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A pre-COSEWIC assessment of Roughhead Grenadier (*Macrourus berglax*) in Canadian Atlantic and Arctic Waters

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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

Roughhead Grenadier (*Macrourus berglax*) is scheduled for assessment by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), under the federal *Species at Risk Act* (SARA). In 2007, COSEWIC assessed Roughhead Grenadier as a species of 'Special Concern' based on its life history characteristics, a probable decline in abundance in the 1980s and 1990s, and lack of a management plan for grenadier-directed and bycatch fisheries. COSEWIC also determined that this species comprised one Designatable Unit (DU) in Canadian waters, consisting of a continuous distribution along the slope of the continental shelf from Davis Strait to the southern Grand Bank. The primary purpose of this paper is to provide COSEWIC with current knowledge of the biology, life history, abundance, and distribution of Roughhead Grenadier in Canadian Atlantic and Arctic waters to support its evaluation of risk of extinction for this species. This document also summarizes existing information on anthropogenic and natural threats and limiting factors that may impact this species, in addition to current management measures.

Examen pré-COSEPAC concernant le grenadier berglax (*Macrourus berglax*) dans les eaux canadiennes de l'Atlantique et de l'Arctique

RÉSUMÉ

Aux termes de la *Loi sur les espèces en péril* (LEP) fédérale, le grenadier berglax (*Macrourus berglax*) doit faire l'objet d'une évaluation par le Comité sur la situation des espèces en péril au Canada (COSEPAC). En 2007, le COSEPAC a désigné le grenadier berglax en tant qu'espèce « préoccupante » en fonction des caractéristiques de son cycle vital, du déclin probable de l'abondance dans les années 1980 et 1990, et de l'absence d'un plan de gestion relative aux prises dirigées et accessoires. Le COSEPAC a également déterminé que cette espèce comprenait une unité désignable (UD) dans les eaux canadiennes, qui compte une répartition continue le long de la pente du plateau continental du détroit de Davis jusqu'au sud des Grands Bancs. Le principal objectif du présent document est de fournir au COSEPAC les connaissances actuelles sur la biologie, le cycle biologique, l'abondance et l'aire de répartition du grenadier berglax dans les eaux canadiennes de l'Atlantique et de l'Arctique afin qu'il les utilise pour son évaluation du risque d'extinction de cette espèce. Ce document résume aussi les renseignements existants sur les menaces anthropiques et naturelles et les facteurs limitatifs qui peuvent avoir une incidence sur cette espèce, ainsi que les mesures de gestion actuelles.

INTRODUCTION

The implementation of the federal *Species at Risk Act* (SARA), proclaimed in June 2003, begins with an assessment of a species' risk of extinction by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC is a non-governmental scientific advisory body that was established under Section 14(1) of SARA to perform status assessments, which provide the scientific foundation for listing species under SARA. COSEWIC evaluated Roughhead Grenadier (*Macrourus berglax* Lacépède, 1801) populations in Canadian waters of the Northwest Atlantic Ocean in 2007, and determined that they constituted one Designatable Unit (DU), consisting of a continuous distribution along the slope of the continental shelf from Davis Strait to the southern Grand Bank. Based on life history characteristics, a probable decline in abundance in the 1980s and 1990s, and lack of a management plan for grenadier-directed and bycatch fisheries, this DU of Roughhead Grenadier was designated as 'Special Concern'. The overall objective of this paper is to update information relevant to a COSEWIC status assessment of Roughhead Grenadier in Canadian Atlantic and Arctic waters, including data concerning the status and trends in population size, and threats to this species inside and adjacent to Canadian waters, and the limitations of this information.

OVERVIEW OF BIOLOGY AND LIFE HISTORY

DISTRIBUTION

Roughhead Grenadier (*Macrourus berglax*) is a demersal (benthopelagic) species that inhabits depths of 100-2,700 m, though it is predominately encountered at depths of 300-1,200 m (Wheeler 1969; Snelgrove and Haedrich 1985; Cohen et al. 1990; de Cárdenas et al. 1996; Murua and de Cárdenas 2005). In east Greenland waters, Fossen et al. (2003) reported a gear-specific sex stratification by depth: in longline catches, males and females occurred with equal frequency in the 400-800 m depth strata, females dominated catches at depths of 800-1,000 m, and males predominated from 1,200-1,600 m; in trawl catches, males predominated at all depths.

Roughhead Grenadier occurs along the continental shelf and slope in temperate to Arctic waters (Fig. 1). It is found in the western North Atlantic, from Georges Bank in the south, northward to the Scotian Shelf; off the Grand Banks and the northeast Newfoundland and Labrador (NL) Shelves; into the Davis Strait off Baffin Island and western Greenland (Scott and Scott 1988). In the eastern North Atlantic, Roughhead Grenadier is distributed from eastern Greenland, to Iceland, the Faroe Islands, Norway, and Spitzbergen; it is also found in the Barents Sea (Cohen et al. 1990).

MORPHOLOGY

The Roughhead Grenadier is characterized by a broad head with a strongly pointed short snout and large orange eyes (Bigelow and Schroeder 1953; Fig. 2). The dorsal surface of its head is covered by scales with spinules, which together form raised ridges, while the underside of the head is nearly naked with a small chin barbel. The small, inferior mouth has 3-5 irregular rows of teeth in its upper jaw, and 1-2 rows in the lower jaw. This species is characterized by an ash-gray body colour with a narrow dark-edged anal fin and, like other grenadiers, they have a moderately slender body which tapers along the tail to a fine point with no definitive caudal fin. Serrations on the front of the large spine of its first dorsal fin are very small and barely visible. The second dorsal fin is longer than the anal fin, its rays are shorter than those of the anal fin,

and both fins do not have spines. The anus is close to the beginning of the anal fin, and surrounded by scaly skin that is no darker-coloured than its back.

This species has a specialized swim bladder: its wall is lipid-rich, which forms a barrier to oxygen diffusion at great depths and water pressures (Wittenberg et al. 1980). This adaptation to deep water results in a low-energy cost for Roughhead Grenadier to maintain neutral buoyancy, even when vertically migrating from the bottom to feed (Priede et al. 2006). The male Roughhead Grenadier has two large, drumming muscles on the front part of its swim bladder. The fish can produce sound by repeatedly contracting these special muscles against its swim bladder. This behavior led the Inuit to call this species “ingminniset”, or "it bellows when dying" (Coad and Reist 2004).

BIOLOGY AND ECOLOGY

Roughhead Grenadier occurs in relatively cold water of -0.5-5.4°C (Atkinson and Power 1987; Cohen et al. 1990; Murua and Motos 2000), and appears to prefer temperatures of 1-4°C (Cohen et al. 1990). During Canadian research surveys on the eastern Grand Banks, the highest catches occurred in waters of 2.0-3.5°C (Scott and Scott 1988). Salinity preferences are not well-documented. The depth range of this species suggests that it prefers full salinity (i.e., 34-35 ppt), and may tolerate 32-35 ppt. In the Barents Sea, they were only found in areas with high salinity, ranging from 34.8 to 35.09 ppt (Dolgov et al. 2008). Little is known of substrate preferences. In NL waters, Roughhead Grenadiers were found at depths of 200-1,000 m in association with deep-sea corals, such as gorgonians, antipatharians, and soft corals (Edinger et al. 2007). Baker et al. (2012) found some association with both soft corals (*Anthomastus* spp.; *Duva florida*) and large corals (*Paragorgia arborea*; *Acanthogorgia armata*). Roughhead Grenadiers were also found to be strongly associated with sponge grounds on the continental slopes of the Grand Banks and Flemish Cap in the Northwest Atlantic Ocean (Kenchington et al. 2010).

Roughhead Grenadier is a generalist predator that feeds primarily on benthic and benthopelagic invertebrates (Geistdoerfer 1986; Cohen et al. 1990). There is evidence of an ontogenetic shift in dietary preference: smaller individuals feed on small bivalves, starfish, shrimp and polychaetes, while larger individuals tend to prefer active benthopelagic organisms, such as shrimp, small fish, and squid (Eliassen and Jobling 1985; Scott and Scott 1988; Jørgensen 1996). In a study conducted on the Grand Bank, individuals less than 5 cm preyed on gammarid amphipods; individuals from 5-15 cm consumed mostly polychaetes; and larger specimens consumed greater quantities of scyphozoans and fish species (González et al. 2006). Pauley (1982) indicated that the major prey items from the Carson Canyon, Labrador Shelf, and Flemish Cap were Northern Shrimp (*Pandalus borealis*), cephalopods, bivalves, gastropods and cumaceans. Román et al. (2004) reported that the most important prey items of individuals captured on the Flemish Cap included *Pandalus borealis*, scyphozoans and *Lampadena speculigera*. González et al. (2006) reported that Roughhead Grenadier on the Grand Bank relied mainly on scyphozoans, polychaetes and fish species as food. Similar dietary preferences were recorded from the Northeast Atlantic: Eliassen and Jobling (1985) reported that over 30 different prey species were found in the stomachs of Roughhead Grenadier off the coast of northern Norway; although crustaceans and fish were the main prey categories. Bjelland et al. (2000) reported that herring, the amphipod *Liljeborgia fissicornis*, *Apherusa* sp., euphausiids, polychaetes, ophiuroids and cephalopods were recovered from stomachs of Roughhead Grenadier captured in the Norwegian Sea. According to Jørgensen (1996), cephalopods, fish, crustaceans, polychaetes and echinoderms constituted the most important prey for Roughhead Grenadier in west Greenland waters.

Roughhead Grenadier is preyed upon by some groundfish species, and at least one species of elasmobranch. According to Savvatimsky (1969), Roughhead Grenadier have been found in the stomachs of Atlantic Cod (*Gadus morhua*). Petrov (1973) reported that the stomachs of White Hake (*Urophycis tenuis*) collected from the southwest slope of the Grand Bank and St. Pierre Bank contained grenadiers, among a number of other fish. González et al. (2006) reported that, on the Grand Bank, the diet of Spinytail Skate (*Bathyraja spinicauda*) consisted mainly of redfishes (*Sebastes* sp.; 28%), Roughhead Grenadier (20%), and Greenland Halibut (*Reinhardtius hippoglossoides*; 19%). Chambers and Dyck (2005, 2007) reported that Roughhead Grenadier was prey for Greenland Halibut and Black Dogfish (*Centrocyllium fabricii*).

Roughhead Grenadier is host to a variety of ecto- and endoparasites: including nematodes (Zubchenko 1981; Kellermanns et al. 2007); platyhelminths (cestodes, trematodes, monogeneans: Noble 1973; Redkozubova 1976; Bray 1979; Zubchenko 1981; Campbell et al. 1982; Campbell 1992); arthropods (the copepod *Sphyrion lumpi*: Magnússon 1987); myxozoan cnidarians (Gaevskaya et al. 1980; Zubchenko and Krasin 1980; Zubchenko 1981; Khan et al. 1983; Khan et al. 1986; Threlfall and Khan 1990); and euglenozoans (trypanosomes: Khan 1986; Khan et al. 1991). Some parasites appear to target only Roughhead Grenadier, such as the trematode *Gibsonia borealis*, which attacks the intestinal tract (Campbell 1992). In general, parasites may infest the blood, esophagus, swim bladder, gall bladder, urinary bladder, stomach, intestine, pyloric caeca, kidney, mesenteries, mouth, fins, body musculature, or gills (or gill cavities/chambers). Some parasites attack more than one organ/site (e.g., the ectoparasitic copepod *Clavella adunca* attaches to the gills, mouth, fin edges, and anal region: Noble 1973; Zubchenko 1981; Ho 1985).

For males, age at 50% maturity has been estimated at approximately eight years (Rodríguez-Marín et al. 2002); females reach maturity at 13-15 years of age (Eliassen and Falk-Petersen 1985; Murua and Motos 2000). According to Murua and Motos (2000), age at 50% maturity occurs between 13-14 years for females, which corresponds to a length of 66.7 cm total length (TL), and a 26.2 cm pre-anal fin length (AFL; Fig. 2). In further studies, Murua (2003) estimated sexual maturity at an AFL of 28.5 cm and at age of 15–16 years. According to Eliassen and Falk-Petersen (1985), the age at 50% maturity for females is 15 years (25.48 cm AFL, 65 cm TL), with all individual females within a year-class reaching maturity and spawning by approximately 18 years. The size at maturity of Roughhead Grenadier in eastern Greenland waters was estimated to be 16 cm and 29.5 cm AFL for males and females, respectively (Fossen et al. 2003). More recently, Garabana et al. (2016) estimated that the size at maturity in NAFO Divs. 3LMN was 25.6 cm AFL (65.3 cm TL) during 2012-15, which was smaller than previously estimated during 2005-11 (27.78 cm AFL, 70.4 cm TL). Previous COSEWIC assessments of Roughhead Grenadier used 27.5 cm AFL (69.7 cm TL) as the size of maturity (COSEWIC 2007).

Little is known of the reproductive biology of Roughhead Grenadier in the Northwest Atlantic. In the eastern Grand Bank area, spawning is thought to occur on the southern and southeastern slopes of the bank (Savvatimsky 1984; Scott and Scott 1988). Spawning depths have not been recorded in these areas; although spawning aggregations have been observed at depths of 700-800 m off of the coast of Norway (Savvatimsky 1989).

Spawning is thought to occur throughout the year, with a possible peak during winter/spring (Geistdoerfer 1979; Savvatimsky 1984; Eliassen and Falk-Petersen 1985; Magnússon and Magnússon 1995; Murua and Motos 2000). Geistdoerfer (1979) reported a well-defined spawning season in the Labrador Sea lasting from the end of spring to the beginning of the summer. Savvatimsky (1989) reported that spawning occurred during winter and early spring on the Grand Bank, while Murua and Motos (2000) suggested that spawning took place in

February-July in Divs. 3LMN. More recently, Murua (2003) suggested that this species may not have a well-defined spawning period in the Northwest Atlantic.

Roughhead Grenadier is a “batch” spawner (releasing eggs in more than one spawning event during each spawning season: Yanulov 1962; Murua and Saborido-Rey 2003) that exhibits “group-synchronous” oocyte development, with at least two batches of oocytes present in the ovary at any one time (Murua and Motos 2000). The development of the oocytes appears to take more than one year (Eliassen and Falk-Petersen 1985). The start of final oocyte maturation corresponds with an oocyte diameter of 1.7-2 mm (Murua and Motos 2000), with mature eggs measuring about 3.5-4.0 mm in diameter (Savvatimsky 1985; Fahay 2007). Overall, fecundity seems to vary between approximately 14,000 and 80,000 eggs per female, and is positively correlated with female size (Murua and Motos 2000; Fossen et al. 2003). Marshall (1965, 1973) proposed that fertilization occurred close to the ocean floor, and the bathypelagic fertilized eggs floated upwards in the water column as they developed, so that feeding grenadier larvae were distributed below the thermocline where they had an abundant supply of food and could avoid dispersal by surface currents (Eliassen and Jobling 1985).

Roughhead Grenadier is characterized by slow growth rates (for both sexes) and a long life span (Scott and Scott 1988; Savvatimsky 1994; Jørgensen 1996; Murua and Motos 2000). This species also exhibits sexual dimorphism: females grow larger, heavier, and live longer than males (Scott and Scott 1988). At approximately seven to nine years of age, females begin to grow faster than males (Murua 2000, 2003). Female growth rate appears to decrease after age 16 (Rodríguez-Marín et al. 2002). The maximum reported size is 110 cm TL (Muus and Neilson 1999; Collette and Klein-MacPhee 2002), and the maximum reported age is 25 years (Savvatimsky 1971).

Using catch data from trawl surveys on the shelf and continental slope of West Greenland, Baffin Island, and NL, Savvatimsky (1989) derived the following length-weight relationship for Roughhead Grenadier (both sexes combined) in the Northwest Atlantic:

$W = 0.00259L^{3.177}$, where W and L are the specimen weight (g) and total length (cm), respectively.

To establish length-weight relationships for specimens collected off of West Greenland, Jørgensen (1996) also used a regression model of the form $W=aL^b$ for males and females separately and for both sexes combined using both AFL and TL. Values for coefficients *a* (slope) and *b* (intercept) were contingent upon sex, as well as whether pre-anal fin length or total length was used to establish the relationship. Further research on Roughhead Grenadier length-weight relationships was conducted in NL and adjacent waters (González-Costas and Murua 2005; Vargas et al. 2006; Murua and González-Costas 2007; Román et al. 2015), using the same approach as Jørgensen (1996). Some of these studies showed a broad range of values for both regression coefficients, which varied according to sex, year, and geographic location; whereas in other cases, the coefficients were very similar. However, the various analyses showed a strong length-weight relationship in all cases, with more than 96% of the variance explained; regardless of the approach used for model parameterization.

GENERATION TIME

Generation time (G) of Roughhead Grenadier was estimated as female age at maturity plus 1/M, where M is the instantaneous rate of natural mortality (COSEWIC 2007). Murua and Motos (2000) estimated that female Roughhead Grenadier mature at approximately 67 cm TL (L_{50}) in the Northwest Atlantic, corresponding to an age of 13-14 years. Thus G was estimated as 19 years, assuming a M value of 0.2 and an age at maturity of 14 years.

The choice of M in this circumstance is largely arbitrary. A number of approaches to estimating M have been devised. González-Costas et al. (2010) argued that a constant M for Roughhead Grenadier should be 0.1 for all ages and years. The reason for selecting this value is that Roughhead Grenadier is a long-lived species which inhabits a stable deep-sea ecosystem. This value has also been applied in the assessment of some Roundnose Grenadier populations with similar biology and inhabiting similar ecosystems (International Council for the Exploration of the Sea [ICES] 2006). Such assumptions would yield a G of 24 years for this species. According to Hewitt and Hoenig (2005), M may be estimated by the relationship $M = 4.22/t_{max}$, where t_{max} is the age at which approximately 1.5% of the population remains (i.e., longevity, as defined by Hoenig (1983)). Murua (2003) indicated that the maximum age of this species was 28 years, which yields a M estimate of 0.15. This yields a G value of approximately 21 years. In their evaluation of several estimators of M, Then et al. (2015) recommended use of the following relationship: $M = 4.899 t_{max}^{-0.916}$. Using 28 years as t_{max}, M would therefore be 0.23, and G would be 18 years.

SPECIALISED NICHE OR HABITAT REQUIREMENTS

None. This species is widespread in the North Atlantic Ocean, in both temperate and Arctic waters. It is also found in a broad range of depths and temperatures.

CONCEPT OF RESIDENCE FOR ROUGHHEAD GRENADIER

Canada's SARA defines "residence" as:

"a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating" (S. 2(1)).

The Fisheries and Oceans Canada (DFO) "Directive on the Application of *S*ARA Section 33 (Residence) to Aquatic Species at Risk" (January 2015) states that the following four conditions will be used to determine whether the concept of residence applies to an aquatic species at risk:

1. There is a discrete dwelling-place that has structural form and function similar to a den or nest or other similar area;
2. An individual of the species has made an investment in the creation and/or modification of the dwelling-place;
3. The dwelling-place has the functional capacity to support the successful performance of an essential life-cycle process such as spawning, breeding, nursing, and rearing; and
4. The dwelling-place is occupied by one or more individuals during one or more parts of their life cycle.

Based on the above criteria, the concept of residence does not apply to Roughhead Grenadier.

SURVEY DATA

NL REGION

DFO-NL bottom trawl research surveys have been conducted annually over the continental shelves of Newfoundland and Labrador in spring (Divs. 3LNOPs; 1971-2015) and fall (Divs. 2GHJ3KLNO; 1977-2015), including areas beyond the Canadian Exclusive Economic Zone (EEZ; Fig. 3). These surveys employed a stratified-random design based on depth intervals and location (latitude, longitude), and were designed to provide information on

abundance, biomass, distribution, and area occupied by numerous demersal and benthic fish, as well as several invertebrate species. Details of these surveys, including changes in gear type and spatial coverage over time, are discussed in Doubleday (1981), Bishop (1994), McCallum and Walsh (1996), Walsh and McCallum (1996), Brodie and Stansbury (2007), Healey and Brodie (2009), and Simpson and Miri (2013). It must be noted that, due to different trawls being deployed during the spring (Yankee 41.5 in 1971-83; Engel 145 in 1984-95; Campelen 1800 in 1996-2015) and fall (Engel 145 in 1977-94; Campelen 1800 in 1995-2015) surveys, combined with a lack of conversion factors to account for differences in Roughhead Grenadier catchability resulting from gear changes, the various survey time-series are not directly comparable. In addition, fall surveys cover deeper strata (~1,400 m) than those in spring (~750 m). Therefore, fall survey time-series are not directly comparable to spring survey series. In addition, due to Canadian research vessels' mechanical difficulties, the spring survey was incomplete in 2006 because most of Subdiv. 3Ps was not sampled, while only shallow strata in Divs. 3NO (to 77 m in Div. 3N; to 103 m in Div. 3O) were surveyed; the fall survey was incomplete in 2014 due to partial coverage of Div. 3L and no sampling of Divs. 3NO. Subdiv. 3Pn was not surveyed in spring 2008 and 2014. Furthermore, in order to allow for inter-annual comparisons, only those strata that were consistently sampled in most years (i.e., core strata) are included in analyses of spring and fall indices of population size and distribution. However, no single survey covers the entire distribution range of this population in Canadian waters.

It should also be noted that measuring total length of Roughhead Grenadier at sea can be difficult. Their tails are often damaged or missing when caught by DFO research trawls; therefore, pre-anal fin length (AFL; Fig. 2) was measured instead of total length (TL). AFL was measured in a straight line from the tip of the grenadier's nose to the base of its first anal-fin ray: a standard method of measurement adopted by the Northwest Atlantic Fisheries Organization (NAFO) in June 1980 for Roughhead and Roundnose Grenadiers (Atkinson 1991).

