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A pre-COSEWIC assessment of three species of Wolffish (*Anarhichas denticulatus, A. minor,* and *A. lupus*) in Canadian waters of the Northwest Atlantic Ocean

Évaluation pré-COSEPAC de trois espèces de loups de mer (*Anarhichas denticulatus, A. minor,* et *A. lupus*) dans les eaux canadiennes du nord-ouest de l'Atlantique

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ABSTRACT

This paper presents the most recent information on the biology, trends in abundance and distribution, for the assessment of *Anarhichas denticulatus* (Northern Wolffish)*, A. minor* (Spotted Wolffish)*,* and *A. lupus* (Atlantic Wolffish) in Canadian waters of the Northwest Atlantic Ocean. The primary purpose of this paper is to provide this information to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for use in its evaluation of risk of extinction for each of these species; focussing on Canadian waters of the Northwest Atlantic Ocean. The results of this study indicate that the centre of distribution for all three Wolffish species is located in Newfoundland and Labrador waters, with the most persistent locations of high concentrations in the Northwest Atlantic Ocean found in areas adjacent to the northern Grand Bank (Northern Wolffish and Spotted Wolffish) and southern Grand Bank (Atlantic Wolffish); the three species are distributed from shallow (25 m) to deep waters (>1400 m) but are temperature seekers, tending to occupy the warmest available waters; considerable declines in indices of relative abundance and distribution occurred through the 1980s and early 1990s, but signs of recovery have been detected for all three species in the last decade. Recent increase in abundance indices for Atlantic Wolffish have also been detected in other geographic areas such as in the Gulf of St. Lawrence, Scotian Shelf and West Greenland.

RÉSUMÉ

Le présent document présente les données biologiques les plus récentes ainsi que les tendances sur le plan de l'abondance et de la répartition relativement à l'évaluation des espèces *Anarhichas denticulatus* (loup à tête large)*, A. minor* (loup de mer tacheté) et *A. lupus* (loup atlantique) dans les eaux canadiennes du nord-ouest de l'Atlantique. Ce document vise surtout à communiquer cette information au Comité sur la situation des espèces en péril au Canada (COSEPAC), qui s'en servira pour évaluer le risque de disparition de chacune de ces espèces, en particulier dans les eaux canadiennes du nord-ouest de l'Atlantique. Les résultats de notre étude indiquent que le centre de répartition de ces trois espèces de loup de mer se situe dans les eaux de Terre-Neuve et du Labrador, et que les foyers de concentration élevée les plus persistants dans le nord-ouest de l'océan Atlantique se trouvent dans les zones adjacentes aux secteurs nord (loup à tête large et loup de mer tacheté) et sud (loup atlantique) du Grand Banc; la répartition de ces trois espèces s'étend des eaux peu profondes (25 m) à profondes (>1 400 m), et ces poissons sont sensibles à la température et ont tendance à occuper les eaux les plus chaudes possible; on a constaté de fortes baisses des indices d'abondance et de répartition relative durant les années 1980 et au début des années 1990, mais on a détecté des signes de rétablissement de ces trois espèces au cours de la dernière décennie. Une hausse des indices d'abondance chez le loup atlantique a également été détectée récemment dans d'autres secteurs géographiques, par exemple le golfe du Saint-Laurent, le plateau néo-écossais et l'ouest du plateau du Groenland.

INTRODUCTION

Wolffish (family Anarhichadidae) inhabit a wide range of northern latitudes and depths in the Atlantic and Pacific Oceans (Scott and Scott 1988). They are named for their large jaws and canine-like teeth used to crush various invertebrate prey (Albikovskaya 1982; Rodriguez-Marin et al. 1994). The family is sometimes referred to as "catfish", particularly by the fishing industry.

Three Wolffish species are found in Canadian Atlantic waters: *Anarhichas denticulatus* (Northern or broadhead Wolffish), *A. minor* (Spotted Wolffish), and *A. lupus* (Atlantic or striped Wolffish). The first two species were designated "threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) under Canada's Species at Risk Act (SARA) in 2001, whereas Atlantic Wolffish was designated "of special concern" (Kulka et al. 2004*a*). The main reasons for listing Wolffish as species at risk included greater than 90 % declines in abundance indices over 2-3 generations (1980s-90s), concurrent with substantial reductions in extent of distribution. Threats due to potential bycatch removals in several commercial fisheries and habitat alteration caused by bottom trawling, in addition to particular life traits (e.g., low fecundity and growth rates, late maturity), further increased the likelihood of these species being at risk of extinction in Canadian waters.

In response to COSEWIC's concerns, the Department of Fisheries and Oceans Canada developed a recovery strategy for Northern and Spotted Wolffish, and a management plan for Atlantic Wolffish (Kulka et al. 2008). However, many of the key aspects of Wolffish biology and population dynamics remain only partially understood. Wolffish tend to be found in low densities, have low mobility, and a generally solitary life style. In addition, they have broad geographic and depth distributions, inhabiting most of the continental shelves in eastern Canada and northeast USA at depths of 10 m-1500+ m (Templeman 1984; Kulka et al. 2004*b*, 2008; Anon. 2009; Dutil et al. 2010).

This paper presents the most recent information available on the biology, trends in abundance and distribution, and other information on these three species of Wolffish for use in formulating appropriate conservation and management strategies in terms of extinction risk. The primary purpose of this paper is to provide this information to COSEWIC for use in its evaluation of risk of extinction for each of these species; focussing on Canadian waters of the Northwest Atlantic Ocean.

LIFE HISTORY CHARACTERISTICS

In the Northeast Atlantic, all three species of Wolffish are distributed from Iceland to the Barents Sea (Barsukov 1959; Baranenkova et al. 1960) and off Southern Greenland (Möller and Rätz 1999; Stransky 2001), the latter contiguous with Canadian waters. Wolffish distribution in the Northwest Atlantic extends from Davis Strait and Northern Labrador to the Southern Grand Bank and Flemish Cap (Albikovskaya 1982; Kulka and DeBlois 1996; Kulka et al. 2004*b*). McRuer et al. (2000) noted that Atlantic Wolffish is also common in the deeper parts of the Gulf of St. Lawrence, on the Scotian Shelf, in the Gulf of Maine, and in the Bay of Fundy. The other two species are only occasionally observed in these areas. All three species extend into USA waters (Musick 1999), but there they are uncommon (Atlantic Wolffish) or rare (Northern and Spotted Wolffish).
Most of the historic knowledge on Wolffish biology and distribution for the Northwest Atlantic is derived from papers published in the 1980s (Templeman 1984, 1985, 1986*a*,

1986*b*). More recent work on population status and habitat association in the NL Region (Labrador Shelf to the Grand Bank) was done by Simpson and Kulka (2002) and Kulka et al. (2004*b*). However, critical habitats for the three species (e.g., spawning grounds, nursery and feeding areas) remain unidentified in Canadian waters.

Wolffish are large demersal fish with maximum reported total length (TL) between 150 cm (Atlantic Wolffish) and 180 cm (Spotted and Northern Wolffish). Reproduction is characterized by internal fertilization with unusually large egg size, and prolonged incubation period. Of the three Wolffish species, Atlantic Wolffish is the most commonly found in coastal shallow waters through visual observation (SCUBA diving and underwater ROV), and as bycatch in inshore fisheries (Keats et al. 1985; Pavlov and Novikov 1993; Kulka and Simpson 2004; Larocque et al. 2008). It is believed that mature Atlantic Wolffish move from offshore waters and undergo inshore spawning migrations in spring and summer (Jonsson 1982; Nelson and Ross 1992; Pavlov and Novikov 1993). During late summer and fall, egg clusters have been observed on boulders and rocky crevices at depths <40 m, and were often cared for by the male spawner (Kulka et al. 2008; Larocque et al. 2008). Spawning behaviour and site characteristics are unknown for Northern and Spotted Wolffish.

Atlantic Wolffish reach maturity by age 5 or 6 years or approximately 60 cm TL (Templeman 1986*b*). In Newfoundland waters, fish mature at smaller sizes in northern areas when compared to faster growing fish from more southern areas. Length at 50 % maturity (L_{50}) was estimated as 51.4 cm in northern areas, 61 cm in intermediate areas, and 68.2 cm in southern areas. Atlantic Wolffish has the lowest fecundity of the three Wolffish species. Fecundity is size and body mass dependent, and increases exponentially with length. Mean fecundity estimates in Newfoundland waters, combined from several NAFO statistical areas, range from 2,440 eggs at 40 cm to 35,320 eggs at 120 cm.

Spotted Wolffish reach maturity by age five or six years when they attain approximately 75-80 cm TL (Templeman 1986*a*). Fish off of west Greenland and on the Flemish Cap appear to mature at smaller sizes than faster growing fish from southern Newfoundland waters. Spawning is reported to occur during July-August, and fecundity estimates from limited sample range from 5,080 eggs at 65 cm to 19,760 eggs at 91 cm (*ibid.*).

Northern Wolffish also reach maturity at age 5-6 years, but in this case the length at 50 % maturity is reported to be approximately 54 cm. No information is available on spawning time or fecundity in Newfoundland and Labrador waters, but Barsukov (1959) reported low fecundity for Northern Wolffish in the Barents Sea, (23,380-23,485 eggs at 112-134 cm).

Diet and feeding habit studies of the three Wolffish species coexisting in Newfoundland and Labrador waters are currently being conducted (DFO-Science, St. John's, NL, Canada), but preliminary results indicate that Atlantic and Spotted Wolffish diets are composed mainly of crabs and echinoderms, and Shrimp and echinoderms, respectively; whereas Northern Wolffish feed mainly on gelatinous zooplankton, and pelagic and benthic fish (hence the different shape and size of teeth in the latter as compared to those of the other Wolffish species).

Although the three Wolffish species are widespread in Canadian waters, their stock structure have not yet been defined. Preliminary univariate and multivariate

morphological and meristics analyses of up to 20 measured characters in 1400 specimens (three species combined) indicated no discrete spatial patterns; thus providing no further insight into Designatable Unit (DU) specification. Johnstone et al. (2007) and Carr et al. (2008) have determined the complete mitochondrial DNA (mtDNA) genome sequences of the three species, and identified the most variable gene regions for population analysis; comprising a first step in defining genetic differentiation.

MATERIALS AND METHODS

SURVEYS

NL Region

Data used in this study were obtained during multi-species bottom trawl surveys conducted throughout the continental shelves of Newfoundland and Labrador (NAFO Div. 2GHJ3KLMNOPs) in spring (1971-2011) and fall (1977-2011); including areas beyond the Canadian EEZ (Fig. 1). The surveys employed a random stratified design based on depth intervals and location (latitude and longitude) and are designed to provide information on abundance, distribution and area occupied by several demersal and benthic fish and invertebrate species. A summary of the survey design employed in the NL Region can be found in Doubleday (1981).

Spring surveys of the Grand Bank (Div. 3LNO) commenced in 1971 with the inclusion of Subdiv. 3Ps (containing St. Pierre Bank) since 1972; fall surveys in NAFO Div. 2J3K were conducted by RV *Gadus Atlantica* between 1977 and 1994 (Table 1). Moreover, fall surveys of the northern Grand Bank (Div. 3L) began in 1981, adding the southern Grand Bank (Div. 3NO) in 1990. The St. Pierre Bank was not surveyed in the fall. Surveys were conducted mainly by CCGS *Teleost* in 1995-2000, although CCGS *Wilfred Templeman* surveyed part of Div. 3K. In Div. 3L, surveys were conducted by RV *A.T. Cameron* (1971-82 in spring) and CCGS *Wilfred Templeman* or its sister ship CCGS *Alfred Needler* (1985-2000 in spring; 1983-2000 in fall). In recent years, CCGS *Teleost* surveyed a portion of Div. 3L. The fall survey was also extended into Div. 3NO in 1990 using CCGS *Wilfred Templeman*. Prior to 1971, surveys were conducted by RV *Marinus* and *Investigator II*, as well as RV *A.T. Cameron* (1946-70). The latter surveys consisted of fixed fishing stations along line transects on the Grand Bank and St. Pierre Bank (Div. 3LNOPs).

Several demersal fishing gears have also been deployed over the lifetime of the spring and fall surveys (Table 1): Yankee 41.5 bottom trawl, spring surveys until 1982; Engel 145 Hi-lift, fall surveys in 1977-94, and spring surveys in 1983-95; Campelen 1800 Shrimp trawl, fall of 1995 and spring 1996 to present. While survey design has remained constant, additional strata were included in recent years, along with modifications to some of the original strata (Bishop 1994). One recent substantial change in the surveys was the addition of shallower (<50 m) and deeper strata (>700 m) after 1993; even though tows at depths <50 m were occasionally recorded in earlier years. It should be noted that no conversion factors exist between gears for Wolffish species; therefore each time series should be considered independently. A thorough description of DFO-NL Region surveys can be found in Kulka et al. (2006).

In addition, stratified random juvenile groundfish surveys were conducted in Div. 3LNO in 1985-94 using a Yankee 41 Shrimp trawl, as well as near-surface trawl surveys for young gadoid fish (International Young Gadoid Pelagic Trawl or IYGPT) were conducted during August-September (1996-2000) in Div. 2J3KLNO (Dalley and Anderson 1998). Both survey series comprise the only available indices of young Wolffish relative abundance (three species) and distribution (Atlantic Wolffish only).

Central and Arctic Region

Depth-stratified random surveys covering depths from 400 m to 1500 m were conducted by DFO with an Alfredo III bottom trawl in NAFO Subarea 0A (1999, 2001, 2004, 2006, 2008), Subarea 0B (2000, 2001), Shrimp Fishing Area (SFA) 1 (2007, 2009), and SFAs 2 and 3 (2005-09). Subarea 1 and parts of Subarea 2 are outside of Canada's 200-mile limit. The 2006 and 2008 surveys included tows in shallower strata (100-800 m) using a Cosmos Shrimp trawl. These surveys were conducted by DFO in collaboration with Nunavut partners and the Greenland Institute of Natural Resources. Surveys were carried out on the Greenlandic RV *Paamiut*.

Other Surveys of Interest

Additional independent scientific surveys were conducted by other countries within or adjacent to the study area often using the same stratification scheme as applied by Canada. Waters adjacent to the Canadian EEZ were surveyed by Spain (Instituto Español de Oceanografía, Far Fishery Program Communication), covering the "Nose" and "Tail" of the Grand Bank in Div. 3LNO (Román et al. 2010; González-Troncoso et al. 2010), and the Flemish Cap in Div. 3M (Pérez-Rodriguez and Koen-Alonso 2010). Surveys from 1997 to 2001 in Div. 3NO were completed by the Spanish RV *Playa de Menduiña* with a Pedreira trawl, and during 2002-09 with the Spanish RV *Vizconde de Eza* equipped with a Campelen trawl. This research trawler was also used in Div. 3L for 2003-04 and 2006-10. In addition, surveys were conducted on the Flemish Cap (Div. 3M) during 1992-2003 with the RV *Cornide Saavedra* using a Lofoten trawl, and in 2004-10 with the RV *Vizconde de Eza* using a Campelen trawl.

Russia and France have also conducted surveys in the study area. In addition, Greenland has conducted an annual bottom trawl survey off of West Greenland since 1988, in waters adjacent to the study area (Nygaard and Jorgenson 2010), and the USA has conducted surveys in the Gulf of Maine, southern New England, and Georges Bank since 1963.

Spatial Distribution and Habitat Associations

Geo-referenced catch and hydrographic data for the spring and fall bottom trawl surveys were used to assess the spatial distribution and habitat associations of the three Wolffish species throughout the study area. First, maps of the geographic distribution of standardized catch rate (kg/tow) were plotted using data from all surveys. The plots were grouped by season and into two 5-year periods, except for the spring survey series during the 1990s, which were grouped for the periods 1990-95 and 1996-99. The periods were chosen to correspond to changes in fishing gear type, in particular from Engel to Campelen trawl in 1995-96. The distribution of catch in relation to depth and temperature was also investigated. At each tow location, the depth and bottom temperature were recorded using trawl-mounted sensors (SIMRAD depth sounder,

Seabird 19 CTD). Plots of mean catch rate in relation to tow depth and temperature were produced for each NAFO Division, year, and season.

Area of occupancy

The area of occupancy (A_t) for each species was calculated in each year t as follows:

$$(1) \qquad A_t = \sum_{k=1}^{S} \sum_{j=1}^{N_k} \sum_{i=1}^{n_j} \frac{a_k}{N_k n_j} I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_{ijkl} > 0 \\ 0 \text{ otherwise} \end{cases}$$

where Y_{ijkl} is the number of fish in length interval l caught in tow i at site j in stratum k, a_k is the area of the stratum k (km^2), N_k is the number of sites sampled in stratum k, n_j is the number of tows conducted at site j, and S is the number of strata. A_t was calculated based on the Index Strata (i.e., those sampled throughout the time series; see below). Sufficient data were available to conduct the analysis for each Wolffish species in Div. 2J3K (fall) and Div. 3LNO (spring and fall).

Abundance indices

Abundance indices have been estimated by areal expansion of the stratified mean catch per tow (Smith and Somerton 1981). Survey indices were expressed as the mean fish number per standard tow and reported for spring (NAFO Div. 3LNOPs) and fall (Div. 2J3K). To estimate abundance indices over a constant sampling area, only strata sampled throughout the time series were included. In addition, each stratum had to be sampled at least twice a year.

A rate of decline in relative abundance over t years (Δ %) was estimated as:

$$(2) \qquad \Delta = 100 \cdot (1 - e^{-\delta \cdot t})$$

and δ was estimated from a regression of log_e catch rate vs t.

COMMERCIAL FISHERIES REMOVALS

Commercial fishery removals of three species of Wolffish in NAFO Subareas 0-2 and Div. 3KLNOP were examined for 1960-2009, using commercial data available in three databases: the Northwest Atlantic Fisheries Organization STATLANT-21A unspeciated Wolffish catch data (1960-2009), reported by NAFO member countries fishing mainly outside Canada's 200-mile limit; DFO-NL ZIF (Zonal Interchange Format) unspeciated Wolffish landings data (1985-2009), reported by Canadian fishers operating in Canada's EEZ; and Canadian Fisheries Observers' speciated catch and discards data (1978-2009), collected on a tow-by-tow basis on board commercial fishing vessels at sea.

With NAFO-reported data, total reported catches of unspeciated Wolffish were calculated by year and Subarea/Division. With ZIF data, total reported landings of unspeciated Wolffish were calculated by year, Subarea/Division, Wolffish bycatch/directed fisheries, and fishing gear type. With Fisheries Observer data, total catches and discards of each species of Wolffish were analyzed by year and Subarea/Division. Observers' discard data were also prorated to ZIF total groundfish landings inside Canada's 200-mile limit to estimate annual Wolffish discards in Canada's

EEZ. This was done by multiplying the total observed Wolffish discards (per species) and ZIF total reported landings of all groundfish species, then dividing this estimate by the total observed catch of all groundfish species. Observers also collected at sea commercial length measurements of each species of Wolffish by year, Subarea/Division, and fishing gear type.

RESULTS

SPATIAL DISTRIBUTION AND HABITAT ASSOCIATIONS

Survey Catch Distribution

The geographic distribution of catch from bottom trawl surveys show that in the case of Northern Wolffish high density tows (>20 kg/tow) occurred mostly from the northern boundary of the Grand Bank (Div. 3L), through the Northeast Newfoundland and southern Labrador shelves (Div. 2J3K) during the late 1970s and 1980s in fall (Fig. 2). Northern Wolffish were nearly absent from tows in most southern areas throughout the time-series (spring and fall), and low density catches (<10 kg/tow) occurred along the shelf slope of the Grand Bank and the Laurentian Channel (Div. 3NOP), as well as the Flemish Cap (Div. 3M). The fall plots indicate that the occurrence and extent of high density tows declined considerably starting in the mid-1980s, and from the mid-1990s to the mid-2000s Northern Wolffish were infrequent in fishing tows conducted in all areas (spring and fall), except along the shelf slope and Laurentian Channel. Of notice, the later decline coincided with the period when the Engel trawl was replaced by the Campelen trawl in 1995 (fall survey) and 1996 (spring survey). However, since 2005 the occurrence of Northern Wolffish in survey tows (mostly <10 kg/tow) has increased over the same historical areas, suggesting a reversing trend from population decline.

For Atlantic Wolffish, the main centre of distribution occurs over shallow waters of southern Grand Bank (Div. 3NO), according to the location of high density tows from both spring and fall (post-1990) surveys (Fig. 3). This distribution pattern has persisted since the mid-1970s even though the extent of the area containing high density tows varied over time and nearly disappeared by the mid-1990s. The latter coincided with the change in survey gear type from Engel to Campelen, but the declining trend in high density tows was detected as early as 1990, thus prior to gear change. For the remaining areas, low density tows were observed through the Northeast Newfoundland and southern Labrador shelves, Flemish Cap and south coast of Newfoundland until 1989, followed by a period of apparent contraction in distribution. Most survey tows containing Atlantic Wolffish (<10 kg/tow) in the 1990s were limited to the outer portion of the continental shelf (Div. 2J3K) and shelf slope (Div. 3LNMO) in fall or near shore (Div. 3P) in spring. However, since 2000 Atlantic Wolffish survey catches have expanded over the same historical areas, displaying distribution patterns similar to those observed in the 1980s, and supporting the view of a reversing trend from population decline for this species as well. Moreover, high density tows in the southern Grand Bank were noticeably more frequent in spring than in fall (since 1990), suggesting that Atlantic Wolffish may undertake seasonal movements during these periods.

The geographic distribution patterns for Spotted Wolffish survey catch varied in similar ways, as described for Northern Wolffish (Fig. 4). High density tows were observed mostly in fall in the area adjacent to the northern Grand Bank (Div. 3L) and southern

Labrador (Div. 2J) through the 1980s, whereas low density tows were found scattered between the two high density areas (Div. 3K). Spotted Wolffish were uncommon in survey catches elsewhere (spring and fall time-series) and limited to the shelf slope (Div. 3NOP) and Flemish Cap (Div. 3M) in low densities. The area and number of survey tows containing Spotted Wolffish in Div. 2J3KL declined during the 1990s and were distributed towards the outer shelf, but this trend was reversed starting in 2000, as the number of tows capturing Spotted Wolffish increased over historical areas of the continental shelf. Like the two other Wolffish species, the observed spatio-temporal patterns of Spotted Wolffish survey catch suggest a reversing trend from population decline in the waters off eastern Newfoundland and southern Labrador during the last decade.

Regarding the geographic distribution of young fish, the cumulative distribution of catch rate (number of fish/tow) from the IYGPT surveys (1996-2000) show that the highest densities of Atlantic Wolfish (14-19 fish/tow) were centered across the Northeast Newfoundland shelf in Div. 3K (Fig. 5). Atlantic Wolffish were mostly absent from survey tows elsewhere in both inshore and offshore (Div. 2J3LNO), except for a few low density tows (<5 fish/tow) off southern Labrador and along the shelf slope of the Grand Bank. No records of Northern Wolffish or Spotted Wolffish occurred through the time-series.

The distribution of spring and fall survey catch in relation to depth show that Northern Wolffish tended to be found in relatively shallower and narrower water layers (100-400 m) in the northern boundary of the distribution range (Div. 2GH) in fall, and over broader and deeper layers (150-1000 m) from the southern Labrador shelf to the Grand Bank and Flemish Cap (Div. 2J3KLMNO) and south coast of Newfoundland (Div. 3P) in spring and/or fall (Fig. 6). Large catches (>100 kg/tow) were mostly observed in northern areas (Div. 2GHJ3K) in fall at depths <400 m, except in Div. 3K. In the latter and in Div. 3L (spring and fall) large catches were observed in deeper waters (300-800 m). Seasonal differences in survey catch were also detected on the Grand Bank (Div. 3LNO), as catch in spring was uncommon below 650 m (as well as in Div. 3P), but extended >1000 m in fall over the same areas. Such patterns are in part the result of changes in survey coverage prior to 1990, as depths >400 m were not well surveyed in Div. 3NOP in spring. Similarly, southern areas were poorly surveyed (Div. 3N) or not surveyed (Div. 3O) in fall prior to 1990, as well as the Flemish Cap (Div. 3M) in the last two decades. These changes, in addition to gear changes in 1995-1996, make it difficult to interpret trends in catch rate and depth distribution in different periods of the time-series. In spring mean catch rate peaked (5-21kg/tow) in Div. 3LNO at depths <400 m prior to the 1990s and between 700-800 m subsequently (Fig. 9). In Div. 3P the surveyed depth remained <800 m through the time-series and catch rates peaked between 600-700 m (4-15 kg/tow). In fall mean catch rate peaked in relatively shallow waters in northern areas, between 100 m in Div. 2H (154 kg/tow) and 200 m in Div. 2G (78 kg/tow) in the early 1980s, and then declined to low values subsequently (<10 kg/tow), as most fish were captured in waters >900 m. Further south catch rate tended to peak in deeper waters, ranging from 600 m in Div. 3LM (4-28 kg/tow) and 800 m in Div. 2J (44 kg/tow) in late 1970s to 900 m in Div. 3K (70 kg/tow) in late 1980s, whereas in Div. 3NO mean catch rate peaked at depths 600-900 m after 1990. Mean catch rate (fall survey) peaked in relatively shallow waters in northern areas, between 100 m in Div. 2H (154 kg/tow) and 200 m in Div. 2G (78 kg/tow) in the early 1980s, and then declined to low values subsequently (<10 kg/tow), as most fish were captured in waters >900 m. Further south catch rate tended to peak in deeper waters, ranging from 600 m in Div. 3L (22-

28 kg/tow) and 800 m in Div. 2J (44 kg/tow) in late 1970s to 900 m in Div. 3K (70 kg/tow) in late 1980s.

In contrast, few differences in survey catch for Atlantic Wolffish were detected in relation to depth (Fig. 7). Most fish were captured at depths <500 m in all areas during the spring and fall surveys. However, large catches occurred mostly in spring and were limited to the southern Grand Bank (Div. 3N), as well as the south coast of Newfoundland (Subdiv. 3Ps), and were in all cases distributed in waters <100 m deep, except for two survey tows in fall (Div. 2HJ). In this case it appears that expansions in area and depth surveyed starting in the early 1990s as well as changes in gear type did not influence trends in catch rate in relation to depth. Mean catch rate peaked (3-10 kg/tow) at depths of 300-400 m in Div. 3L and <100 m in Div. 3OP through the spring time-series (Fig. 10), whereas in Div. 3N catch rate had a bi-modal distribution in relation to depth, mostly with peaks at depths <100 m and between 300-400 m. In fall mean catch rate peaked between 300-400 m in all areas and time periods, and seasonal differences were observed in Div. 3N, as fall catch rates did not display peak values in shallow waters.

The depth distribution of survey catch for Spotted Wolffish varied similarly as observed for Atlantic Wolffish. Most fish were captured at depths <500 m in all areas and both seasons (Fig. 8). However, large catches occurred in Div. 3L mainly in fall at depths <350 m, but otherwise no seasonal differences in depth distribution of survey catch were detected in Div. 3LNO, despite the changes in survey coverage and fishing gear type. In spring mean catch rate peaked (3-8 kg/tow) at depths of 300-400 m in Div. 3LN until the mid-1980s and then between 600-800 m when deeper strata started to be surveyed (Fig. 11). In Div. 3OP mean catch rates were in general lower (<2 kg/tow) and picked in shallower waters (100-300 m) when compared to the remaining areas. The highest mean catch rates (15-60 kg/tow) were observed in fall at depths of 100-300 m prior to the mid-1980s in Div. 2H. Catch rates peaked at the same depth range and time period in Div. 2G and Div. 2J as observed for Div. 2H, even though peak values were considerably lower (5-9 kg/tow). Mean catch rates declined in Div. 2GHJ in the mid-1980s and remained low since then (<5 kg/tow) and tended to peak in waters >400 m. Catch rates tended to peak at depths ranging between 300-500 m in Div. 3KMNO through the time-series (3-17 kg/tow), whereas in Div. 3L catch rate peaked (6-12 kg/tow) in waters 200-400 m deep prior to 1990 and 300-700 m subsequently when catch rates were lower (<3 kg/tow).

