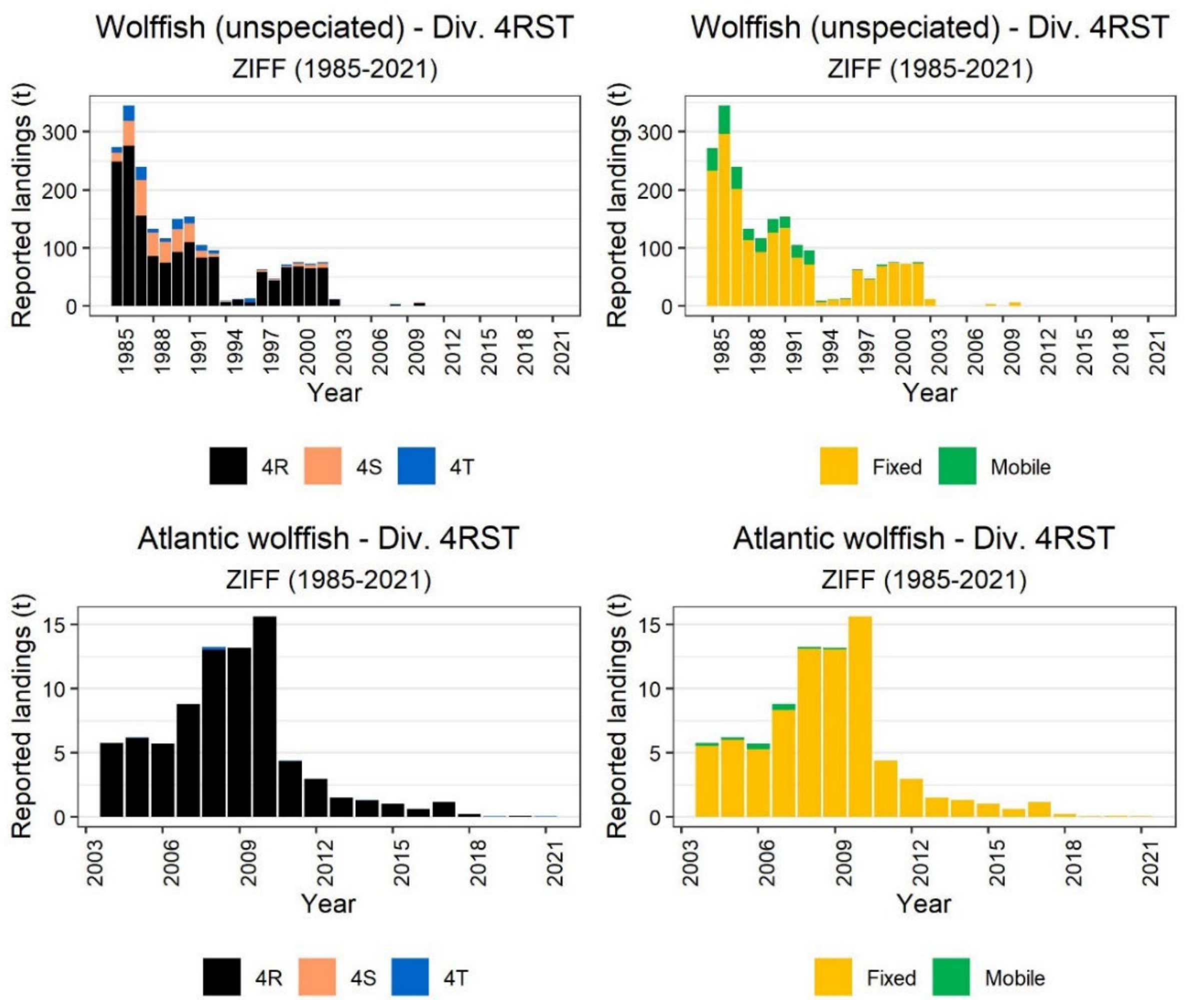


Figure 67. Total reported Canadian landings of unspeciated wolffish and Atlantic Wolffish in the Gulf of St. Lawrence (Div. 4RST) from the ZIFF database, categorized by NAFO Division and gear type.