MARITIMES REGION

The DFO-Maritimes Region (MAR) summer research survey has been conducted annually on the Scotian Shelf (Divs. 4VWX5Yb) since 1970, using a stratified-random design based on depth and geographic area. Forty-two survey strata were grouped into three depth categories: 50-92 m, 93-181 m, and 182-400 m. In 1995, coverage was expanded into three deep-water strata (365-732 m) on the shelf edge. In 2010, five deep strata were added on the Scotian slope in the area south of Emerald Bank at depths of 731-1,828 (stratum 501), 1,829-2,285 (stratum 502), 2,286-2,742 (stratum 503), 2,743-3,199 (stratum 504), and 3,200-3,656 (stratum 505). Only stratum 501 was sampled in 2011, and 502 in 2011 and 2012. Various vessels and trawl types have been used over the span of this survey (see Claytor et al. 2014 for details). Since 1982, the primary vessel has been the CCGS *Alfred Needler* deploying a Western IIA trawl.

The March Divs. 4VsW research survey was conducted on the eastern half of the Scotian Shelf in 1986-2010 (Claytor et al. 2014). This survey did not include all of Divs. 4VW, used a stratification scheme differing from that of the summer survey, and attempted to optimize abundance estimates for Atlantic Cod in Divs. 4VsW. No surveys were conducted in 1998 and 2004, and the 2009 survey was incomplete. The CCGS *Alfred Needler* was used in all years with a Western IIA trawl (except in 2007 and 2008). The CCGS *Wilfred Templeman* was used (with the same trawl) in 2007, and the CCGS *Teleost* in 2008. In 1993, deep-water strata (i.e., 365-549 m) in the Laurentian Channel were added to this survey. Coverage of eastern strata was restricted in some years due to ice coverage.

The February/March research survey on Georges Bank (Subdiv. 5Ze) commenced in 1986, using a Western IIA trawl and a stratified-random design (Fig. 3). Sampling was concentrated

on the Canadian side of the bank (Subdiv. 5Zc), with additional sets on the USA side of Georges Bank; thereby covering the remainder of the bank and some sampling sites north of the bank.

In 1982-88, annual stratified-random bottom surveys were conducted along the edge of the Scotian shelf at 200-900 m depths to assess redfish stocks. These surveys extended into the Laurentian Channel and the deeper areas of the Gully.

Two exploratory surveys were conducted in November 1994 and March 1995 by the commercial fishing trawler *Cape Chidley* at bottom depths of 901-1,830 m. Sampling was stratified by area and depth. In 1994, discrete areas were fished south of Browns, LaHave, Western, and Banquereau Banks. Larger contiguous areas located south of Browns, LaHave, Emerald, and Western-Sable Island banks were fished in 1995. Each area was divided into five 183 m depth strata, which were sampled with a minimum of two randomly-selected tows. A commercial Engel high-lift bottom trawl was used with a 51.8 m footrope equipped with 52 and 61 cm disc rock hopper gear (see Halliday et al. 2012b for details).

Fishing trials with bottom fixed gears (gillnets, shrimp and crab traps, longlines) were conducted in 1991 on the slope of Emerald Bank and at the mouth of the Gully. Fishing was conducted at several depths between 500 and 2,800 m (Halliday et al. 2012a).

CENTRAL AND ARCTIC REGION

DFO-Central and Arctic (C&A) has conducted a series of deep-water bottom trawl surveys in Baffin Bay, Davis Strait, and Hudson Strait since 1999. Southern Div. 0A (Baffin Bay to approx. 72°N) has been surveyed the most frequently (1999, 2001, every second year in 2004-12, and annually since 2014: Treble 2016). Northern Div. 0A (73°N-75.5°N) was surveyed in 2004, 2010, and 2012 (Treble 2013). Inshore areas along the Baffin coast were covered in 2006 and 2008, and Hudson Strait-Ungava Bay was surveyed every second year in 2007-13. Div. 0B was surveyed in 2000, 2001, 2011, and 2013-15 (Treble 2016). The Greenland Institute of Natural Resources' research vessel *Pâmiut* was used to conduct these stratified-random design surveys based on depth in fall. During 2006-15, two gear types were used: an Alfredo III otter trawl at 400-1,500 m depths in Div. 0A and 0B targeting Greenland Halibut, and a Cosmos® 2000 shrimp trawl at 100-800 m depths in Div. 0A and Ungava Bay (the Western Assessment Zone targeting Northern Shrimp (*P. borealis)* and Striped Shrimp (*P. montagui*).

OTHER SURVEYS - INSIDE CANADA'S EEZ

The Northern Shrimp Research Foundation (NSRF) conducted annual surveys since 2005 using a Campelen 1800 shrimp trawl in Shrimp Fishing Areas (SFAs) 2EX and RISA, and added the Western Assessment Zone to its surveyed areas in 2014.

OTHER SURVEYS - OUTSIDE CANADA'S EEZ

EU Survey - Div. 3L

The EU-Spain survey of the Div. 3L NAFO Regulatory Area (NRA) was initiated in 2003. The survey has been conducted by the research vessel *Vizconde de Eza* equipped with a Campelen 1800 bottom trawl (see Román et al. 2015 for details).

EU Survey - Divs. 3NO

The EU-Spain survey of the Divs. 3NO NRA was initiated in 1995. The survey began with the vessel C/V *Playa de Menduíña* equipped with a Pedreira bottom trawl until 2001, which was

then replaced by the R/V *Vizconde de Eza* with a Campelen bottom trawl (see González-Troncoso et al. 2015 for details).

EU Survey - Div. 3M

The EU-Spain Flemish Cap (Div. 3M) survey was initiated in 1988. The survey began with the vessel B/O *Cornide de Saavedra* (except in 1989-90) equipped with a Lofoten bottom trawl until 2005, which was then replaced by the R/V *Vizconde de Eza* using a Lofoten bottom trawl (see Casas and González-Troncoso 2015 for details).

West Greenland

Annual stratified-random bottom trawl surveys were conducted in Div. 1C-D during 1988-2011 (no survey in 1996). Only deep-water strata >800m were included in the analysis of Roughhead Grenadier trends (see Jørgensen et al. 2014 for details). These surveys have been conducted by two research vessels: the *Shinkai Maru* (1988-95) and *Pâmiut* (1997-2011), with two different fishing trawls. No comparative tows/conversion factors between both trawls were available for converting one of these Roughhead Grenadier abundance time-series into comparable estimates.

SPATIAL DISTRIBUTION AND HABITAT ASSOCIATION

Spatial distribution of Roughhead Grenadier was investigated using point plots of the geographic distribution of standardized catch rate (number of fish per tow) for each regional survey time-series (NL, MAR, C&A). In addition, density surface maps of geographic distributions of standardized catch rate (number of fish per tow) were created with ArcGIS for these regional surveys. Prediction density surfaces were estimated using Kernel interpolation. A radially symmetric Epanechnikov kernel with first order polynomials was used to generate Roughhead Grenadier density surfaces for each map.

NL REGION

Roughhead Grenadiers were caught in DFO-NL fall surveys from 32-1,504 m (i.e., to maximum depths surveyed), with the majority captured in 750-1,500 m depths (Fig. 4). Although this survey provides the primary data used to assess the status of this species in NL waters, the portion of this population in 1,600-3,000 m depths remains unknown. Roughhead Grenadiers were caught in 0-10°C, with the majority found in 2-6°C waters. A similar pattern in the spring research survey was observed; however, due to shallower depths sampled, the pattern is less obvious (Fig. 5).

In both spring and fall surveys (2001-15), catch rates of Roughhead Grenadier were consistently higher (>20 fish/tow) along the continental shelf slope (Figs. 6, 7). This pattern was most notable in Divs. 2J3KLN in the fall and, to a lesser extent, in Divs. 3LN in spring. Lower catch rates (<20 fish/tow) tended to be observed in Div. 3O in spring and fall, as well as in Subdiv. 3Ps in spring. This species was largely absent across the NL continental shelves (Divs. 3LNO) in both seasons; except in the deeper and outer region of the Northeast Newfoundland Shelf (Div. 3K), and in areas adjacent to Hawke Channel (Div. 2J) in the fall.

Density surface maps covering periods when large fluctuations in population size occurred on a decadal time-scale indicated that habitat occupied by Roughhead Grenadier remained unchanged in both spring and fall, with the majority of the population concentrated along the continental shelf slope in NL waters, as well as the Flemish Cap and Pass (Figs. 8-9). However, despite this observed consistency regarding habitat occupied by Roughhead Grenadier, there

were noticeable latitudinal shifts in density distribution over the years. For example, there were only a few high density areas found in Divs. 3LN in spring and Divs. 3KLN in fall when population size was low (1970s and 1980s), including movement of Roughhead Grenadiers out of the deep channels across the NL shelves, in particular the Okak Trough (Div. 2H), Hawke Channel (Div. 2J), and the Bonavista Corridor (Div. 3K); but high density areas became widespread when population size increased from the late 1990s onwards: from the tail of the Grand Bank in spring and fall (Div. 3N) to the Labrador Trough in fall (Div. 2H). A survey gear change from an Engel to Campelen trawl in the mid-1990s likely influenced perceived trends in survey indices of population size. However, such trends were consistent within each time-series in fall surveys: declining until the mid-1990s (Engel), and increasing thereafter (Campelen); thereby suggesting that observed distribution patterns were mostly influenced by density-dependent processes.

MARITIMES REGION

Collectively, DFO-MAR research surveys indicated that Roughhead Grenadier was broadly distributed along the slope bordering Divs. 4VWX at greater depths than those usually sampled during the summer, Divs. 4VsW, and Georges Bank surveys (Fig. 10). No Roughhead Grenadiers were caught in these surveys during 1970-94; except for two fish in a 371 m deep tow on the southern edge of Banquereau in 1971, and four fish in a 349 m deep tow at the edge of the Laurentian Channel in 1981. Roughhead Grenadier was caught in eleven of the fifteen years that strata 496-498 were sampled, usually in stratum 496 between the Gully and Laurentian Channel. This species was also caught in deep strata sampled to 1,370 m depths in 2010-11. These apparent trends were likely influenced by the survey depth stratification scheme: the near absence of Roughhead Grenadier on the Scotian Shelf when the survey fished mostly at depths <350 m, followed by a recurring presence in survey catches after deeper strata were added as of 1995. However, caution should be exercised (i.e., the possibility of misinterpretation) when considering results from these surveys due to the sporadic and very low number of specimens caught over the years; particularly in the Laurentian Channel.

DFO-MAR redfish surveys conducted in 1982-88 (546 sets) caught a total of 110 fish weighing 52 kg in the Laurentian Channel, and on the slope south of Banquereau and Emerald Banks (Fig. 11).

The Cape Chidley cruises conducted in 1984-85 (89 sets) caught a total of 140 fish weighing 228 kg in 910-1,794 m depths (Fig. 12).

In 1991, a total of 110 Roughhead Grenadiers weighing 144 kg were caught by 15 cm gillnets in 889-2,800 m depths (Halliday et al. 2012a). Catches were higher in the Gully than south of Emerald Basin. Mean number and weight were comparable at 900 and 1,350 m depths, and declined at 1,800 m.

CENTRAL AND ARCTIC REGION

Roughhead Grenadier caught during bottom trawl research surveys conducted by DFO-C&A in 1999-2015 were in 443-1,463 m depths and -0.1^{o} to 4.59^{o} C waters, with the majority occurring in Div. 0B along the shelf edge. This species was nearly absent from tows conducted on the continental shelf, in Div. 0A, and in Hudson Strait-Ungava Bay throughout this time-series (Fig. 13).

The composite surface density distribution of Roughhead Grenadier in the Arctic Region indicates that its spatial pattern remained unchanged in 1999-2004 and 2006-15, with most fish inhabiting southern limits of the surveyed area (Div. 0B; Fig. 14). In Div. 0A, this species can be found in low densities over most of the continental shelf off of eastern Baffin Island.

OTHER CANADIAN SURVEYS

Catch patterns of Roughhead Grenadier by NSRF surveys (2006-15) mirrored to a large extent those from DFO-C&A surveys in Div. 0A and 0B (despite the difference in fishing gears), as well as DFO-NL surveys in Div. 2G; except for a few relatively large catches (>150 fish/tow) since 2011 (Fig. 15).

AREA OF OCCUPANCY

The design-weighted area of occupancy ($DWAO_t$) for Roughhead Grenadier was calculated in each year *t* as follows:

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

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.

NL REGION

The *DWAO* index for Roughhead Grenadier in Divs. 3LNOPs varied without trend in spring, ranging from 0.02 to 0.12 in 1971-82 (Yankee trawl), 0.01-0.06 in 1984-95 (Engel), and 0.04-0.07 in 1996-2015 (Campelen; Fig. 16). The fall index for Divs. 3LNO also varied without trend in 1990-94 (Engel; range: 0.03-0.08) and 1995-2007 (Campelen; range: 0.05-0.09), then increased to its highest value (0.13) in 2014 prior to declining to 0.08 in 2015. In contrast, the fall *DWAO* index for Divs. 2J3K displayed strong temporal trends and was considerably higher in both the Engel and Campelen time series when compared to those for Divs. 3LNO: declining from 0.6 in 1982 to 0.1 in 1994 (Engel), then increasing to 0.5 in 2013-14 and 0.4 in 2015.

MARITIMES REGION

Data were insufficient to allow estimation of *DWAO*.

CENTRAL AND ARCTIC REGION

Data were insufficient to allow estimation of *DWAO*.

ABUNDANCE AND BIOMASS INDICES

NL REGION

DFO-NL survey abundance and biomass indices were expressed as mean number and mean weight (kg) of Roughhead Grenadier per standard tow for spring (Divs. 3LNO and Subdiv. 3Ps) and fall (Divs. 2GHJ3KLNO). Total abundance and biomass from both spring and fall surveys were estimated by areal expansion of the stratified mean catch number and weight per tow (Smith and Somerton 1981). Estimates were also obtained separately for adult (>27.5 cm AFL) and juvenile (≤27.5 cm AFL) Roughhead Grenadier. It should be noted that, due to sexual dimorphism in this species, this estimate of juveniles will also include some mature males.

Spring survey total abundance and biomass (mature and immature fish) fluctuated without trend over 1971-2015 in Divs. 3LNO and Subdiv. 3Ps (Table 1a,b; Fig. 17). Catch rates in Divs. 3LN ranged from 0.05 to 1.9 fish/tow and 0.06-1.4 kg/tow in 1971-83 (Yankee trawl),

0.007-1.3 fish/tow and 0.009-0.8 kg/tow in 1984-95 (Engel), and 0.7-4.7 fish/tow and 0.03-2.9 kg/tow in 1996-2015 (Campelen). The lowest catch rates were observed in Div. 3O and Subdiv. 3Ps, ranging from 0.001 to 0.01 fish/tow and 0.001-0.01 kg/tow in 1971-83 (Yankee), 0.001-0.05 fish/tow and 0.001-0.03 kg/tow in 1984-95 (Engel), and 0.002-0.3 fish/tow and 0.0003-0.1 kg/tow in 1996-2015 (Campelen).

Fall survey total abundance and biomass also varied without trend in the northern (Divs. 2GH) and southern areas (Divs. 3LNO) surveyed, while exhibiting a declining trend in catch rates in Divs. 2J3K over 1977-94 (Engel trawl), followed by an increasing trend in 1995-2015 (Campelen; Table 2a,b; Figs. 18-19). Catch rates in Divs. 2GH ranged from 0.2 to 7.6 fish/tow and 0.05-5.3 kg/tow in 1977-94 (Engel), and 1.3-9.2 fish/tow and 0.3-1.9 kg/tow in 1995-2015 (Campelen). In Divs. 2J3K, catch rates ranged from 0.3 to 6.5 fish/tow and 0.2-5.3 kg/tow in 1977-94 (Engel), and 2.2-10.1 fish/tow and 0.2-4.4 kg/tow in 1995-2015 (Campelen). In Divs. 3LN, catch rates ranged from 0.03 to 5.6 fish/tow and 0.03-5.4 kg/tow in 1977-94 (Engel), and 1.0-5.7 fish/tow and 0.1-3.4 kg/tow in 1995-2015 (Campelen). Catch rates in Div. 3O were consistently lower, ranging from 0.05 to 0.08 fish/tow and 0.03-0.06 kg/tow in 1991-94, and 0.03-0.2 fish/tow and 0.005-0.07 kg/tow in 1995-2015.

Spring survey estimates of population size indicated that most Roughhead Grenadier were found in Div. 3L (regardless of trawl used), followed by Div. 3N (especially since 1996), with only a small portion in Divs. 3O and Subdiv. 3Ps (Fig. 20). Total abundance and biomass estimates fluctuated between 1.0-5.5 million fish and 600-4,000 t (respectively) in 1971-82, then exhibited a declining trend to 0.9 million fish and 320 t in 1995. In 1996-2015 (Campelen), these indices ranged from 8 to16 million fish and 2,000-7,000 t.

Fall survey estimates of population size in Divs. 2GHJ3KLNO indicated a declining trend over 1978-94 (Engel), followed by an increasing trend thereafter (Campelen trawl; Fig. 21). Most Roughhead Grenadier were consistently found in Divs. 3KL, followed by Divs. 2J3N since 1995 (Campelen), and only a small portion in Divs. 2GH3O. Total abundance and biomass indices declined by an order of magnitude over 1987-94: from 31 million fish and 25,000 t (respectively) to 3 million fish and 2,000 t. Since 1995 (Campelen), these estimates increased from 29 million fish and 7,000 t to 98 million fish and 38,000 t in 2013, but then declined to 61 million fish and 29,000 t by 2015.

Decline rates were calculated for each DFO-NL gear-survey time period available. During 1977-94, Roughhead Grenadier in Divs. 2J3K underwent an 89.3% decline in fall survey abundance (Fig. 22). Following this decline, this species underwent a 99.9% increase in abundance over 1995-2015. It should be noted that, due to lack of a conversion factor between Engel and Campelen gear, the rates of decline and increase are not directly comparable as a consequence of different catchabilities of both trawls. The Campelen trawl has been found to be more effective in capturing small fish. A similar pattern of decline and increase was also observed in Divs. 3LNO during the fall survey: declining by 79% over 1990-94, and then increasing by 72.6% in 1995-2015 (Fig. 23). On the Grand Banks, Roughhead Grenadier declined by 53.2% in the spring survey over 1984-95, and continued to decline in 1996-2015; although at a lower rate (14.6%; Fig. 24). In Subdiv. 3Ps, this species increased in abundance by 92.6% during 1984-95, followed by a 82.8% decline in 1996-2015 (Fig. 25).

Total annual abundance-at-length from DFO-NL spring surveys of Divs. 3LNO and Subdiv. 3Ps in 1996-2015 (Campelen trawl) periodically represented at least one year-class through modes of 6.5 cm AFL in 1996 (another at 14.5 cm), 9.0 cm in 1997 (another at 14.5 cm), 11 cm in 1998 (another at 15.5 cm), 11.5-13 cm in 1999, 13.5-14 cm in 2000, 14-15.5 cm in 2001, and 17 cm in 2002 (Fig. 26). A pulse of recruits at 5.5 cm AFL was caught in 2003 and then found at 6.5 cm in 2005, while another year-class appeared as modes of 15.5 cm fish in 2003, 16 cm in

2004, 17.5-18 cm in 2005, and 18.5 cm in 2006. In 2007, a different year-class may have been represented by modes of 14-14.5 cm AFL fish (another mode at 22 cm), 15-16 cm in 2008, 15 cm in 2009, 16-17.5 cm in 2010, and 16.5-18 cm in 2011. A pulse of recruits at 6 cm and 6.5 cm were caught in 2010 and 2012, respectively. In 2015, a pulse of recruits at 5.5 cm was also caught, along with another year-class of 16.5-17 cm AFL fish.

Total annual abundance-at-length from DFO-NL fall surveys of Divs. 2J3K in 1995-2015 (Campelen trawl) appeared to periodically track at least one year-class through modes of: 4.5 cm AFL in 1995 (another at 11-11.5 cm), 7 cm in 1996 (another at 13 cm), 9.5 cm in 1997 (another at 14 cm), 11-12 cm in 1998 (another at 15 cm), 11.5-12.5 cm in 1999 (another at 16.5 cm), 14 cm in 2000, 16 cm in 2001, 17 cm in 2002, and 18 cm in 2003-04 (Fig. 27). In 2004, a different year-class may have been represented by modes of 12 cm AFL fish, 14 cm in 2006, 15 cm in 2008, 16 cm in 2009, 16.5 cm in 2010, 17 cm in 2011, and 19 cm in 2013. Except in 1997-99 and 2007, a pulse of recruits ≤8 cm AFL was caught annually. Fall surveys of Divs. 3LNO in 1995-2015 indicated that a pulse of recruits at 4-4.5 cm AFL was caught in 1995 and then found at 7-7.5 cm in 1996, at 10 cm in 1997, at 12 cm in 1998, at 13 cm in 1999, at 14 cm in 2000, at 15 cm in 2001, at 16 cm in 2002, at 17 cm in 2003, and at 18 cm in 2004 (Fig. 28). Another year-class may have been represented by modes of 12 cm AFL fish in 1995, 13.5 cm in 1996, 15 cm in 1997, 16 cm in 1998, 17 cm in 1999, and 18.5 cm in 2001. Furthermore, a pulse of recruits ≤8 cm AFL was caught in most years.