The distribution of mean catch rate in relation to mean fishing tow temperature indicates that all three Wolffish species are temperature seekers associated with narrow temperature ranges. Northern Wolffish were captured in waters ranging from -0.8 to 7 °C (Fig. 12). High catch rates (>20 kg/tow) were observed consistently in fall on the Grand Bank (Div. 3LNO), Div. 3K and further north (Div. 2GHJ) in water temperatures of 2.5-4.5 °C. However the highest catch rates (30-80 kg/tow) were observed in colder waters (0-2.5 °C) in Div. 2GHJ during the 1980s. Distribution patterns were similar in spring (Div. 3LNOP), as well as in Div. 3M in fall, even though catch rates were in all cases <20 kg/tow.

Atlantic Wolffish were captured in water temperatures ranging from -0.45 to 6.5 °C (Fig. 13). High catch rates (>2.5 kg/tow) were observed in a relatively colder range of temperatures (0.5-3 °C) over the Grand Bank (Div. 3LN) in both seasons and all time periods, except for Subdiv. 3Ps in spring (-0.45 to 0.8 °C). Notwithstanding, the highest

catch rates (>10 kg/tow) occurred in water temperatures >2 °C in fall (prior to the 1990s) in areas other than the Grand Bank (Div. 2HJ3KM) with a few exceptions.

Spotted Wolffish were captured in waters varying from -1 to 6 °C (Fig. 14). High catch rates (>2.5 kg/tow) were observed mostly in Div. 3L in spring and fall, but in a wider range of temperature in fall (-1 to 3.5 °C) when compared to the spring time-series (2.5-3.5 °C). In addition, the temperature associated with high catch rates varied according to area and time period. Fall catch rates were higher in water temperatures of 0-2 °C prior to the 1990s in Div.2GHJ, whereas catch rates were associated with relatively warmer temperatures in Div. 3K (2.5-4 °C), and Div. 3M (3-4 °C). Further differences were also detected in Div. 3N, as spring catch rate was higher in water temperatures of 2-4.2 °C through the time-series, but mostly between 2 and 3 °C in fall prior to 1990s.

Area of Occupancy

The area of occupancy (A_t) for Northern Wolffish in Div. 2J3K (fall) declined steadily from 76 % in 1977 to <1 % in 2003 before reversing the trend and increasing between 11-20 % afterwards, but further south in Div. 3LNO (fall) A_t declined from 25 % in 1982 to <2 % in 2000, then increased to 7 % in 2008 before declining to 4 % in 2009, whereas in spring A_t fluctuated without trend through the time series in the same area (Fig. 15). For Atlantic Wolffish in Div. 2J3K (fall), A_t has initially decreased from 68 % (1979) to 10 % (1994), and increased subsequently from 30 % (1995) to 47 % (2007); A_t varied between 6 % and 26 % in Div. 3LNO prior to 1995 (spring and fall), except in 1978 (fall) when A_t peaked at 80 %, but increasing trends in A_t were observed through the Campelen series peaking at 28-29 % in 2006-2007 (Fig. 16). Similarly, in the case of Spotted Wolffish A_t decreased from 57 % (1978) to 4 % (1994) and then increased, from 6 % (1995) to 32 % (2008) in Div. 2J3K (fall), and from 1-3 % to 14-16 % in Div. 3LNO (spring and fall) during the latter period, but varied without trend prior to 1995 (Fig. 17). Overall, some degree of temporal variability in area of occupancy was consistently observed for all three species and in both spring and fall series.

ABUNDANCE INDICES

Pre- 1971 Surveys

Casey (2000) indicated that Wolffish biomass (mostly Atlantic Wolffish) increased from 1952 until the mid-1970s on St. Pierre Bank (Subdiv. 3Ps), when the biomass peaked and then declined subsequently. However, on the southern Grand Bank (Div. 3NO), biomass estimates increased steadily over 1952-95.

Spring and fall bottom trawl surveys

Overall, an index of relative abundance (mean standardized catch rate per survey and area) for Northern Wolffish was highest in fall in Div. 2J3K (up to 5 fish/tow) prior to the mid-1980s when compared to the fall and spring indices on the Grand Bank (Div. 3LNO) and spring index in Subdiv. 3Ps (Fig. 18). The index for Div. 2J3K declined to very low values starting in 1986 (0.8-0.1 fish/tow), and continuing through the mid-1990s (Engel time-series) and early 2000s (Campelen time-series); followed by small increases in more recent periods. Similar temporal trends in relative abundance in Div. 3LNO and Subdiv. 3Ps in spring were higher prior to the mid-1980s (up to 0.2 fish/tow), then

declined to low values subsequently (<0.1 fish/tow), but showing some signs of improvement in later years (>0.1 fish/tow), particularly in Div. 3NOP (spring and fall time-series). However, it is difficult to interpret temporal trends in abundance indices due to the gear changes in 1983 and 1995-96.

Trends in Atlantic Wolffish abundance indices varied similarly as observed for Northern Wolffish (Fig. 19). The index was highest in Div. 2J3K in fall (up to 8.3 fish/tow) during the late 1970s and then declined steadily, reaching the lowest estimation by 1994 (0.13 fish/tow). With the introduction of the Campelen trawl in 1995, the index increased (≈ 2 fish/tow) and varied little since then. Likewise, the variability of both spring and fall indices was relatively low in Div. 3LNO for all periods (0.5-1.2 fish/tow), despite the changes in fishing gears; except for the most recent period (2005 onwards) when increasing trends in the spring and fall indices occurred (up to 2.5 fish/tow). Trends in the spring abundance index in Subdiv. 3Ps were characterized by a declining period from the early 1970s (4.6 fish/tow) to the mid-1990s (0.2 fish/tow), followed by a period of relative abundance increase (>3 fish/tow) since the introduction of the Campelen trawl in 1996, and that despite some considerable inter-annual variability in some cases.

As observed for the other Wolffish species, an index of abundance for Spotted Wolffish was highest in fall in Div. 2J3K during the late 1970s (1.25 fish/tow), but declined steadily through the 1980s and nearly disappeared from the time series (0.02 fish/tow) in 1995 (Fig. 20). The index increased through the Campelen series and peaked in 2008 (0.56 fish/tow). In Div. 3LNO, the index was relatively high during the Yankee trawl series in spring, then declined and fluctuated without a clear trend during most of the 1980s until the mid-1990s (Engel trawl series), and increased since the introduction of the Campelen trawl and peaking in 2006, according to both spring (0.57 fish/tow) and fall time-series (0.35 fish/tow). The abundance index in Subdiv. 3Ps peaked in 1975 (0.2 fish/tow), but was very low overall (<0.02 fish/tow), and fluctuated without trend throughout the spring time series.

The estimated decline rate index (Δ) shows that Northern Wolffish relative abundance increased by 12.5 % in Div. 3LNO in spring prior to 1983, then declined by 4.5 % in 1984-95, but has increased 3.3 % subsequently (Table 2). The latter increase was also detected in the fall time-series (Δ = +5.3 %). The index declined by > 96 % in Div. 2J3K in fall during 1978-94, but increased by nearly 19 % in 1995-2009.

Atlantic Wolffish showed the largest rate of change in relative abundance, increasing between 191 % (spring) and 312 % (fall) in Div. 3LNO since the mid-1990s, after experiencing declines ranging from 15 % (1975-82) to 28 % (1984-95) according to the spring time-series (Table 2). In Div. 2J3K (fall), Atlantic Wolffish experienced the largest decline in relative abundance in 1978-94 (Δ = -99.8 %), but have since then experienced a strong rate of increase (162.4 %).

Spotted Wolffish showed the least variable rate of change in relative abundance, increasing by 10 % in Div. 3LNO (spring) during 1975-1983, then declining by nearly 7 % in 1984-95 before undergoing another increase of 31 % in 1996-2010 (Table 2). The fall series also showed a similar trend during the latter period, with an increase of 26.7 %. In Div. 2J3K (fall), the rate of change in the abundance index showed similar patterns as observed in Div. 3LNO, with a decline of 67 % in 1978-94, but reversing the trend in 1995-2009 as the index increased by nearly 41 %.

Juvenile Surveys

The indices of relative juvenile abundance (mean number/tow by survey) indicate that Atlantic Wolffish comprised the most common species present in Div. 3LNO during the period 1985-94 (Fig. 21). The index varied between 0.04-0.33 fish/tow until 1992 and then increased 2-4 times afterwards (up to 0.8 fish/tow). The index was lower for Northern Wolffish (<0.03 fish/tow) and Spotted Wolffish (<0.02 fish/tow); except for the former in 1988 (0.4 fish/tow), and varied without a clear trend.

Central and Arctic Region

The three Wolffish species were also found in NAFO Subarea 0. However, abundance was low and there was never a directed fishery. Research surveys conducted by DFO (1999-2006) captured both Northern and Spotted Wolffish in Subarea 0, but close to the boundary with Subarea 1 (Greenland waters) and Div. 2G, and may reflect an extension of stocks from one or both of these areas (Fig. 22). Catches of all three Wolffish species were nearly zero in NAFO SA 0A and in waters deeper than 400 m in SA 0B. Atlantic Wolffish were only caught in shallow water surveys covering Shrimp Fishing Areas 2 and 3, and the largest catches of the other two species also occurred in SFA 2 and 3. Records exist for catch location of Wolffish caught in SFA 2 and 3, but they still need to be compiled.

Reported bycatch in the Greenland Halibut and Northern Shrimp fisheries indicated that these three Wolffish species were caught in Subarea 0. Northern Wolffish comprised the majority of bycatch, and Atlantic Wolffish the least; but all three species were caught at very low levels with no observed trend over time (Fig. 23-25).

COMMERCIAL FISHERIES REMOVALS

NAFO data from 1960-2009 indicated that the majority of reported Wolffish catches (unspeciated) occurred in Subarea 1 until 1990, averaging 5,431 t in 1960-83 (with a 16,665 t peak in 1979), and 1,655 t in 1984-1989 (Fig. 26). Reported catches then decreased to 28 t in 1998, with a 550 t peak in 2003-07. In 1960-2009, the next significant catches of unspeciated Wolffish were found in Subarea 2 and Div. 3KL: averaging 1,214 t and 2.057 t (respectively) in 1973-76, and 1,472 t in 1967-85. By 2008-09, total NAFO-reported Wolffish catches in all areas combined (i.e., Subareas 1 and 2, Div. 3KLNOP) were 150 t.

Canadian fisheries targeting Wolffish in Canada's EEZ were almost nonexistent: 40 t of unspeciated Wolffish were reported landed in 1988, and 18 t in 1992 (Fig. 27). Wolffish were thus almost always reported as bycatch in other Canadian fisheries prosecuted in Subareas 2 and 3 over 1985-2009; albeit reported landings for all areas became insignificant by 2004. In 1985-91, a 960 t average was landed, with a 1,351 t peak in 1987. In 1999-2002, 382 t of Wolffish were landed on average, with a 450 t peak in 2002.

With respect to areas fished, Canadian reported landings of unspeciated Wolffish in Subarea 2 and Div. 3KLNO of Canada's EEZ averaged 1,132 t in 1985-89, with a 1,351 t peak in 1987 (Fig. 28). Canadian landings decreased almost to zero in 1994-97. In 1998-2002, Wolffish landings averaged 337 t in Div. 3KLNP, with 226 t in Div. 3P alone. By 2004, reported landings fell to zero in Div. 3KLN, and became insignificant in Div. 3P.

Regarding fishing gears used in Canada's EEZ, Canadian fishers deployed primarily bottom trawls in 1985-1993, averaging 803 t annually, with a 1,075 t peak in 1987 (Fig. 29). In 2001-02, trawls reportedly landed an average of 190 t of Wolffish, with a 274 t peak in 2002. Gillnets landed on average 156 t annually in 1985-1989, with insignificant values reported after 1990. Wolffish landings from longlines were rare until 1998, whereupon a 210 t average was reported in 1998-2002, with a peak of 339 t in 2000.

At-sea speciated Wolffish catch data collected by Canadian Fisheries Observers in Div. 2GHJ3KLNOP within Canada's 200-mile limit suggested that Northern Wolffish was the predominant Wolffish species bycaught in 1985-92; averaging 1,088 t annually, with a 1,898 t peak in 1987 and 996 t peak in 1991 (Fig. 30). In 1993-2005, average annual catch of this species decreased to 89 t. In 1985-1991, bycatch of Spotted Wolffish averaged 636 t; with a 735 t peak in 1989 and 712 t peak in 1991. Since 1985, Observer data indicated that annual catches of Atlantic Wolffish were most significant in 2001-05; with a 375 t average and a 628 t peak in 2004.

At-sea Observer data from Canada's EEZ also showed that Northern Wolffish total catch averaged 515 t annually in Subarea 2 over 1985-91, and 439 t in Div. 3K and 175 t in Div. 3L, respectively (Fig. 31). For Spotted Wolffish during the same period, total catch averaged 132 t annually in Subarea 2, and 244 t in Div. 3K and 261 t in Div. 3L, respectively. Atlantic Wolffish total catch in 2001-05 averaged 357 t annually in Div. 3N, with a 609 t peak in 2004.

Length frequencies taken by Observers at sea indicated that bottom trawls (including "twin" trawls) with 145-156 mm codend mesh fishing in Subarea 0 and Div. 2HJ3KL caught Northern Wolffish in a 25-131 cm TL size range (Fig. 32). Gillnets with 152-203 mm mesh also caught this species in Subarea 0 and Div. 3K in a 47-123 cm size range. Longline gear fishing in Subarea 0 and Div. 2GH3O caught Northern Wolffish in a 39-132 cm range, and pots with 127-152 mm mesh fishing in Div. 2HJ3K caught this species in a 35-125 cm size range. For Spotted Wolffish, a range of 41-134 cm TL was caught by bottom trawls with 145-156 mm codend mesh fishing in Subarea 0 and Div. 2J3KL (Fig. 33), gillnets with 152-162 mm mesh caught a 30-118 cm size range in Div. 3L, longlines caught a 51-160 cm range in Div. 3O, and pots with 130-152 mm mesh caught a 31-117 cm range in Div. 2J3KL. Atlantic Wolffish were caught in a range of 35-130 cm TL by bottom trawls with 145-156 mm codend mesh fishing in Subarea 0 and Div. 3NOPs (Fig. 34), gillnets with 135-165 mm mesh caught this species in a 40-106 cm range in Div. 3LPs, longlines caught a 28-130 cm range in Div. 3P, and pots with 130-152 mm mesh caught a 36-104 cm range in Div. 3K.

Although Observer data showed that commercial fishing gears do not catch Wolffish young-of-the-year (YOY), an exception is the Shrimp trawl, which catches YOY. A size range of 5-25 cm TL for these three Wolffish species was retained by Shrimp trawls with a 40-50 mm codend mesh fishing in Subarea 0 and Div. 2GHJ3K (Fig. 35). However, Wolffish adults are not retained by this gear, due to a groundfish excluder (e.g., Nordmore grate) installed below a "bycatch exit window" in the trawl.

Discard data from Fisheries Observers suggested that a 441 t average of Wolffish was discarded annually at sea in Div. 3L over 1986-1991 (Fig. 36), 628 t in 1985 and 875 t in 1994 were discarded in Subarea 2, a 475 t average was discarded in Div. 3K over 1998-2002 (with a 1,128 t peak in 1999), and a 162 t average in Div. 3N in 2004-06. By 2006,

Wolffish discards in all areas of Canada's EEZ (combined) decreased to approximately 200 t annually.

DISCUSSION

This study analyzed the most recent information available on the biology, distribution, abundance trends from research surveys and commercial fisheries, and strengthened the knowledge about several key aspects of the life history of all three Wolffish species in the Northwest Atlantic Ocean. The main findings can be summarized as (i) the three Wolffish species are at the centre of their distribution in Newfoundland and Labrador waters, reaching the highest density and covering the largest area on the northeast Newfoundland and southern Labrador shelves; (ii) the three species are distributed over a wide range of depths, from about 25 m to >1400 m, with Northern Wolffish occupying the widest range (150-1000 m) and Atlantic Wolffish the narrowest (100-500 m); (iii) historically the area centered at Lat. 48^{o} 30', Lon. 51^{o} just north of the Grand Bank constitutes the most persistent location of high concentrations of Northern Wolffish and Spotted Wolffish in the Northwest Atlantic, and on the southern Grand Bank in the case of Atlantic Wolffish; (iv) habitat associations have been partially driven by temperature preferences, and depth distribution is likely related to water mass thermal characteristics; (v) considerable declines in indices of relative abundance and area occupied by all three species occurred through the 1980s and early 1990s; and (vi) some signs of stock recovery have been detected, as the indices of relative abundance and distribution for all three species tended to increase in most areas surveyed during the last decade.

Wolffish species have undergone considerable changes in their distribution during the period up to 2003 in Newfoundland and Labrador waters. These changes occurred concomitantly with a period of declining abundance (Simpson and Kulka 2002). The observed changes were greatest at the centre of distribution of the species: on the northeast Newfoundland and Labrador Shelves. For example, Northern Wolffish are currently found along the shelf slope and into the outer extent of troughs separating the banks (Hopedale, Cartwright, and Hawke Channels, and Funk Island Deep). In previous years when abundance was higher (1978-84), the distribution extended farther into the troughs and channels and over the banks and shallower waters (Kulka et al. 2004*b*). The highest concentrations of fish occurred within the depth range of 450-1100 m since 1995. However, during the period of high abundance the larger concentrations were observed in shallower waters of 150-450 m, and relatively lower beyond 900 m. Thus, Northern Wolffish experienced not only a decrease in abundance but also a shift to greater depths. Moreover, Northern Wolffish experienced the largest reduction in area occupied (>99 %) of the three species. Since 1995, the area occupied by this species has fluctuated with the highest value observed in 2007 (20 % in Div. 2J3K). Kulka et al. (2004*b*) reported that total area occupied during 1995-2003 was 24 % of the surveyed area, but when abundance was highest (1978-84), locations occupied reached up to 57 %. However, it must be noted that due to survey design changes, the time periods are not directly comparable.

In comparison, Atlantic Wolffish are presently found over most of the survey area; except the inner portions of the banks and along much of the coastal areas. In addition, Atlantic Wolffish continued to occupy the shallow portion of the southern Grand Bank: an area where the other two species only rarely occur. Since 1995 there has been little change

observed in the distribution, and in recent periods (2007-09) the area occupied in fall ranged between 60-73 % (Div. 2J3KLNO), which is greater in extent to what was observed during the years of peak abundance (57 %) in 1978-84 (Kulka et al. 2004*b*). The current distribution of Spotted Wolffish is similar to that observed for Atlantic Wolffish; except for the southern Grand Bank. Since 1995 the area occupied by Spotted Wolffish has increased steadily, particularly on the northeast Newfoundland Shelf and the northern edge of the Grand Bank. The greatest increase occurred in recent periods, as Spotted Wolffish occupied between 37-49 % of the area surveyed in 2008-09; within the range observed during the years of peak abundance (48 %) in 1978-84, and coinciding with recent increases in abundance indices from both spring and fall surveys.

Of the three species, Atlantic Wolffish is the one which indices of relative abundance and distribution have varied the least over different time periods, particularly on the Grand Bank (1975-2010) and the northeast Newfoundland and Labrador shelves (1995-2009), whereas Northern Wolffish underwent the largest decline in the indices of relative abundance and in area occupied over the same period. All three species are associated with a narrow temperature range (1.5-4.5^{o}C). During periods of low abundance, each of the Wolffish species was restricted mainly to warmer waters along the outer shelf edge. In particular Northern Wolffish and Spotted Wolffish were more narrowly distributed at the centre of their temperature range during the period of lowest abundance. As such, temperature could potentially be a limiting factor to Wolffish recovery because Wolffish are temperature seekers, and these species may be susceptible to deleterious environmental effects related to climate change (Reid and Valdés 2011). It would also imply that critical habitat cannot be permanently geo-referenced in the areas where Wolffish occur. The impact of density-dependency as well as the dynamic aspects of temperature regimes on wolfish distribution likely contributed to the large inter-annual variability in survey indices of abundance and distribution observed in some instances, and should be considered when developing recovery strategies for Wolffish.

Overall, recent survey trends suggest that population abundance of all three species of Wolffish inhabiting Newfoundland and Labrador waters have stopped declining, and indeed some initial signs of recovery have been detected throughout the survey area. Indices of relative abundance and distribution have shown increasing trends since the early 2000s, as Wolffish started to return to several historical areas, displaying distribution patterns similar to those observed during periods of high abundance.

Although commercial records of Wolffish are unspeciated and do not include discards at sea (except for Fisheries Observers' data), reported Wolffish catches and landings declined substantially through the 1980s and early 1990s; mainly in southern Labrador and northern Newfoundland shelves (Div. 2J3KL). Reported commercial catches remained low through the 1990s, but increased in the early 2000s before declining abruptly thereafter. However, this late decline does not reflect a decline in Wolffish abundance, but rather resulted from the placement of all three species of Wolffish on Schedule 1 of Canada's SARA and subsequent mandatory live release of these species in Canadian waters. Moreover, although the impacts of Wolffish removals by commercial fisheries (bycatch and discards) in recent periods are unknown, the upward trends in survey abundance indices for all three species during the same period suggest that fishing mortality is not a main factor driving population dynamics at present.

In other geographic areas such as West Greenland, at least for Atlantic Wolffish, population declines appear to have recently reversed (Nygaard and Jorgensen 2010).

Biomass indices derived from Greenlandic and German surveys show an increasing trend since the early 2000s. In addition, McRuer et al. (2000) noted an increase in Atlantic Wolffish abundance after the late 1980s in the Gulf of St. Lawrence and on the Scotian Shelf. However, such patterns were not observed further south. Indices of relative abundance derived from US NEFSC surveys conducted in the Gulf of Maine, southern New England, and Georges Bank in spring and fall (1963-2009) show declining trends through the 2000s; reaching the lowest estimates of the time series towards the end of the decade (Anon. 2009). Such patterns suggest that recent trends in Wolffish population abundance are limited to the northern range of the species distribution, and are influenced mainly by biological and/or environmental processes observed at very large scales (e.g., ecosystem); as there are no directed fisheries for Wolffish species in the Northwest Atlantic Ocean.

In Newfoundland and Labrador waters, Wolffish are considered data-poor species, due to partial information or lack of knowledge of several important aspects of life history, in addition to poor records from commercial fisheries: all of which are necessary to conduct a comprehensive assessment of stock status. The former includes individual and area-specific growth rates, survival rates, age structures of immature and adult components of populations, reproductive potential, identification of reproductive units, and relationships between spawning population and recruits; while the latter includes unspeciated or unreported catches, and unreported discards from commercial fisheries. Furthermore, variation in annual spatial coverage of Canadian research surveys, as well as changes in survey gear in 1983 and 1995-96, impose some limitations on the available data; especially given the lack of comparative surveys between survey gear types and no size-based conversion factors for Wolffish species. However, despite its limitations, the information provided in this paper should be helpful for assessing and formulating appropriate conservation and management strategies for each of the three Wolffish species in Newfoundland and Labrador waters in terms of risk of extinction.

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Table 1. List of bottom trawl research surveys conducted in the Newfoundland and Labrador Region (NAFO Division 2HJ3KLMNOPs) during the period 1971-2010. Various vessels and fishing gears were used over the years. Vessels: A.T. Cameron, Gadus Atlantica, Wilfred Templeman, Alfred Needler, and Teleost. Survey gear: Yankee 41.5 otter trawl (brown), Engel 145 otter trawl (blue), and Campelen 1800 Shrimp trawl (yellow). White cell: no survey was conducted in the area/season/year. Winter/fall surveys (*).

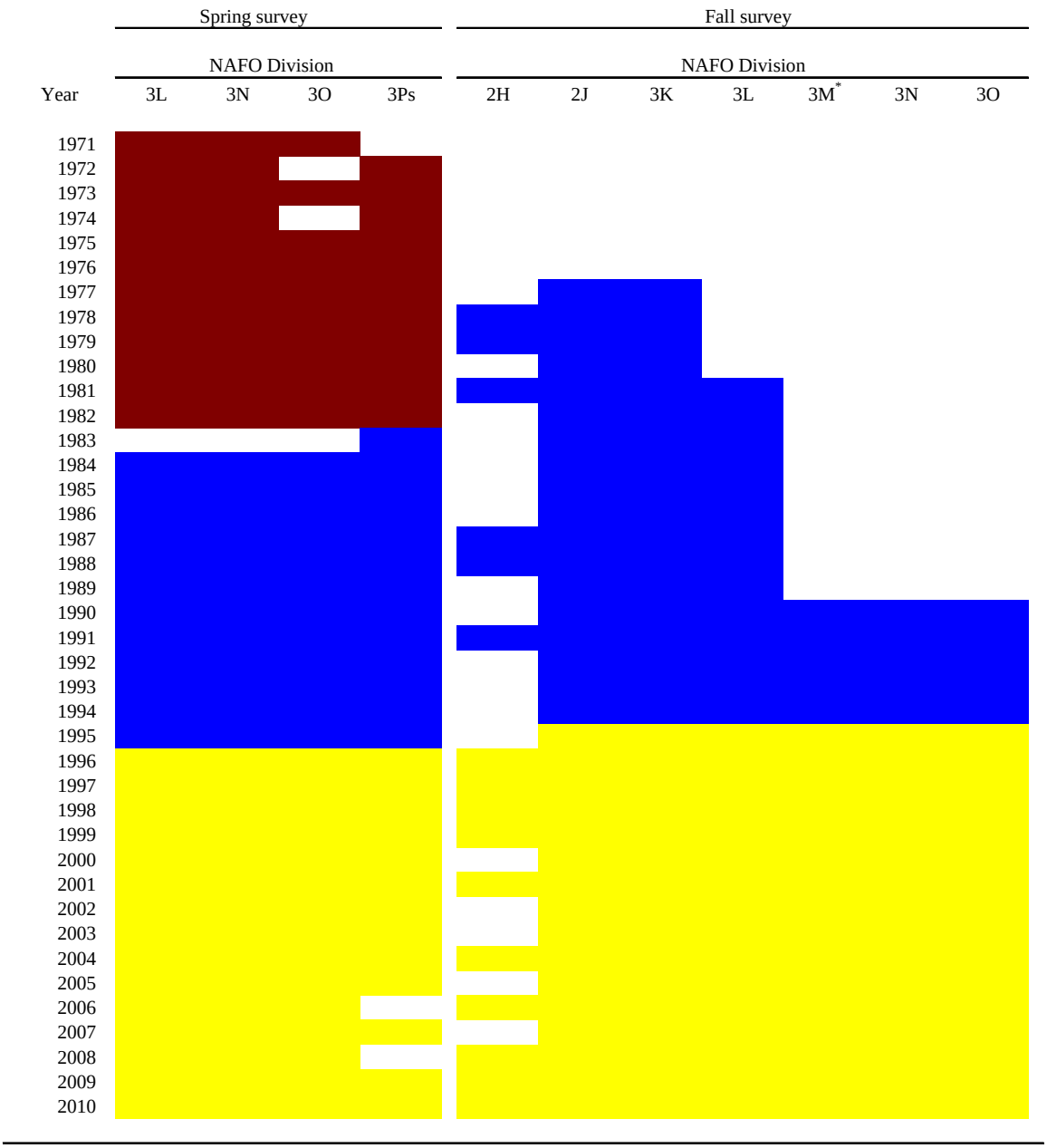


Table 2. Rate of decline in relative abundance of Wolffish species by surveyed area, time-series, and period. Rate of decline was estimated from a regression of $\log_e$(catch rate) versus year. See text for details.