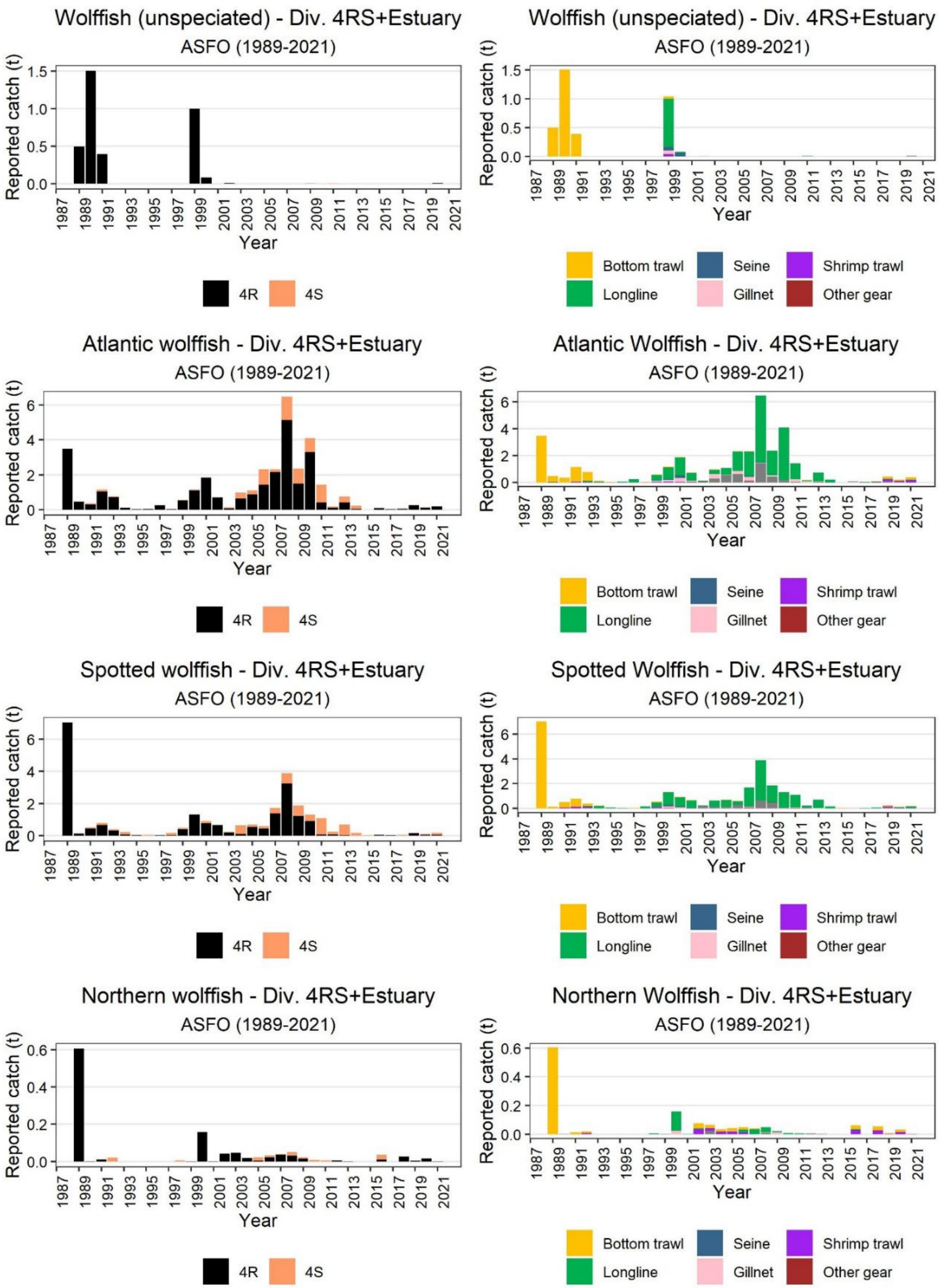
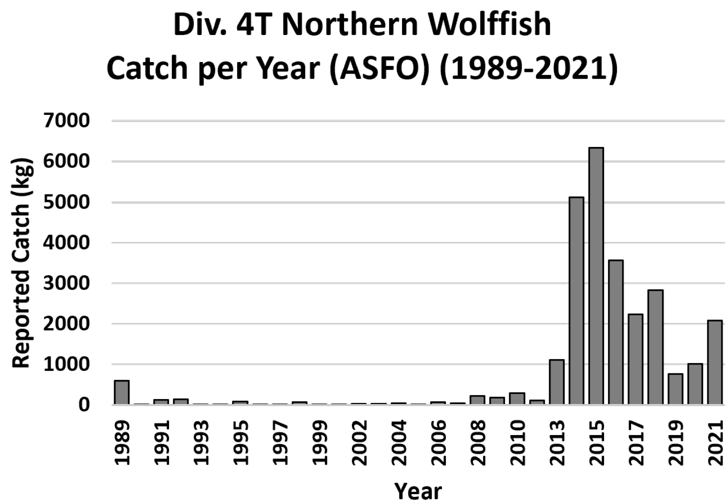
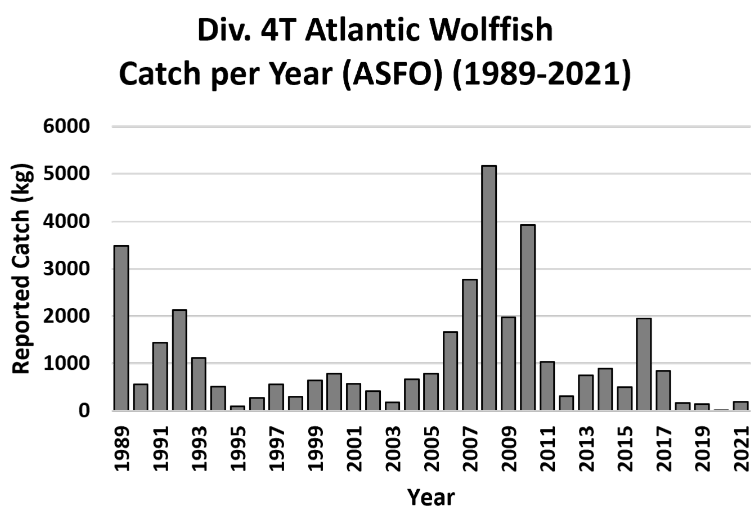