Relative abundance-at-length by life history stage from DFO-NL research surveys suggested trends in the adult (>27.5 cm) components of the Roughhead Grenadier population over time (Figs. 29-34). Spring surveys of Divs. 3LNO and Subdiv. 3Ps in 1985-95 (Engel trawl) indicated that adult abundance declined in the mid-1980s then stabilized at low levels (Fig. 29). After changing to Campelen trawl, these surveys over 1996-2015 showed the adult component of the population continued to fluctuate at low levels (Fig. 30). Fall surveys of Divs. 2J3K in 1978-94 (Engel) also indicated adult fish declined since the early 1980s to their lowest levels in 1994 (34 adults), while the proportion of adult fish decreased (7 to 1%; Fig. 31). After switching to the Campelen trawl, these surveys over 1995-2015 showed a gradual increase in the relative abundance of adults, with a slightly increasing proportion of adults captured over 2010-15 (1 to 4%; Fig. 32). Fall surveys of Divs. 3LNO in 1990-94 (Engel) indicated that adult Roughead Grenadier declined to low levels (53-ave. for adults), while the proportion of adult fish decreased (9 to 2%; Fig. 33). These surveys over 1995-2015 (Campelen) showed a gradual increase in the relative abundance of adults, with a peak in 2010 (Fig. 34).

MARITIMES REGION

DFO-MAR survey abundance and biomass indices were expressed as mean number and mean weight (kg) of Roughhead Grenadier per standard tow for stratum 496 in 1995-2014. The stratum was not sampled in 1999, 2004, 2007, and 2008. Roughhead Grenadiers were caught in eleven of the fifteen years sampled, and ranged from 0-3 fish per tow within years, with one exceptional catch of 34 fish in 1998 (Fig. 35). Biomass showed a similar uninformative series.

Length frequencies indicated that juvenile and adult fish were present along the slope. Only juvenile fish were caught in DFO-MAR research surveys (<69.7 cm TL), with an average of 32 cm TL (Fig. 36). Roughhead Grenadiers caught in redfish surveys averaged 48.3 cm TL, and only 5 of 58 fish measured were longer than 69.7 cm TL. The *Cape Chidley* cruises and fishing trials indicated that individuals exceeding 69.7 cm TL were present at depths >900 m. Average total length in the *Cape Chidley* cruises was 61 cm (range: 29-88 cm), with 41% of fish exceeding 69.7 cm TL. Halliday et al. 2012a reported a bimodal length frequency with peaks near 55 and 80 cm TL.

CENTRAL AND ARCTIC REGION

DFO C&A survey abundance and biomass indices were expressed as mean number and mean weight (kg) of Roughhead Grenadier per standard tow for Div. 0B, and varied from 3-16 fish/tow and 3-7 kg/tow (respectively; Fig. 37). Total biomass and abundance estimates for 2000 and 2001 were similar to those from 2011-15: 2,500 t and 6 million fish (respectively; Fig. 38). Pre-anal fin length from Div. 0B surveys ranged from 2 to 38 cm with a mode of 13 cm in 2000-01 surveys (combined), and 17 cm in 2011-15 surveys (combined; Fig 39). Ninety-seven percent of Roughhead Grenadier exceeded 27.5 cm AFL; thereby indicating maturity. Mature females comprised only 3% of the catch.

Roughhead Grenadier were nearly absent from the continental shelf throughout the surveyed area, as well as in Div. 0A and the Hudson Strait-Ungava Bay; thereby precluding estimation of catch rates and abundance for these areas.

OTHER SURVEYS - OUTSIDE CANADA'S EEZ

EU Survey - Div. 3L

The abundance index averaged 25.7 fish/tow, and increased from the beginning of this survey until 2008, when it reached a peak of 38.4 fish/tow (Fig. 40). Estimates then declined to their lowest value of 16.5 fish/tow in 2012, and subsequently increased. Over 2003-15, this index showed a 38.4% increase.

EU Survey - Divs. 3NO

The abundance index averaged 7.3 fish/tow, and increased from 3.8 fish//tow in 1997 to a peak of 12.1 fish/tow in 2004 (Fig. 40). After 2006, estimates declined to 4.1 fish/tow in 2014, but reached 6.8 fish/tow in 2015. Over 1997-2015, this index showed a 17.8% increase.

EU Survey - Div. 3M

Although the EU has conducted a Div. 3M survey as of 1988, abundance estimates for strata down to 1,400 m depths were available only since 2004. Roughhead Grenadier averaged 4.9 fish/tow at depths >700 m. Prior to 1996, this index was variable, then showed an increasing trend over 1996-2006 (Fig. 40). Since 2007, estimates declined to a survey minimum of 0.5 fish/tow in 2014, and 0.6 fish/tow in 2015. This survey indicated a 55.3% decline over 1990-2015. The 2004-15 portion of this survey (i.e., sampling >1,400 m) showed an abundance index of 7.0 fish/tow on average; declining from an initial peak of 14 fish/tow to a minimum of 3.0 fish/tow in 2015 (77.8% decline).

West Greenland

Annual abundance estimates for Roughhead Grenadier in Div. 1C-D (summarized in Jørgensen et al. 2014) varied without trend over 1988-95; ranging from 1 to 5 million fish. In 1997-2011, abundance estimates increased from an initial 5 million fish to 20 million fish by 2000, then steadily declined to 5 million fish in 2011.

COMMERCIAL FISHERIES REMOVALS

Commercial fisheries removals of Roughhead Grenadier in Subareas 2+3 were examined for 1970-2015, using commercial data from three sources: the Northwest Atlantic Fisheries Organization STATLANT-21A landings (1970-2015), as reported by NAFO-member countries; DFO-Zonal Interchange File Format (ZIFF) landings (1985-2015), as reported by Canadian

fishers (recorded in their logbooks and on fish plants' purchase slips); and Canadian At-Sea Fisheries Observers' (ASO) catch and discard data (1985-2014), collected on a set-by-set basis in a standardized format on board commercial fishing vessels at sea. Canadian ASOs constitute the sole source of data on speciated total catch and discards at sea, while fishers from Canada and other NAFO-member countries never record discards. It must be noted that observer coverage in most Canadian Atlantic groundfish fisheries is very low to non-existent (<5% annually).

Roughhead Grenadier landings were primarily from Greenland Halibut (Turbot)-directed gillnet fisheries in Divs. 3LN (Figs. 41, 42). In the Canadian EEZ, Roughead Grenadiers were also caught as bycatch mainly in the Divs. 2J3KL (Fig. 43) Turbot gillnet fishery (Figs. 44, 45).

Roughhead Grenadier bycatch from Quebec and Gulf Region ASOs in the Divs. 0A and 0B Greenland Halibut fishery increased from less than 10 t during 1997-2011 to 40-50 t in the last two years (2014, 2015; Table 3); attributed to the expanding fishery and increased at-sea observer coverage of this gillnet fishery since 2012.

Regarding grenadier bycatch in Turbot-directed fisheries conducted by EU-Portugal and EU-Spain in Divs. 3LMN, it must be noted that most landings of Roughhead Grenadier in 1988-96 were reported to NAFO as Roundnose Grenadier, as a consequence of the NAFO data reporting forms listing "Grenadier" only as "Roundnose" at that time. The NAFO landings statistics have been corrected for EU-Portugal data, but those from EU-Spain for 1992-96 (Junquera 1998) remain unchanged. Roughhead Grenadier landings have been reported correctly to NAFO as of 1997. Power and Maddock-Parsons (1998) estimated that Roughhead Grenadier landings (taken primarily by EU-Portugal and EU-Spain) averaged 4,500 t annually in 1990-96.

The size composition of Roughhead Grenadier bycatch in Turbot-directed fisheries were recorded by EU-Spain in Divs. 3LMNO (130 mm mesh; 2010-15), and ranged from 5-40 cm AFL with modes of 15-17 cm (Fig. 46). Similarly, EU-Portugal reported 6-40 cm AFL Roughhead Grenadiers from Divs. 3LMN (130 mm mesh; 2010-15) with a mode of 12 cm; except for a 17 cm mode from Div. 3N in 2010 and Div. 3M in 2013 (Fig. 47). Russian bycatch of this species ranged from 22-97 cm TL in Divs. 3LMN, with modes of 42-46 cm in 2009-13 and 49-51 cm in 2014-15 (Fig. 48).

Although at-sea observers of Canadian fisheries do not collect length data on bycatch species unless tasked to do so, an ASO aboard a Canadian trawler fishing Turbot (using 148 mm mesh) in Subarea 0 in 1996 reported Roughhead Grenadiers ranging from 31-84 cm TL, with modes of 42 and 49 cm (Fig. 49).

Based on Canadian ASO (NL Region) catch data over 1995-2014, the distribution of Roughhead Grenadier corresponded well to that observed from research survey catches (Fig. 50). Most Roughhead Grenadiers were caught primarily as bycatch in the Greenland Halibut fishery and secondarily in the Northern Shrimp fishery conducted along the continental shelf slope in Divs. 2J3K and Div. 3O, while catches were very low to absent in Divs. 3LN. Similar patterns were observed further north in Divs. 2GH and 0AB: most catches occurred along the shelf slope, and were almost absent on the shelf (Fig. 51). These patterns were consistent throughout this time-series.

Based on Canadian ASO (Maritimes Region) data, no Roughhead Grenadier were landed in Maritime waters over 2003-15. Locations of observed grenadier-directed fisheries are shown in Figure 52. These occurred in 1993-97 for Roundnose Grenadier, mainly in the area south of LaHave Bank (Table 4). Figure 53 indicates the distribution of Roughhead Grenadier caught as

bycatch in all observed fisheries, including predominantly a Silver Hake fishery during the 1980s.

REVIEW OF DESIGNATABLE UNITS

There is no evidence of more than one DU within Canadian waters. However, for management purposes three stock units have been established in the North Atlantic: West Greenland (Subareas 0, 1), East Greenland, and the Norwegian Sea (Katsarou and Naevdal 2001).

Rescue of Canadian populations by populations off of Greenland, on the Flemish Cap, and the NRA of the Grand Banks may be possible due to the widespread distribution of the species in the North Atlantic, as well life history characteristics (e.g., bathypelagic distribution, long life span, year-round spawning).

COSEWIC CRITERIA

DECLINING TOTAL POPULATION

An overall trend for the Roughhead Grenadier population in the Northwest Atlantic and Arctic Ocean is difficult to determine, with recent research surveys providing conflicting results. Furthermore, the portion of this population that probably inhabits depths below 1,600 m remains unknown, as these depths are beyond those surveyed by DFO.

THREATS TO ABUNDANCE

Potential anthropogenic threats to Roughhead Grenadier abundance include bycatch in other directed fisheries (i.e., primarily the offshore Turbot fishery), oil and gas exploration and production, marine shipping, marine pollution (e.g., plastics), aquatic invasive species, and marine aquaculture siting/activities. Current limitations of quantitative data prevent assessment of the nature and magnitude of potential effects of these threats on Roughhead Grenadier populations. However, impacts of near-shore disturbances (e.g., aquaculture, waste water outflows, aquatic invasive species) are likely not significant. Natural threats to the abundance of this species potentially arise from the effects of climate change (e.g., increasing seawater temperatures, increasing ocean acidification, decreasing oxygen concentration/expanding hypoxia at greater depths). Impacts of various offshore activities (e.g., seismic surveys, oil and gas drilling, marine shipping) and effects of climate change on specific life stages of Roughhead Grenadier (e.g., pelagic eggs and larvae, juveniles, deep-water adults) are presently unknown.

CURRENT PROTECTION AND MANAGEMENT

Roughhead Grenadier in Canada's EEZ is managed federally under the *Fisheries Act*.

Reported Roughhead Grenadier landings are primarily from bycatch in gillnet fisheries directing for Greenland Halibut (Murua et al. 2005; DFO-NL ZIFF data).

In 2007, COSEWIC assessed the status of Roughhead Grenadier in Canada, and designated it as 'Special Concern', citing a decline of over 90% in a Canadian survey abundance index through the 1980s and early-1990s, as well as indications of a range contraction in Canadian waters (COSEWIC 2007). COSEWIC (2007) also indicated that life history traits of this species (e.g., slow growth, late maturation) render it particularly vulnerable to human-induced mortality, and would limit its recovery. Roughhead Grenadier is currently not listed on Schedule 1 of Canada's SARA.

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TABLES

Table 1a. Abundance index of Roughhead Grenadier from Canadian spring research surveys in Div. 3LNOPs, 1971-2015. Surveys were conducted with a Yankee trawl (1971-82), an Engel trawl (1983-spring 1995), and a Campelen trawl (spring 1996-2015). Subdiv. 3Ps was not surveyed in 1971, 2006; Div. 3O was not surveyed in 1972, 1974, 1983; and Div. 3N was not surveyed in 1983.

Trawl	Year	3L	3N	3O	3Ps	3LNOPs
Yankee	1971	1,328,011	650,256	-	-	1,978,267
Yankee	1972	457,254	446,125	-	-	903,379
Yankee	1973	430,105	252,191	-	-	682,296
Yankee	1974	1,897,504	45,764	-	-	1,943,268
Yankee	1975	1,814,384	163,359	-	-	1,977,744
Yankee	1976	880,375	-	-	4,767	885,142
Yankee	1977	1,001,092	708,422	-	1,745	1,711,259
Yankee	1978	1,447,601	1,662,578	2,302	-	3,112,481
Yankee	1979	2,690,481	168,369	-	-	2,858,850
Yankee	1980	5,004,580	484,665	1,451	-	5,490,696
Yankee	1981	3,241,823	273,071	-	-	3,514,894
Yankee	1982	986,218	140,107	11,905	-	1,138,231
Yankee	1983	-	-	-	19,066	19,066
Engel	1984	-	96,908	-	8,783	105,690
Engel	1985	3,775,714	117,400	-	4,053	3,897,168
Engel	1986	1,253,409	33,929	-	5,405	1,292,743
Engel	1987	2,219,381	274,210	-	-	2,493,591
Engel	1988	765,092	13,061	-	1,351	779,504
Engel	1989	1,530,032	9,233	-	18,804	1,558,068
Engel	1990	569,857	8,707	-	-	578,565
Engel	1991	729,310	123,856	21,196	6,576	880,938
Engel	1992	2,025,670	39,334	43,712	-	2,108,716
Engel	1993	874,198	184,733	47,262	5,600	1,111,793
Engel	1994	1,450,703	115,613	70,523	19,652	1,656,491
Engel	1995	869,656	51,719	26,911	11,034	959,320
Campelen	1996	10,685,030	757,625	137,258	-	11,579,913
Campelen	1997	9,035,555	1,707,580	11,349	-	10,754,485
Campelen	1998	12,568,035	3,307,618	552,664	50,714	16,479,031
Campelen	1999	10,589,210	2,154,084	759,428	145,674	13,648,397
Campelen	2000	10,044,513	4,025,772	581,504	168,829	14,820,619
Campelen	2001	10,832,068	4,367,511	236,796	62,948	15,499,323
Campelen	2002	8,110,114	2,383,989	293,171	75,975	10,863,249
Campelen	2003	12,834,961	2,207,147	51,899	17,333	15,111,340
Campelen	2004	8,329,049	1,741,461	113,836	-	10,184,346
Campelen	2005	24,958,001	7,177,847	73,309	-	32,209,158
Campelen	2006	11,100,485	-	-	-	11,100,485
Campelen	2007	12,131,446	8,545,845	70,706	-	20,747,997
Campelen	2008	9,916,962	1,969,811	120,762	-	12,007,536
Campelen	2009	6,898,553	3,953,008	299,368	24,266	11,175,195
Campelen	2010	9,194,489	4,186,780	106,824	20,221	13,508,314
Campelen	2011	8,418,495	2,813,817	86,866	4,524	11,323,703
Campelen	2012	12,839,591	3,300,371	65,030	11,555	16,216,546
Campelen	2013	6,200,960	2,798,850	123,066	17,975	9,140,851
Campelen	2014	4,781,153	2,659,233	119,393	-	7,559,779
Campelen	2015	4,381,183	2,261,939	80,473	-	6,723,595

Table 1b. Biomass (tonnes) index of Roughhead Grenadier from Canadian spring research surveys in Div. 3LNOPs, 1971-2015. Surveys were conducted with a Yankee trawl (1971-1982), an Engel trawl (1983-1995), and a Campelen trawl (1996-2015). Subdiv. 3Ps was not surveyed in 1971, 2006; Div. 3O was not surveyed in 1972, 1974, 1983; Div. 3N was not surveyed in 1983.

Trawl	Year	3L	3N	3O	3Ps	3LNOPs
Yankee	1971	1,198,385	1,017,597	-	-	2,215,982
Yankee	1972	648,735	483,033	-	-	1,131,768
Yankee	1973	381,272	241,202	-	-	622,474
Yankee	1974	1,638,760	52,632	-	-	1,691,391
Yankee	1975	1,690,273	147,387	-	-	1,837,660
Yankee	1976	625,682	-	-	4,595	630,277
Yankee	1977	1,164,589	866,724	-	785	2,032,098
Yankee	1978	1,055,369	1,697,354	1,565	-	2,754,288
Yankee	1979	1,949,966	155,392	-	-	2,105,358
Yankee	1980	3,601,805	467,844	1,161	-	4,070,810
Yankee	1981	2,829,464	285,663	-	-	3,115,127
Yankee	1982	513,390	95,013	6,868	-	615,271
Yankee	1983	-	-	-	15,756	15,756
Engel	1984	-	49,763	-	3,513	53,276
Engel	1985	2,348,180	83,603	-	2,702	2,434,486
Engel	1986	1,070,297	26,182	-	3,918	1,100,397
Engel	1987	1,826,509	253,079	-	-	2,079,588
Engel	1988	787,853	17,415	-	1,351	806,619
Engel	1989	1,427,621	11,079	-	19,412	1,458,112
Engel	1990	463,802	11,320	-	-	475,122
Engel	1991	249,349	14,884	5,365	5,702	275,300
Engel	1992	1,110,228	18,227	13,031	-	1,141,486
Engel	1993	454,919	84,410	21,470	1,629	562,428
Engel	1994	611,646	28,164	39,090	12,947	691,847
Engel	1995	322,689	23,589	11,916	8,276	366,469
Campelen	2,776,940	76,881	28,679	-	2,882,500	2,776,940
Campelen	2,747,597	375,142	763	-	3,123,502	2,747,597
Campelen	4,221,212	697,993	158,541	8,430	5,086,176	4,221,212
Campelen	2,986,979	777,124	279,303	41,079	4,084,484	2,986,979
Campelen	3,620,601	1,267,269	207,197	65,598	5,160,665	3,620,601
Campelen	3,707,099	1,161,355	79,787	15,729	4,963,970	3,707,099
Campelen	2,526,538	598,090	87,730	56,461	3,268,819	2,526,538
Campelen	3,609,206	670,772	21,141	8,840	4,309,958	3,609,206
Campelen	3,657,962	637,605	65,009	-	4,360,576	3,657,962
Campelen	12,204,986	3,501,591	31,518	-	15,738,095	12,204,986
Campelen	5,415,188	-	-	-	5,415,188	5,415,188
Campelen	6,393,925	7,057,479	24,197	-	13,475,601	6,393,925
Campelen	3,882,941	1,016,254	77,971	-	4,977,167	3,882,941
Campelen	2,375,617	1,786,415	137,983	11,728	4,311,744	2,375,617
Campelen	3,532,421	2,151,419	54,824	6,875	5,745,539	3,532,421
Campelen	3,310,849	1,228,697	36,945	1,041	4,577,532	3,310,849
Campelen	5,077,702	1,682,203	31,405	6,009	6,797,318	5,077,702
Campelen	2,526,463	1,280,006	45,301	5,123	3,856,892	2,526,463
Campelen	2,257,458	1,184,341	53,435	-	3,495,234	2,257,458
Campelen	1,321,138	1,059,830	21,127	-	2,402,095	1,321,138

Table 2a. Abundance index of Roughhead Grenadier from Canadian fall research surveys in Div. 2GHJ3KLNO, 1977-2015. Surveys were conducted with an Engel trawl (1977-94), and a Campelen trawl (1995-2015). Deep strata of Div. 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Div. 3NO was surveyed in 2014.

Trawl	Year	2G	2H	2J	3K	3L	3N	3O
Engel	1977	-	-	10,325,163	109,706	-	-	-
Engel	1978	1,825,783	2,242,693	10,675,617	15,315,999	-	-	-
Engel	1979	1,734,537	3,708,147	6,733,220	11,164,694	-	-	-
Engel	1980	-	-	10,233,237	10,940,539	-	-	-
Engel	1981	2,870,489	2,564,713	5,191,416	9,466,045	6,655,142	-	-
Engel	1982	-	-	7,970,725	11,861,860	8,931,032	-	-
Engel	1983	-	-	7,665,956	8,105,202	2,597,672	-	-
Engel	1984	-	-	6,014,261	9,378,890	16,146,469	-	-
Engel	1985	-	-	2,673,192	6,527,749	8,827,315	-	-
Engel	1986	-	-	5,525,797	3,197,660	6,902,652	-	-
Engel	1987	3,553,461	994,492	3,718,108	4,100,860	13,340,579	-	-
Engel	1988	1,557,487	1,686,669	3,109,362	3,173,133	3,913,559	-	-
Engel	1989	-	-	4,352,067	1,528,421	2,795,285	-	-
Engel	1990	-	-	4,486,157	4,699,283	5,656,087	34,379	-
Engel	1991	-	146,863	2,966,230	5,101,103	4,151,813	173,091	101,659
Engel	1992	-	-	3,152,560	852,786	1,310,124	72,437	-
Engel	1993	-	-	1,102,717	1,620,362	1,675,596	567,598	106,425
Engel	1994	-	-	1,033,211	1,003,396	1,265,264	339,360	73,300
Campelen	1995	-		6,212,429	10,152,476	8,875,235	3,919,868	473,531
Campelen	1996	2,751,342	4,385,622	12,234,456	20,158,173	12,340,798	2,346,113	263,452
Campelen	1997	8,828,497	7,772,768	17,015,197	18,930,351	6,604,762	4,992,859	210,531
Campelen	1998	1,315,015	6,662,089	17,413,245	21,072,418	8,508,159	6,389,949	509,733
Campelen	1999	2,787,931	6,187,517	12,539,794	16,969,231	16,343,261	5,781,058	502,778
Campelen	2000	-	-	14,496,025	17,347,501	8,803,329	4,242,450	514,886
Campelen	2001	-	3,680,490	18,944,382	33,542,675	14,961,375	7,387,531	185,075
Campelen	2002	-	-	14,711,930	20,250,641	13,114,753	7,407,226	362,920
Campelen	2003	-	-	11,597,823	22,575,165	10,848,957	4,954,623	163,186
Campelen	2004	-	6,799,795	13,123,151	32,521,787	4,642,659	7,644,243	95,047
Campelen	2005	-	-	13,048,409	25,321,412	9,443,285	6,709,187	79,113
Campelen	2006	-	8,334,962	9,890,681	28,411,147	11,305,258	3,997,346	126,457
Campelen	2007	-	-	13,083,043	32,519,488	14,062,013	7,228,151	152,460
Campelen	2008	-	6,857,399	10,605,221	23,388,663	20,927,722	13,578,136	235,443
Campelen	2009	-	-	15,776,650	34,519,864	21,062,855	7,517,498	206,237
Campelen	2010	-	7,157,116	10,097,264	36,389,454	19,670,359	5,290,714	270,718
Campelen	2011	-	7,207,296	17,613,710	31,662,044	7,665,126	5,018,345	149,231
Campelen	2012	-	5,280,719	13,978,760	31,134,501	13,822,424	7,952,811	303,227
Campelen	2013	-	10,726,677	20,860,581	39,894,560	20,697,404	6,928,021	76,779
Campelen	2014	-	6,181,563	27,100,730	42,584,232	14,791,640	-	-
Campelen	2015	-	2,809,512	20,251,529	28,262,753	12,975,210	3,894,084	91,845

Table 2b. Biomass index of Roughhead Grenadier from Canadian fall research surveys in Div. 2GHJ3KLNO, 1977-2015. Surveys were conducted with an Engel trawl (1977-94), and a Campelen trawl (1995-2015). Deep strata of Div. 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Div. 3NO was surveyed in 2014.