Species	Area (NAFO Div.)	Time-series (Season-Fishing Gear)	Period	Decline Rate (%)
Northern Wolffish	3LNO	Spring-Yankee	1975-1982	12.5
		Spring-Engel	1984-1995	-4.5
		Spring-Campelen	1996-2010	3.3
		Fall-Campelen	1995-2009	5.3
	2J3K	Fall-Engel	1978-1994	-96.2
		Fall-Campelen	1995-2009	18.7
Atlantic Wolffish	3LNO	Spring-Yankee	1975-1982	-14.7
		Spring-Engel	1984-1995	-28.2
		Spring-Campelen	1996-2010	190.7
		Fall-Campelen	1995-2009	311.8
	2J3K	Fall-Engel	1978-1994	-99.8
		Fall-Campelen	1995-2009	162.4
Spotted Wolffish	3LNO	Spring-Yankee	1975-1982	10
		Spring-Engel	1984-1995	-6.8
		Spring-Campelen	1996-2010	31.3
		Fall-Campelen	1995-2009	26.7
	2J3K	Fall-Engel	1978-1994	-67
		Fall-Campelen	1995-2009	40.8

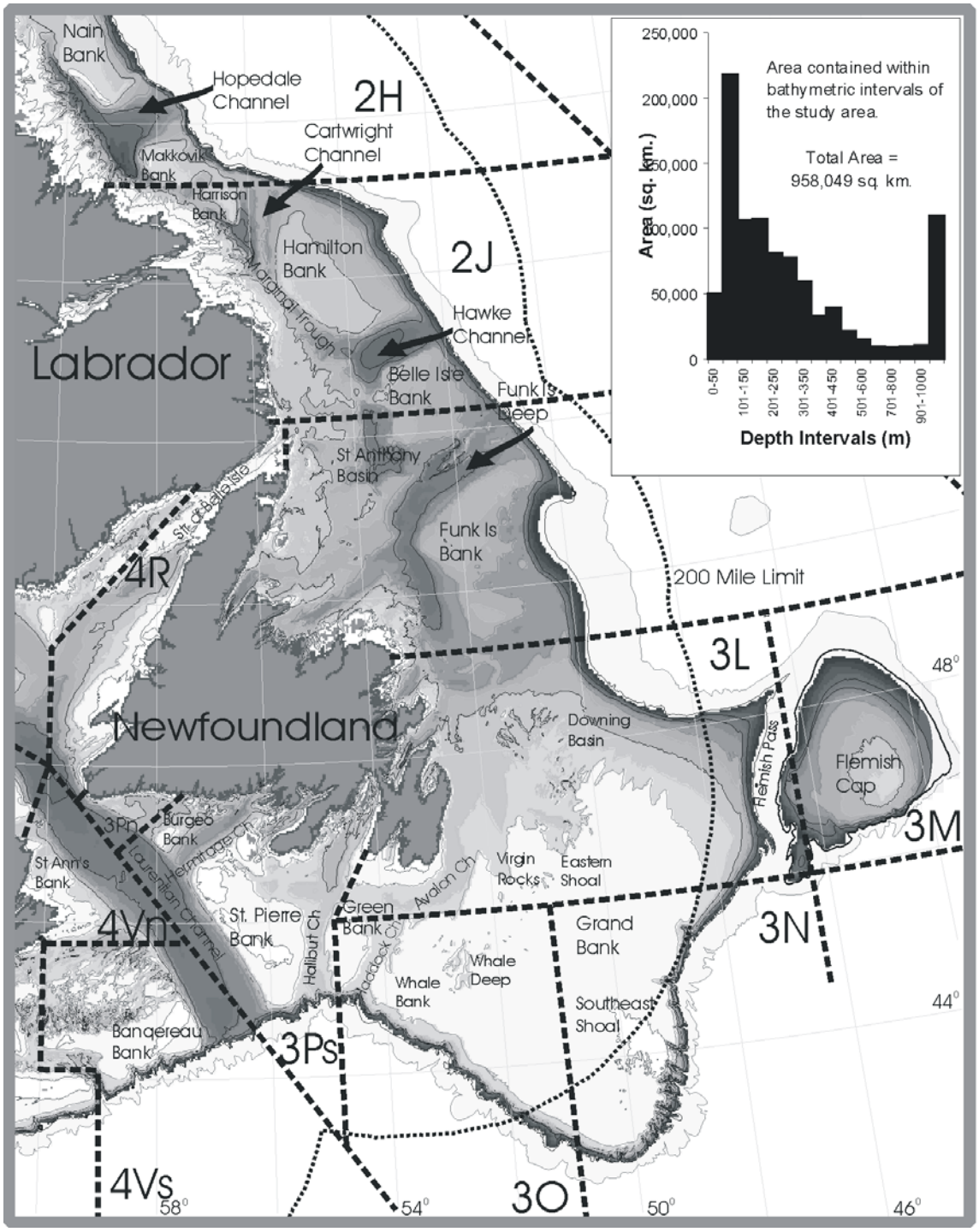


Figure 1. Map of the continental shelf off Eastern Canada and geographic features mentioned in the text. Depth range: <100 m (light grey) to >1000 m (dark grey). Canada's 200-Mile Limit is delineated by a fine dotted line, and NAFO Divisions by coarse dotted lines.

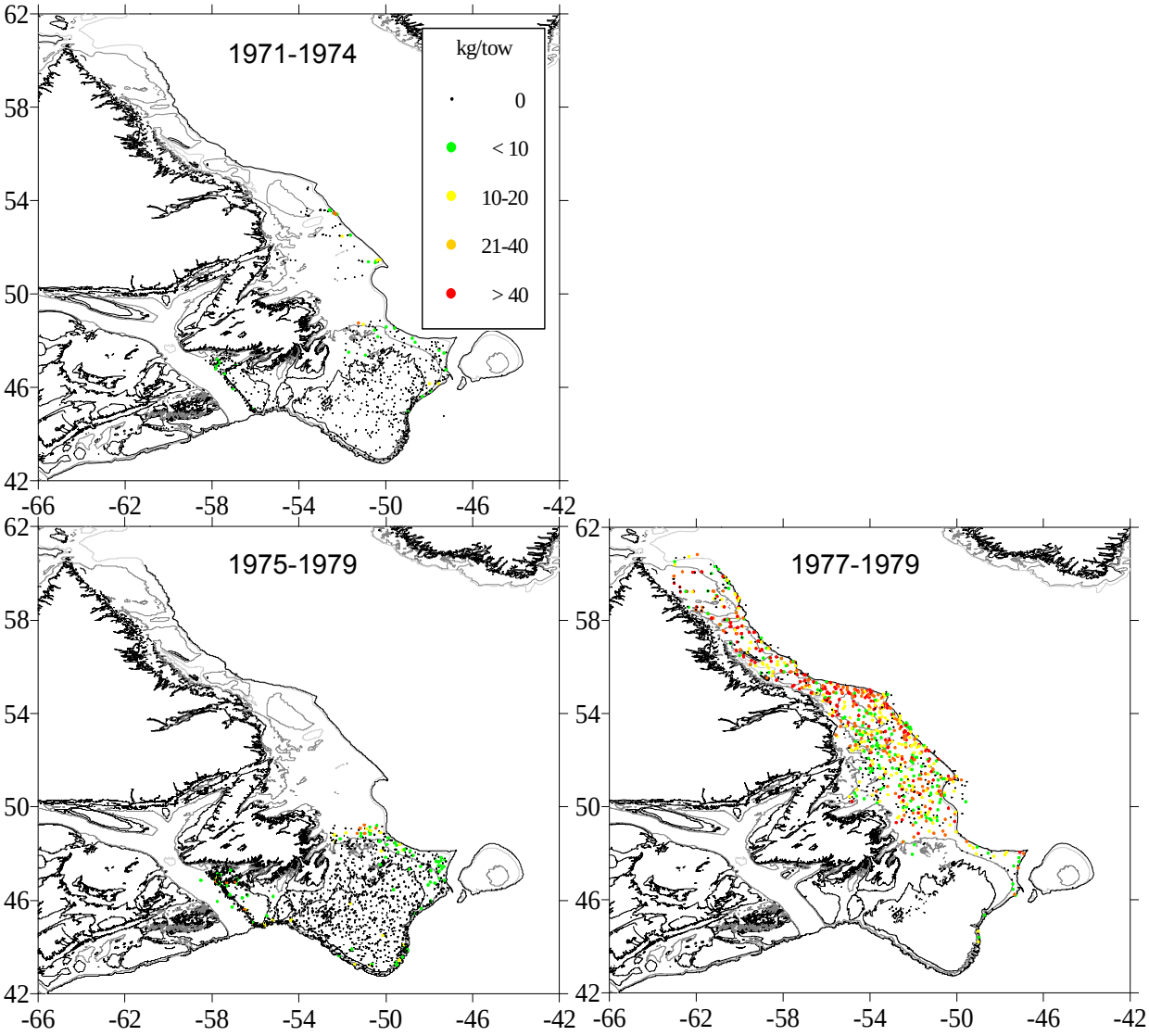


Figure 2. Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Northern Wolffish in the NL Region, 1971-79.

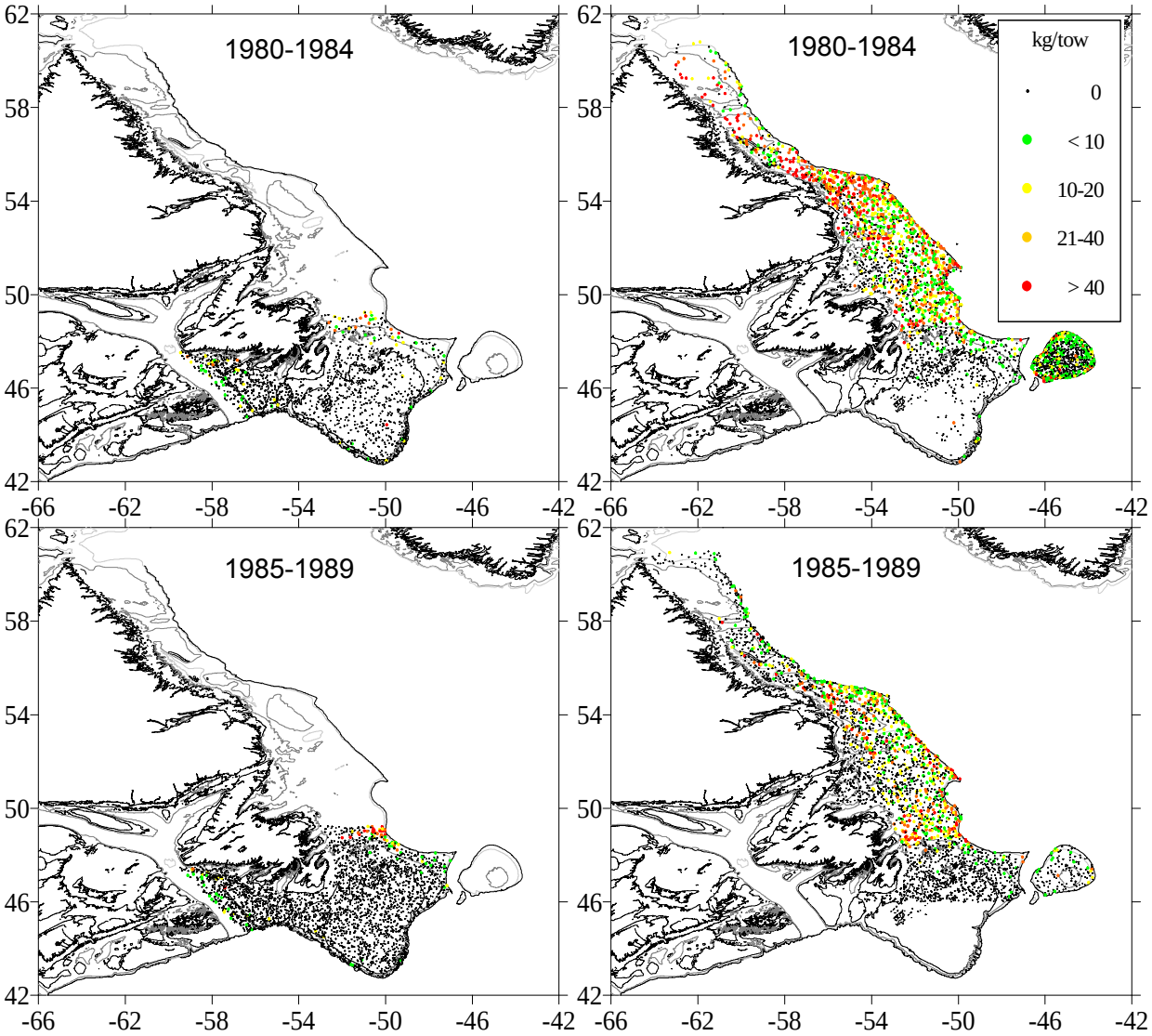


Figure 2 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Northern Wolffish in the NL Region, 1980-89.

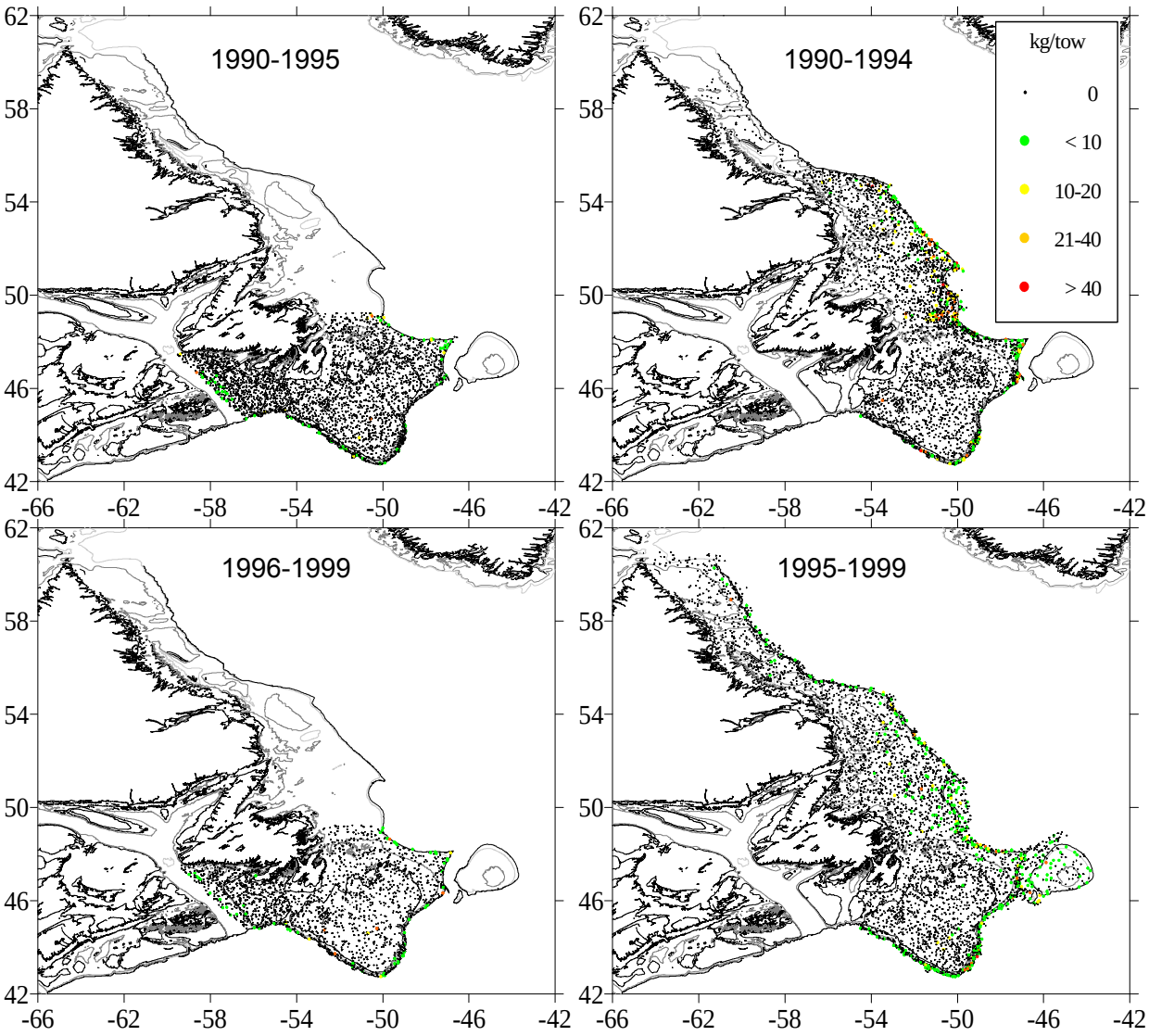


Figure 2 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Northern Wolffish in the NL Region, 1990-99.

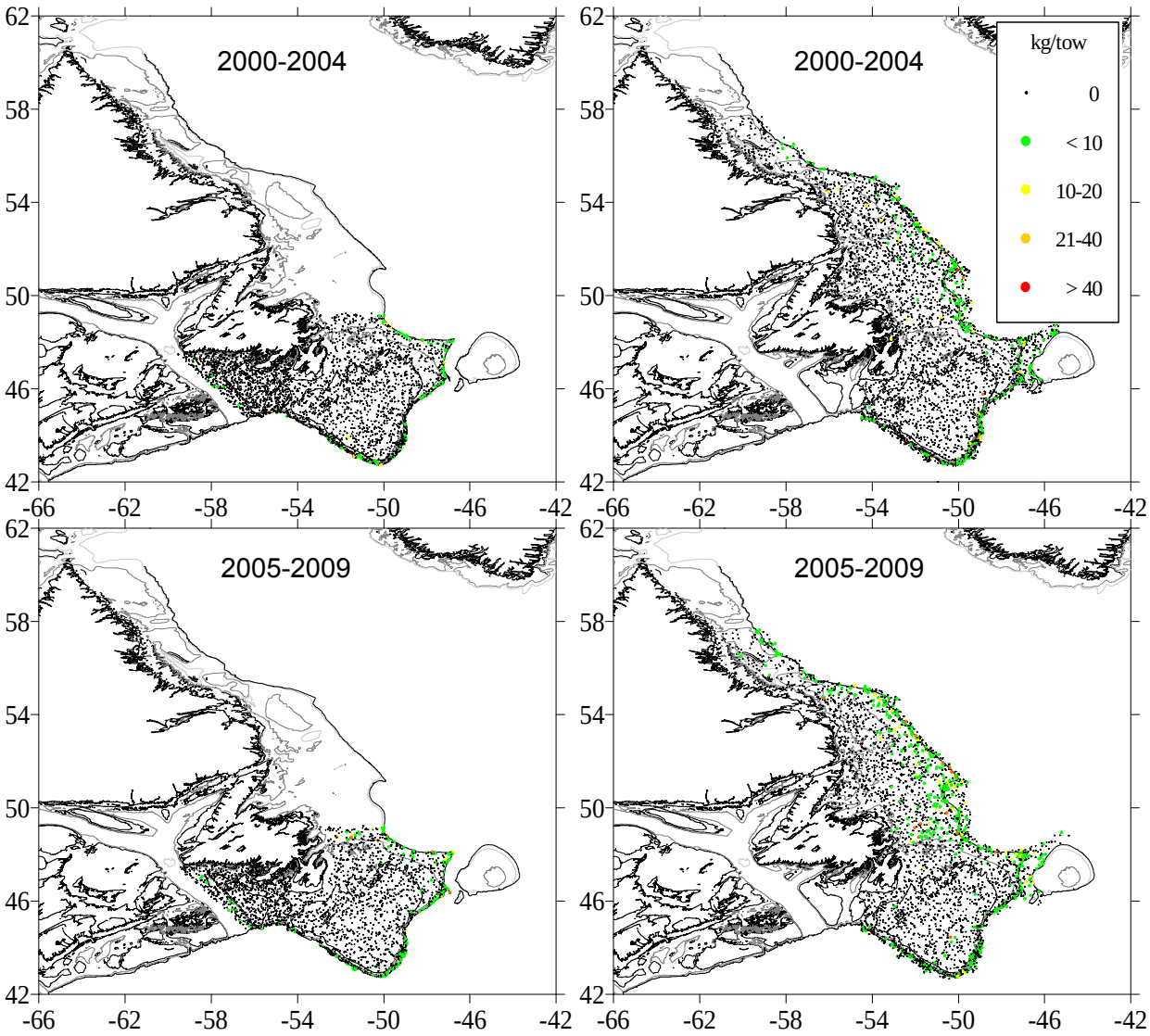


Figure 2 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Northern Wolffish in the NL Region, 2000-09.

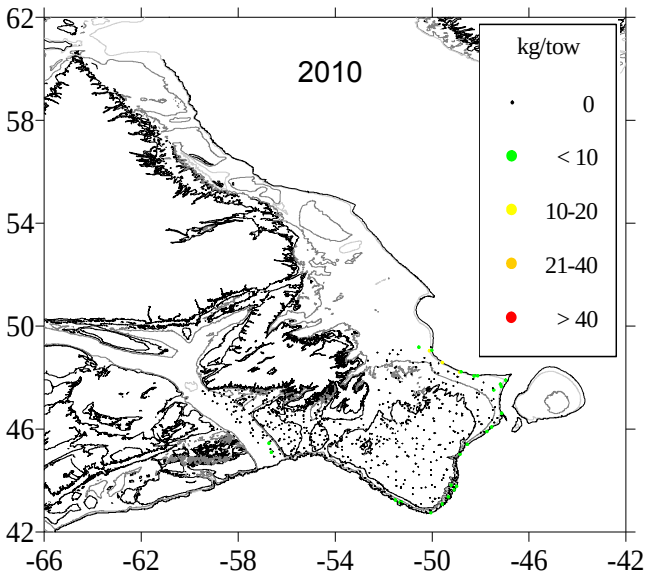


Figure 2 (cont.). Geographic distribution of spring research survey catch rates (kg/tow) for Northern Wolffish in the NL Region, 2010.

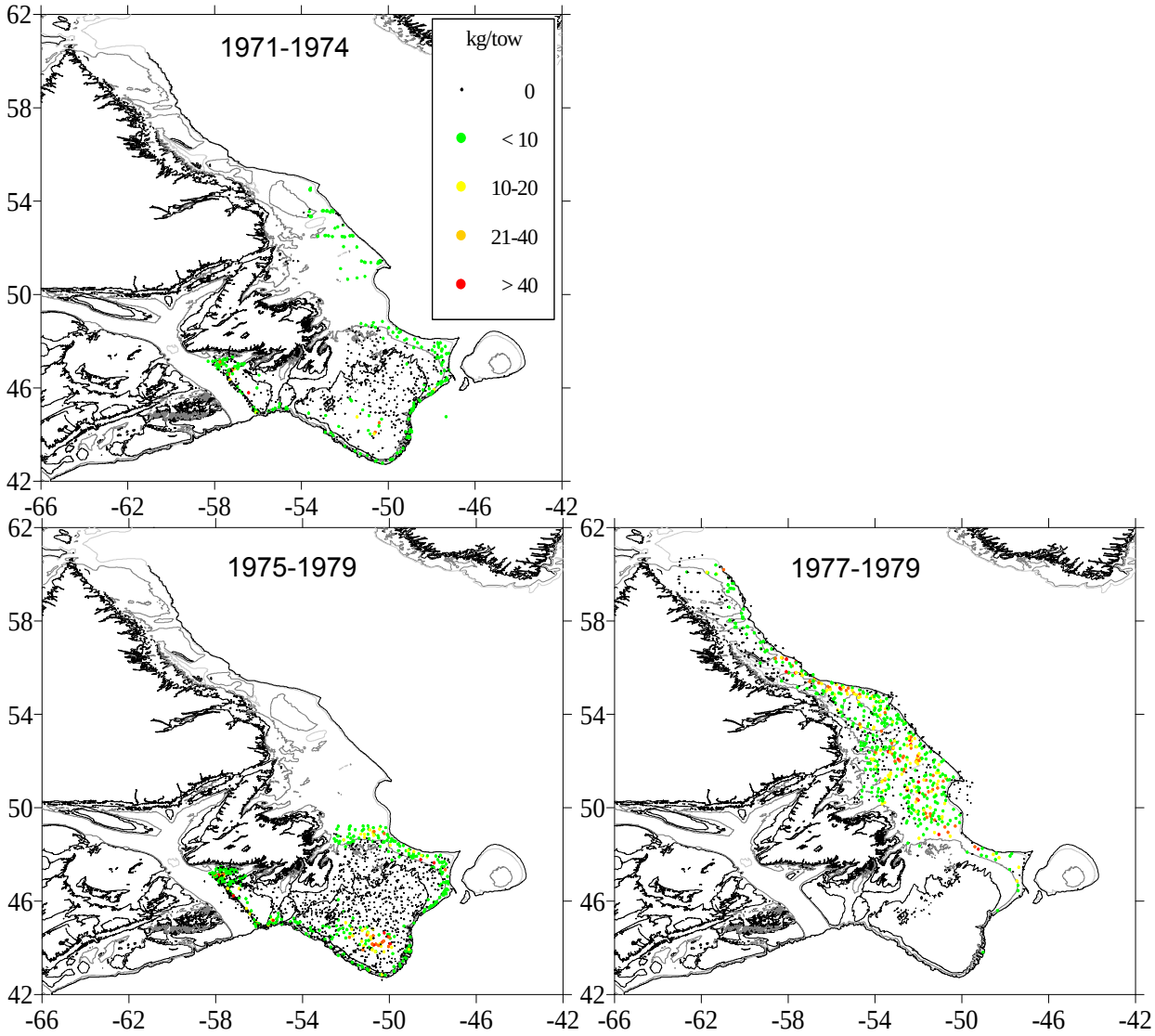


Figure 3. Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Atlantic Wolffish in the NL Region, 1971-79.

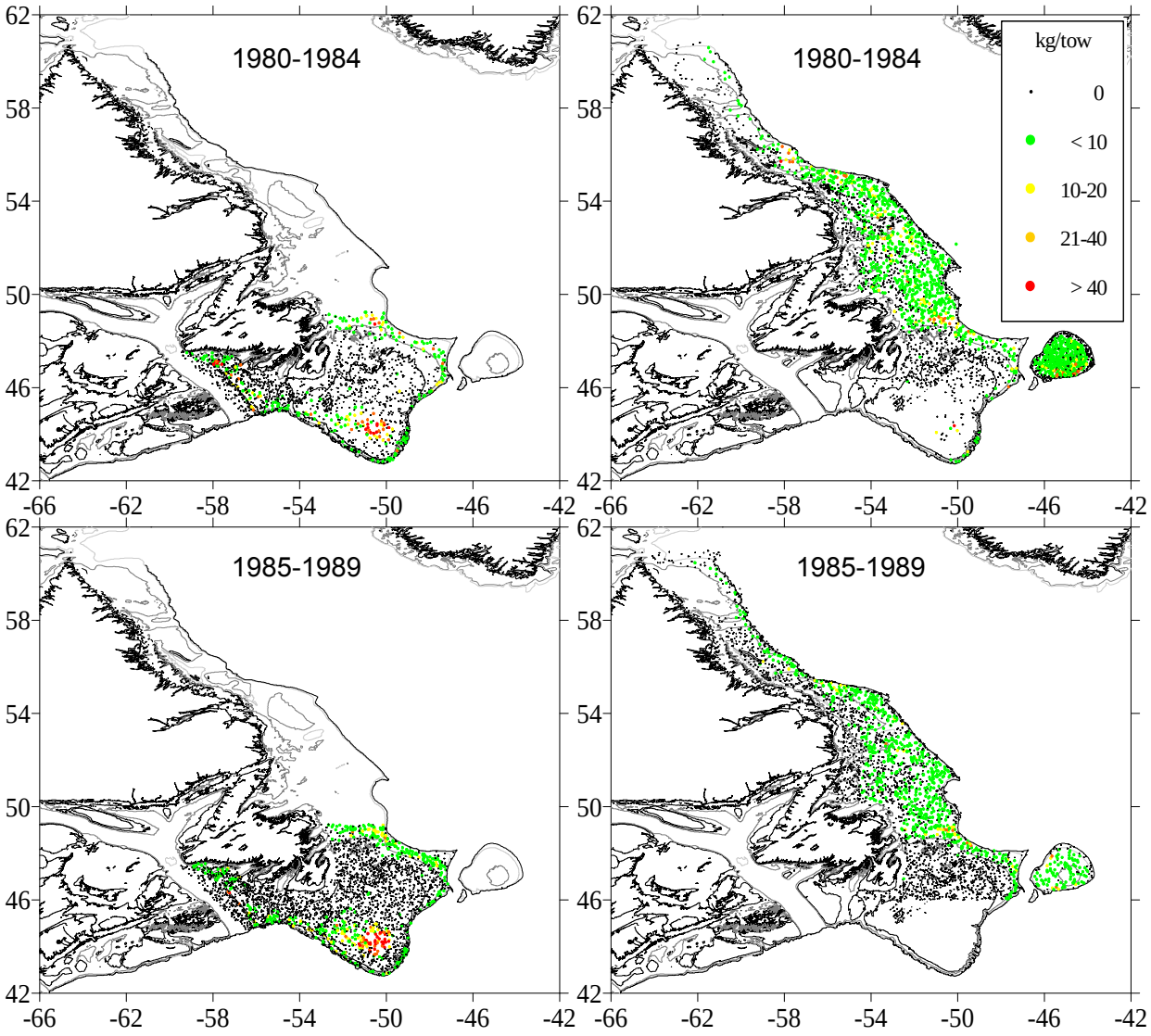


Figure 3 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Atlantic Wolffish in the NL Region, 1980-89.