Figure 68. Total reported catch of unspeciated, Atlantic, Spotted and Northern Wolffish in the northern Gulf of St. Lawrence (Div. 4RS) from the ASFO database (1989–2021), categorized by NAFO Division and gear type.





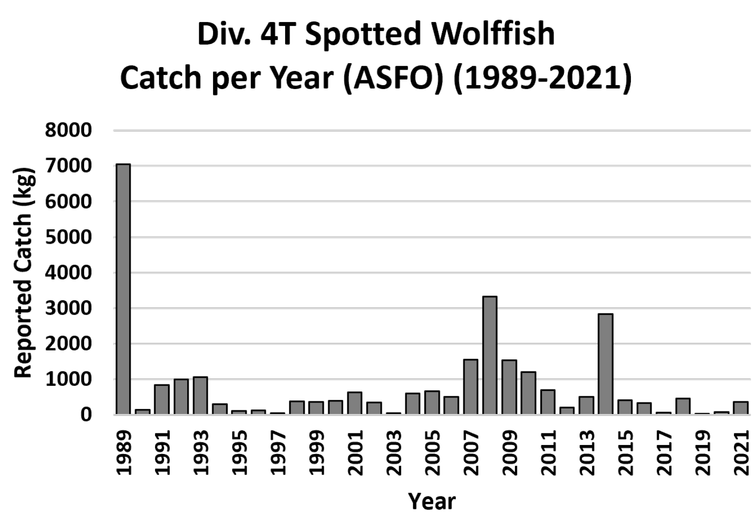


Figure 69. Reported catch of wolffish from the ASFO database for Div. 4T.