Trawl	Year	2G	2H	2J	3K	3L	3N	3O
Engel	1977	-	-	9,564,240	84,296	-	-	-
Engel	1978	1,073,567	1,545,166	7,385,660	10,947,718	-	-	-
Engel	1979	852,749	3,072,248	5,848,277	10,143,167	-	-	-
Engel	1980	-	-	8,412,648	8,816,826	-	-	-
Engel	1981	2,130,999	2,538,428	5,536,718	7,741,235	5,355,436	-	-
Engel	1982	-	-	7,530,092	8,663,707	7,127,426	-	-
Engel	1983	-	-	6,284,100	8,065,893	2,128,967	-	-
Engel	1984	-	-	5,837,430	7,321,982	13,171,594	-	-
Engel	1985	-	-	2,203,135	4,890,743	8,610,804	-	-
Engel	1986	-	-	4,172,131	2,600,316	6,951,752	-	-
Engel	1987	2,494,297	637,582	2,918,741	3,075,279	14,769,076	-	-
Engel	1988	937,623	726,156	2,742,530	2,357,334	4,633,903	-	-
Engel	1989	-	-	2,345,823	930,096	3,328,918	-	-
Engel	1990	-	-	2,992,730	3,730,360	5,712,052	32,998	-
Engel	1991	-	28,117	1,400,562	3,173,317	4,145,902	156,091	71,998
Engel	1992	-	-	1,262,807	412,161	1,163,139	71,654	-
Engel	1993	-	-	563,111	809,428	864,286	440,665	79,196
Engel	1994	-	-	432,881	442,958	717,106	273,699	47,652
Campelen	1995	-	-	565,801	3,066,371	1,640,732	1,433,707	159,519
Campelen	1996	581,659	1,289,997	2,694,622	4,769,718	3,142,997	327,357	48,597
Campelen	1997	1,856,241	1,781,417	3,100,947	5,418,618	1,562,128	1,549,568	75,369
Campelen	1998	412,095	1,652,538	3,638,265	6,255,107	2,310,848	2,786,856	114,996
Campelen	1999	532,857	1,473,566	3,317,992	5,291,856	5,104,399	1,800,994	172,905
Campelen	2000	-	-	2,900,358	6,145,469	2,200,613	1,639,401	160,192
Campelen	2001	-	740,275	3,946,283	10,197,372	5,144,821	2,908,763	93,598
Campelen	2002	-	-	3,637,870	6,853,905	4,142,353	3,042,662	178,039
Campelen	2003	-	-	2,718,616	7,262,716	3,181,638	1,892,068	61,664
Campelen	2004	-	1,823,204	4,351,653	10,465,204	1,326,139	5,295,665	46,677
Campelen	2005	-	-	3,968,061	9,865,273	3,023,692	3,845,641	32,104
Campelen	2006	-	2,308,192	3,101,812	11,285,802	4,484,120	2,128,010	54,187
Campelen	2007	-	-	4,571,712	12,864,801	4,920,833	3,659,120	76,293
Campelen	2008	-	2,124,131	2,923,087	7,843,932	7,738,367	8,264,416	162,429
Campelen	2009	-	-	6,389,198	13,302,023	8,423,147	4,185,987	85,779
Campelen	2010	-	2,190,580	4,151,129	16,753,469	8,082,832	3,390,918	165,509
Campelen	2011	-	2,162,155	7,161,964	17,859,966	3,028,603	3,216,737	50,297
Campelen	2012	-	1,503,008	5,201,109	14,166,037	5,071,410	3,596,763	162,156
Campelen	2013	-	2,594,474	7,731,933	16,555,049	8,200,981	3,145,496	49,268
Campelen	2014	-	1,387,193	10,527,231	18,521,261	7,109,181	-	-
Campelen	2015	-	910,823	7,612,162	13,284,071	5,356,827	1,878,340	12,809

Table 3. Roughhead Grenadier bycatch (kg) by gear type in the Divs. 0A and 0B Greenland Halibut fishery, 1997-2015. Data are from Canadian At-Sea Fisheries Observers - Quebec and Gulf Regions.

Year	Gillnet - Sum of Kept weight (kg)	Gillnet - Sum of Discard weight (kg)	Single Trawl - Sum of Kept weight (kg)	Single Trawl - Sum of Discard weight (kg)	Twin Trawl - Sum of Kept weight (kg)	Twin Trawl - Sum of Discard weight (kg)	Total Sum of Kept weight (kg)	Total Sum of Discard weight (kg)
1997	-	-	0	11,780	-	-	0	11,780
1999	-	-	0	3,208	-	-	0	3,208
2000	-	-	0	4,004	0	7	0	4,011
2001	-	-	0	160	0	1,320	0	1,480
2002	-	-	0	1,467	0	705	0	2,172
2004	-	-	16	44	415	271	431	315
2005	-	-	0	158	0	443	0	601
2006	-	-	0	1,661	5	2,894	5	4,555
2007	-	-	0	2,734	0	4,047	0	6,781
2008	-	-	0	615	0	1,812	0	2,427
2009	-	-	0	1,273	0	7,524	0	8,797
2010	0	1,190	8	1,770	65	5,714	73	8,674
2011	-	-	9	2,842	191	2,304	200	5,146
2012	0	1,139	165	2,829	639	11,462	804	15,430
2013	37	22,741	496	1,969	998	4,400	1,531	29,110
2014	333	35,108	560	1,835	3,101	9,220	4,032	46,171
2015	227	29,743	127	3,873	992	7,922	1,346	41,538

Table 4. Weight (mt) of Roundnose and Roughhead grenadiers during observed grenadier-directed Maritime fisheries, 1993-97. Data are from Canadian At-Sea Fisheries Observers - Maritimes Region.

Year	Roundnose Grenadier Kept	Roundnose Grenadier Discarded	Roughhead Grenadier Kept	Roughhead Grenadier Discarded
1993	345.599	0.003	0.648	0
1994	89.993	0	0	0.005
1995	356.711	2.908	0.282	0
1996	47.15	0	0	0
1997	12.2	0	0.041	0

FIGURES

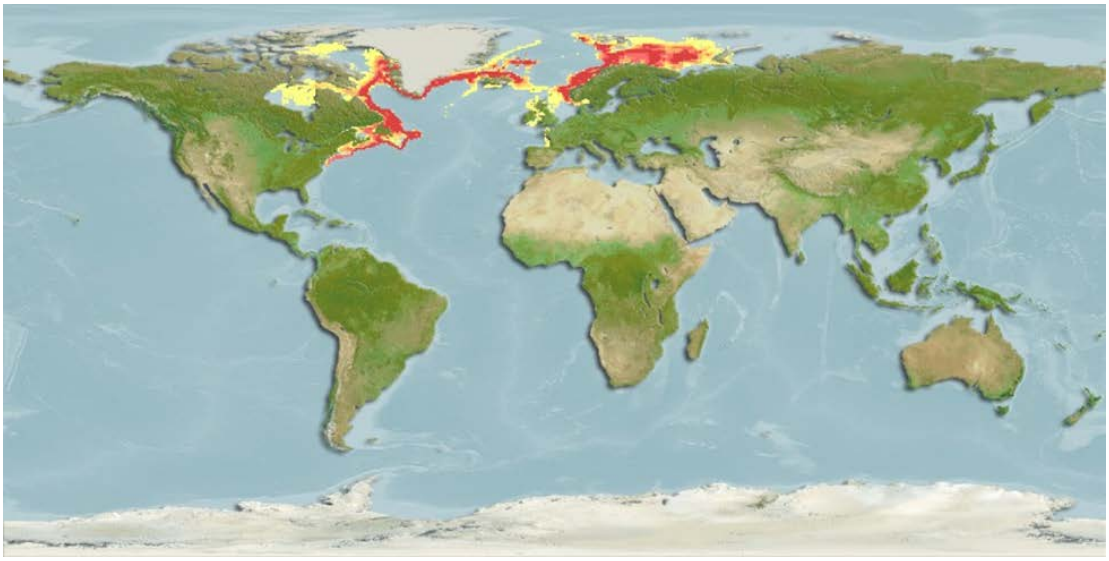

Figure 1. Reviewed distribution maps for Roughhead Grenadier, with modelled year 2100 native range map based on IPCC A2 emissions scenario. www.aquamaps.org, Aug. 2013 version. (Web accessed 19 February 2016).

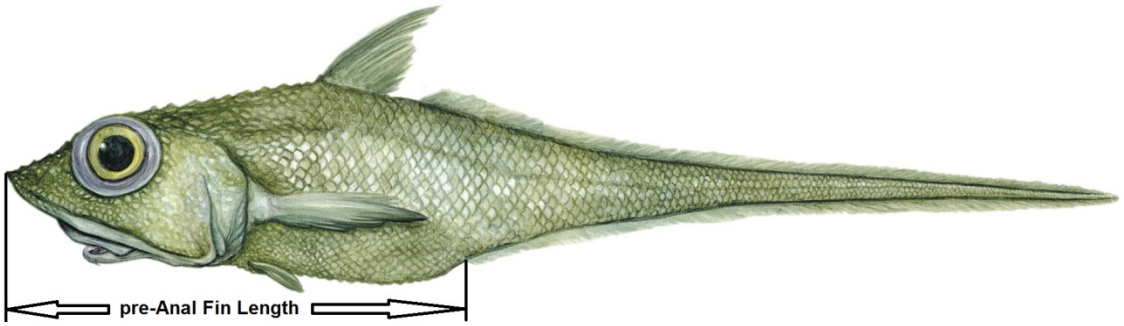

Figure 2. Roughhead Grenadier depicting pre-anal fin length. (Original grenadier painting by Gary Taylor.

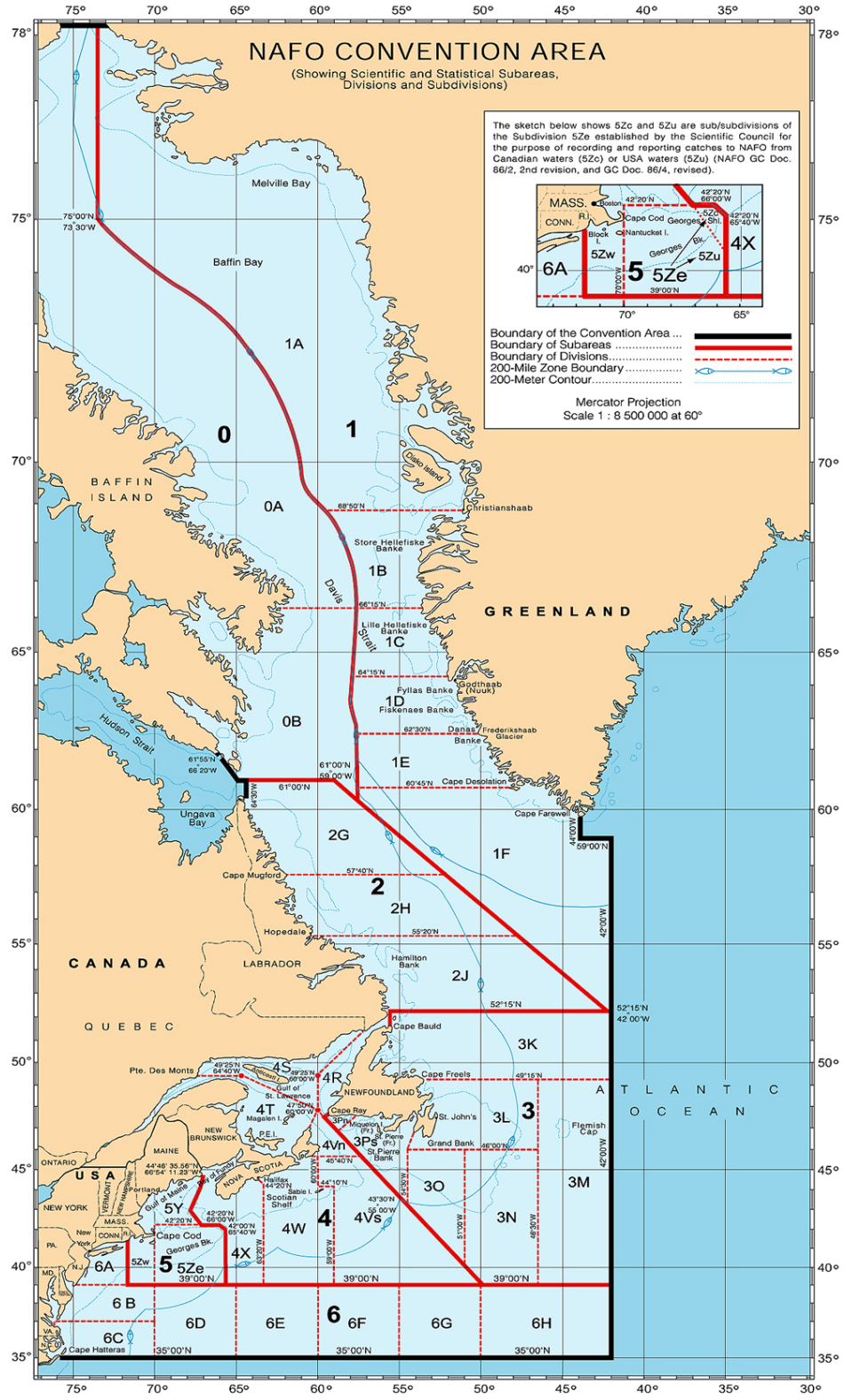

Figure 3. Map of Canadian Atlantic and Arctic waters mentioned in the text. Canada's Exclusive Economic Zone is delineated by the thin blue line (emphasized with fish outlines), NAFO Subareas by thick red lines, NAFO Divisions by thick dashed red lines, and a 200-meter contour by the thin blue dashed line.

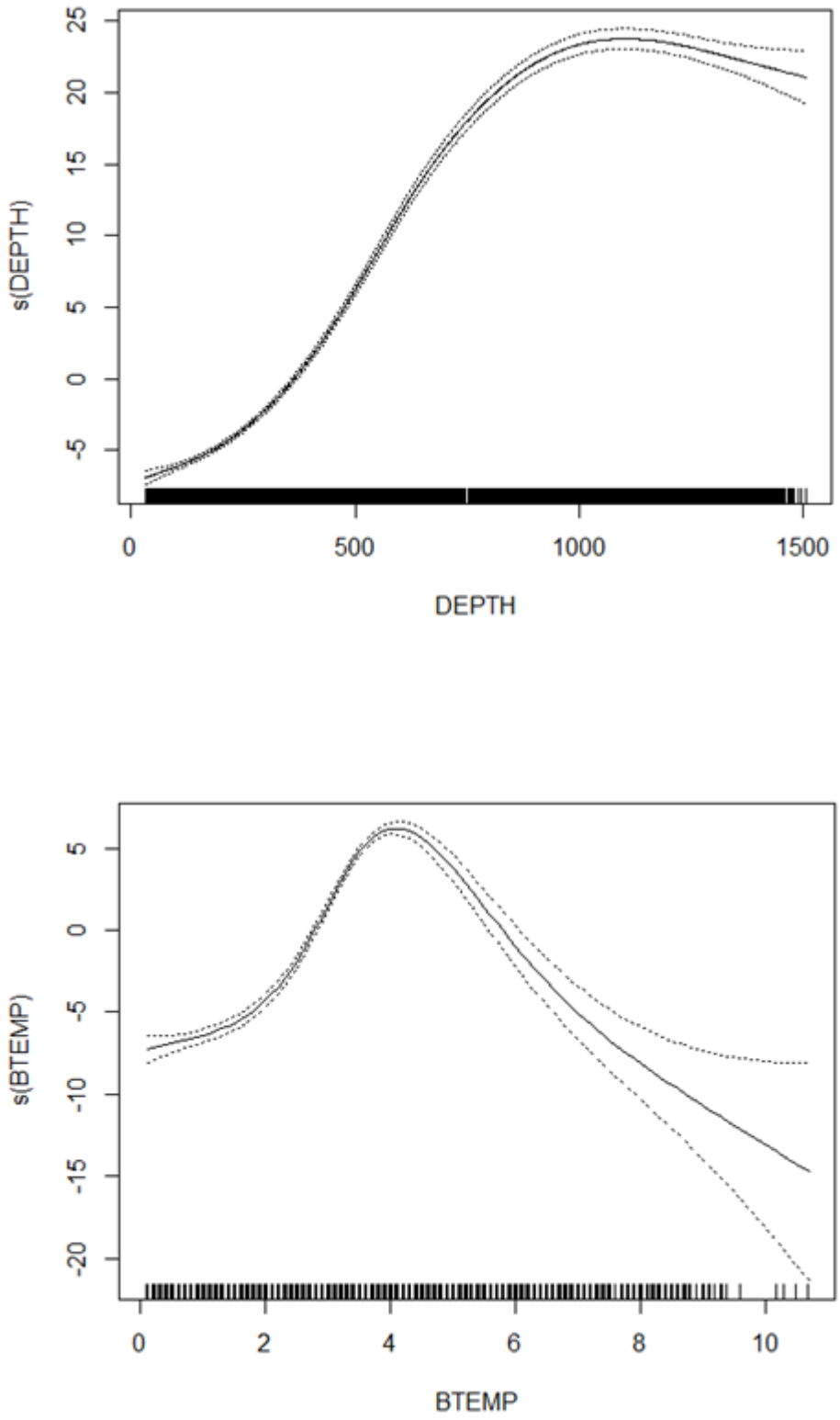

Figure 4. Roughhead Grenadier depth (top panel) and bottom temperature (bottom panel) associations in Div. 2GHJ3KLNO from DFO-NL fall Campelen surveys, 1995-2015. Dotted lines represent 95% confidence limits.

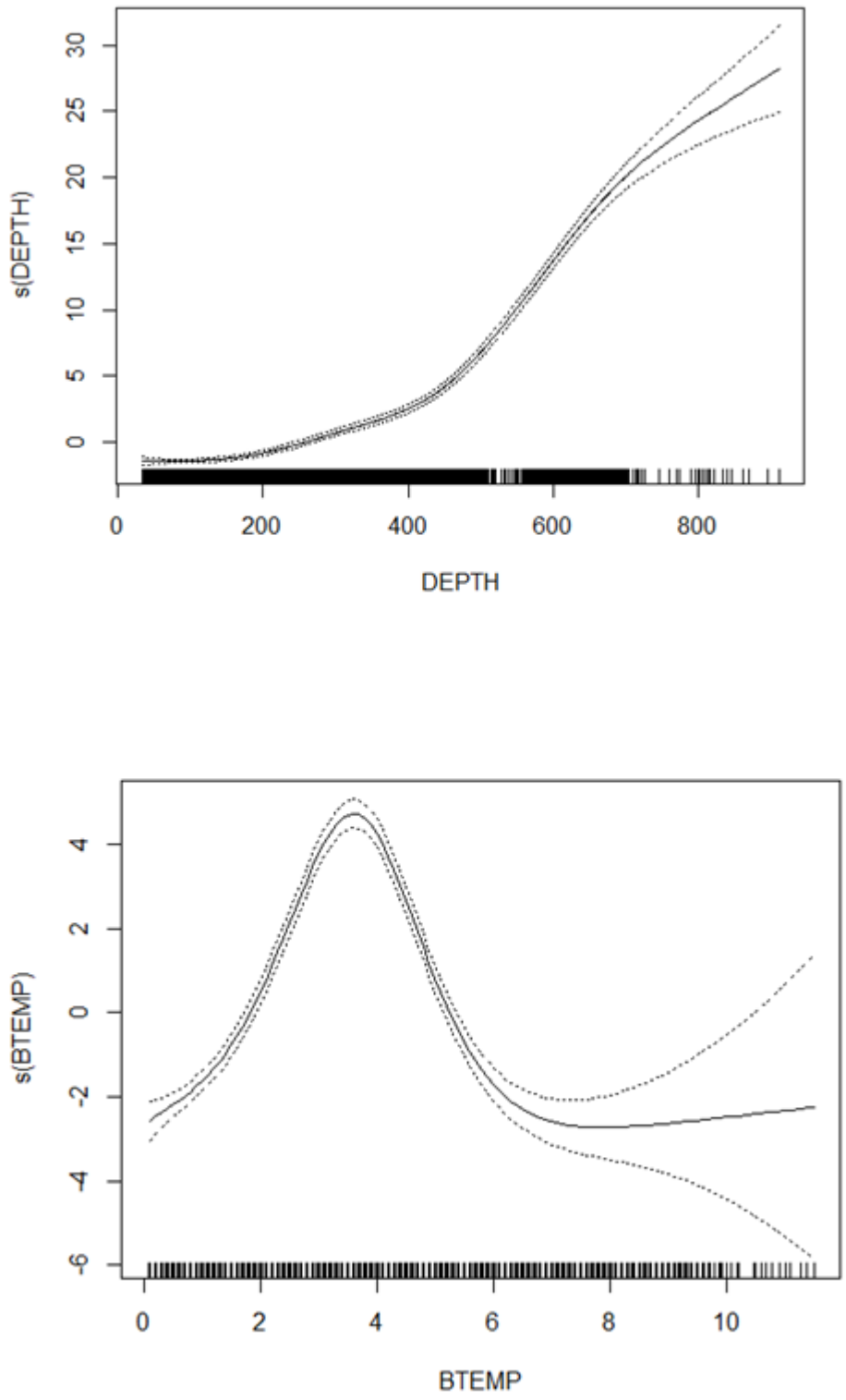

Figure 5. Roughhead Grenadier depth (top panel) and bottom temperature (bottom panel) associations in Div. 3LNOPs from DFO-NL spring Campelen surveys, 1996-2015. Dotted lines represent 95% confidence limits.