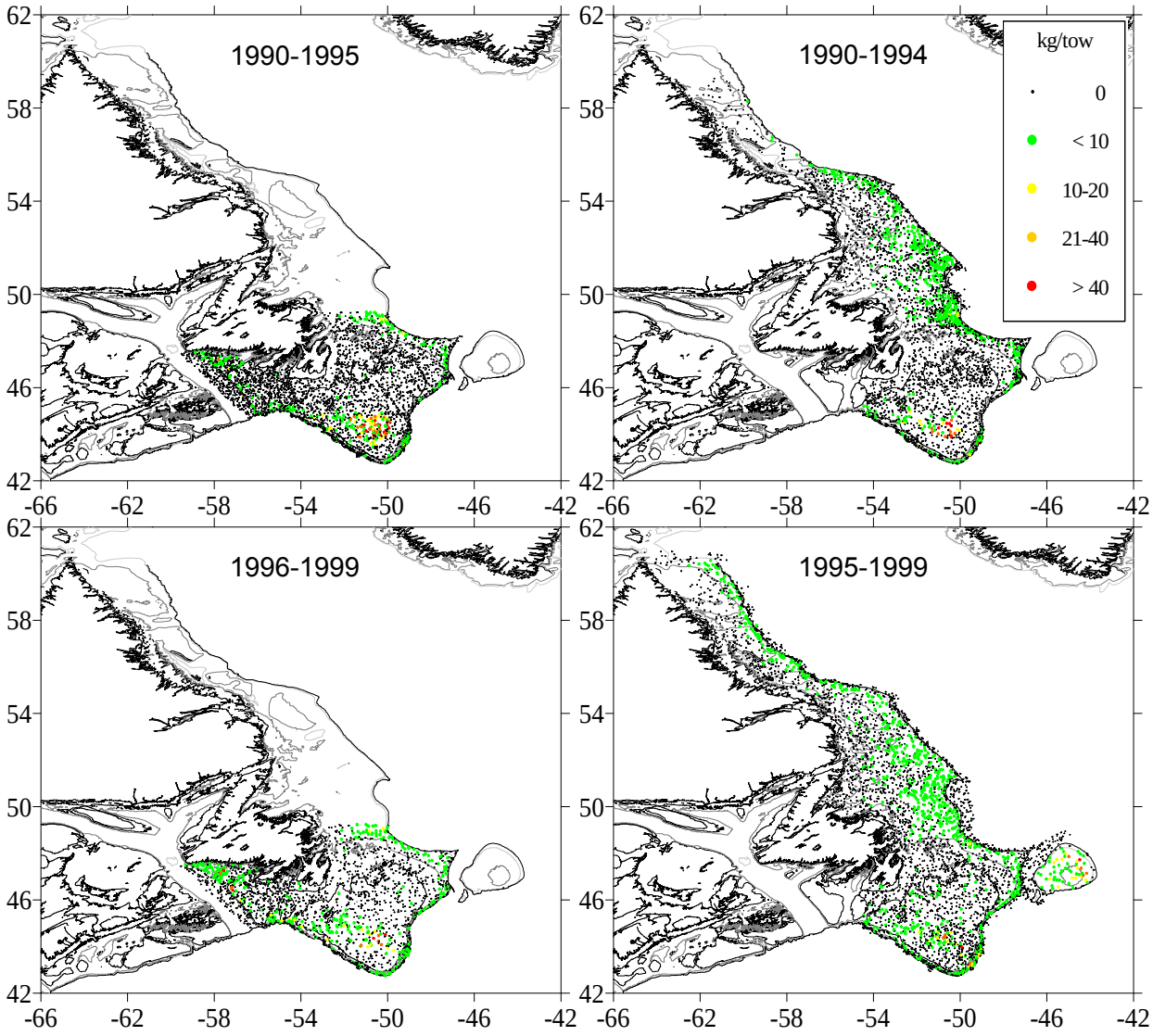


Figure 3 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Atlantic Wolffish in the NL Region, 1990-99.

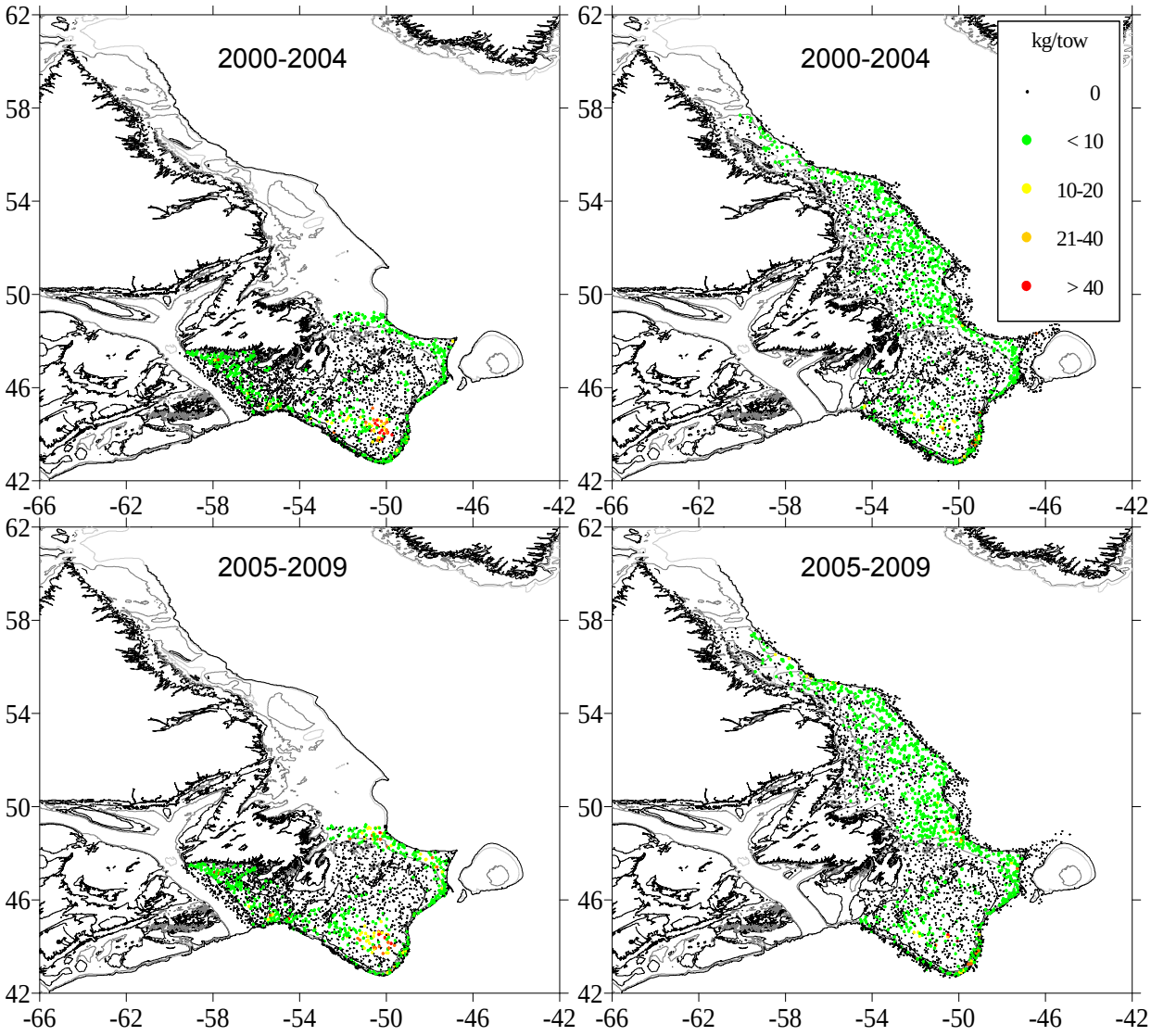


Figure 3 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Atlantic Wolffish in the NL Region, 2000-09.

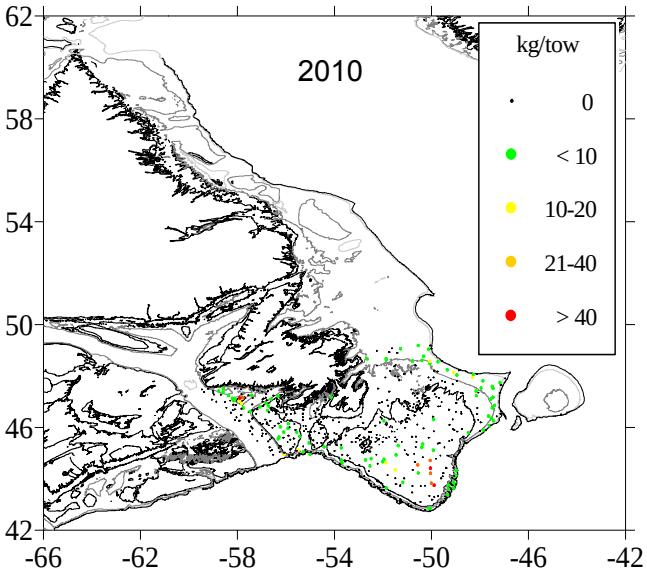


Figure 3 (cont'd.). Geographic distribution of spring research survey catch rates (kg/tow) for Atlantic Wolffish in the NL Region, 2010.

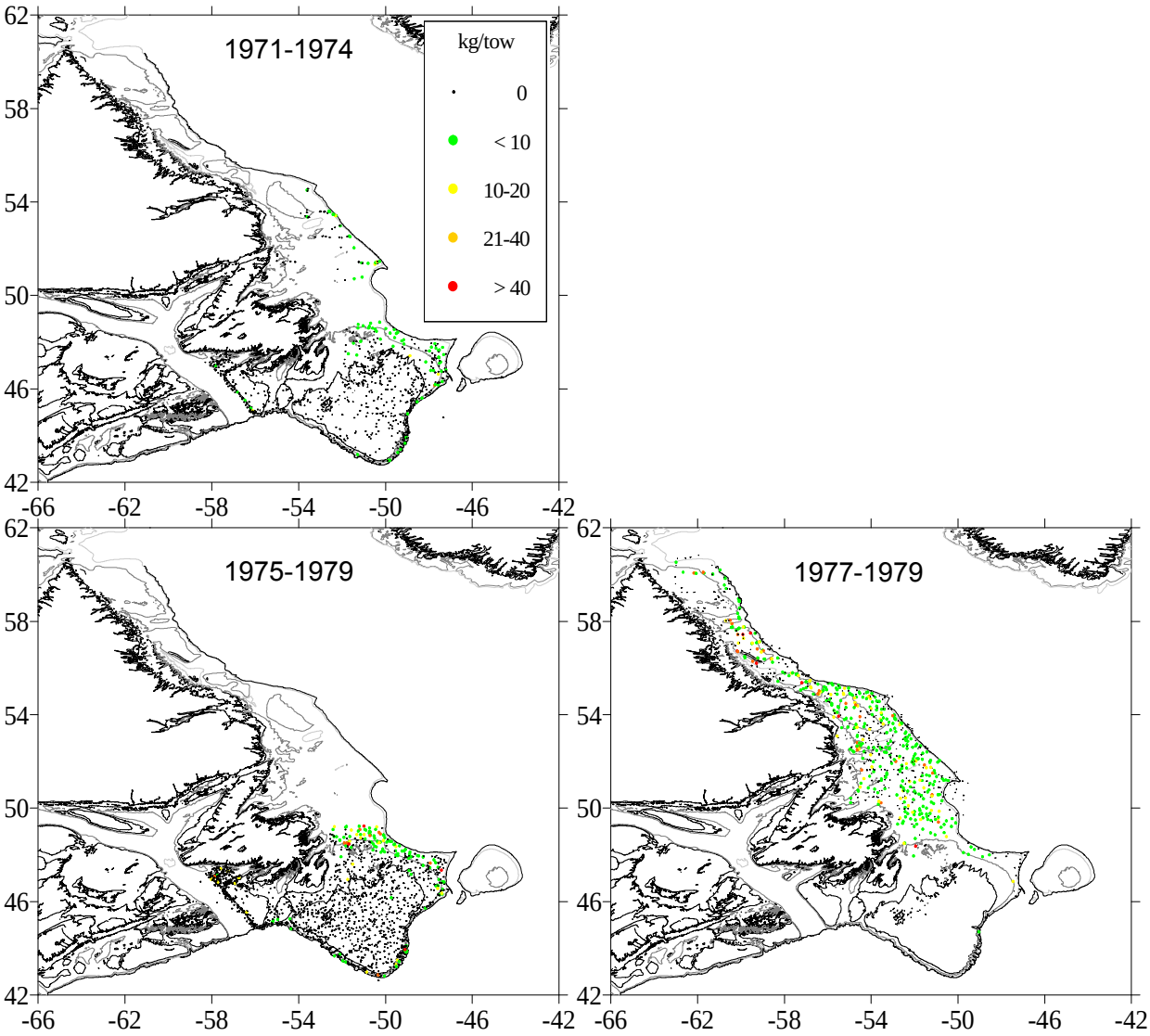


Figure 4. Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Spotted Wolffish in the NL Region, 1971-79.

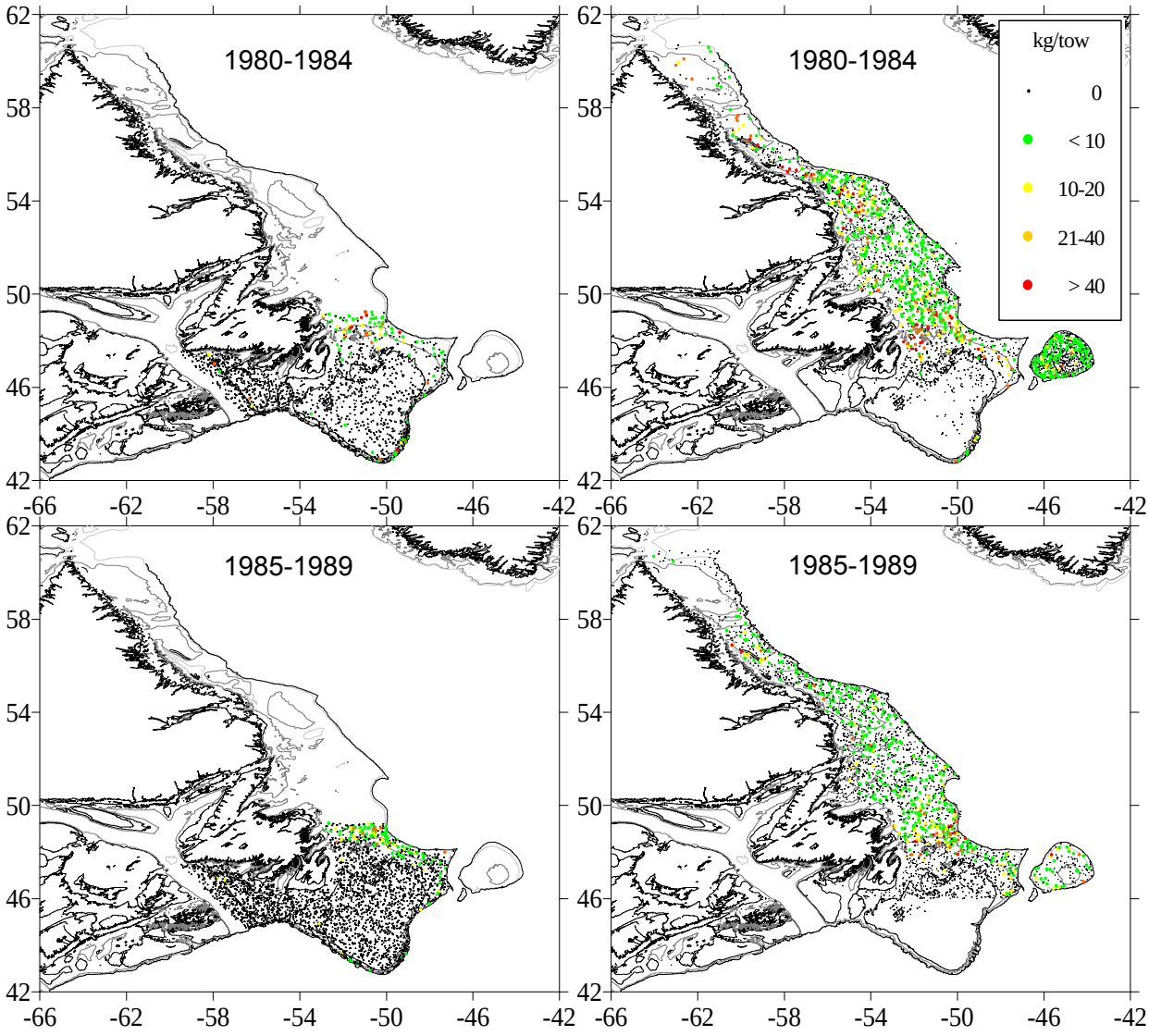


Figure 4 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Spotted Wolffish in the NL Region, 1980-89.

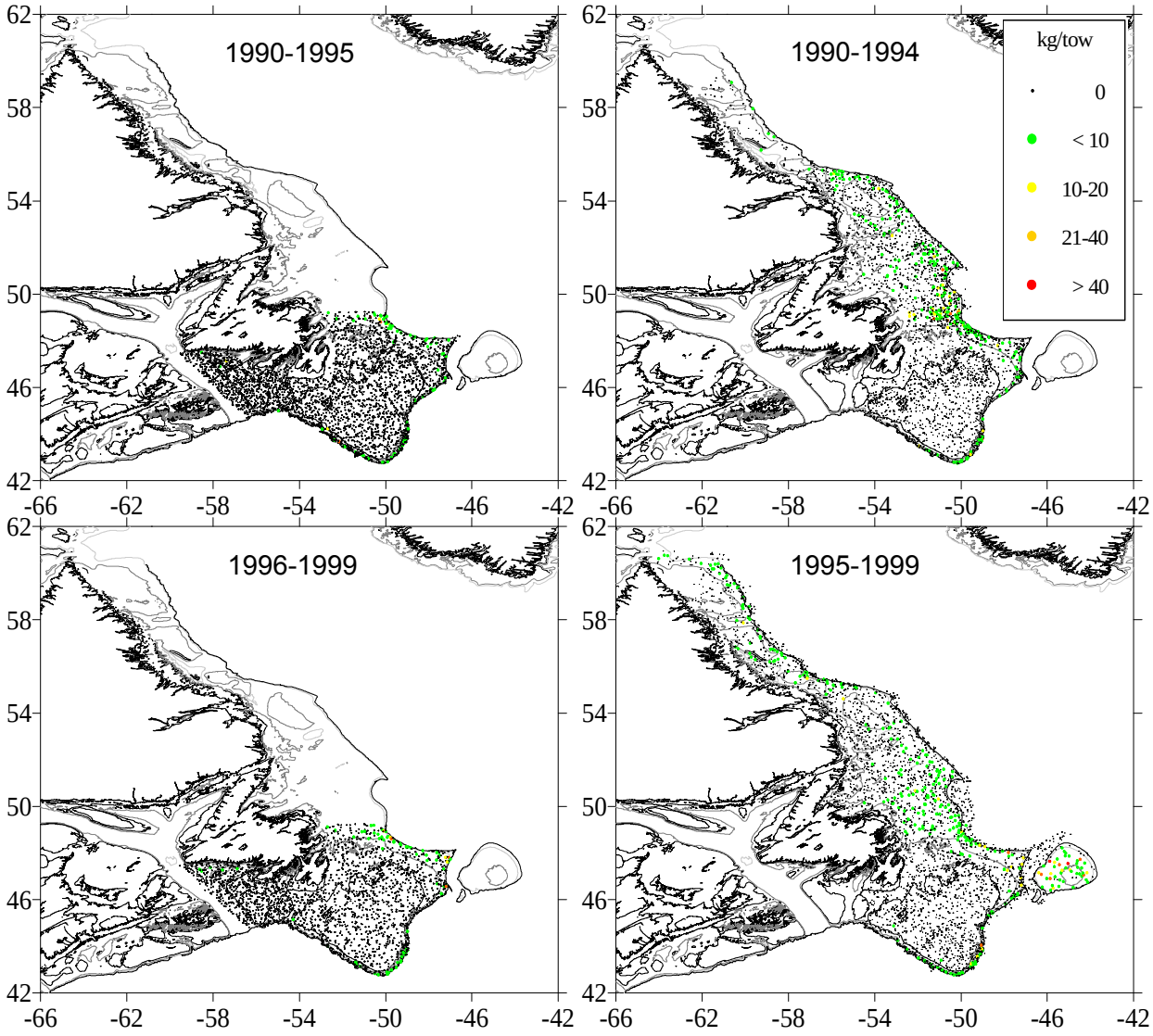


Figure 4 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Spotted Wolffish in the NL Region, 1990-99.

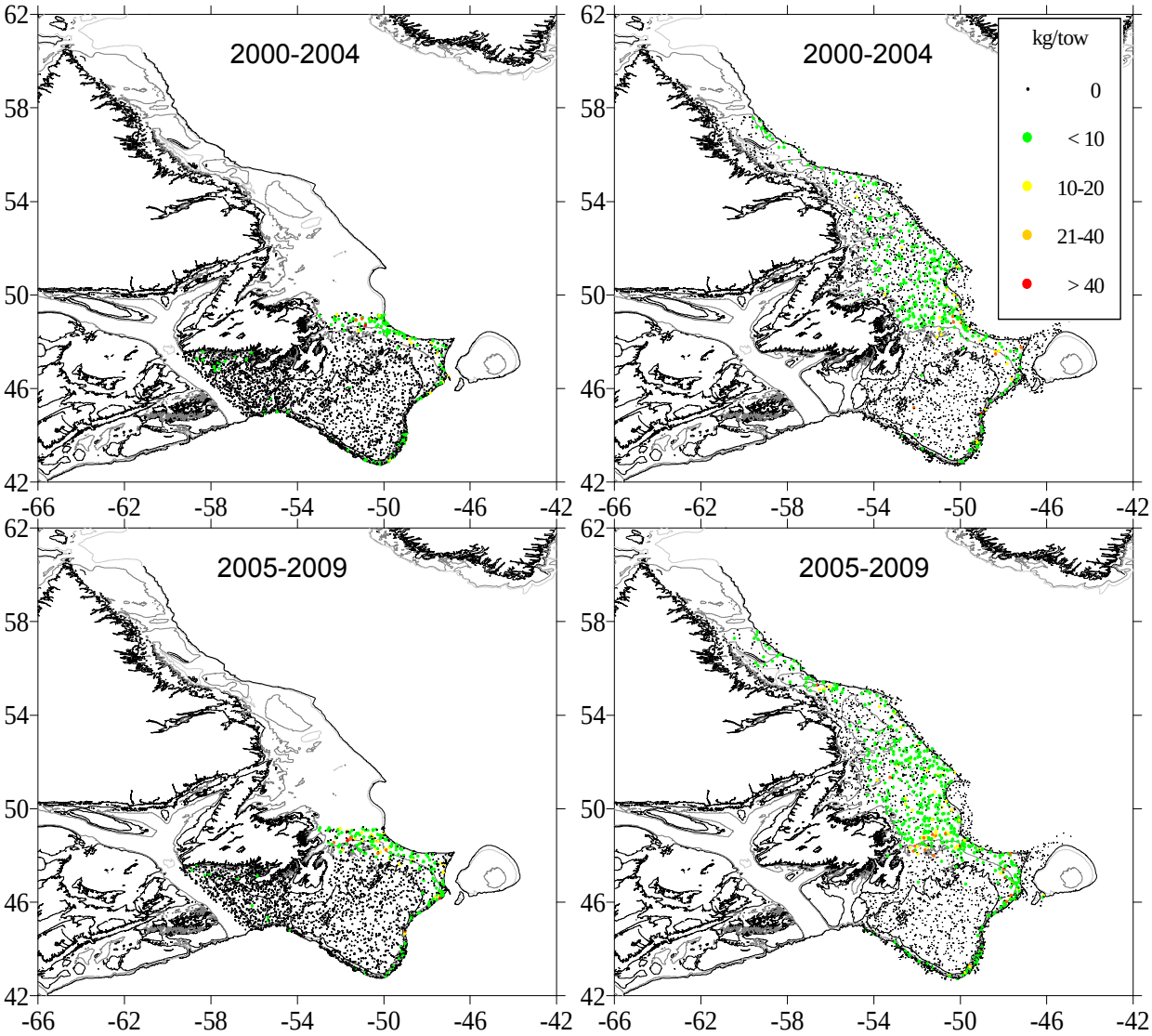


Figure 4 (cont'd.). Geographic distribution of spring (left panels) and fall (right panels) research survey catch rates (kg/tow) for Spotted Wolffish in the NL Region, 2000-09.

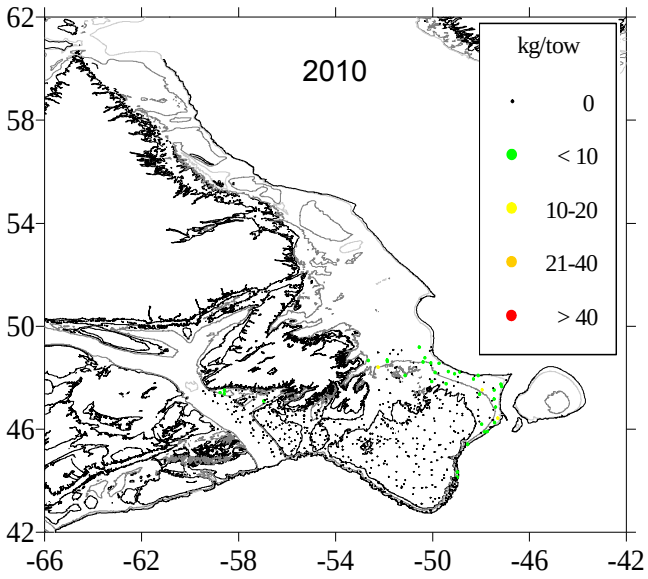


Figure 4 (cont'd.). Geographic distribution of spring research survey catch rates (kg/tow) for Spotted Wolffish in the NL Region, 2010.

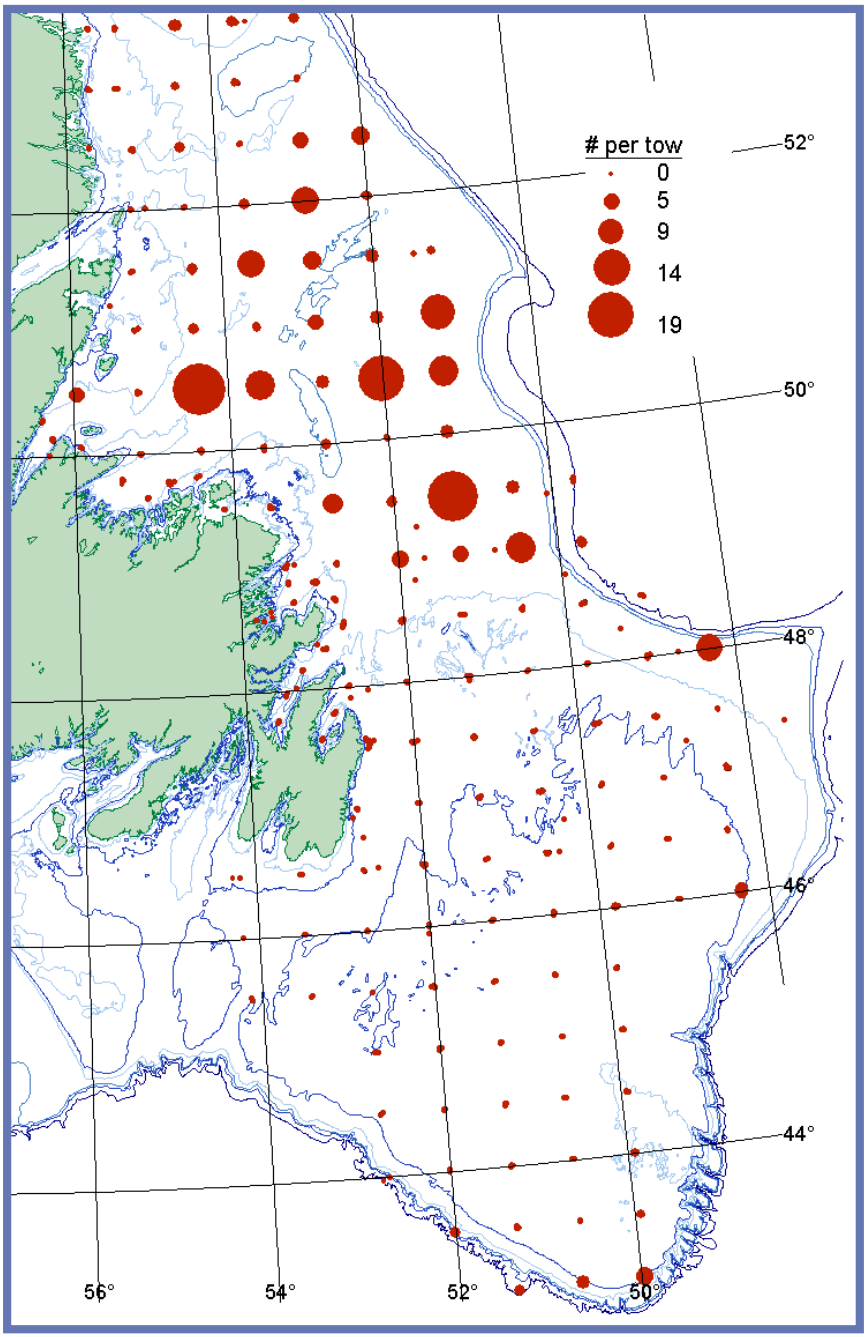


Figure 5. Geographic distribution of the IYGPT Juvenile Groundfish research survey catch rates (number/tow) for Atlantic Wolffish in the NL Region. Plots represent the cumulative distribution of juvenile fish for the entire time series (1985-94).