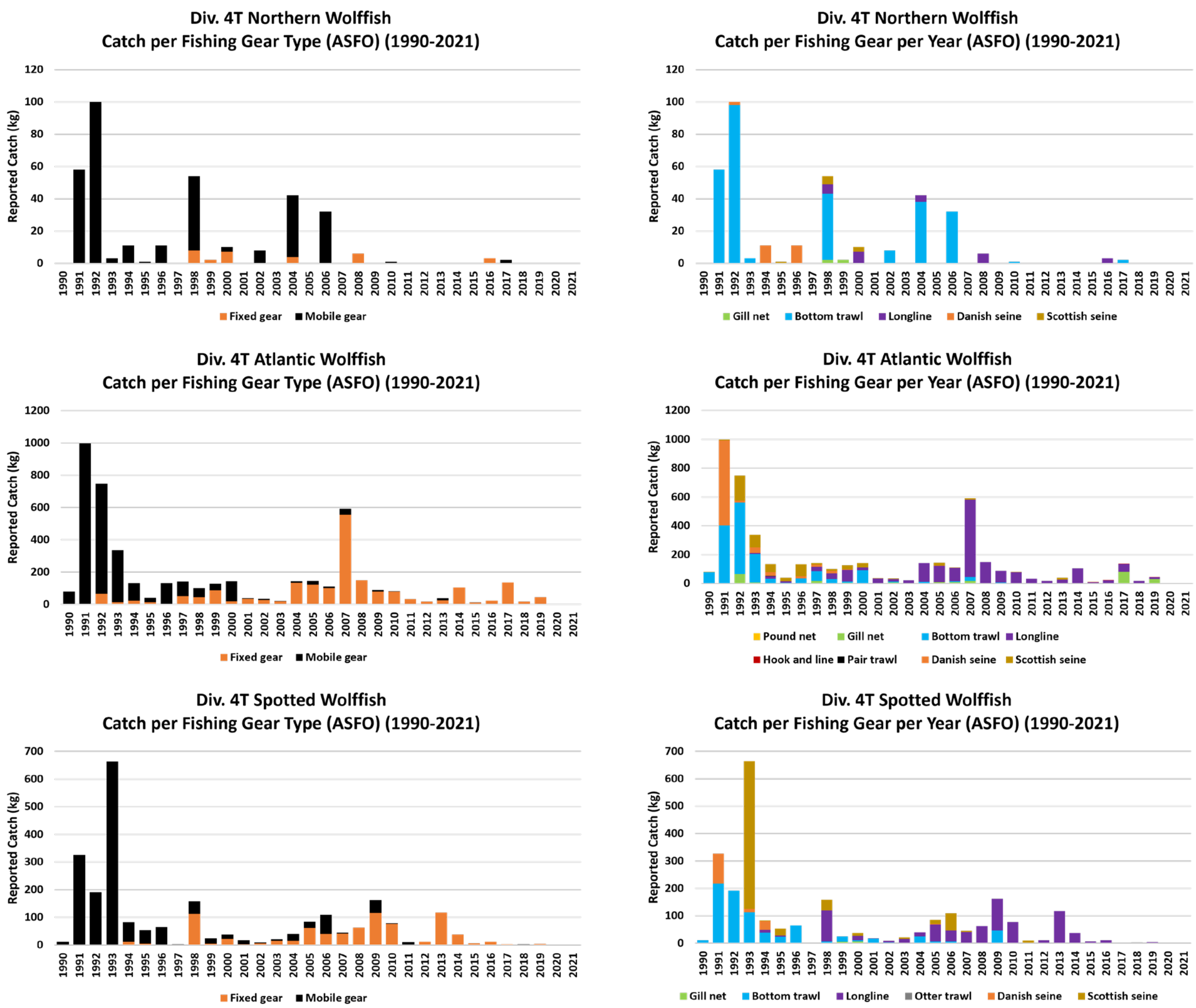


Figure 70. Reported catch of Northern Wolffish from the ASFO database for Div. 4T categorized by gear type.

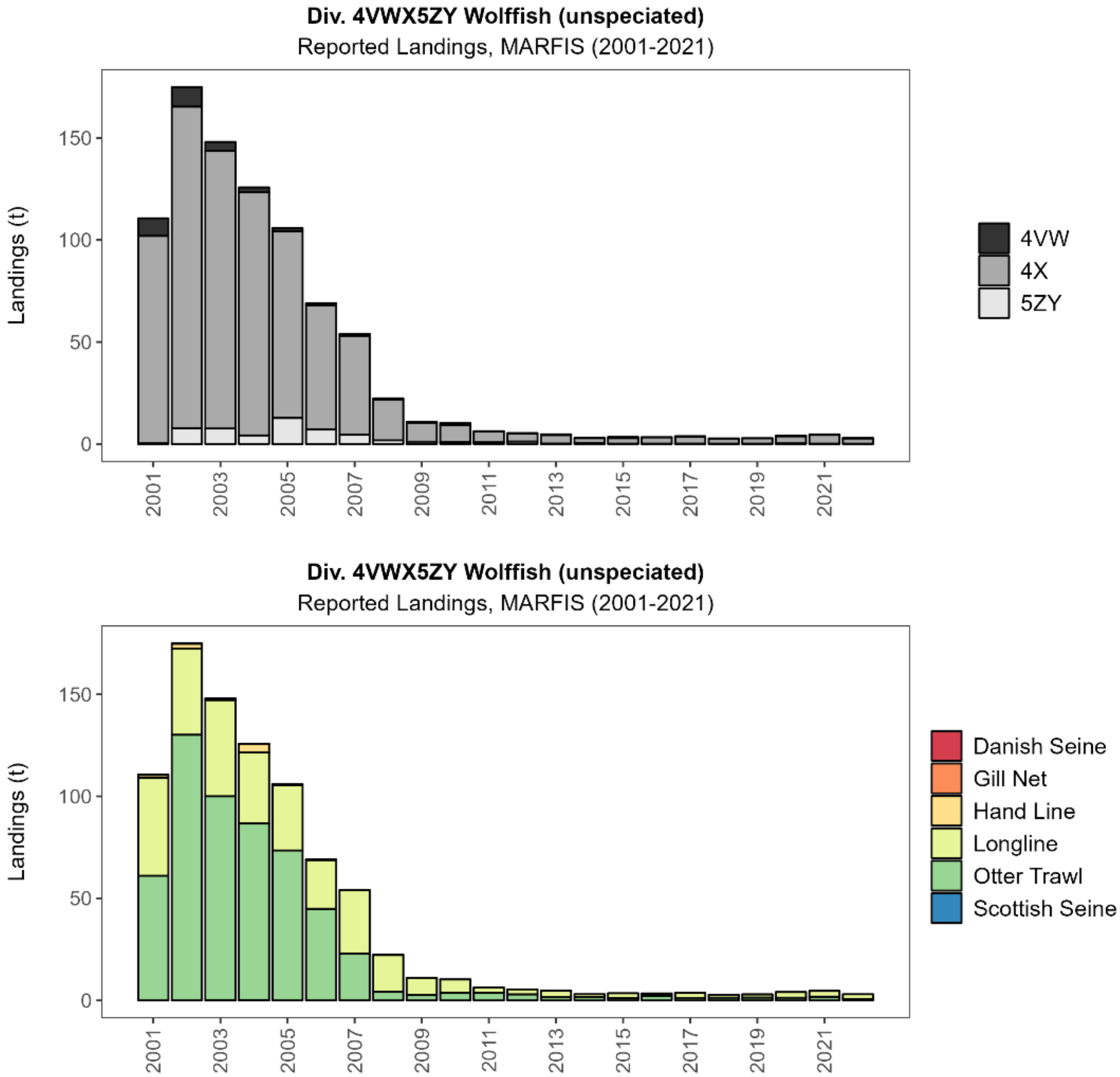


Figure 71. Commercial landings of wolffish (unspeciated) from Div. 4VWX5ZY categorized by NAFO area and gear type as reported from the MARFIS database (2001–22).