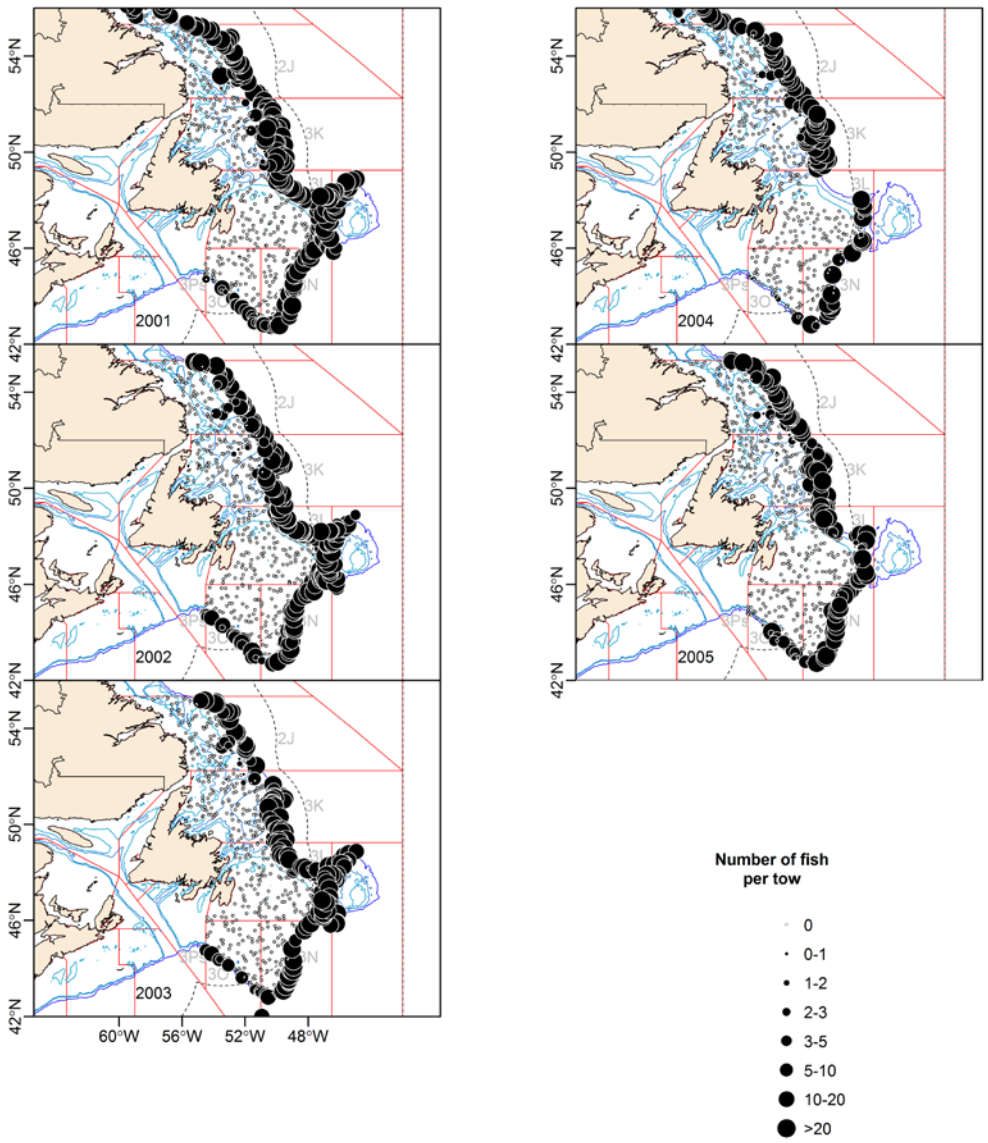

Figure 6a. Distribution of Roughhead Grenadier in DFO-NL fall research surveys, 2001-05.

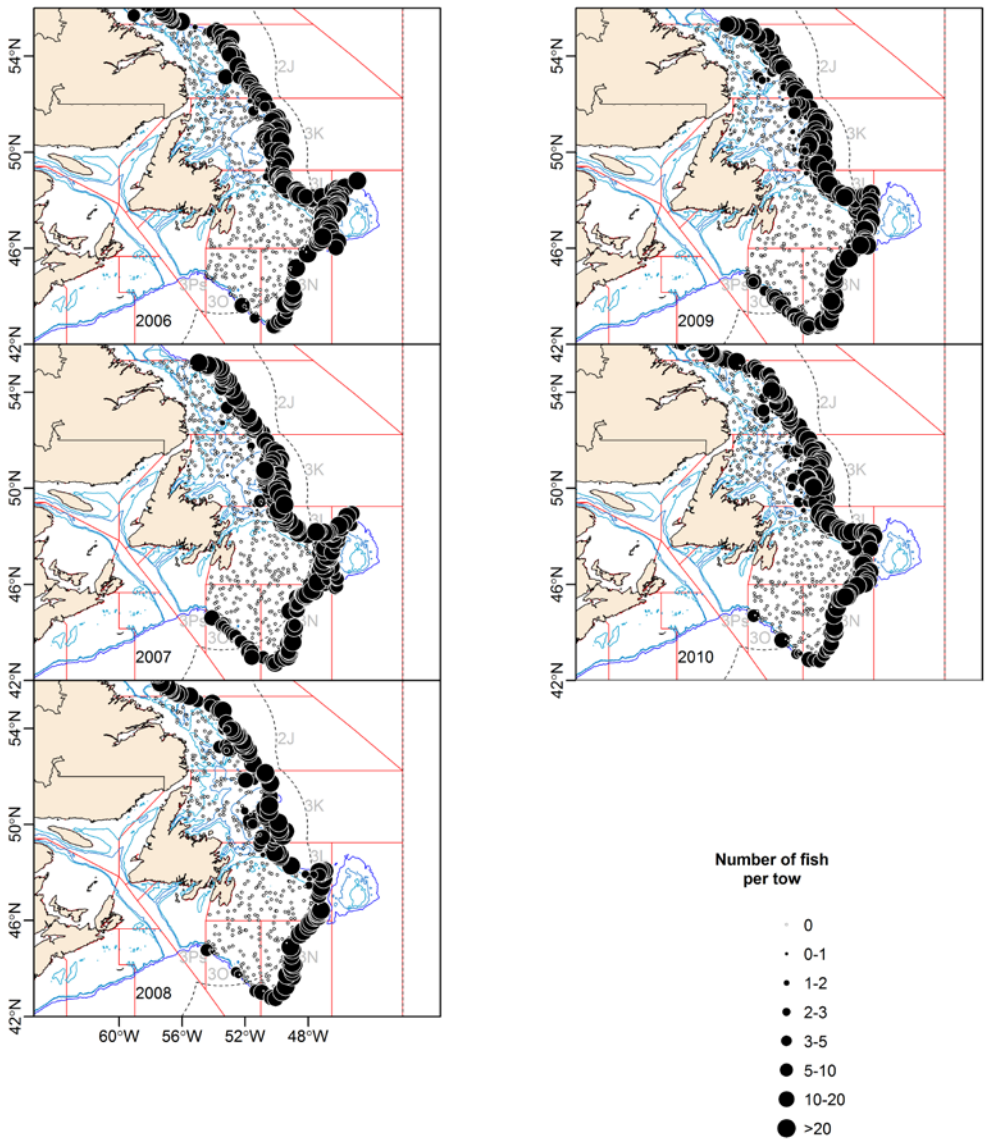

Figure 6b. Distribution of Roughhead Grenadier in DFO-NL fall research surveys, 2006-10.

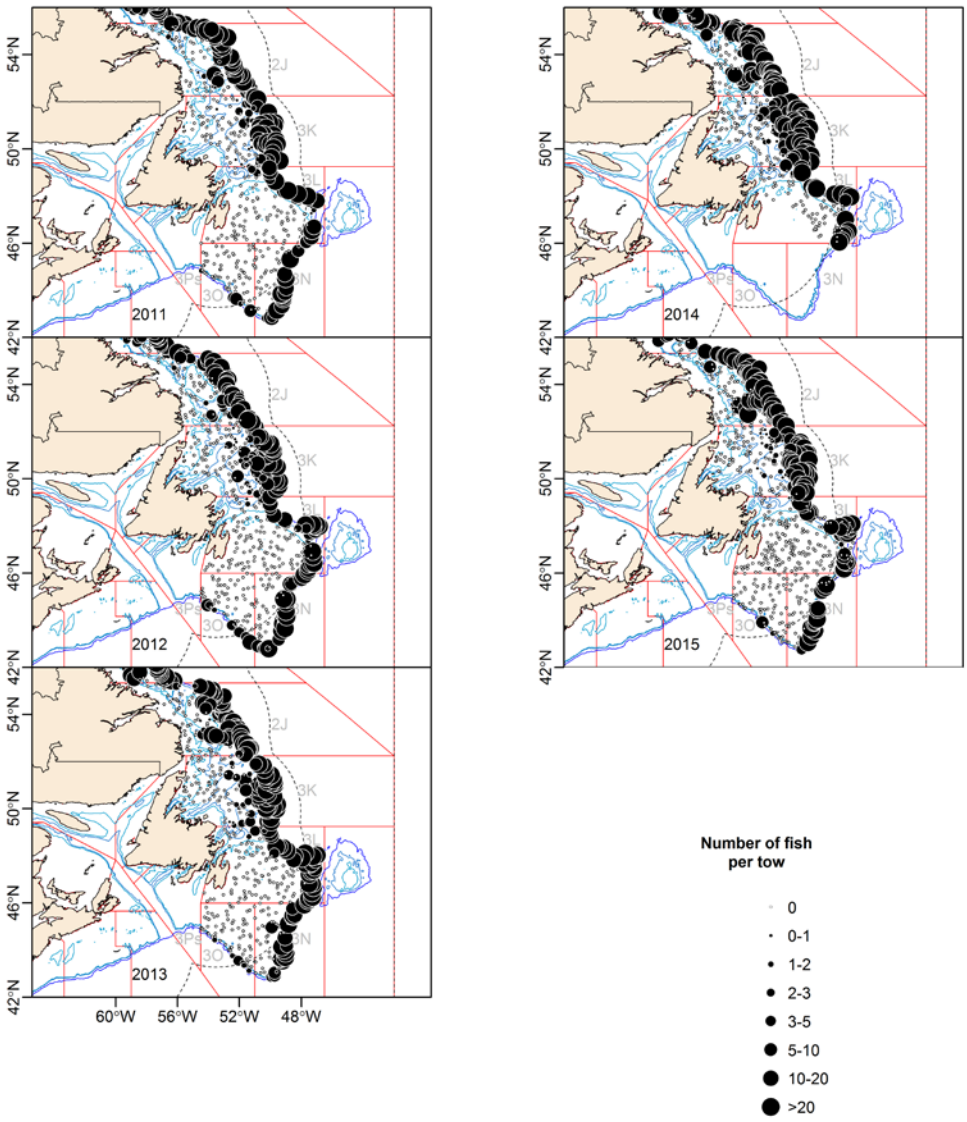

Figure 6c. Distribution of Roughhead Grenadier in DFO-NL fall research surveys, 2011-15. Due to Canadian research vessels' mechanical difficulties, Divs. 3NO were not surveyed in 2014, with only partial coverage of Div. 3L.

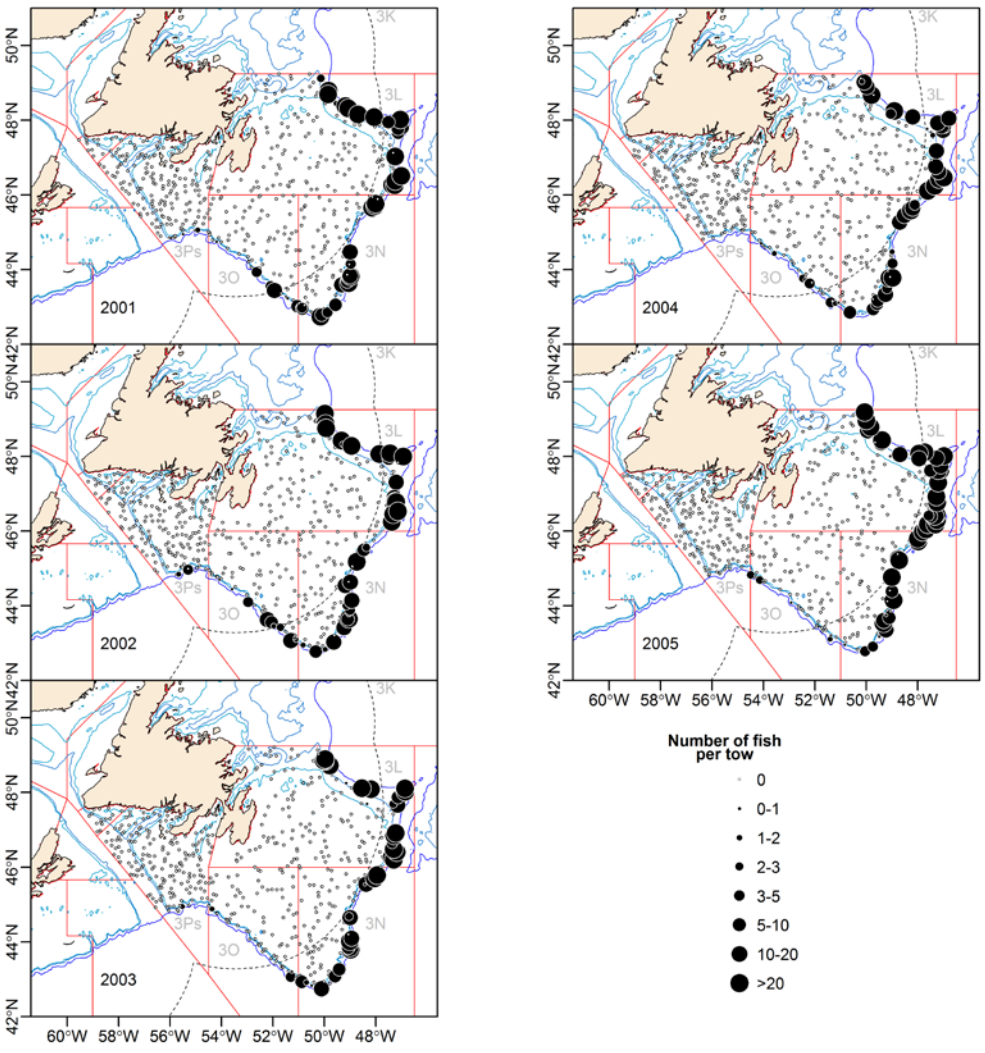

Figure 7a. Distribution of Roughhead Grenadier in DFO-NL spring research surveys, 2001-05.

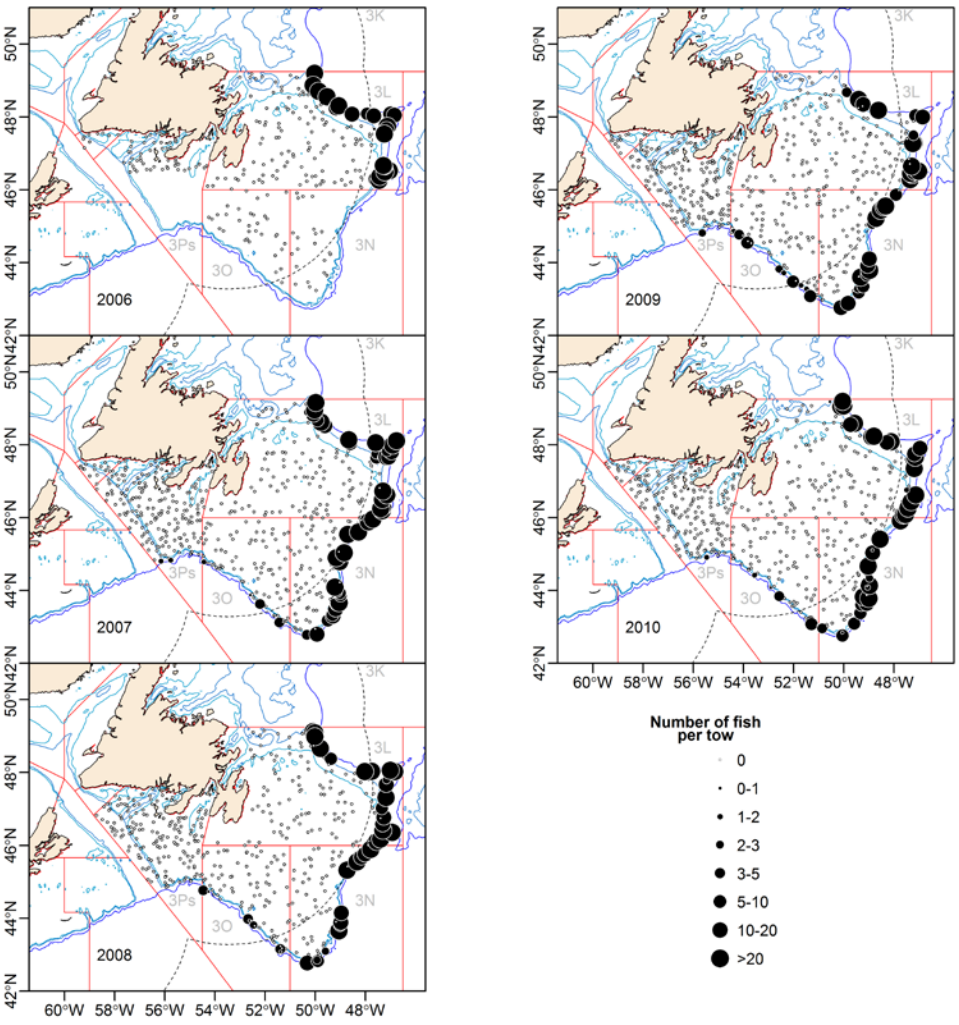

Figure 7b. Distribution of Roughhead Grenadier in DFO-NL spring research surveys, 2006-10. Due to Canadian research vessels' mechanical difficulties, most of Subdiv. 3Ps was not surveyed in 2006, with only shallow strata covered in Divs. 3NO. Subdiv. 3Pn was not surveyed in 2008.

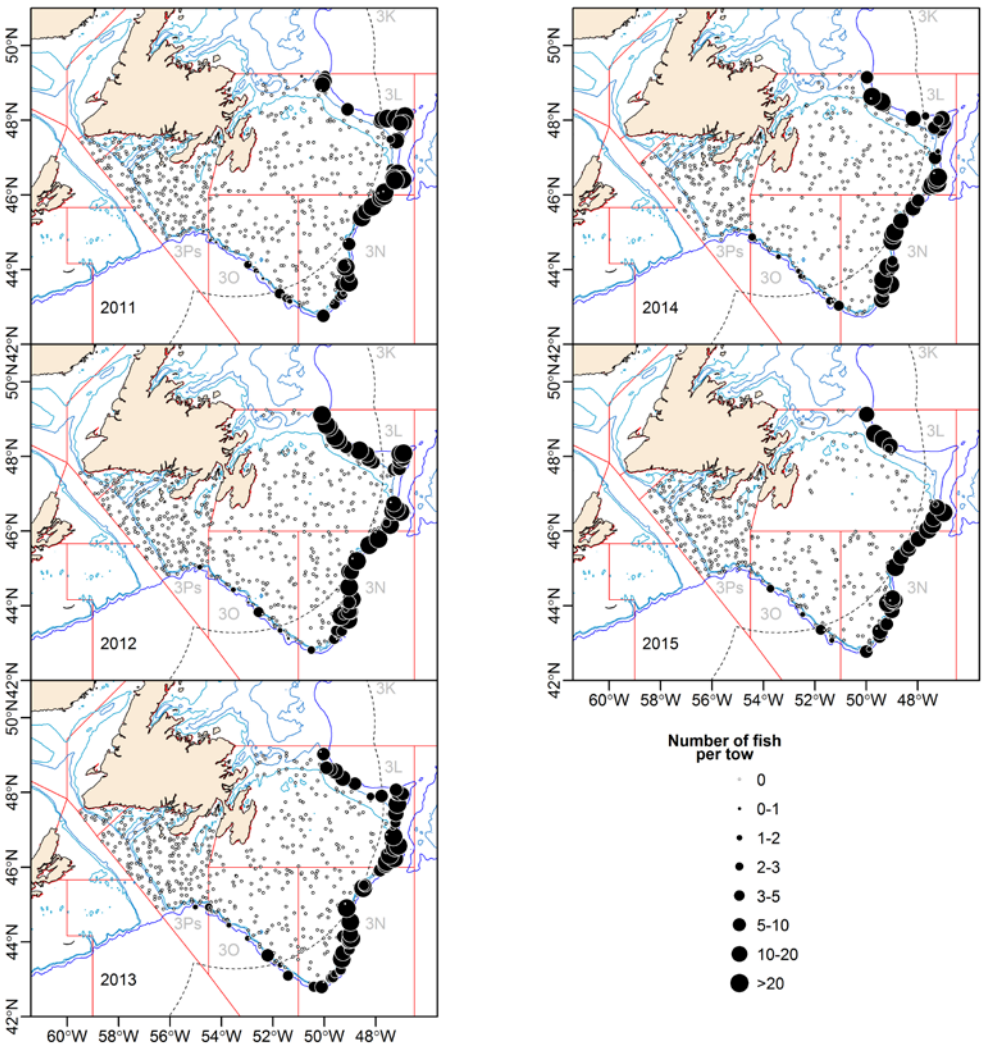

Figure 7c. Distribution of Roughhead Grenadier in DFO-NL spring research surveys, 2011-15. Due to Canadian research vessels' mechanical difficulties, Subdiv. 3Pn was not surveyed in 2014.