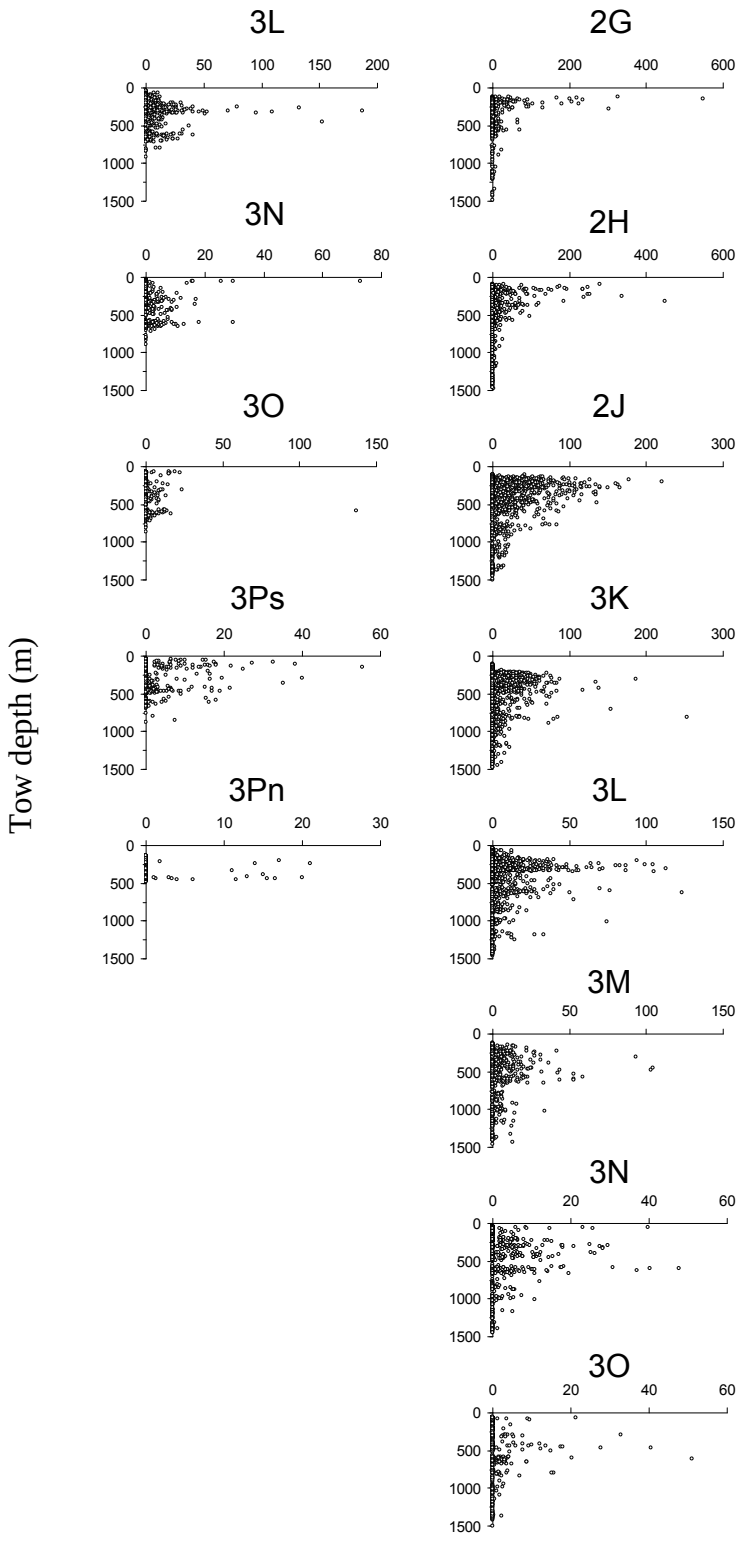


Figure 6. Distribution of spring (1971-2010; left column) and fall (1977-2009; right column) research survey catch rates (kg/tow) for Northern Wolffish by depth in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

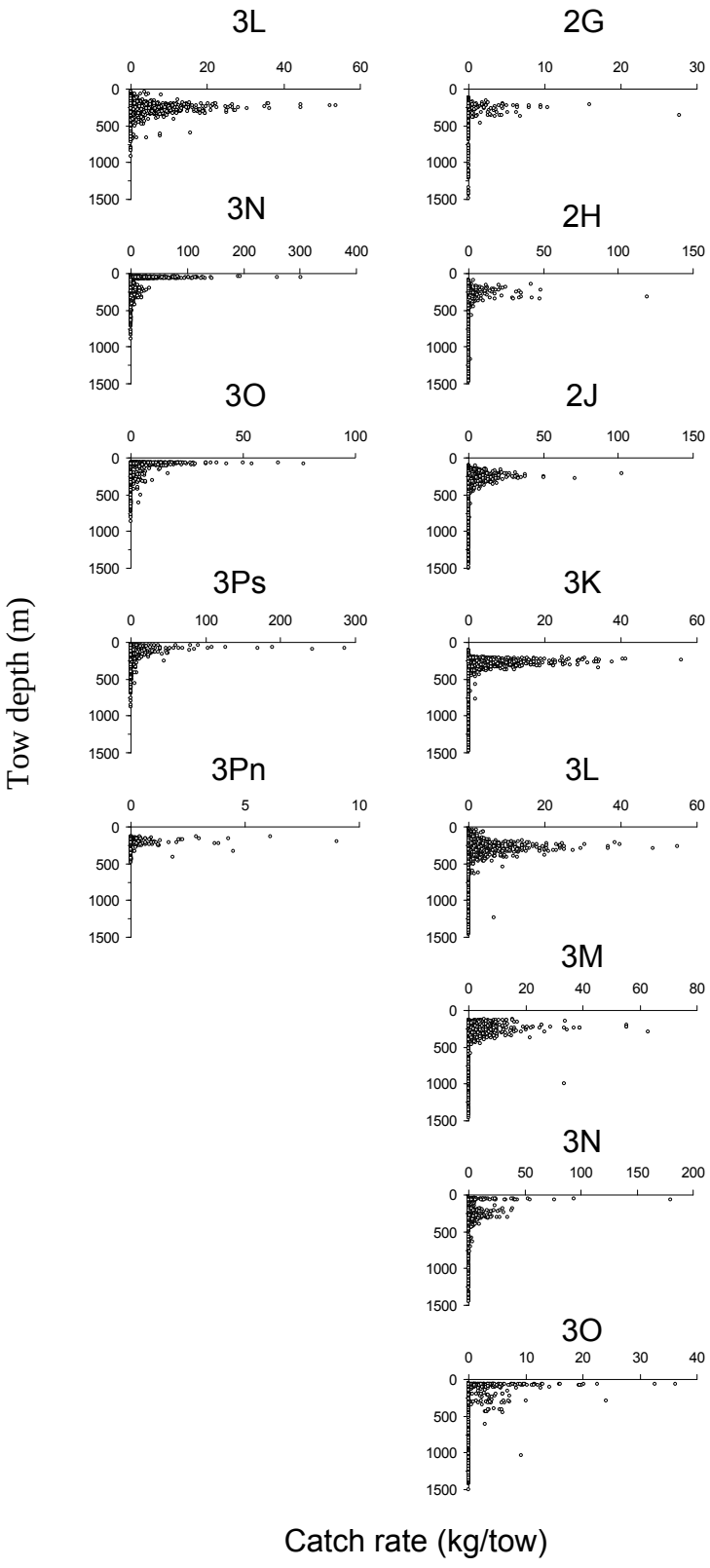


Figure 7. Distribution of spring (1971-2010; left column) and fall (1977-2009; right column) research survey catch rates (kg/tow) for Atlantic Wolffish by depth in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

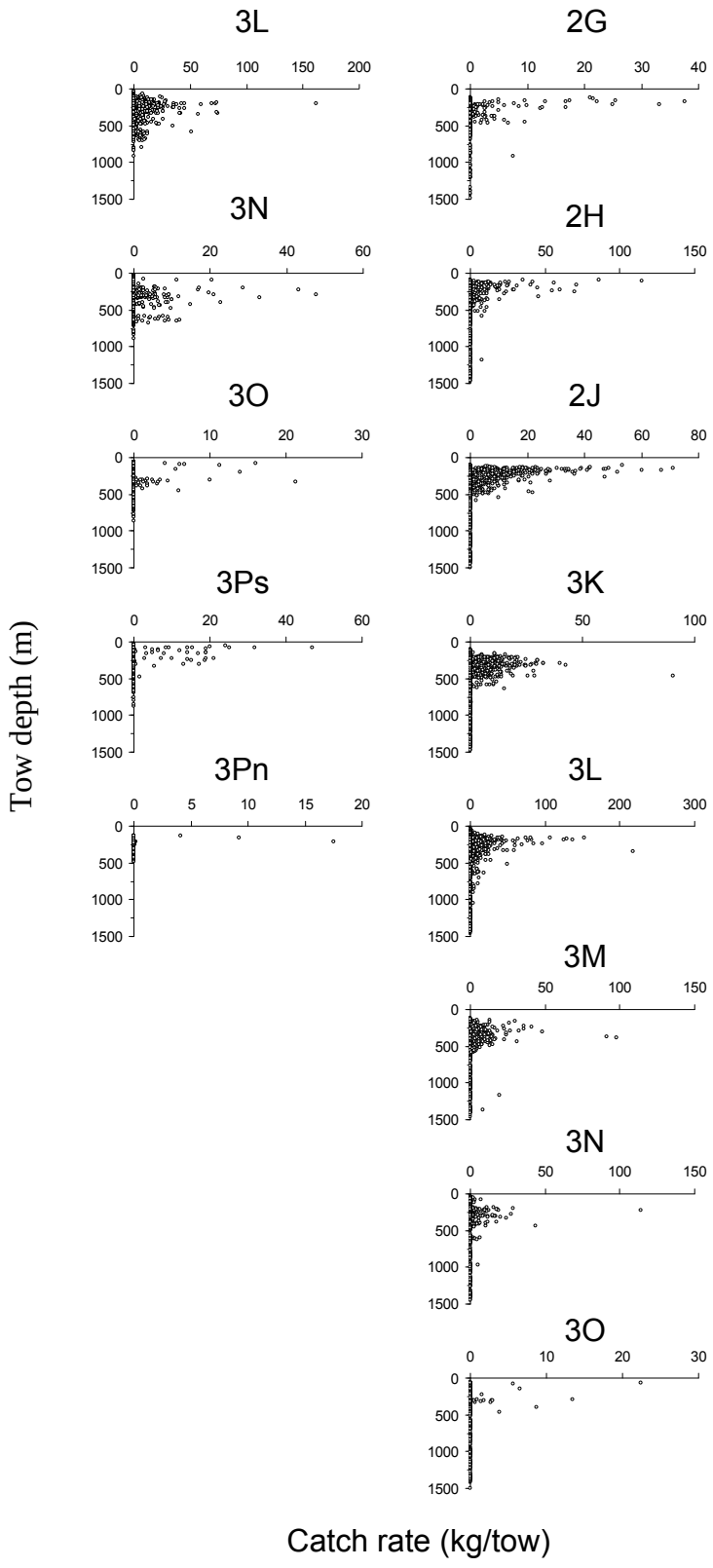


Figure 8. Distribution of spring (1971-2010; left column) and fall (1977-2009; right column) research survey catch rates (kg/tow) for Spotted Wolffish by depth in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

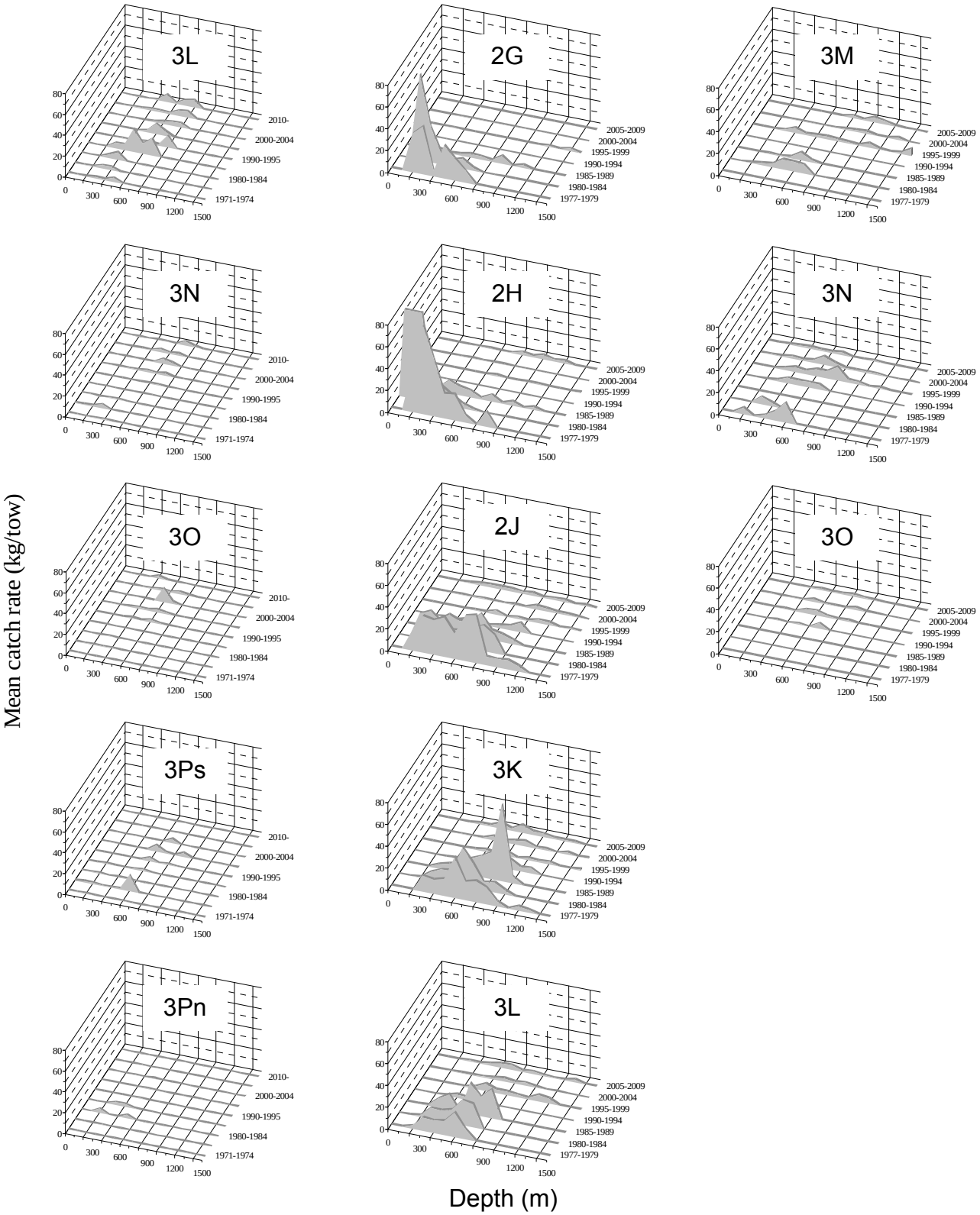


Figure 9. Distribution of Northern Wolffish mean catch rates by depth during spring (1971-2010; left column) and fall (1977-2009; center and right columns) research surveys in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

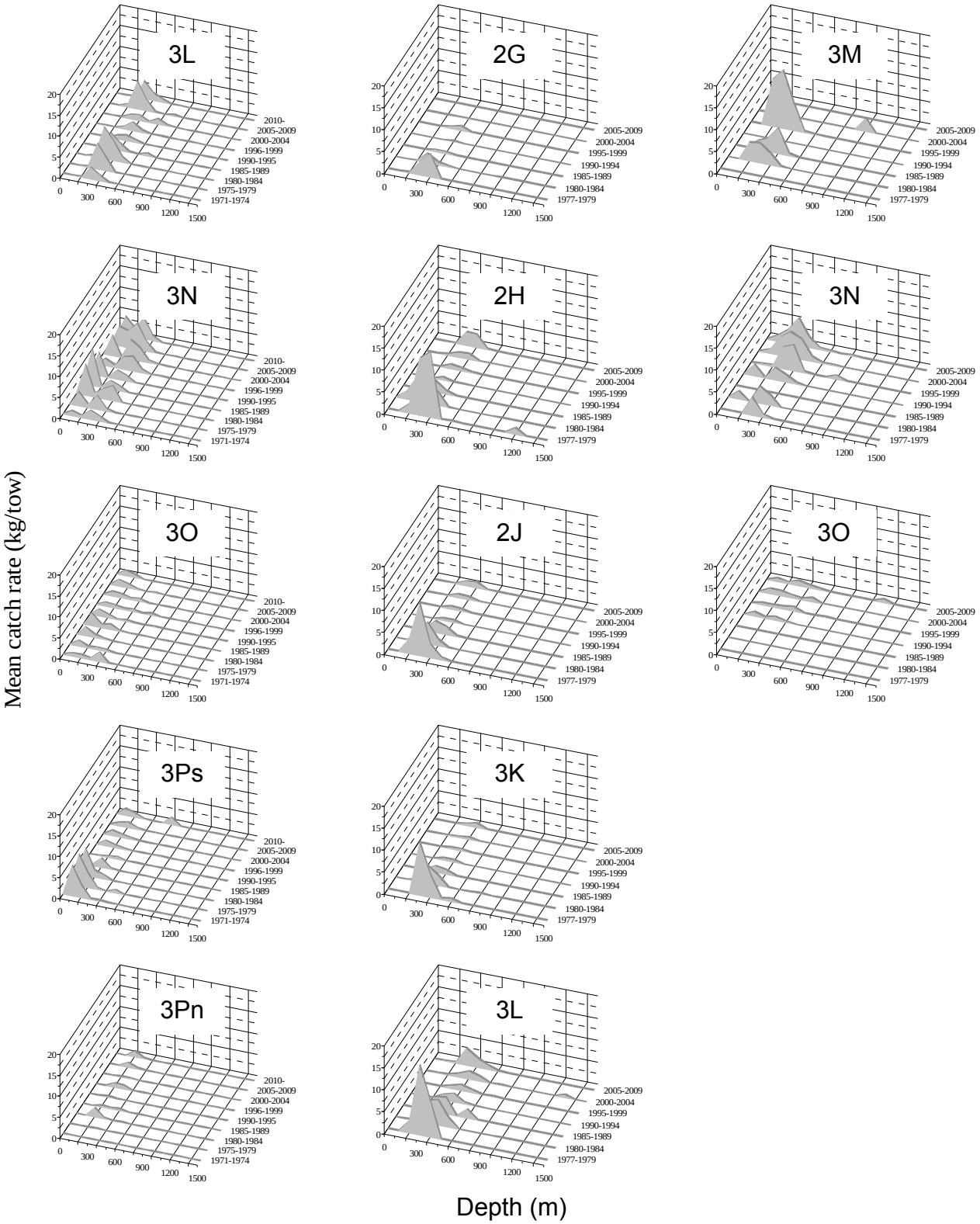


Figure 10. Distribution of Atlantic Wolffish mean catch rates by depth during spring (1971-2010; left column) and fall (1977-2009; center and right columns) research surveys in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

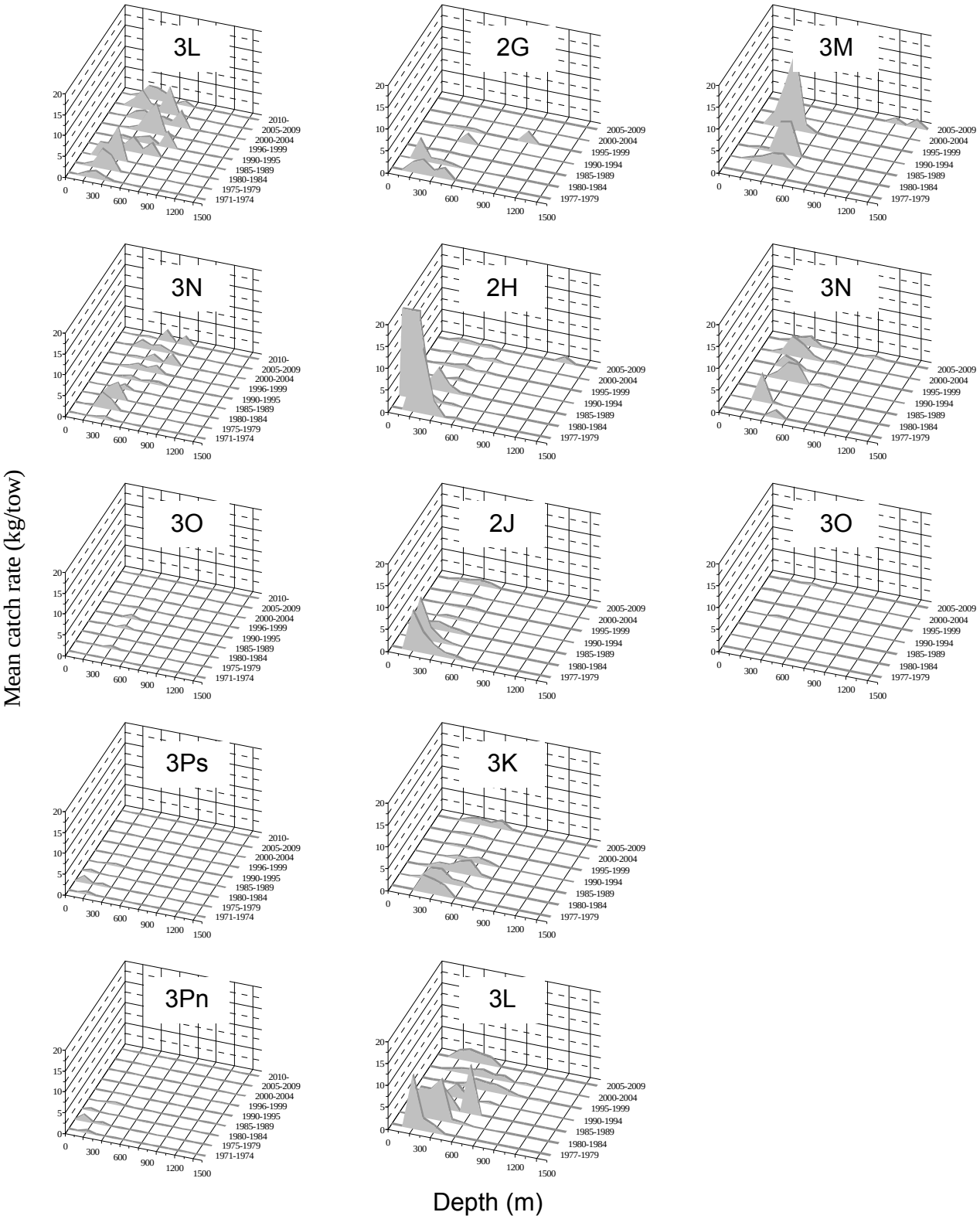


Figure 11. Distribution of Spotted Wolffish mean catch rates by depth during spring (1971-2010; left column) and fall (1977-2009; center and right columns) research surveys in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

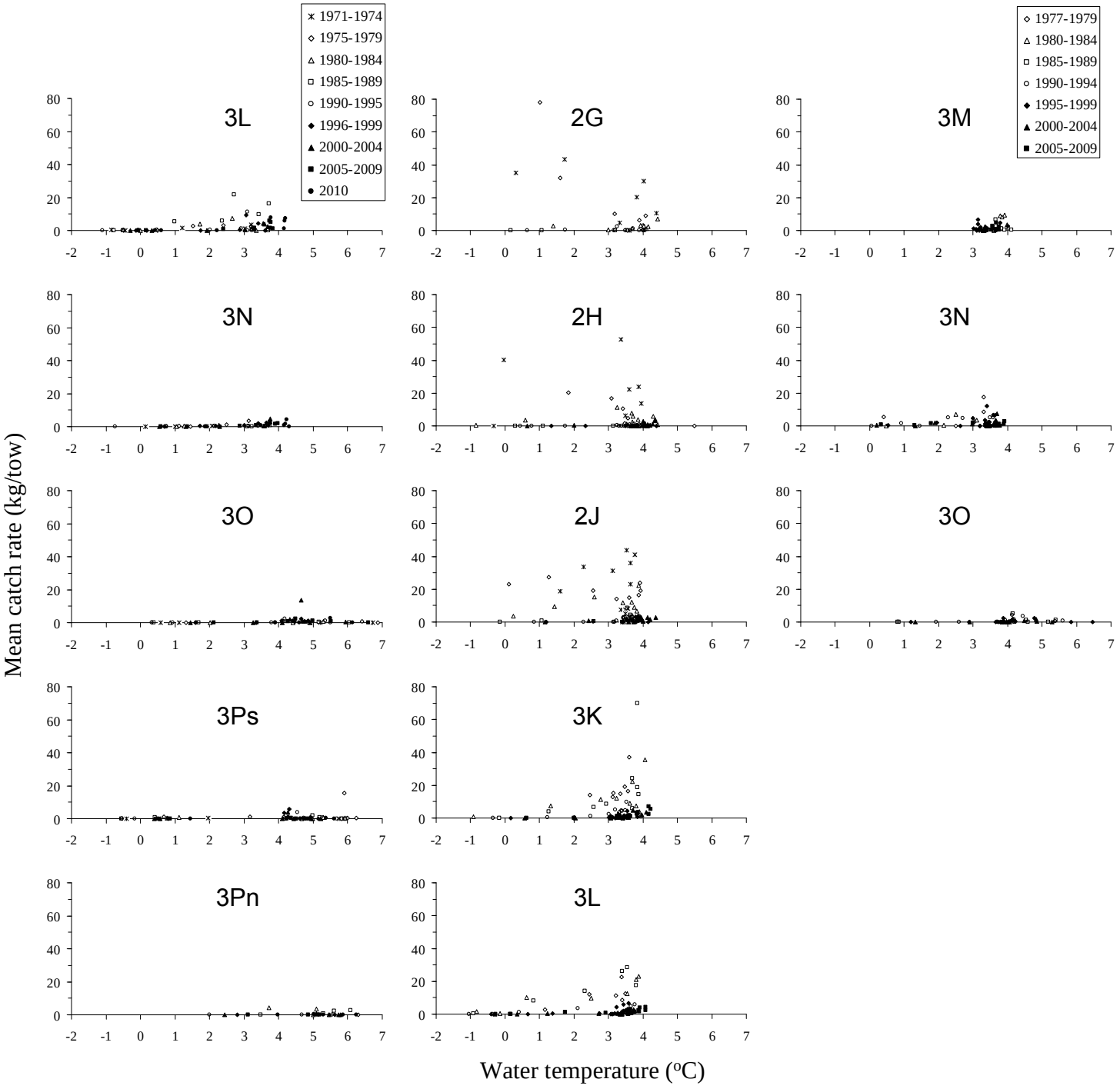


Figure 12. Distribution of Northern Wolffish mean catch rates by temperature at tow depth during spring (1971-2010; left column) and fall (1977-2009; center and right columns) research surveys in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