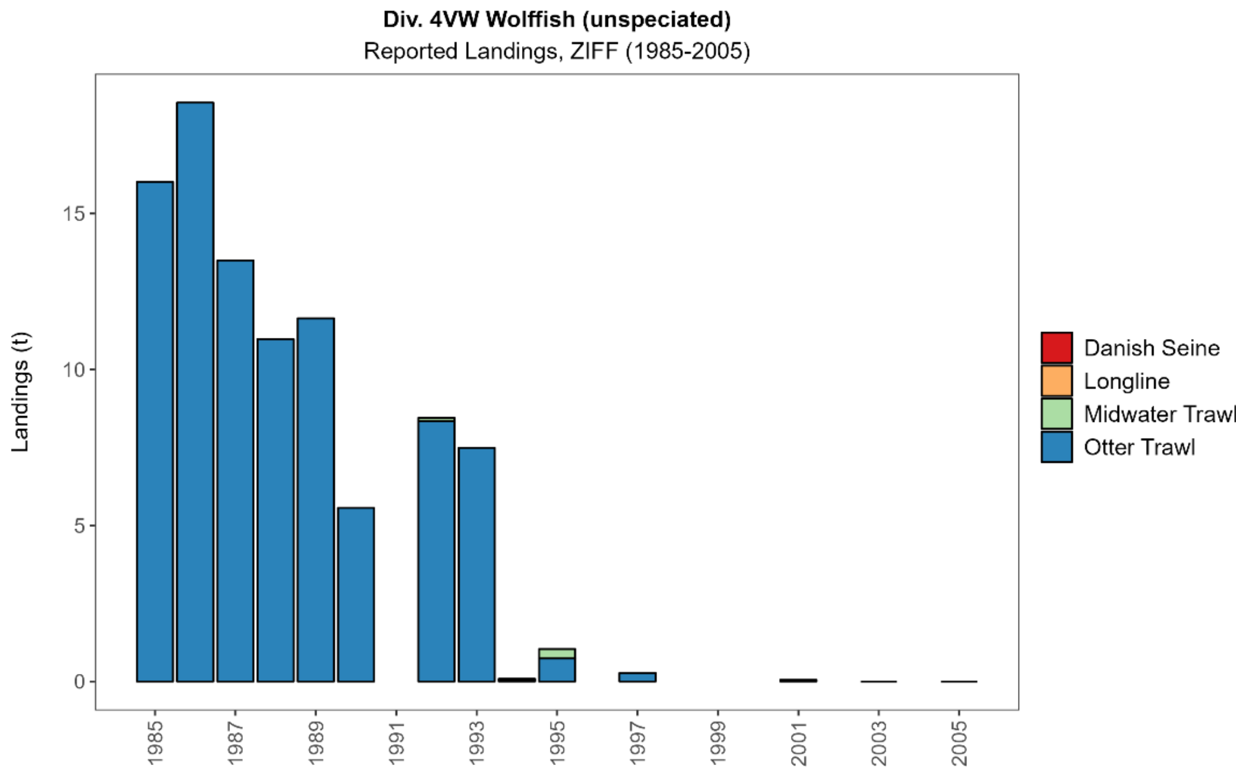


Figure 72. Commercial landings of wolffish (unspeciated) by gear type from Div. 4VW as reported from the ZIFF database (1985–2005).