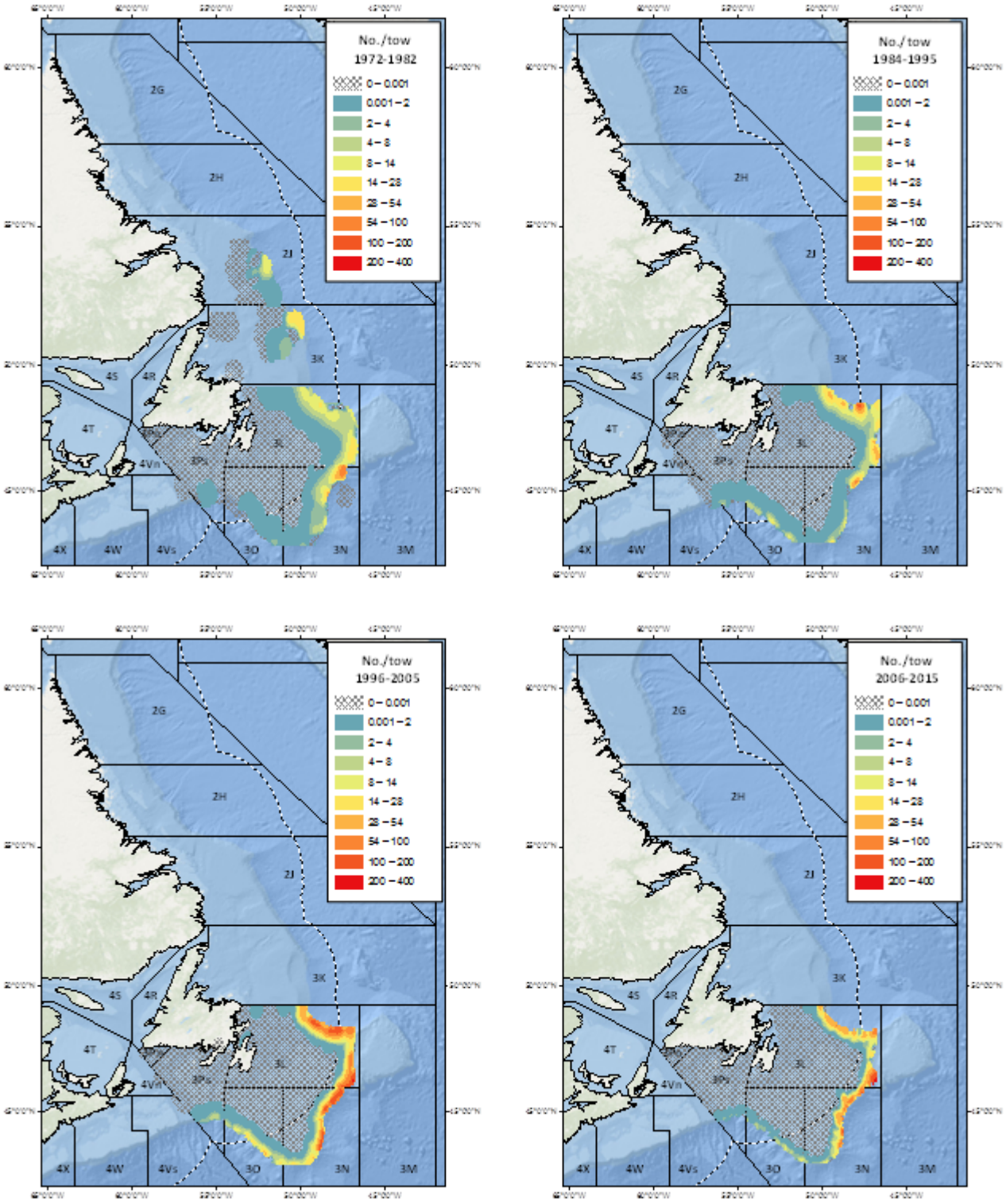

Figure 8. Surface density maps (spring survey) for Roughhead Grenadier in Divs. 3LNOPs, 1972-95 (Engel trawl) and 1996-2015 (Campelen trawl).

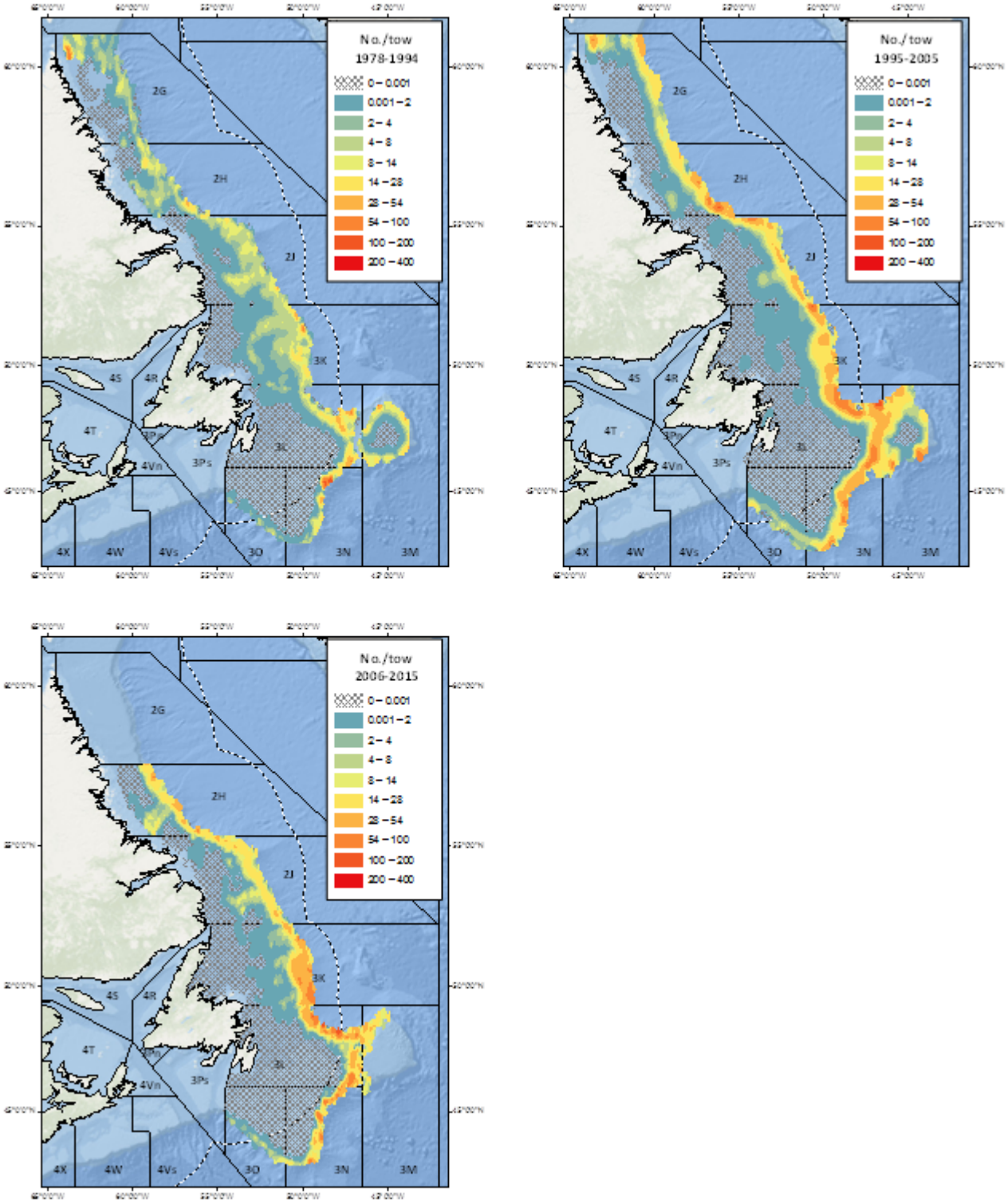

Figure 9. Surface density maps (fall survey) of Roughhead Grenadier in Divs. 2GHJ3LMNO, 1978-94 (Engel) and 1995-2015 (Campelen trawl).

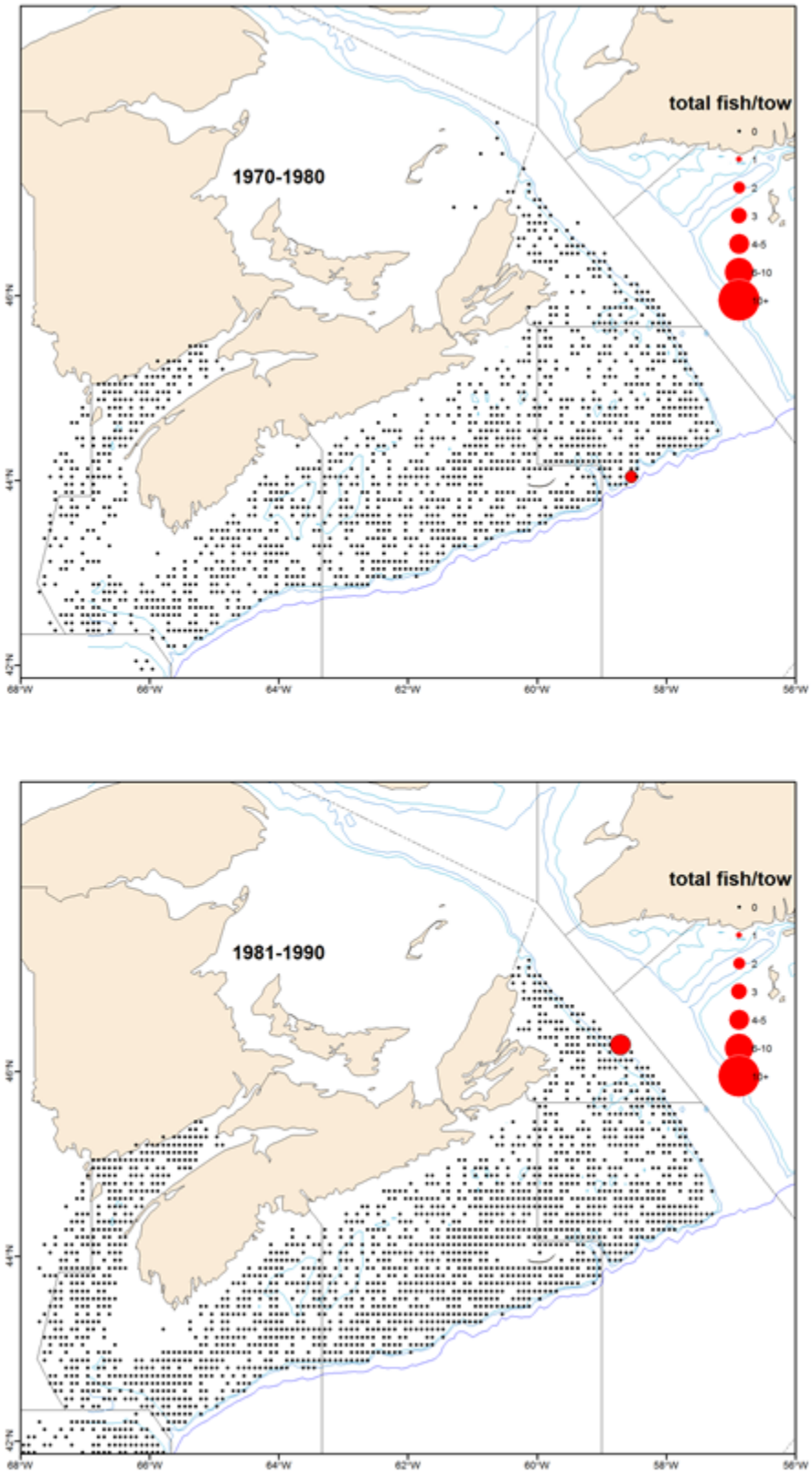

Figure 10a. Distribution of Roughhead Grenadier in DFO-MAR research surveys.

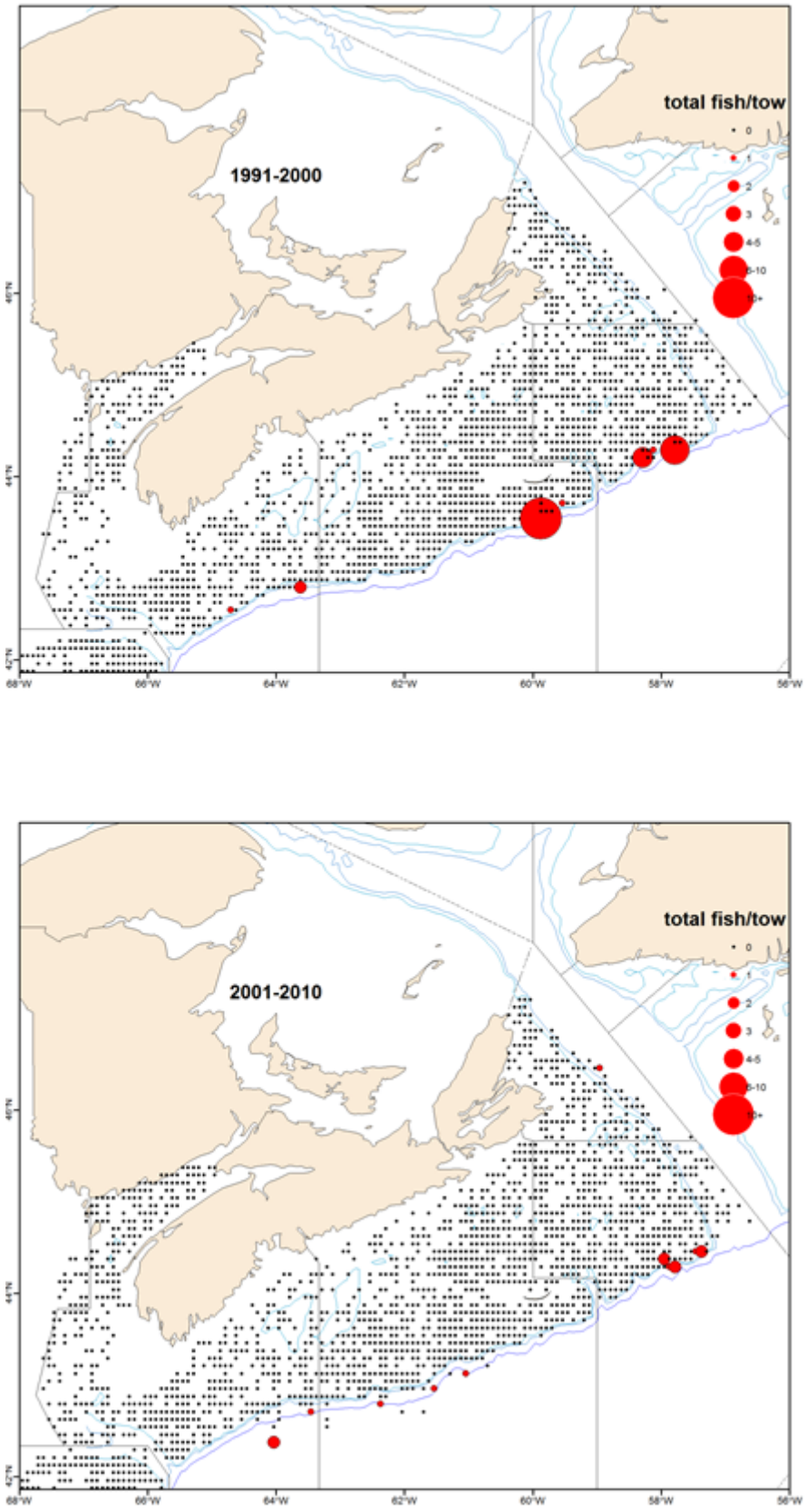

Figure 10b. Distribution of Roughhead Grenadier in DFO-MAR research surveys.

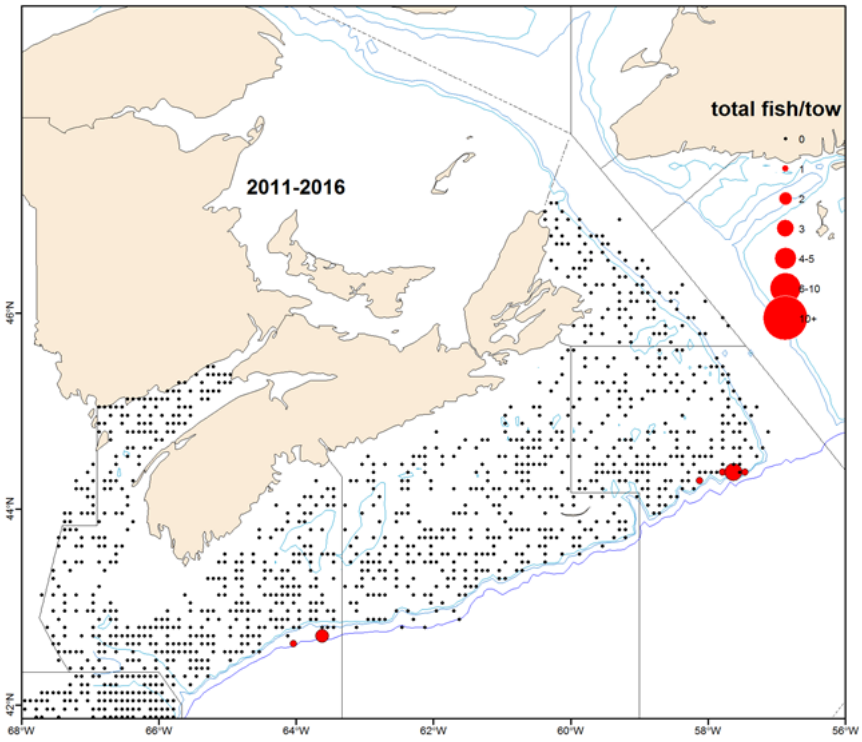

Figure 10c. Distribution of Roughhead Grenadier in DFO-MAR research surveys.

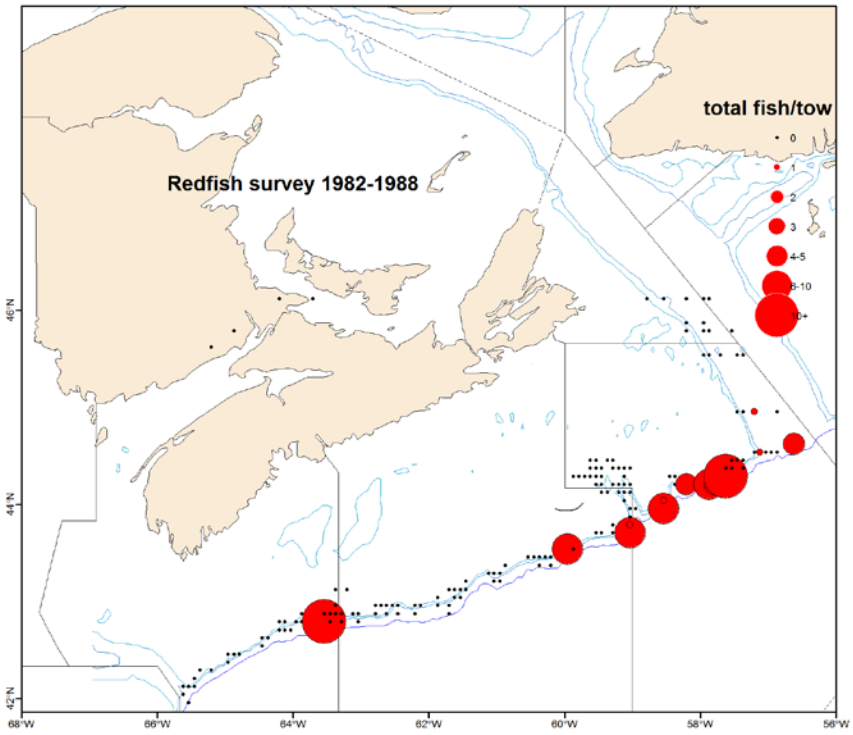

Figure 11. Distribution of Roughhead Grenadier in DFO-MAR redfish surveys.