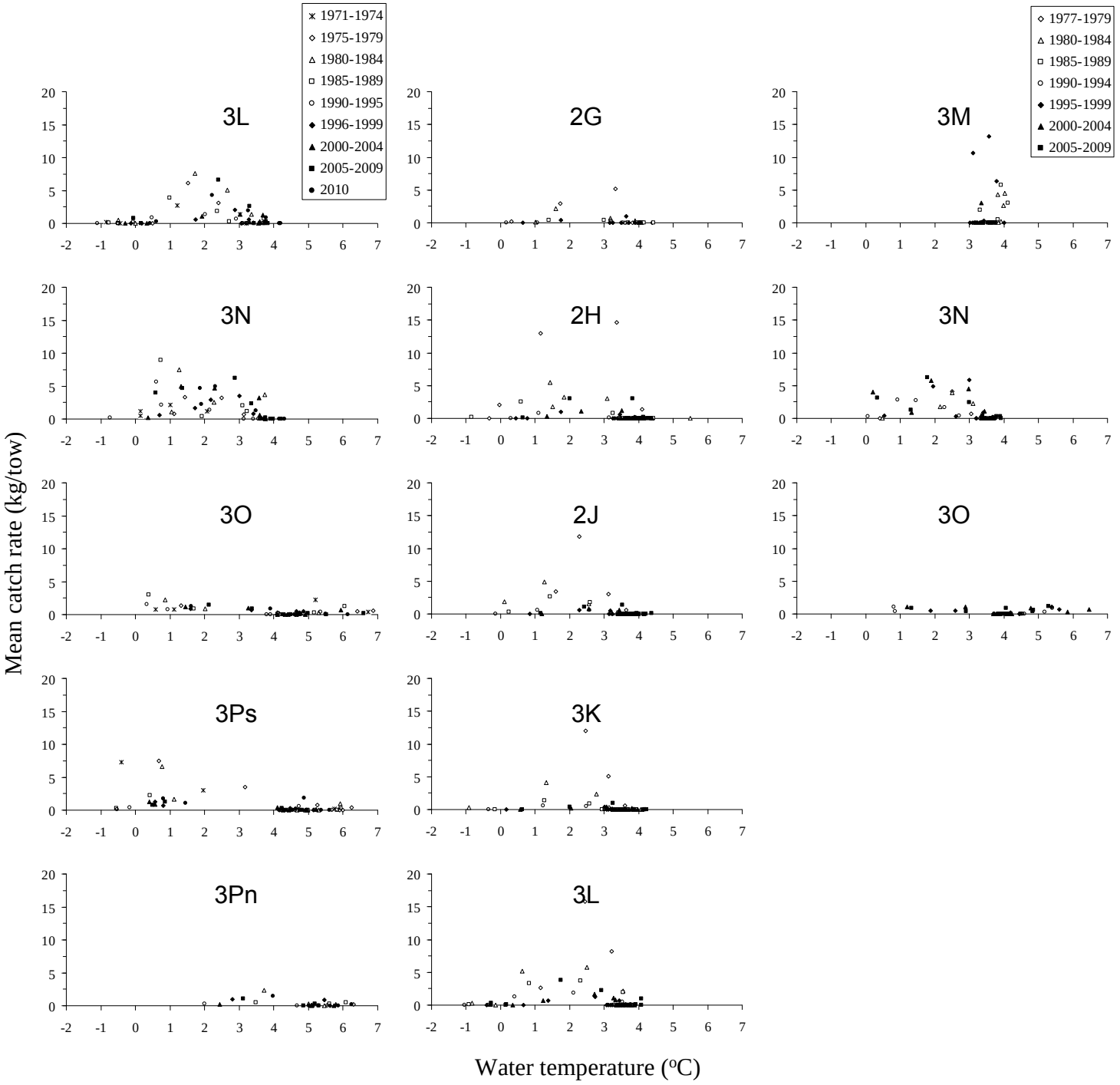


Figure 13. Distribution of Atlantic Wolffish mean catch rates by temperature at tow depth during spring (1971-2010; left column) and fall (1977-2009; center and right columns) research surveys in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

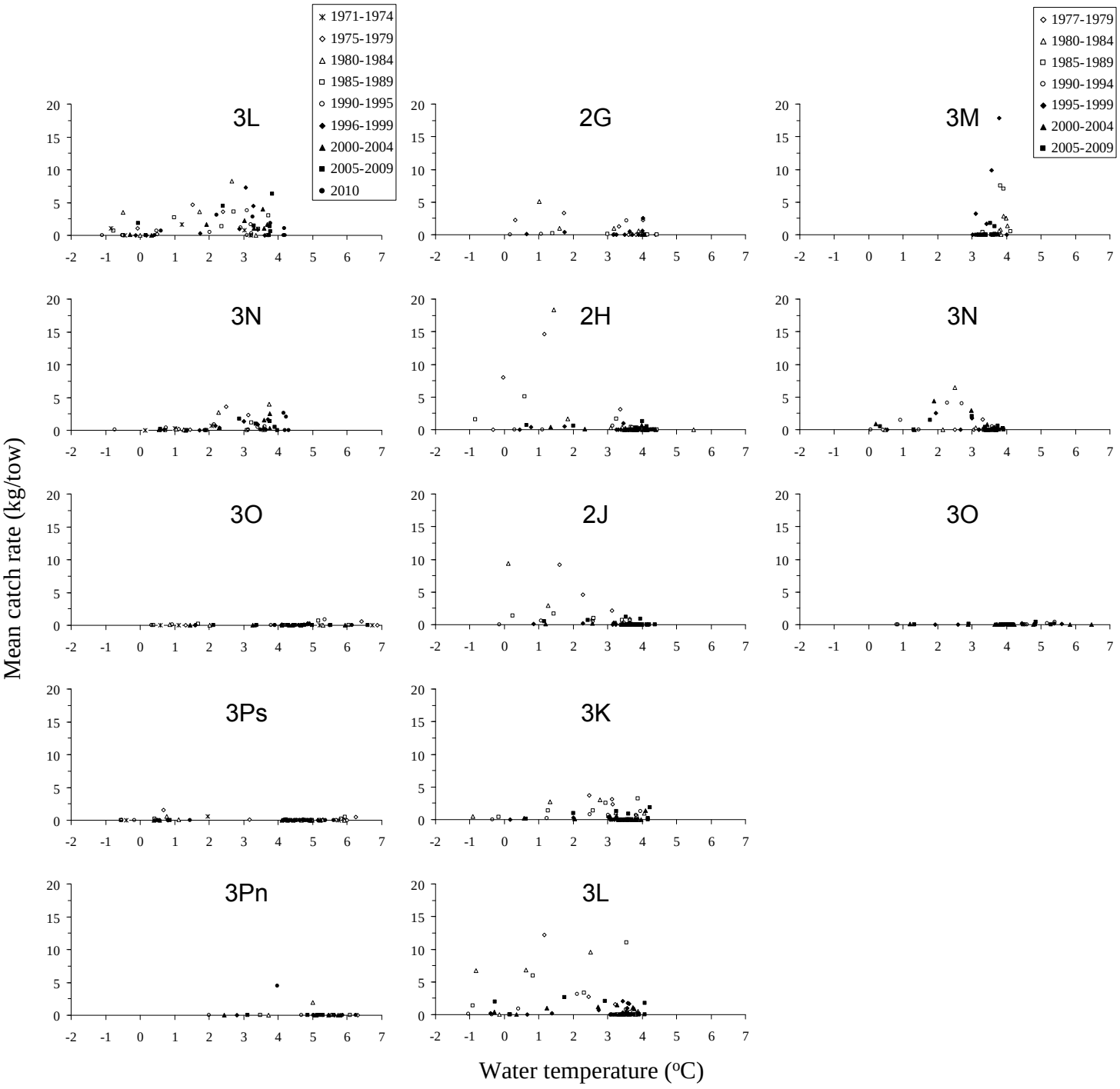


Figure 14. Distribution of Spotted Wolffish mean catch rates by temperature at tow depth during spring (1971-2010; left column) and fall (1977-2009; center and right columns) research surveys in Division 2GHJ3KLMNO and Subdivision 3Ps, 3Pn.

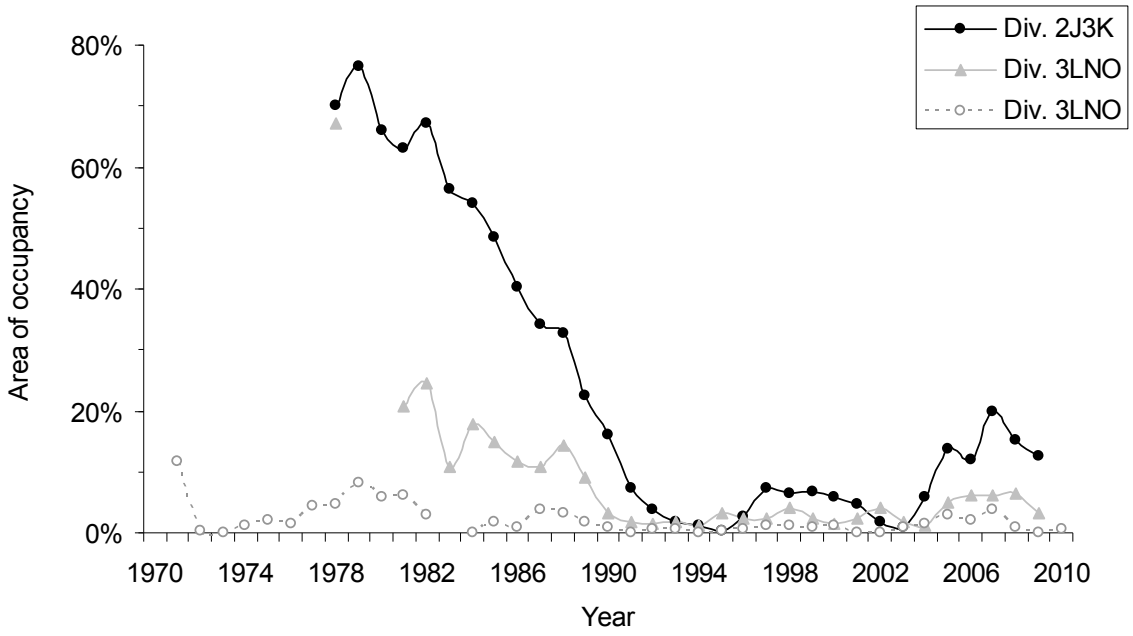


Figure 15. Area of occupancy for Northern Wolffish in Division 2J3K and Division 3LNO in spring (1971-2010; open symbol) and fall (1978-2009; closed symbol). Survey trawl gear changed from Yankee to Engel in 1983, and from Engel to Campelen in fall 1995 and spring 1996.

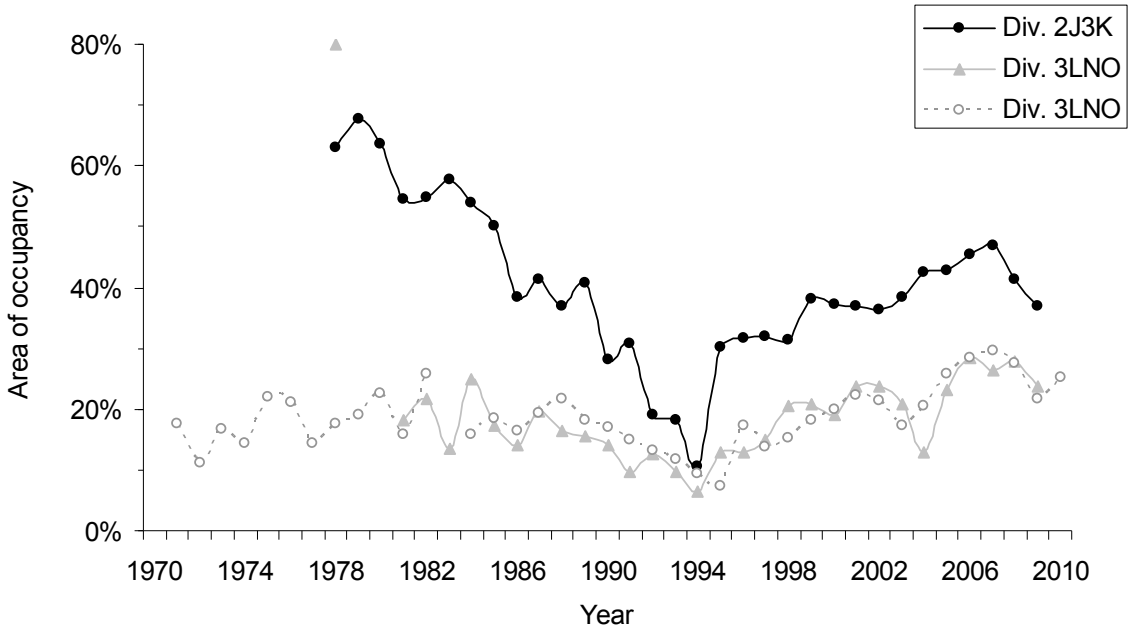


Figure 16. Area of occupancy for Atlantic Wolffish in Division 2J3K and Division 3LNO in spring (1971-2010; open symbol) and fall (1978-2009; closed symbol). Survey trawl gear changed from Yankee to Engel in 1983, and from Engel to Campelen in fall 1995 and spring 1996.

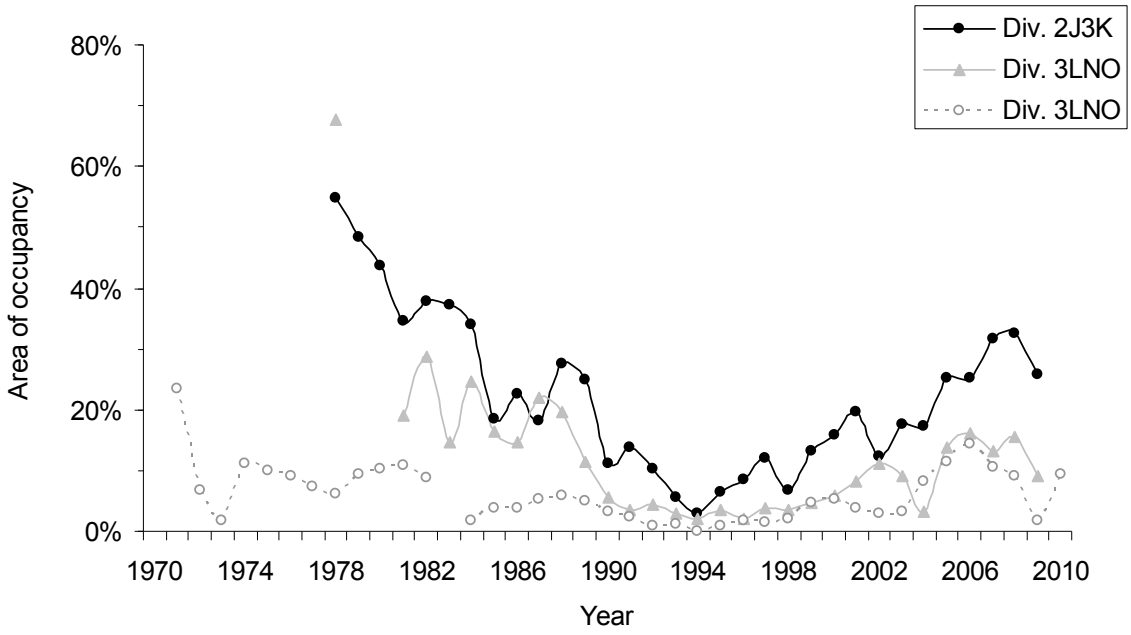


Figure 17. Area of occupancy for Spotted Wolffish in Division 2J3K and Division 3LNO in spring (1971-2010; open symbol) and fall (1978-2009; closed symbol). Survey trawl gear changed from Yankee to Engel in 1983, and from Engel to Campelen in fall 1995 and spring 1996.

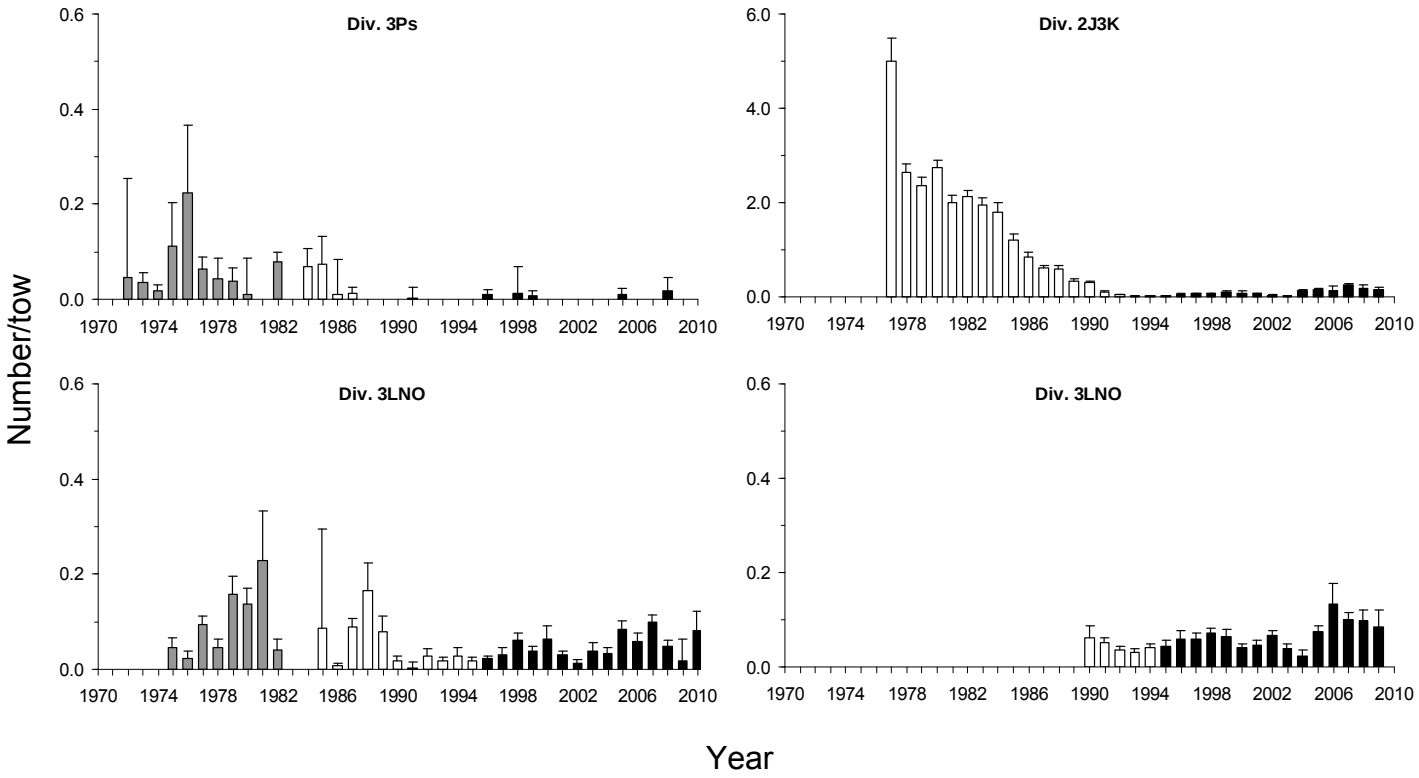


Figure 18. Research survey standardised indices of relative abundance for Northern Wolffish in Division 3LNO and Subdivision 3Ps in spring (left column), and Division 2J3K and Division 3LNO in fall (right column). T-bar = 1 SE. Survey trawl gear changed from Yankee (grey bar) to Engel (white bar) in 1983, and from Engel to Campelen (black bar) in fall 1995 and spring 1996.

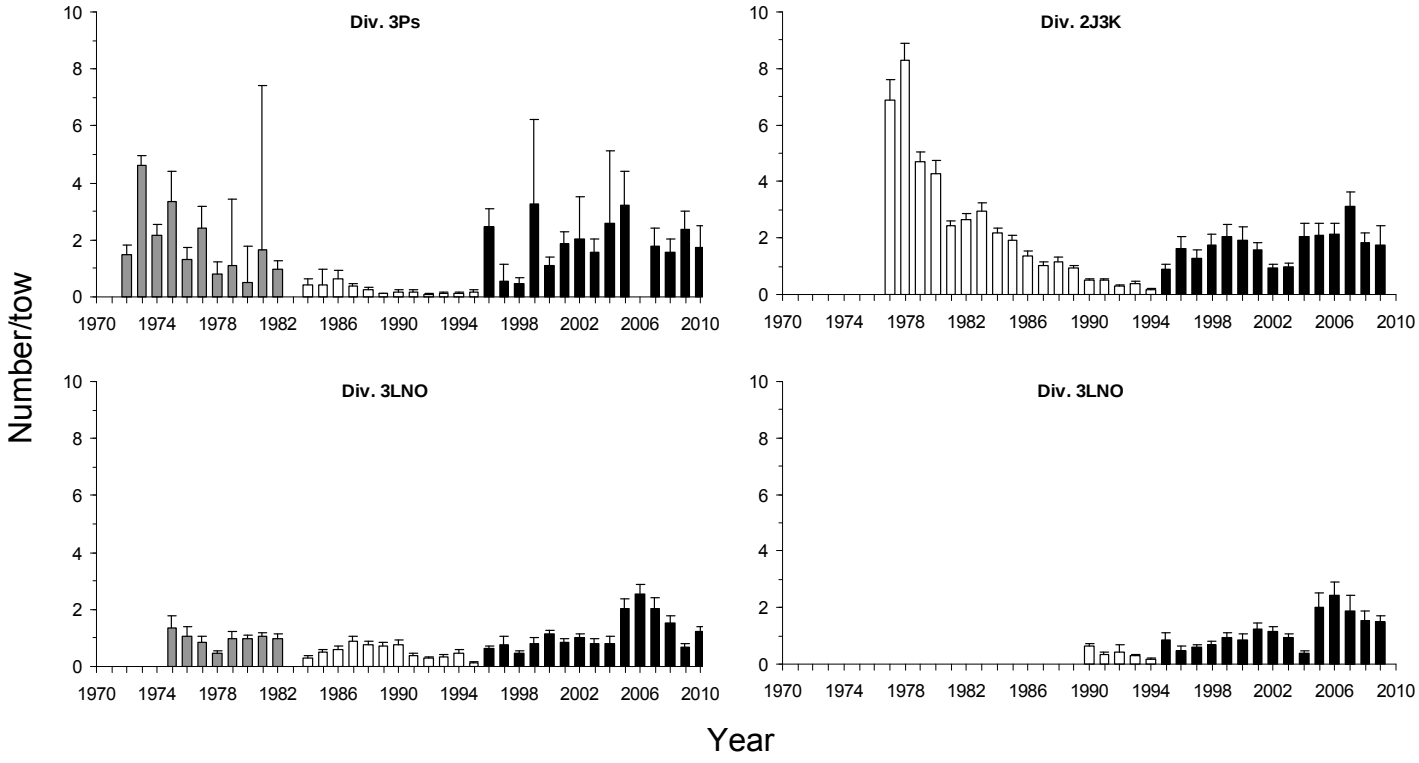


Figure 19. Research survey standardised indices of relative abundance for Atlantic Wolffish in Division 3LNO and Subdivision 3Ps in spring (left column), and Division 2J3K and Division 3LNO in fall (right column). T-bar = 1 SE. Survey trawl gear changed from Yankee (grey bar) to Engel (white bar) in 1983, and from Engel to Campelen (black bar) in fall 1995 and spring 1996.

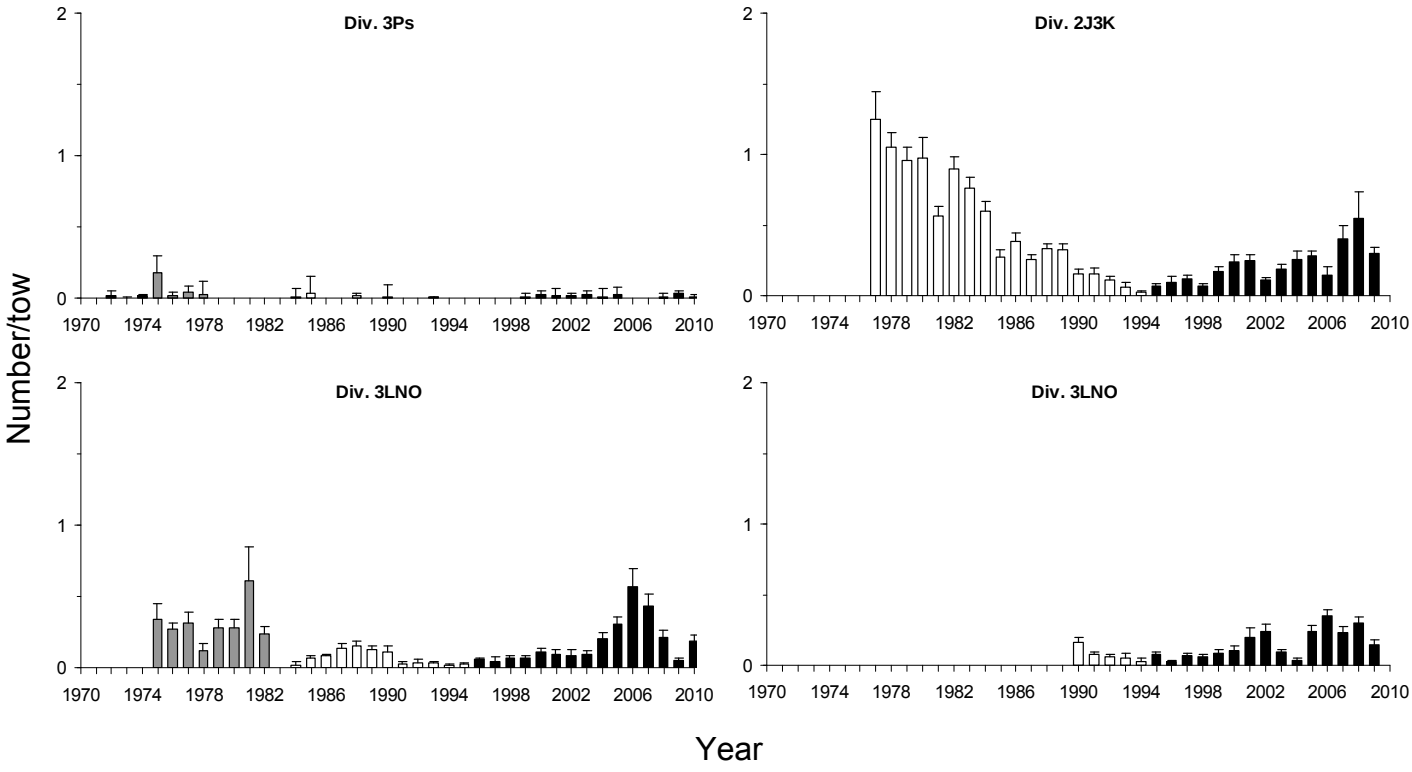


Figure 20. Research survey standardised indices of relative abundance for Spotted Wolffish in Division 3LNO and Subdivision 3Ps in spring (left column), and Division 2J3K and Division 3LNO in fall (right column). T-bar = 1 SE. Survey trawl gear changed from Yankee (grey bar) to Engel (white bar) in 1983, and from Engel to Campelen (black bar) in fall 1995 and spring 1996.

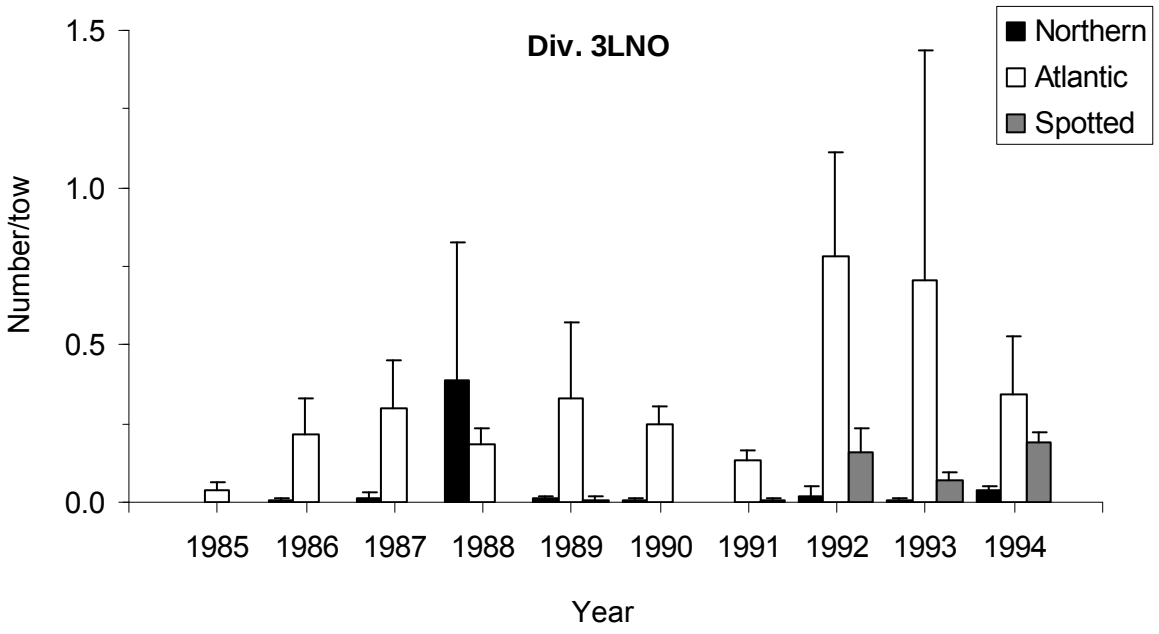


Figure 21. Juvenile Groundfish research survey indices of relative abundance (mean number/tow by survey) for Wolffish species in Division 3LNO in 1985-94. T-bar = 1 SE.