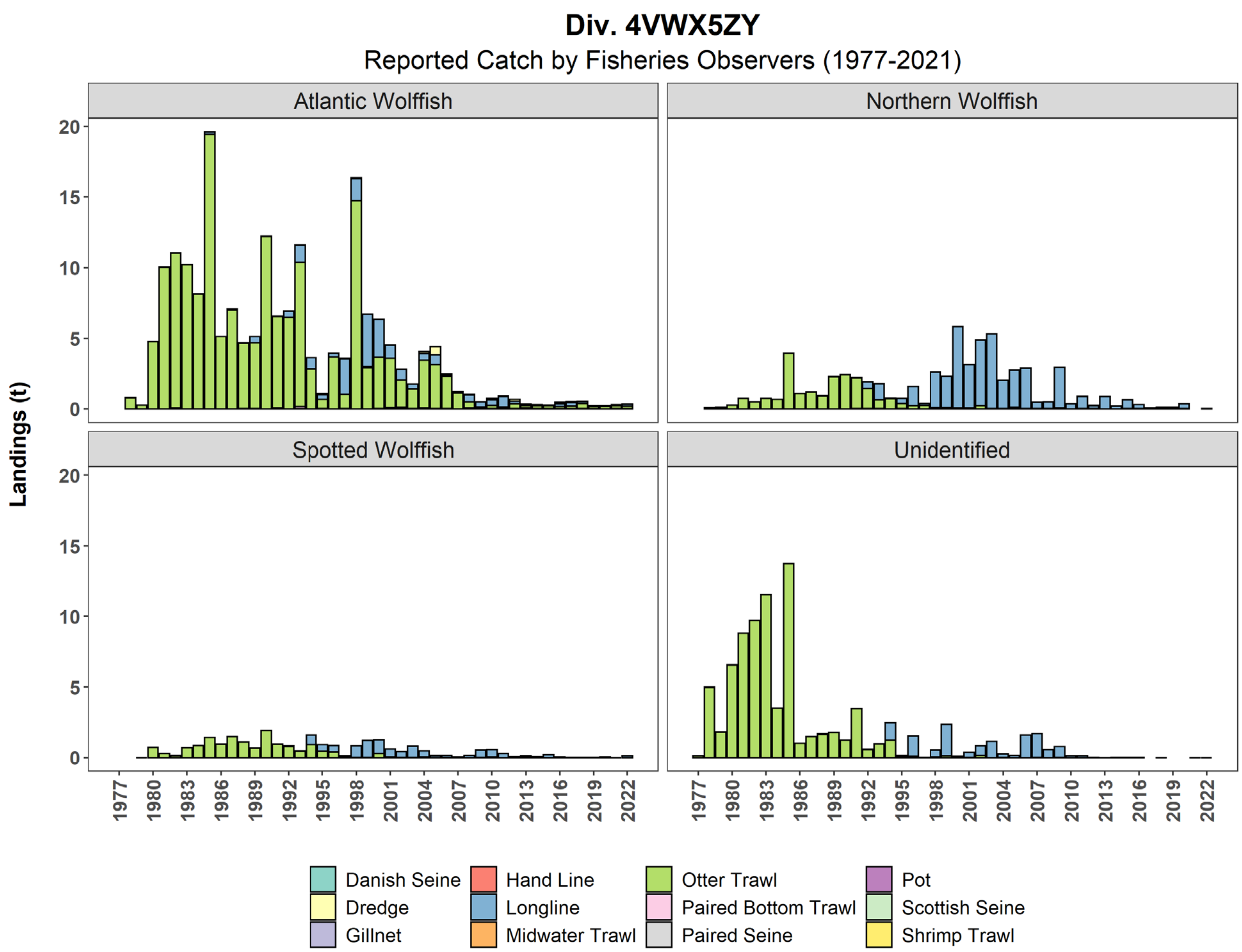


Figure 73. Cumulative catch (kept + discarded) of wolffish categorized by gear type from Div. 4VWX and 5ZY reported by Canadian ASFO, 1977–2022. Data are not scaled by observer coverage.