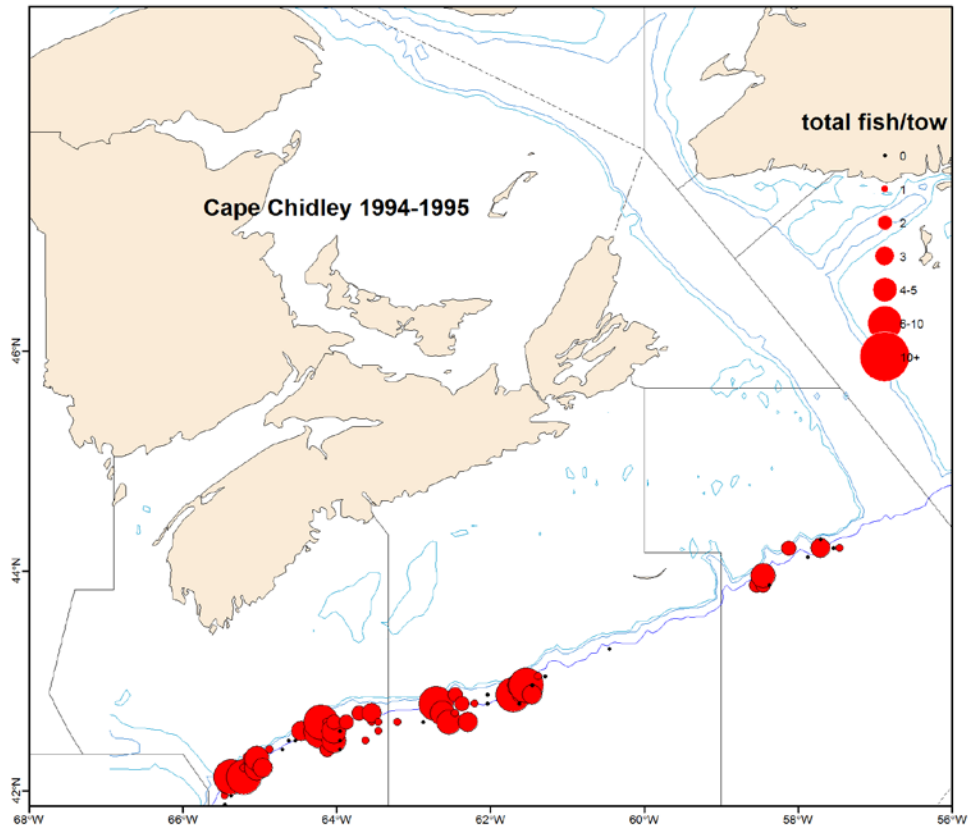

Figure 12. Distribution of Roughhead Grenadier in Cape Chidley cruises.

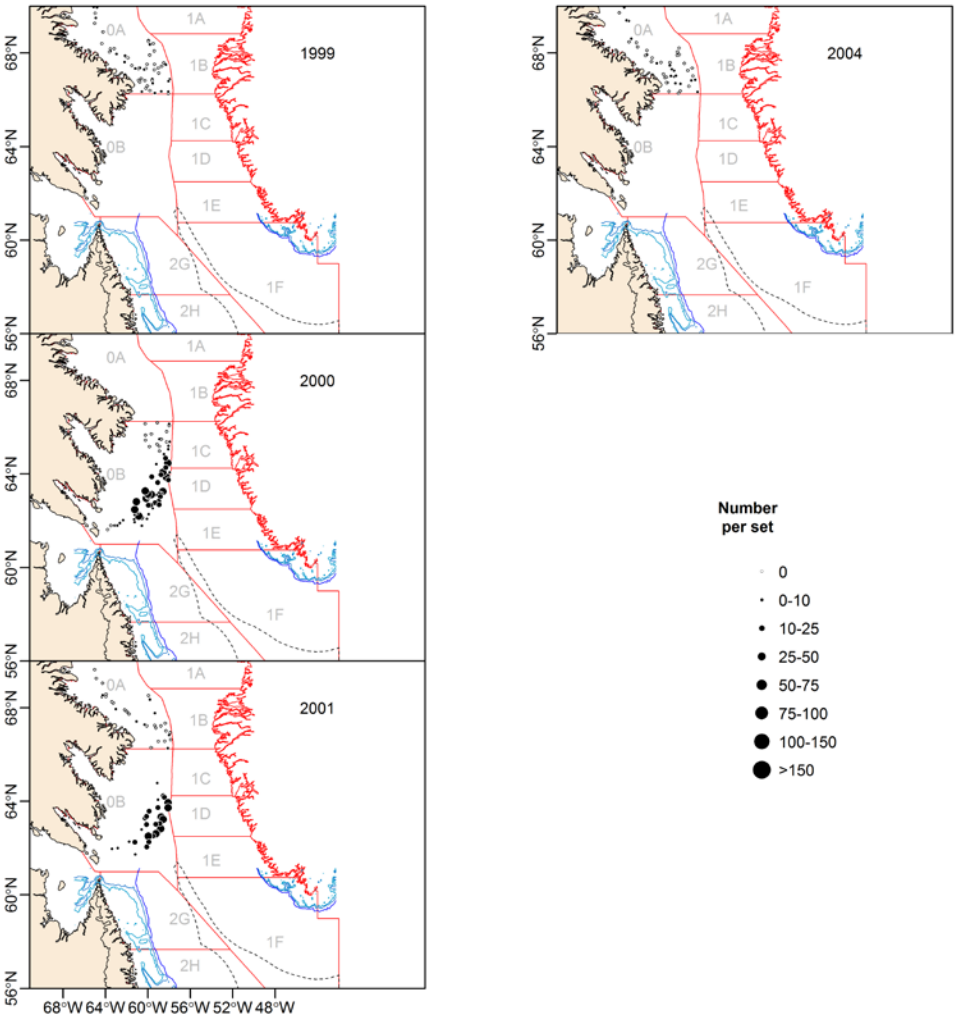

Figure 13a. Distribution of Roughhead Grenadier in DFO-C&A research surveys, 1999-2004.

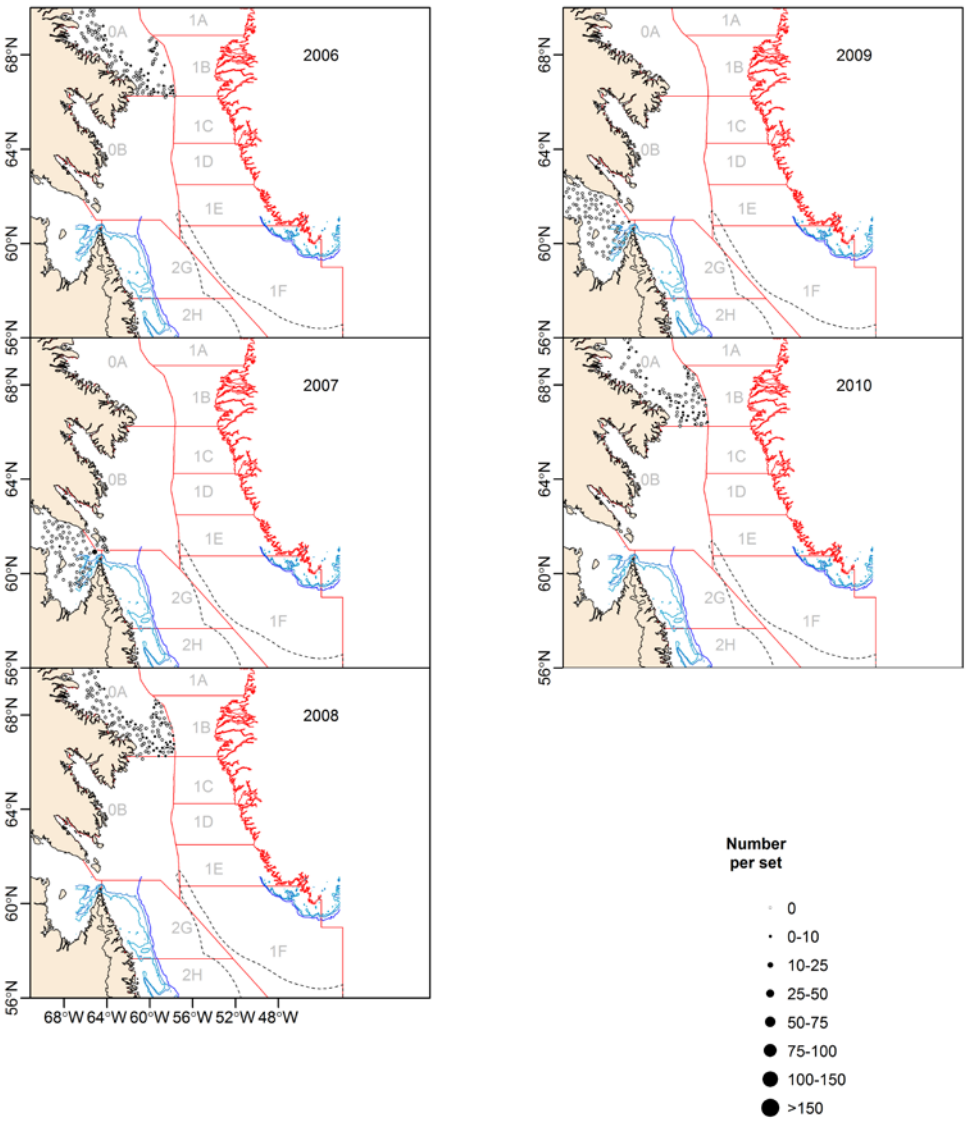

Figure 13b. Distribution of Roughhead Grenadier in DFO-C&A research surveys, 2006-10.

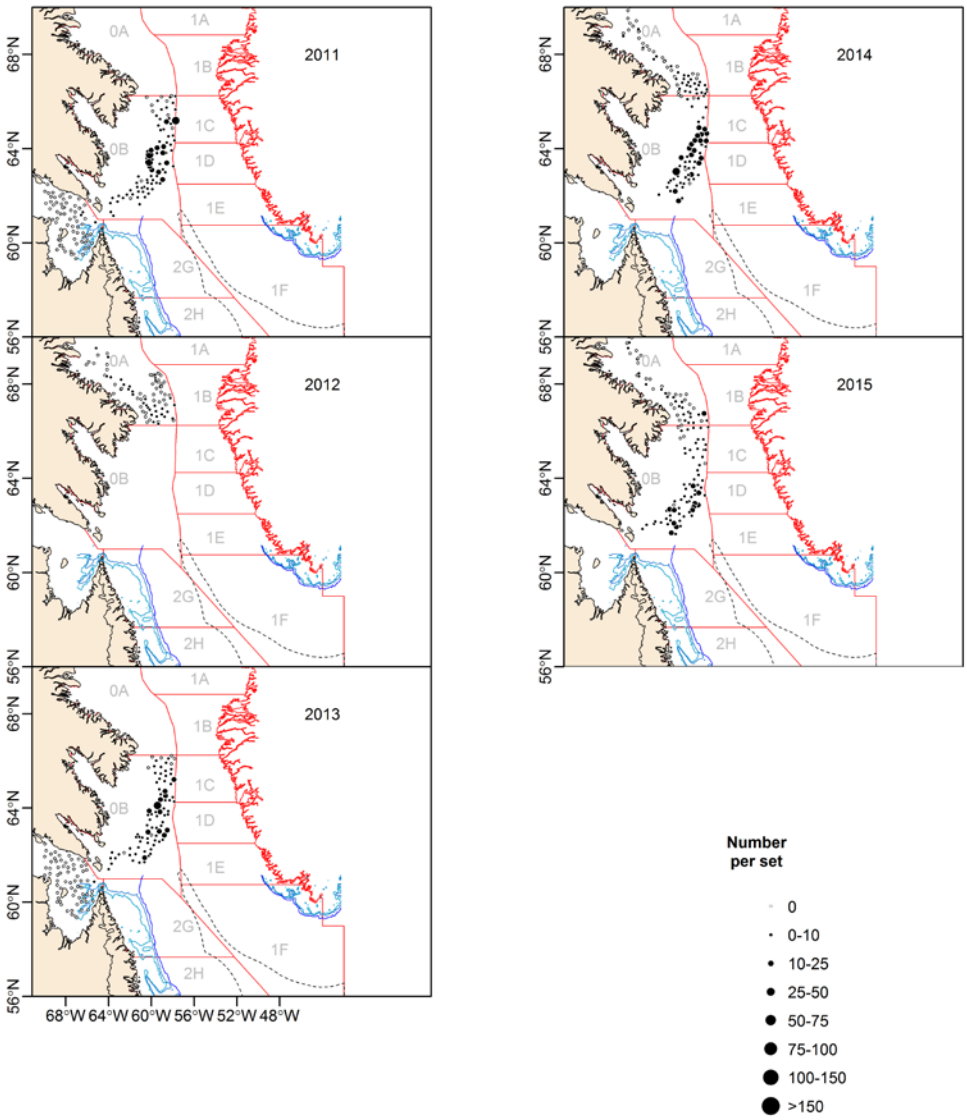

Figure 13c. Distribution of Roughhead Grenadier in DFO-C&A research surveys, 2011-15.

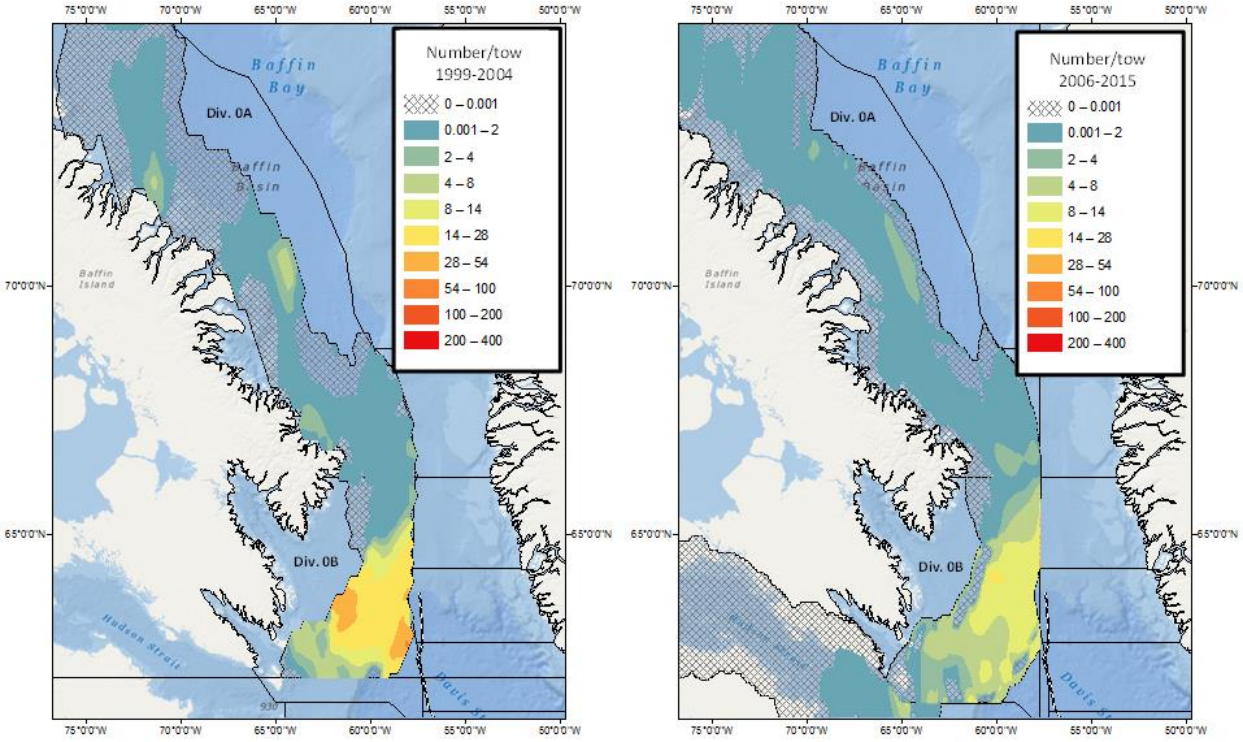

Figure 14. Surface density maps for Roughhead Grenadier in Div. 0A and 0B, 1999-2004 (left panel) and 2006-15 (right panel).

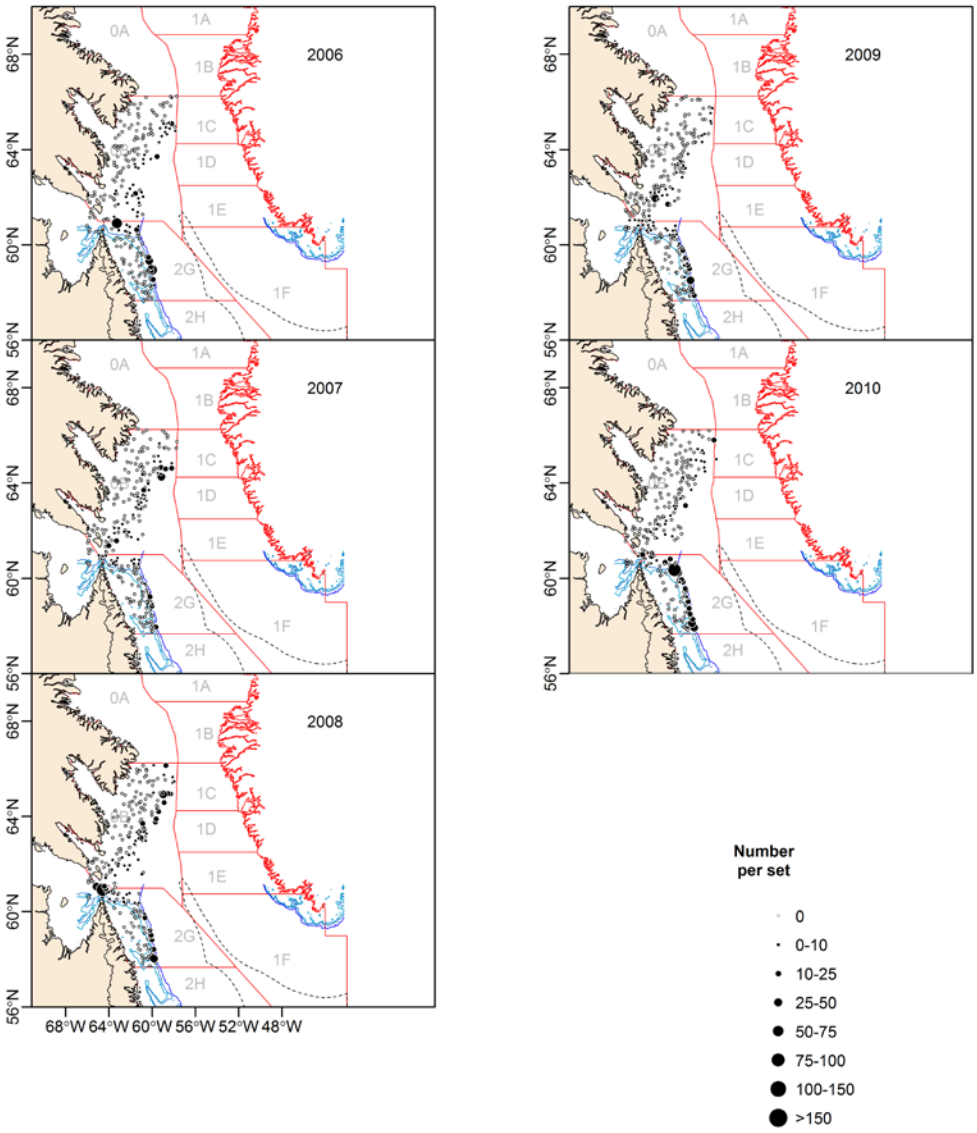

Figure 15a. Distribution of Roughhead Grenadier in NSRF research surveys, 2006-10.

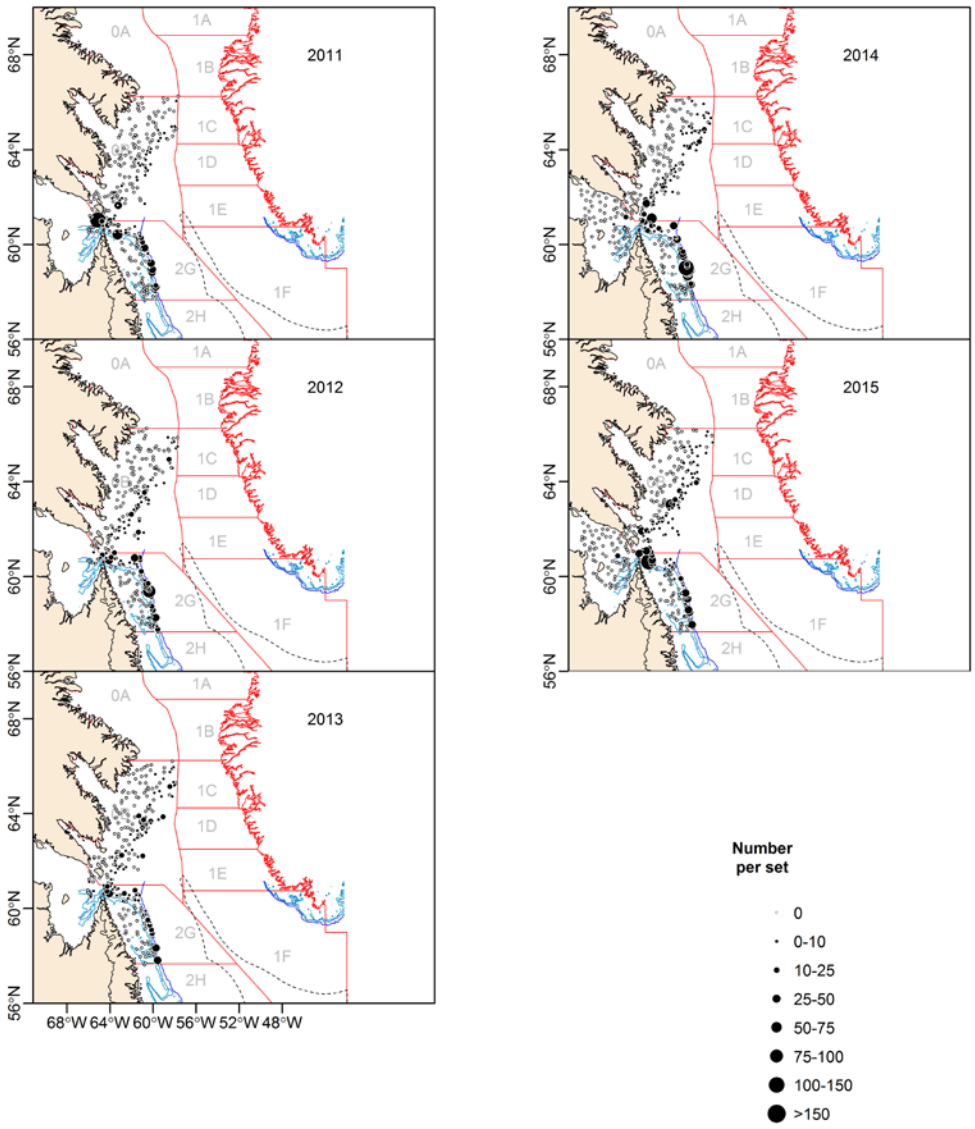

Figure 15b. Distribution of Roughhead Grenadier in NSRF research surveys, 2011-15.