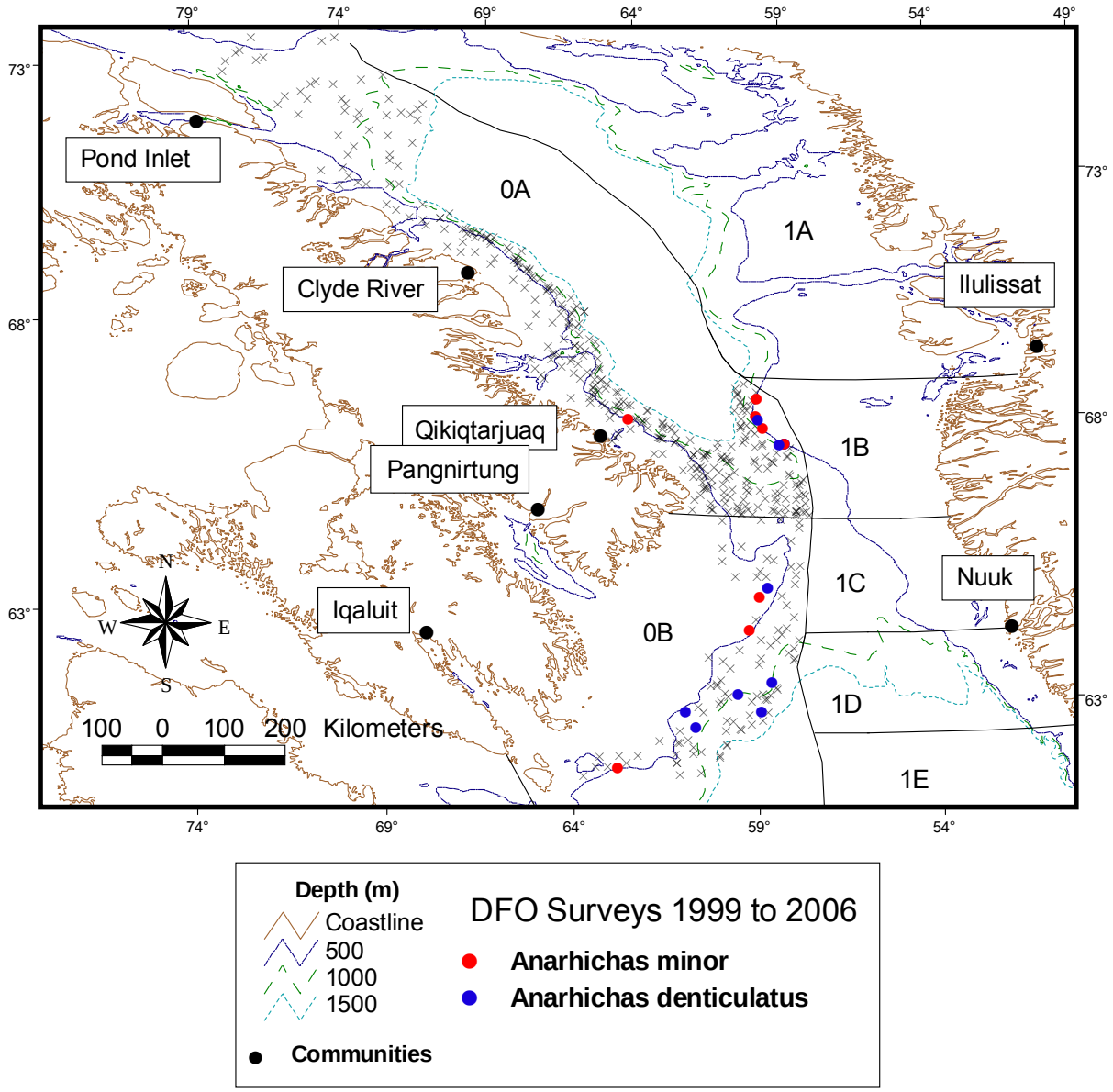
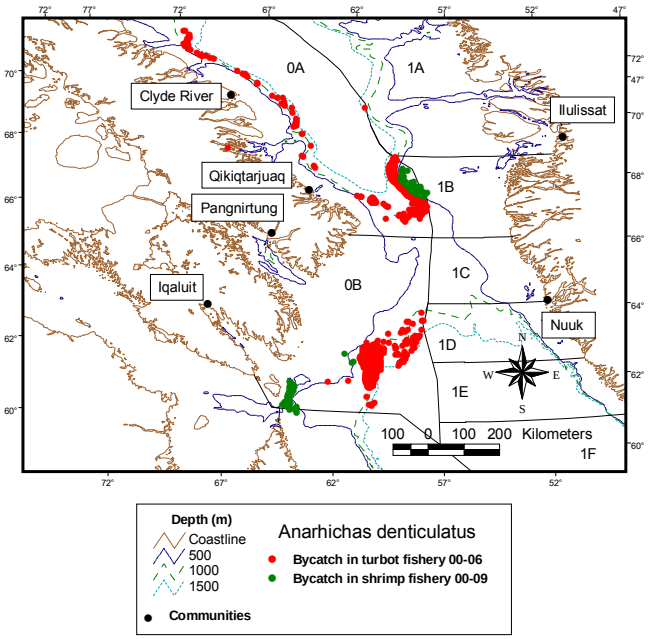


Figure 22. Distribution of DFO survey tows with the occurrence of Wolffish in NAFO SA 0 and Hudson Strait, 1999-2006. Depth information and tow locations with no catch (×) are also shown.



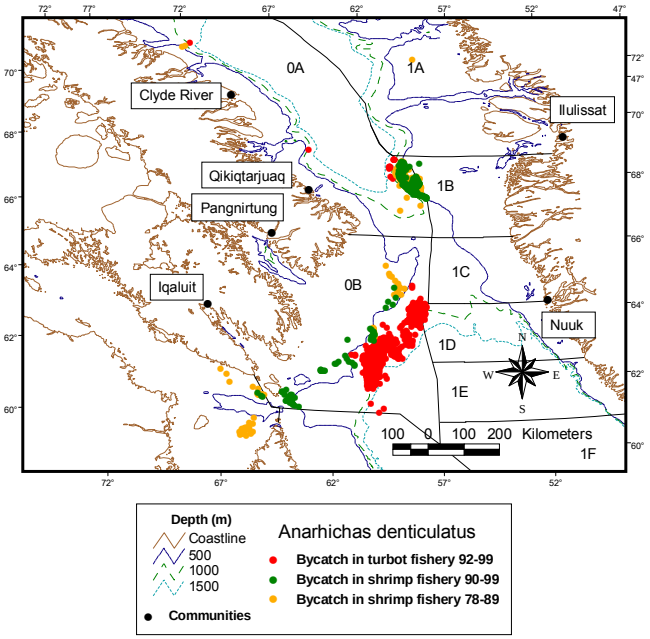


Figure 23. Distribution of commercial tows with the occurrence of Northern Wolffish bycatch in the Greenland Halibut fishery in NAFO SA 0A and 0B (red circles), and the Northern Shrimp fishery in SFA 0, 1, 2, and 3 (green and yellow circles). Depth information is also shown.

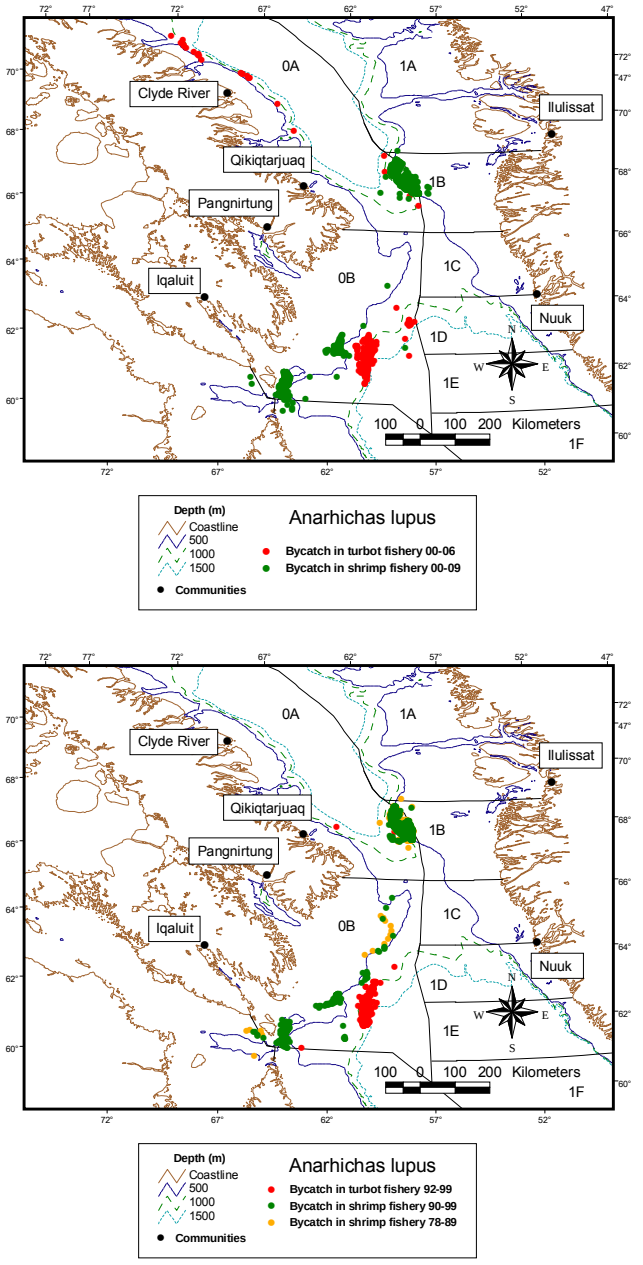


Figure 24. Distribution of commercial tows with the occurrence of Atlantic Wolffish bycatch in the Greenland Halibut fishery in NAFO SA 0A and 0B (red circles), and the Northern Shrimp fishery in SFA 0, 1, 2, and 3 (green and yellow circles). Depth information is also shown.

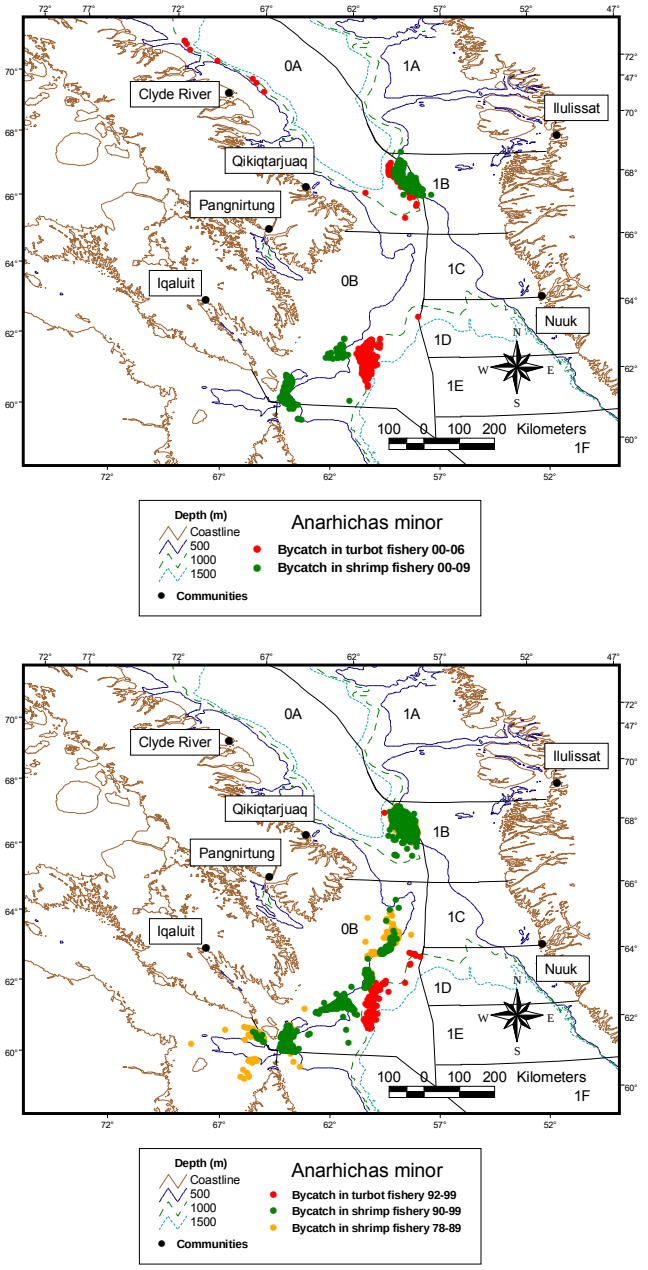


Figure 25. Distribution of commercial tows with the occurrence of Spotted Wolffish bycatch in the Greenland Halibut fishery in NAFO SA 0A and 0B (red circles), and the Northern Shrimp fishery in SFA 0, 1, 2, and 3 (green and yellow circles). Depth information is also shown.

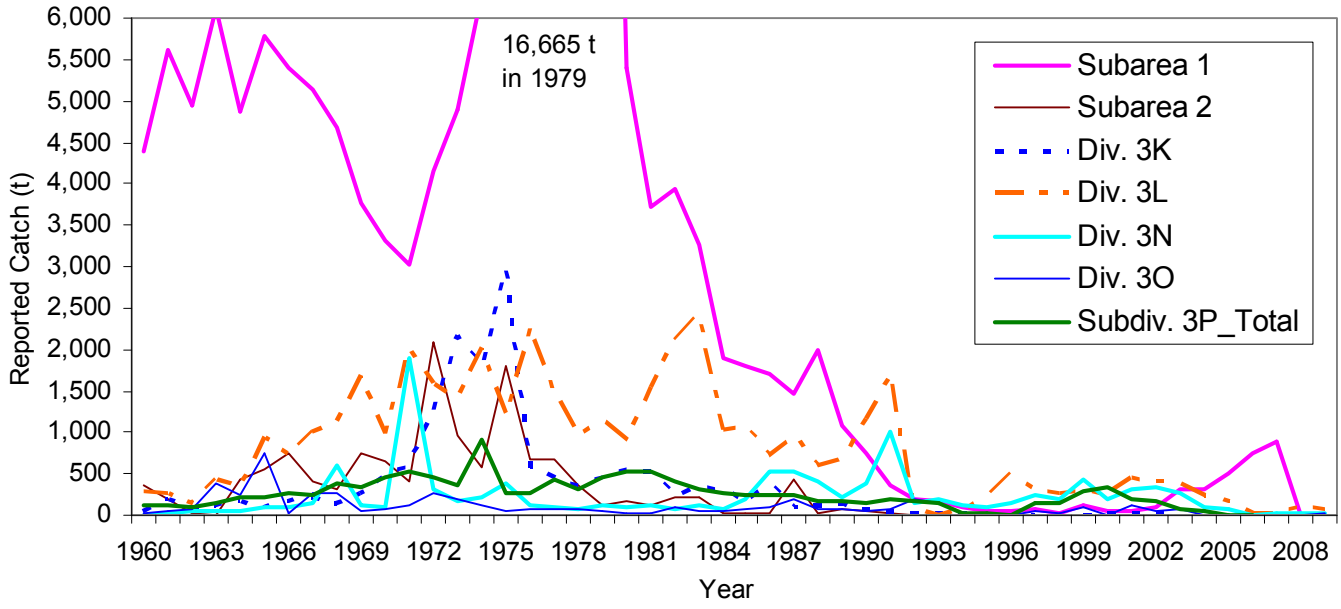


Figure 26. Reported catches of Wolffish (unspeciated; in tonnes) by Canada and other countries in NAFO Subareas 1, 2, and 3 in 1960-2009. Data are from NAFO's STATLANT-21A database. Subarea 1 and parts of Subarea 2 fall outside of Canadian waters.

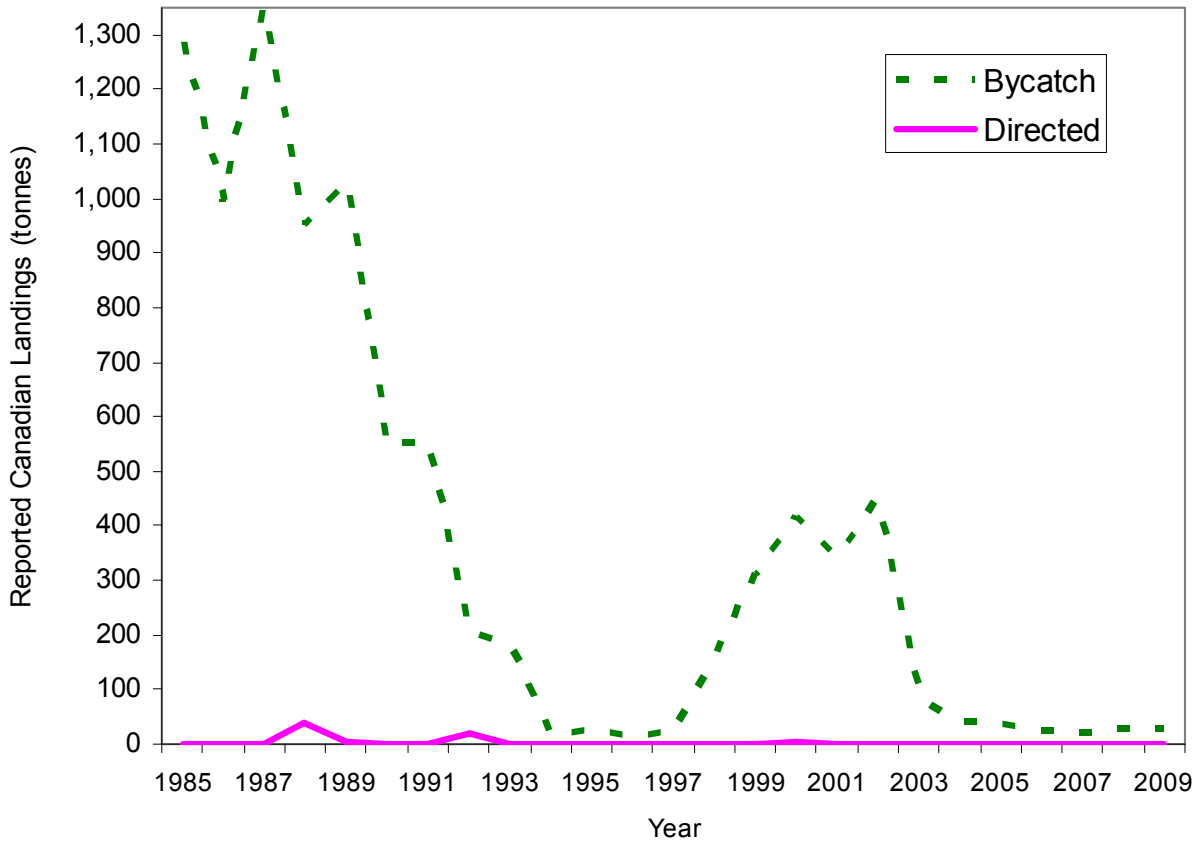


Figure 27. Directed and non-directed reported Wolffish landings (unspeciated; in tonnes) in Canada's EEZ of NAFO Subarea 0 and Division 2GHJ3KLNOP in 1985-2009. Data do not include discards at sea.

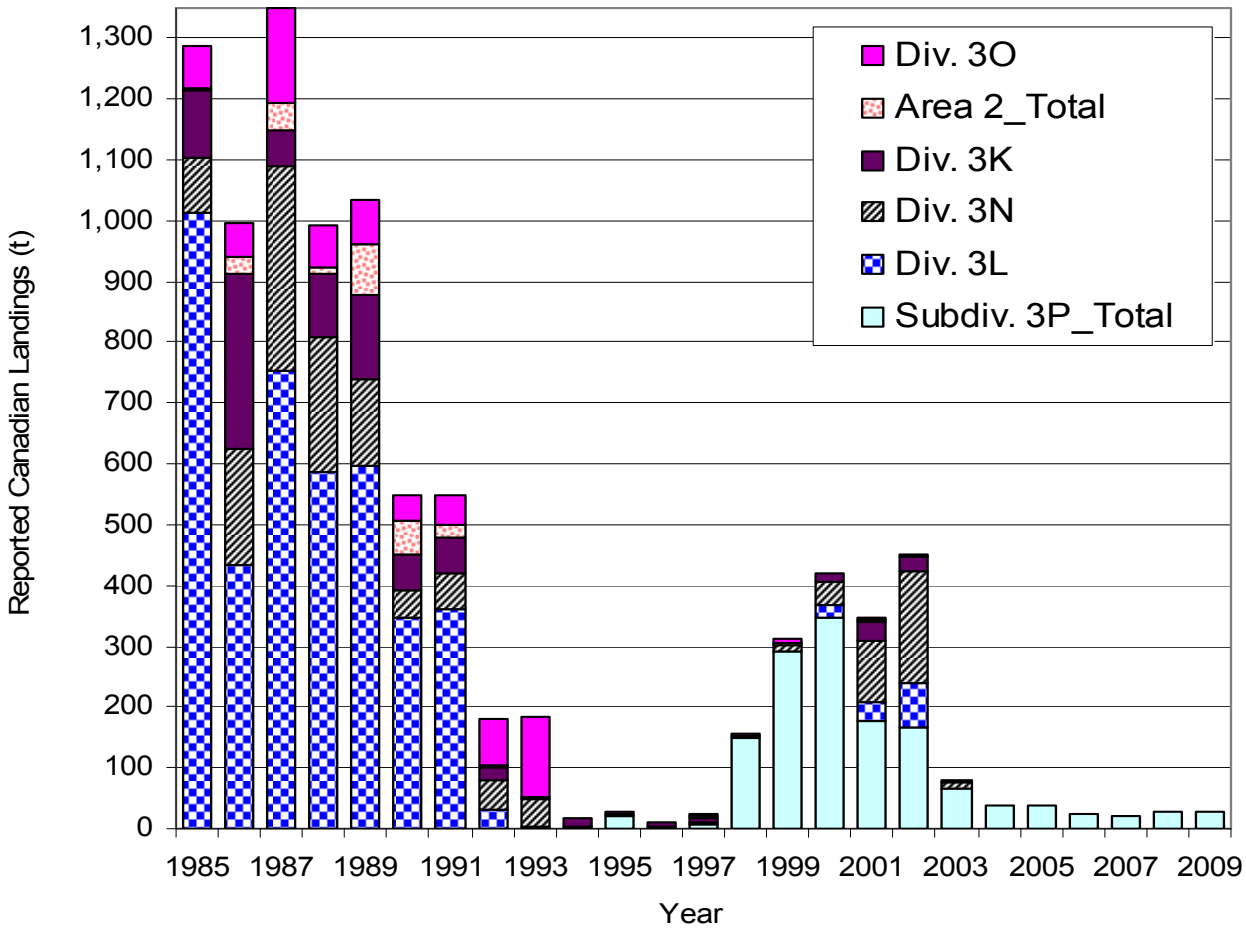


Figure 28. Reported Wolffish landings (unspeciated; in tonnes) in Canada's EEZ of NAFO Subarea 2 and Division 3KLNOP in 1985-2009. Data do not include discards at sea.

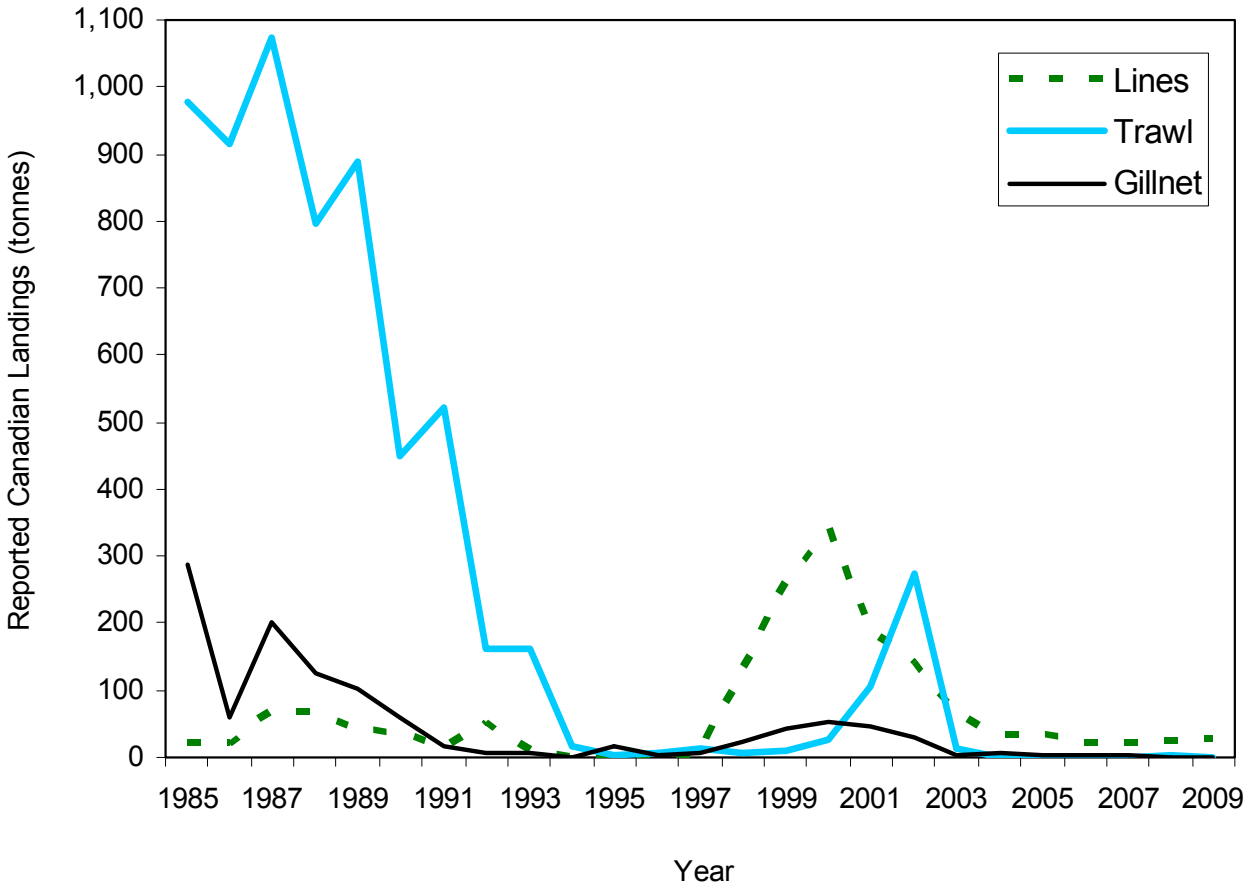


Figure 29. Reported Wolffish landings (unspeciated; in tonnes) by gear type in Canada's EEZ of NAFO Subarea 0 and Division 2GHJ3KLNOP in 1985-2009. Data do not include discards at sea.