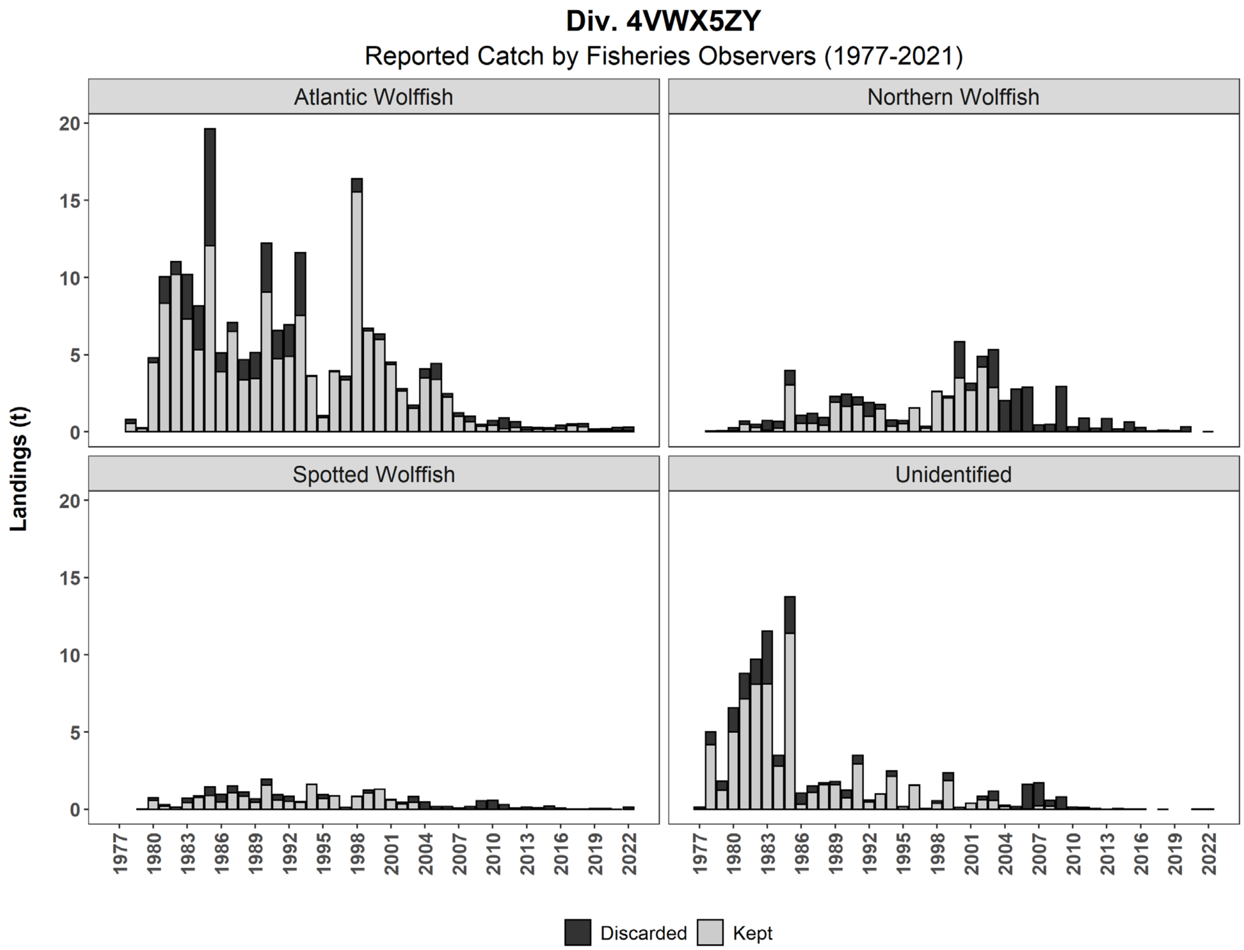


Figure 74. Proportion of kept vs. discarded wolffish catch from all commercial fisheries in Div. 4VWX and 5ZY reported by Canadian ASFO, 1977–2022. Data are not scaled by observer coverage.