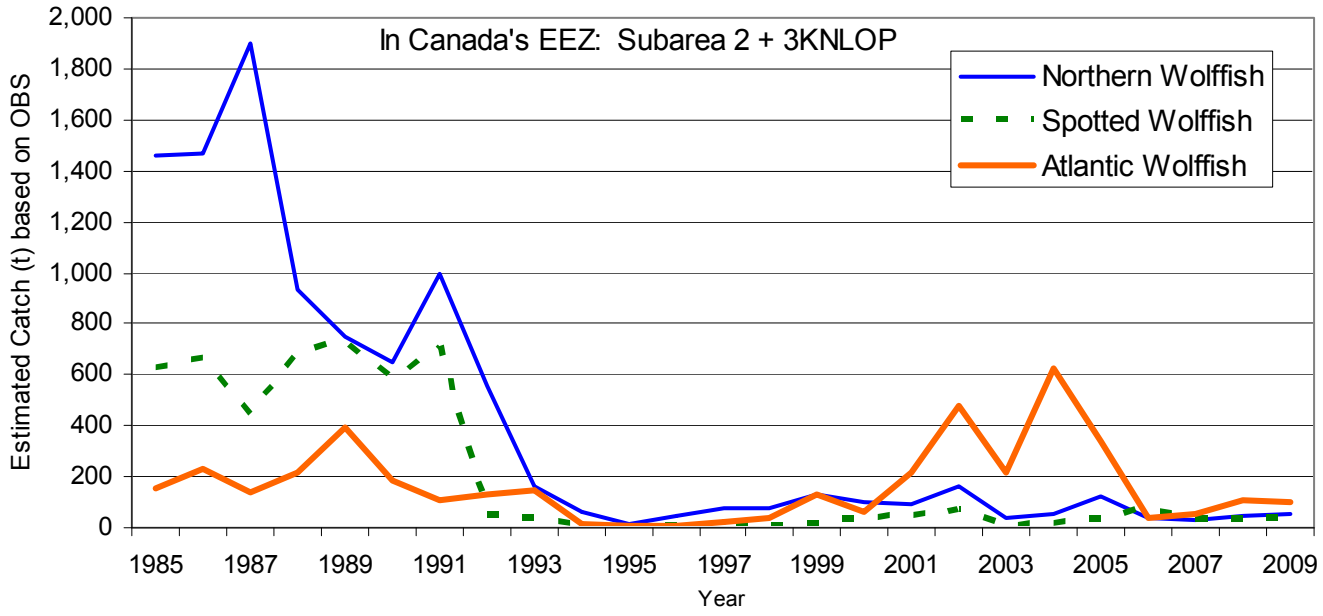
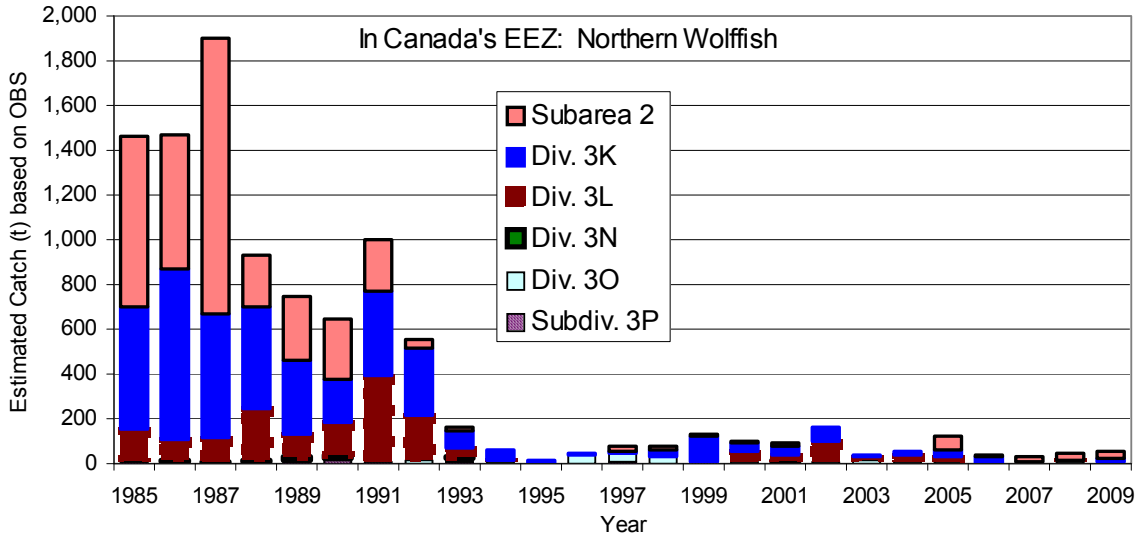
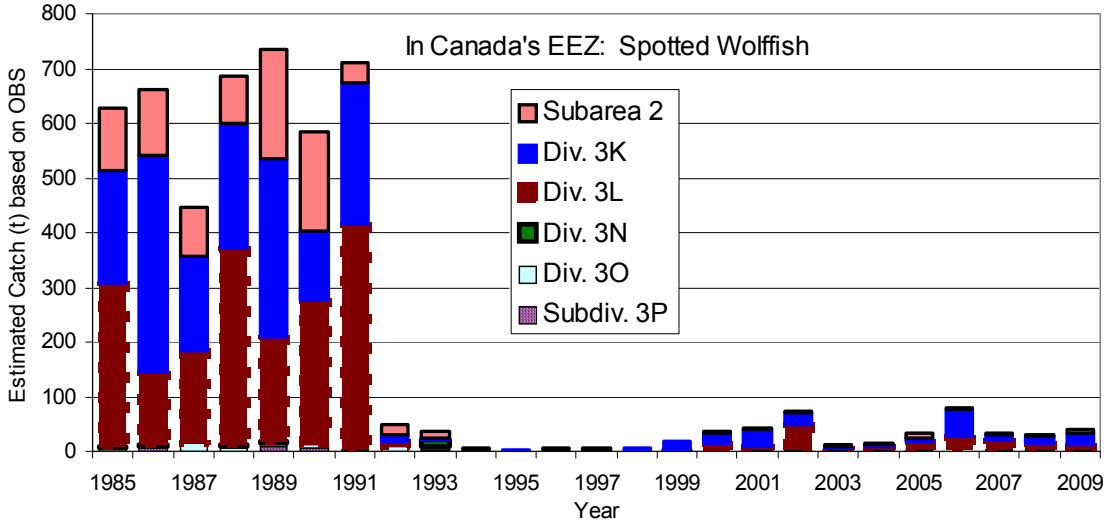


Figure 30. Speciated Wolffish at-sea catch estimates (in tonnes) from various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Division 3KLNOP in 1985-2009. Data are from Canadian Fisheries Observers.





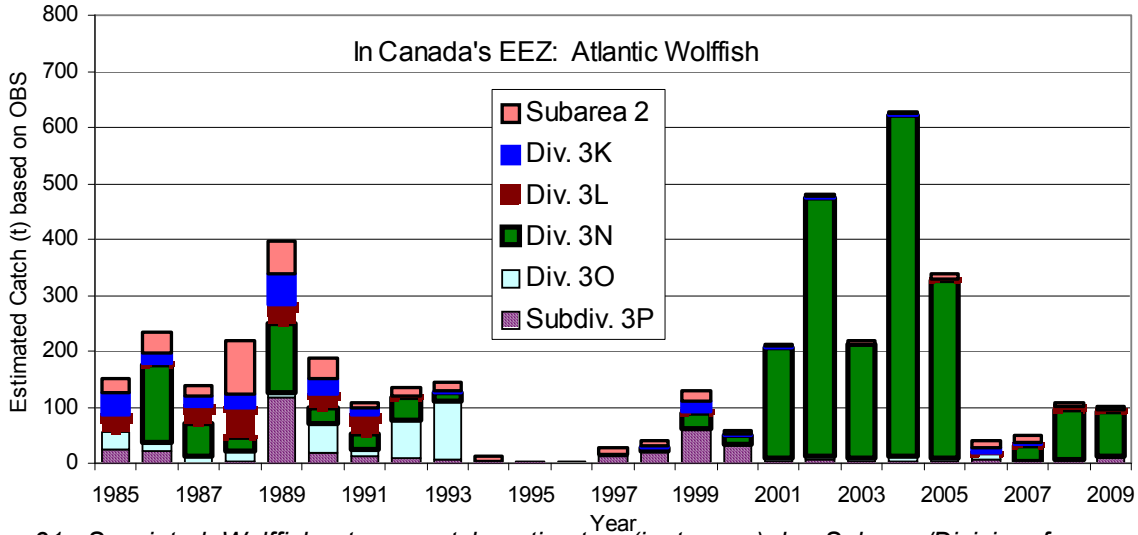


Figure 31. Speciated Wolffish at-sea catch estimates (in tonnes) by Subarea/Division from various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Division 3KLNOP in 1985-2009. Data are from Canadian Fisheries Observers.

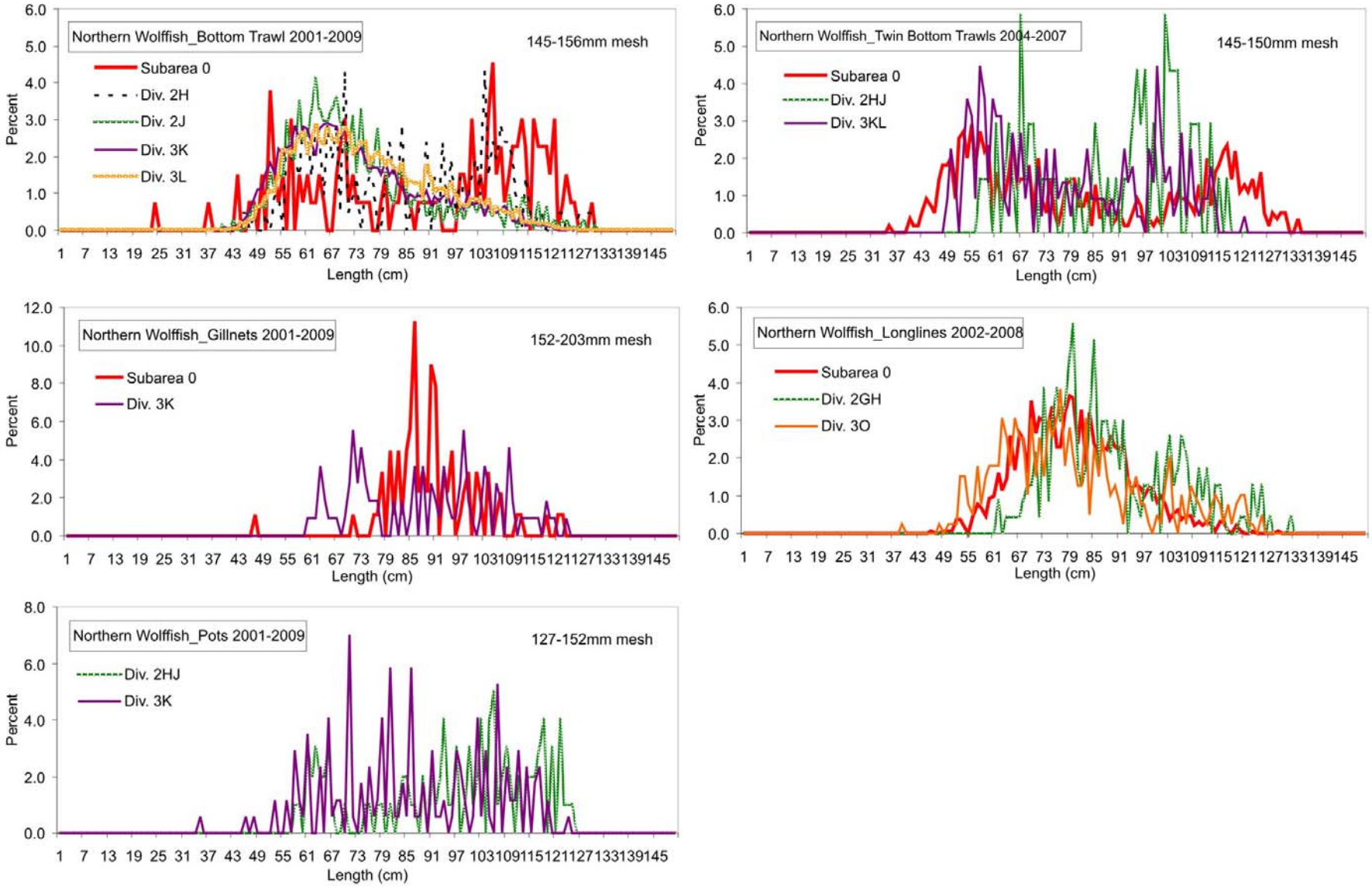


Figure 32. Available length frequency data for Northern Wolffish caught by commercial bottom trawls, gillnets, longlines, and pots in Canada's EEZ of NAFO Subareas 0, 2, and 3 in 2001-09. Data are from Canadian Fisheries Observers.

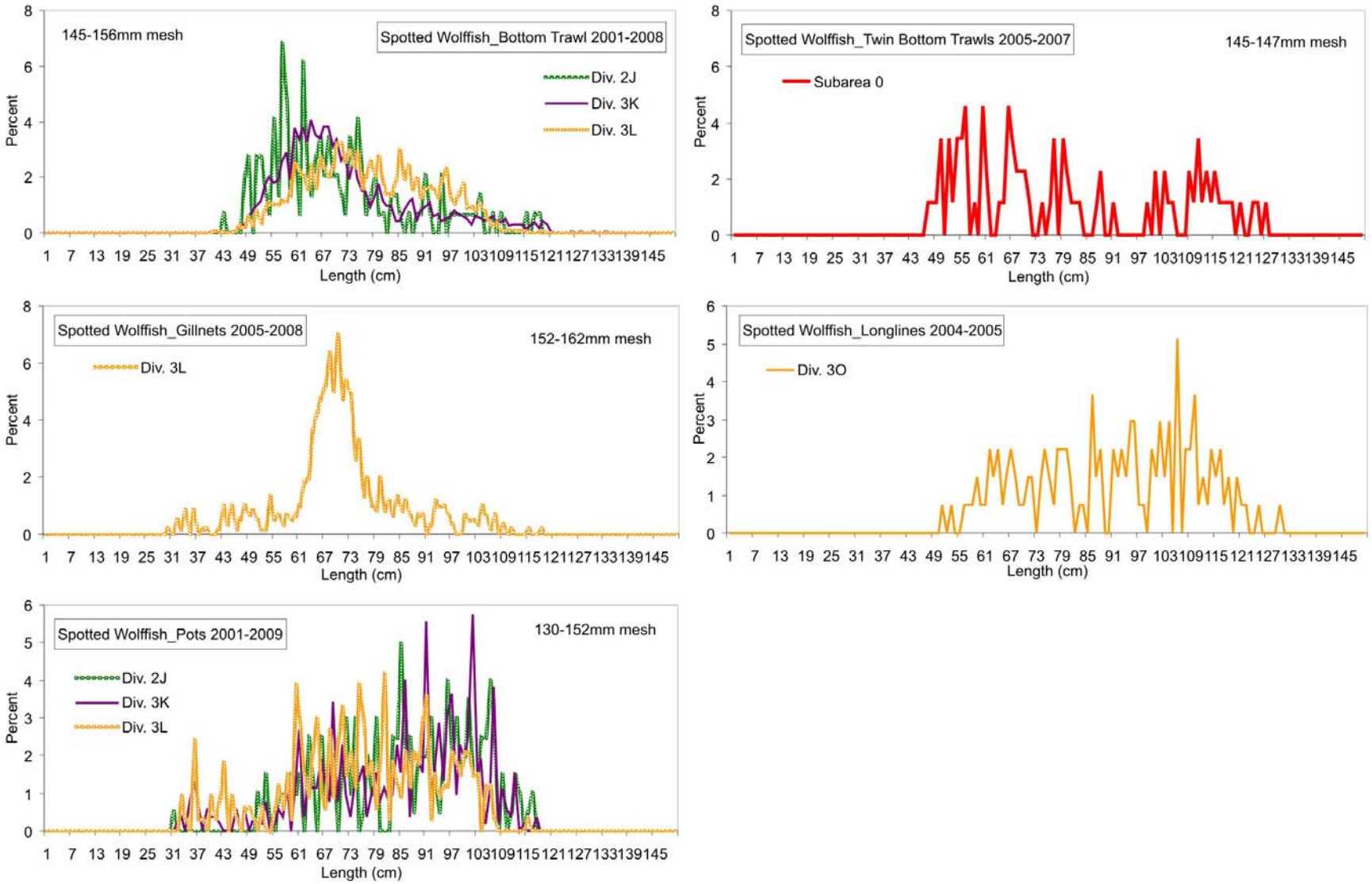


Figure 33. Available length frequency data for Spotted Wolffish caught by commercial bottom trawls, gillnets, longlines, and pots in Canada's EEZ of NAFO Subareas 0, 2, and 3 in 2001-09. Data are from Canadian Fisheries Observers.

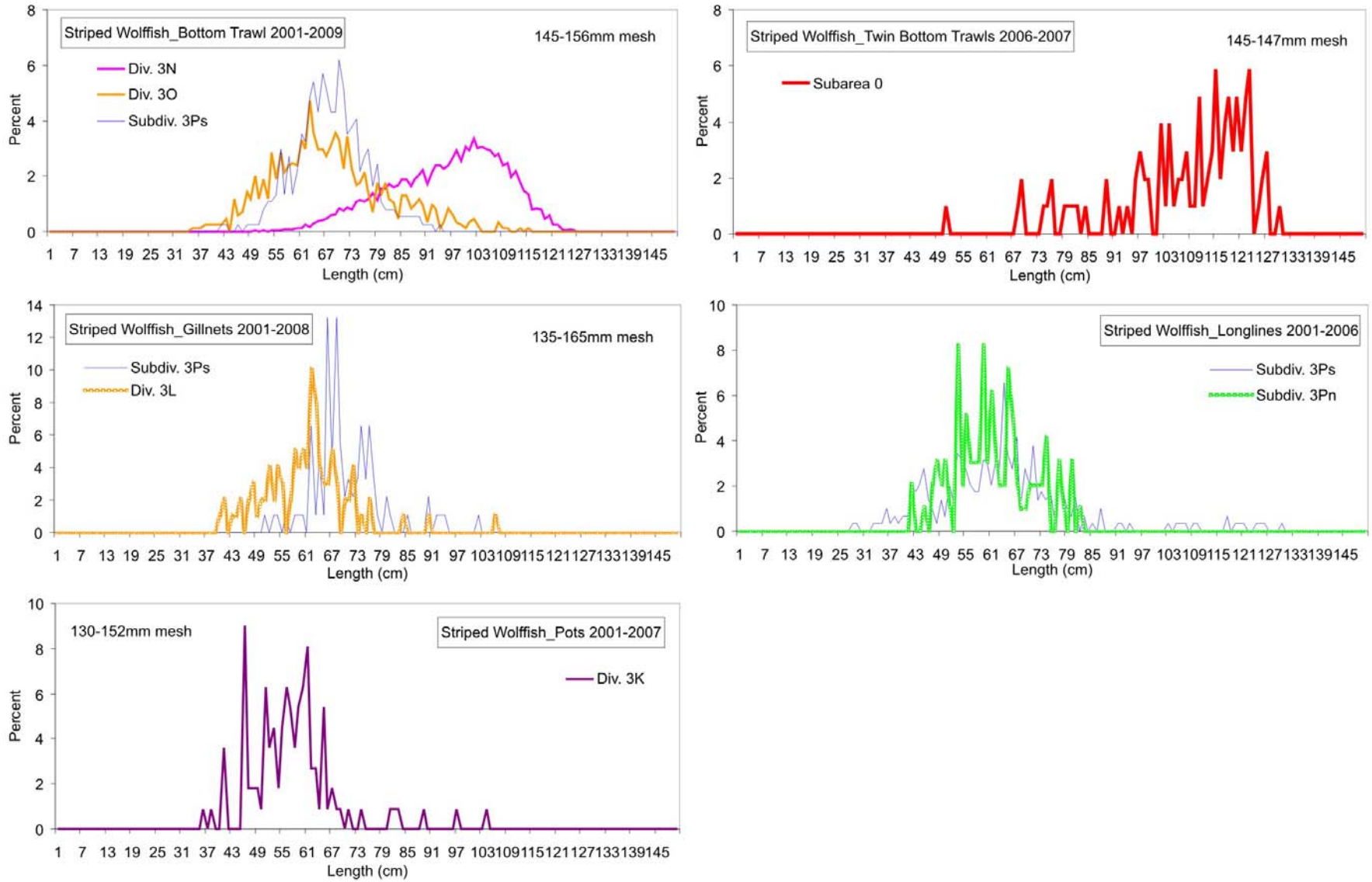


Figure 34. Available length frequency data for Atlantic Wolffish caught by commercial bottom trawls, gillnets, longlines, and pots in Canada's EEZ of NAFO Subareas 0 and 3 in 2001-09. Data are from Canadian Fisheries Observers.

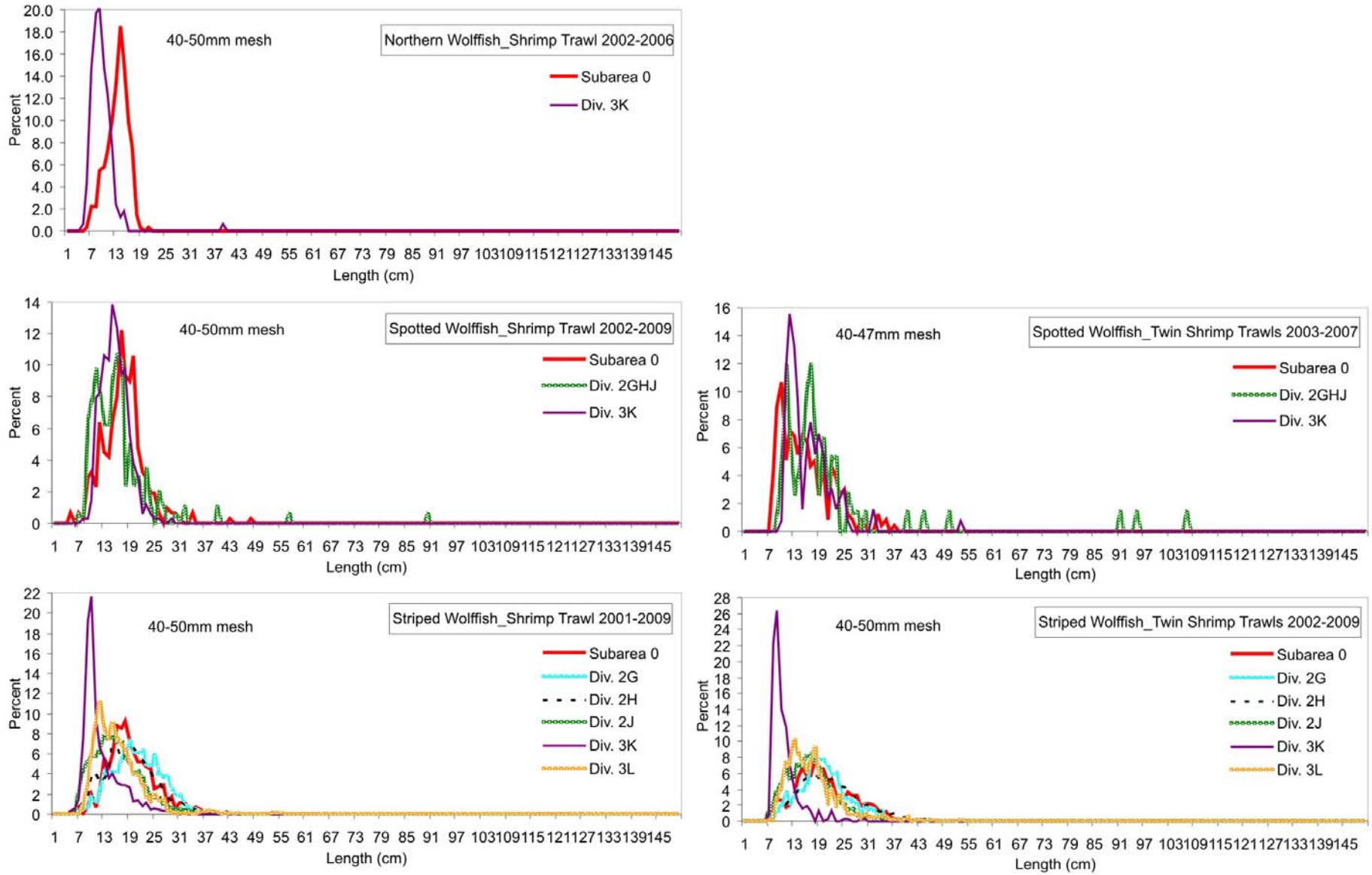


Figure 35. Available length frequency data for three species of Wolffish caught by commercial Shrimp trawls in Canada's EEZ of NAFO Subareas 0, 2, and 3 in 2001-09. Data are from Canadian Fisheries Observers.

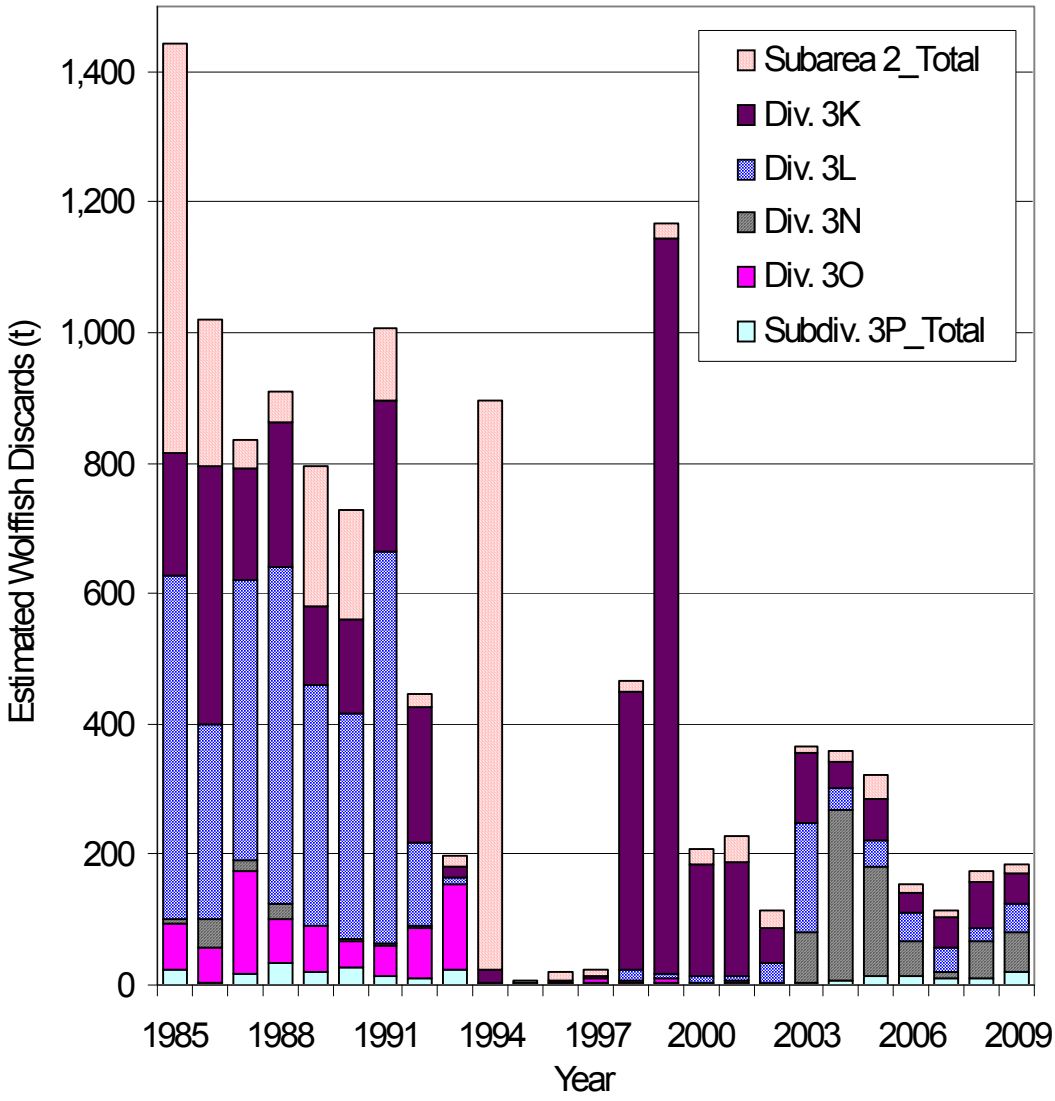


Figure 36. Wolffish at-sea discard estimates (in tonnes) from various commercial fisheries in Canada's EEZ of NAFO Subarea 2 and Division 3KLNOP in 1985-2009. Data are from Canadian Fisheries Observers.