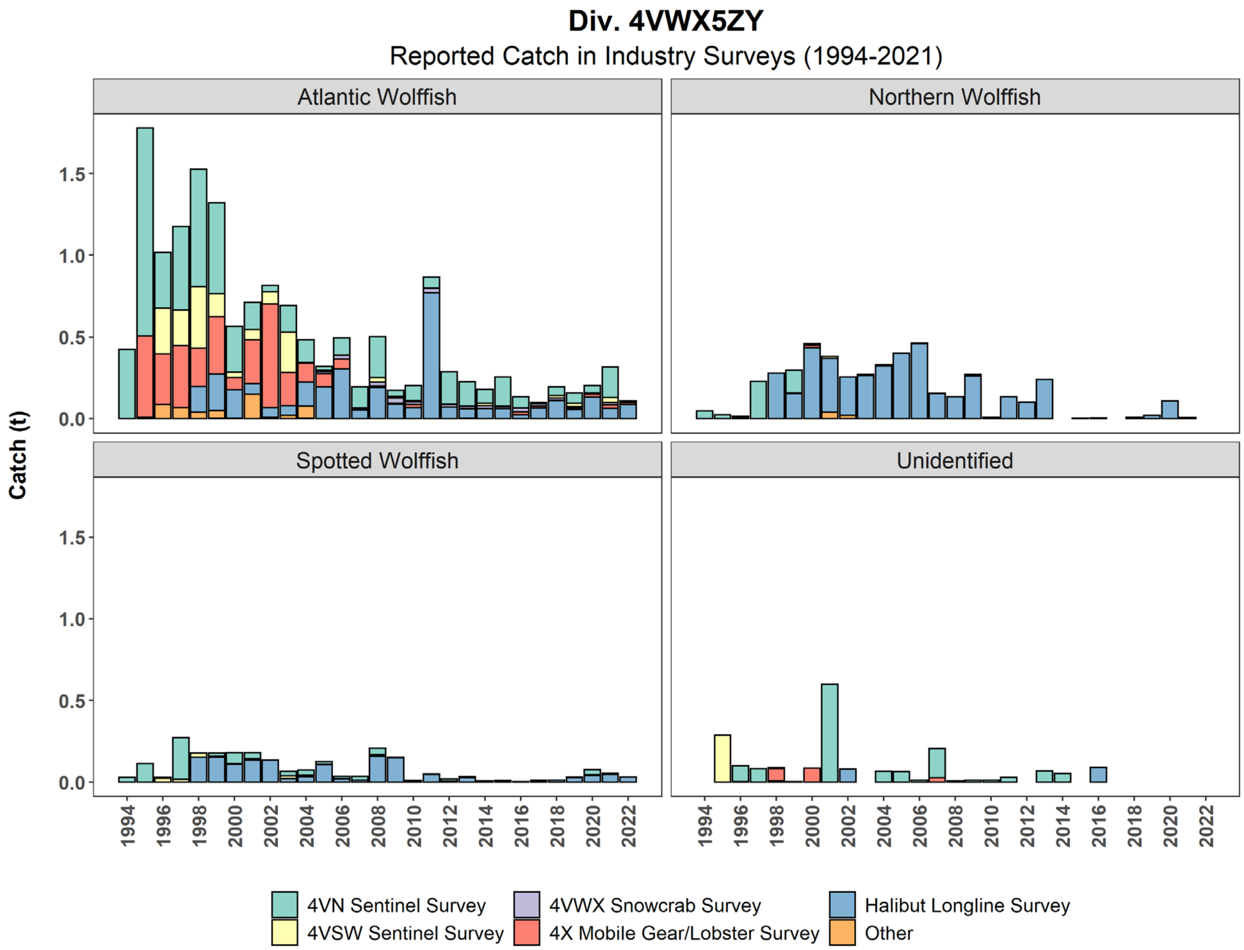


Figure 75. Cumulative catch of wolffish reported from DFO-fishing industry surveys in Div. 4VWX5Z, 1994–2022.

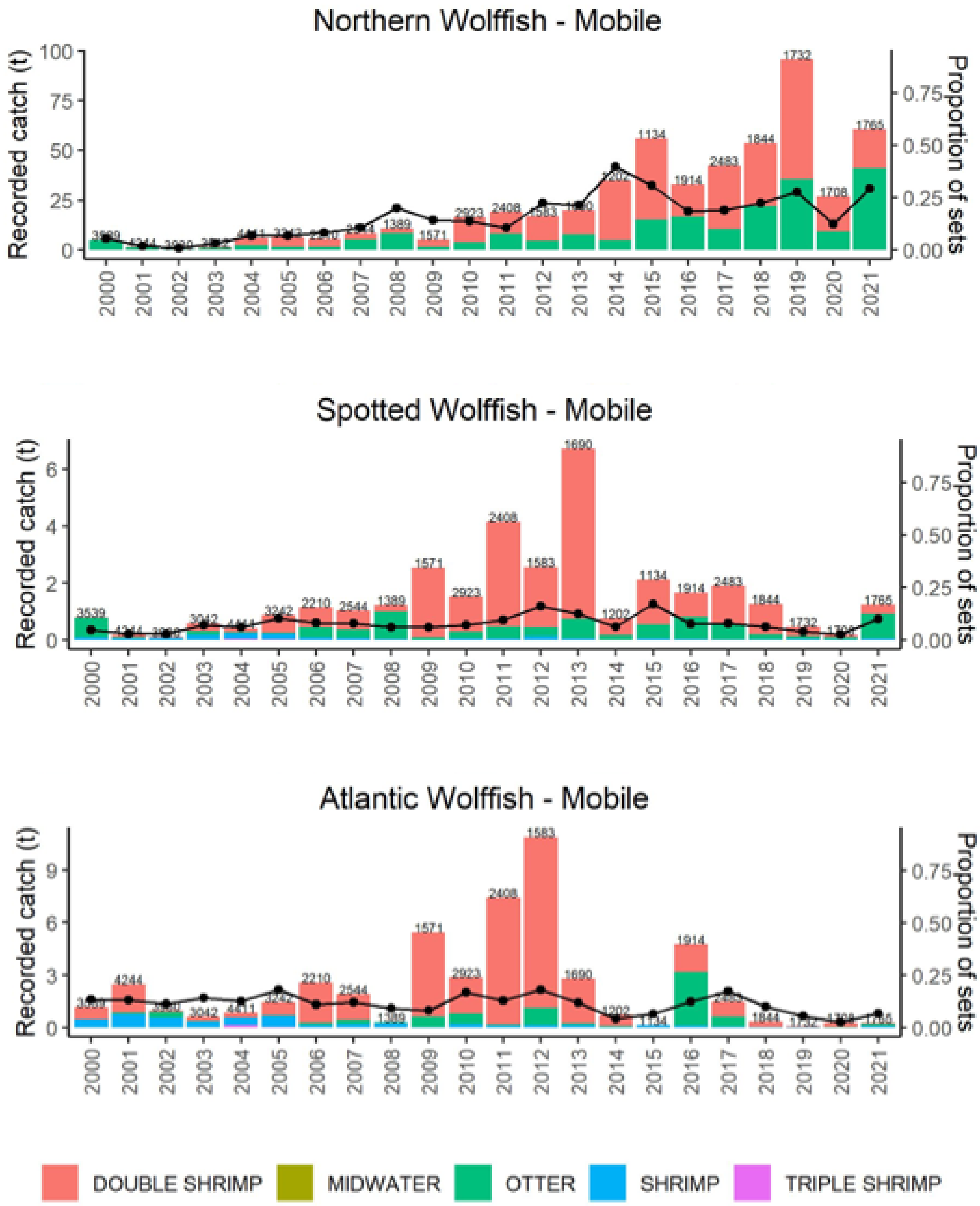


Figure 76. Recorded catch (t) of Northern, Spotted, and Atlantic Wolffish from the ASFO database from the mobile gear fishery in Div. 0AB. Data are not corrected for observer coverage. Black line indicates the proportion of sets where wolffish were observed with the number above each bar indicating the number of sets with observer data.