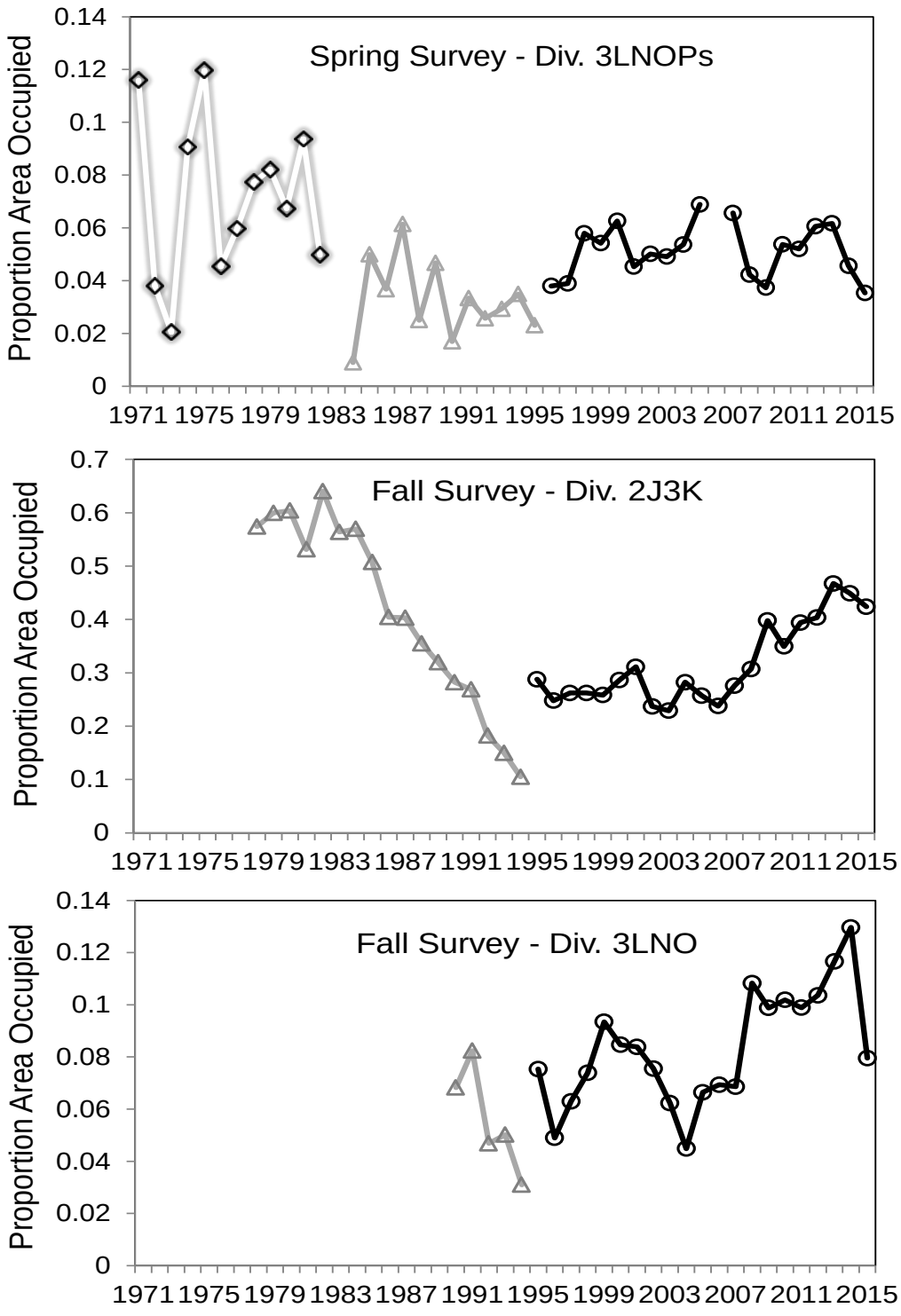

Figure 16. Proportion area occupied by Roughhead Grenadier from DFO-NL surveys in spring (top panel) and fall (lower panels). Survey trawls used: Yankee (white line), Engel (grey line), and Campelen (black line). Note that Y-axis values are higher in the fall Divs 2J3K panel. In spring, Div. 3N was not surveyed in 1983; Div. 3O was not surveyed in 1972, 1974, 1983; and Subdiv. 3Ps was not surveyed in 1971, 2006. In fall, deep strata of Divs. 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Divs. 3NO was surveyed in 2014.

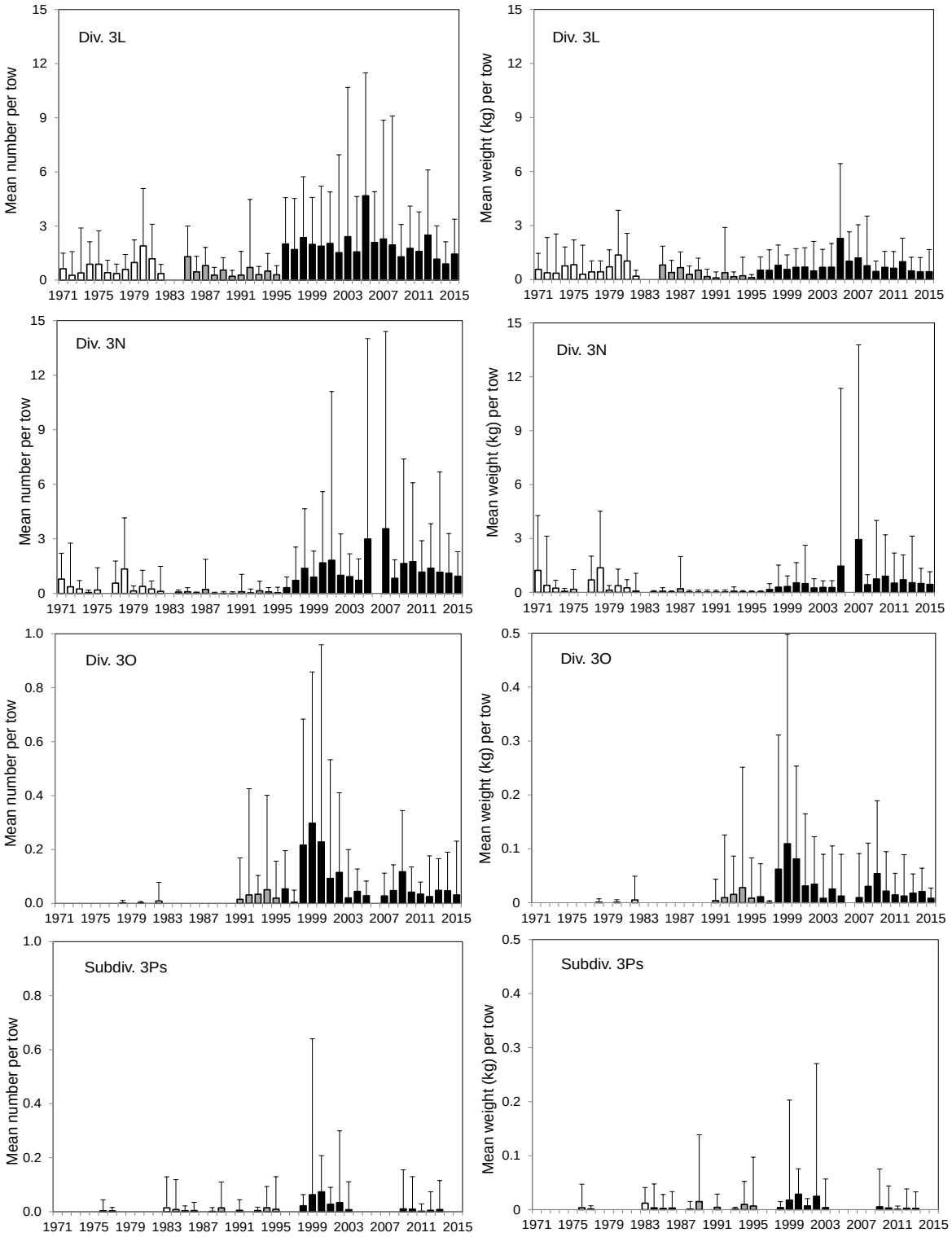

Figure 17. Mean numbers (left panels) and mean weights (kg; right panels) per tow (+95 % CI) of Roughhead Grenadier from DFO-NL spring research surveys in Div. 3LNOPs, 1971-2015. Survey trawl changed from Yankee (white bars) to Engel (grey bars) in 1984, and to Campelen (black bars) in 1996. Due to Canadian research vessels' mechanical difficulties, Div. 3N was not surveyed in 1983; Div. 3O was not surveyed in 1972, 1974, 1983; and Subdiv. 3Ps was not surveyed in 1971, 2006.

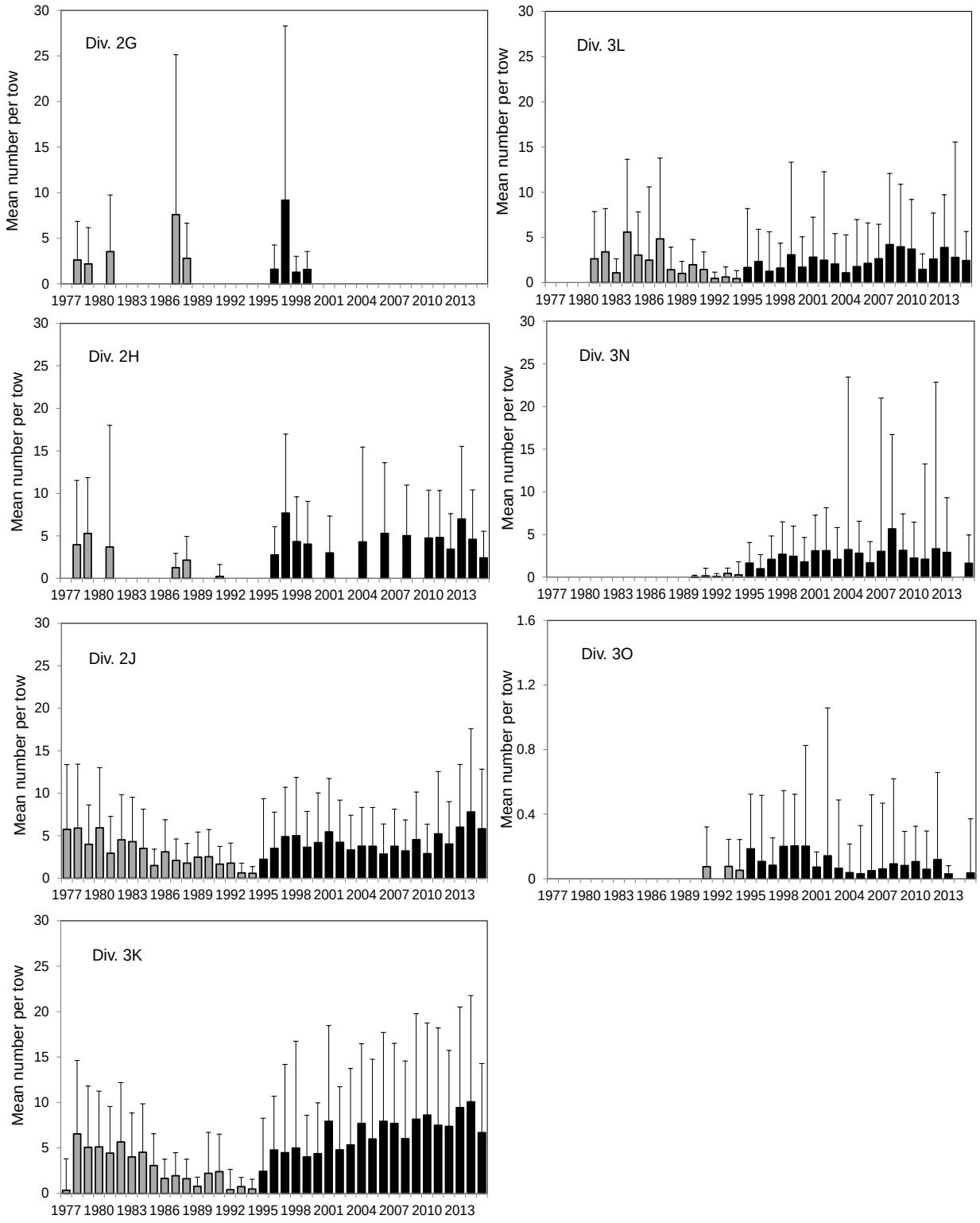

Figure 18. Mean numbers per tow (+95 % CI) of Roughhead Grenadier from DFO-NL fall research surveys in Divs. 2GHJ3KLNO, 1977-2015. Survey trawl changed from Engel (grey bars) to Campelen (black bars) in 1995. Due to Canadian research vessels' mechanical difficulties, deep strata of Divs 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Divs. 3NO was surveyed in 2014.

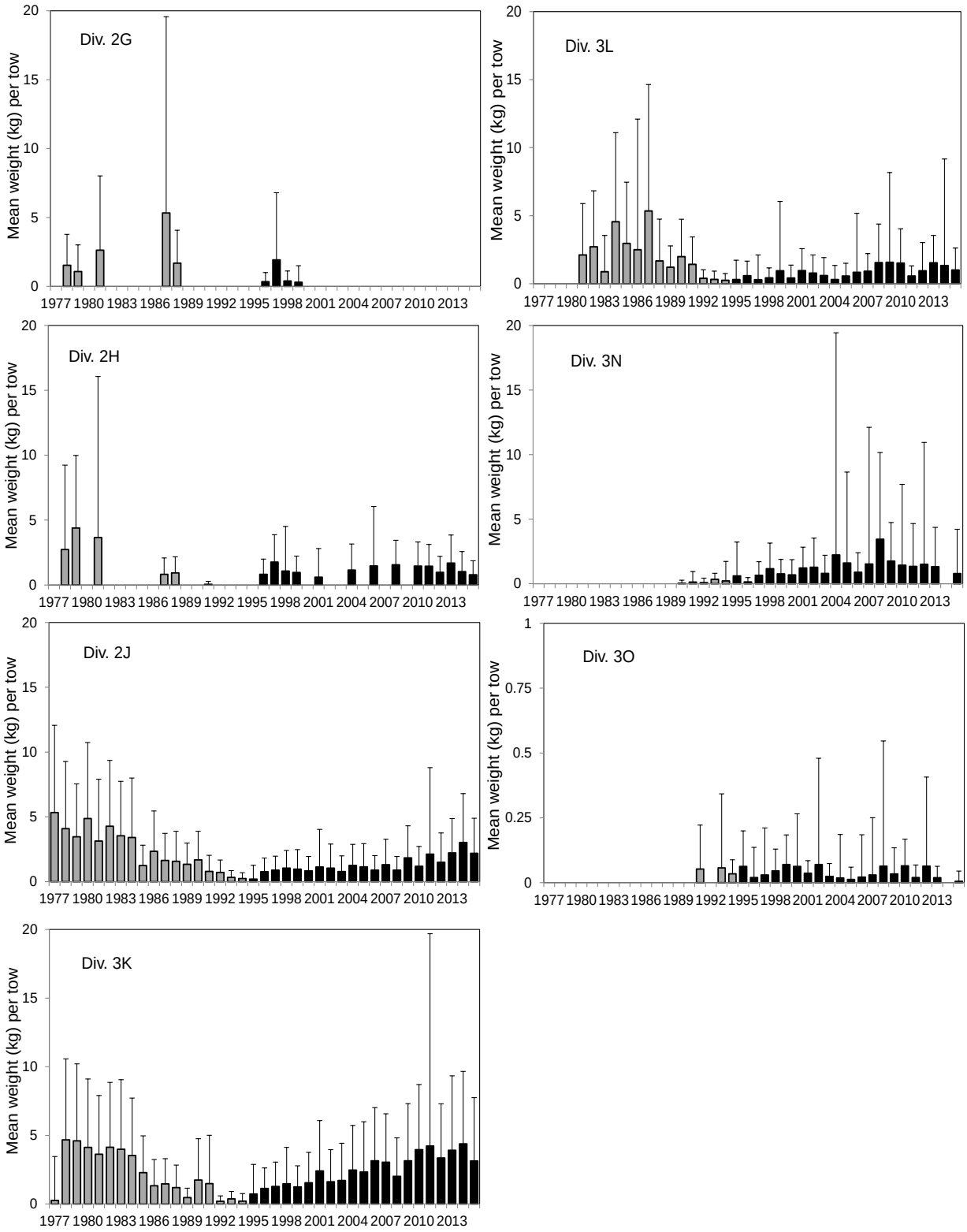

Figure 19. Mean weights per tow (kg; +95 % CI) of Roughhead Grenadier from DFO-NL fall research surveys in Divs. 2GHJ3KLNO, 1977-2015. Survey trawl changed from Engel (grey bars) to Campelen (black bars) in 1995.

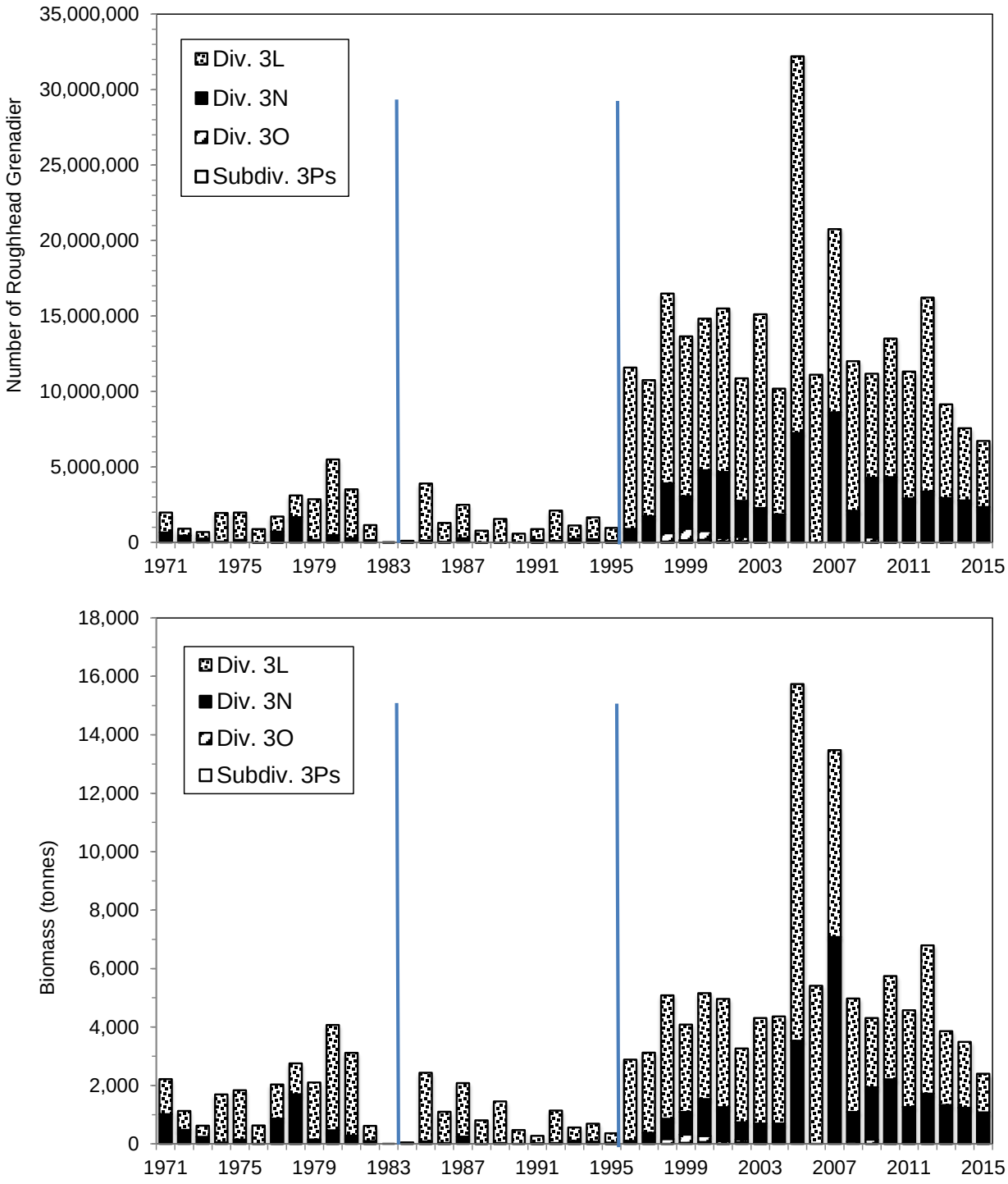

Figure 20. Abundance (upper panel) and biomass (tonnes; lower panel) indices for Roughhead Grenadier from DFO-NL spring research surveys in Divs. 3LNOPs, 1971-2015. Thin vertical bars indicate changes in survey trawls from Yankee to Engel in 1984, and to Campelen in 1996.

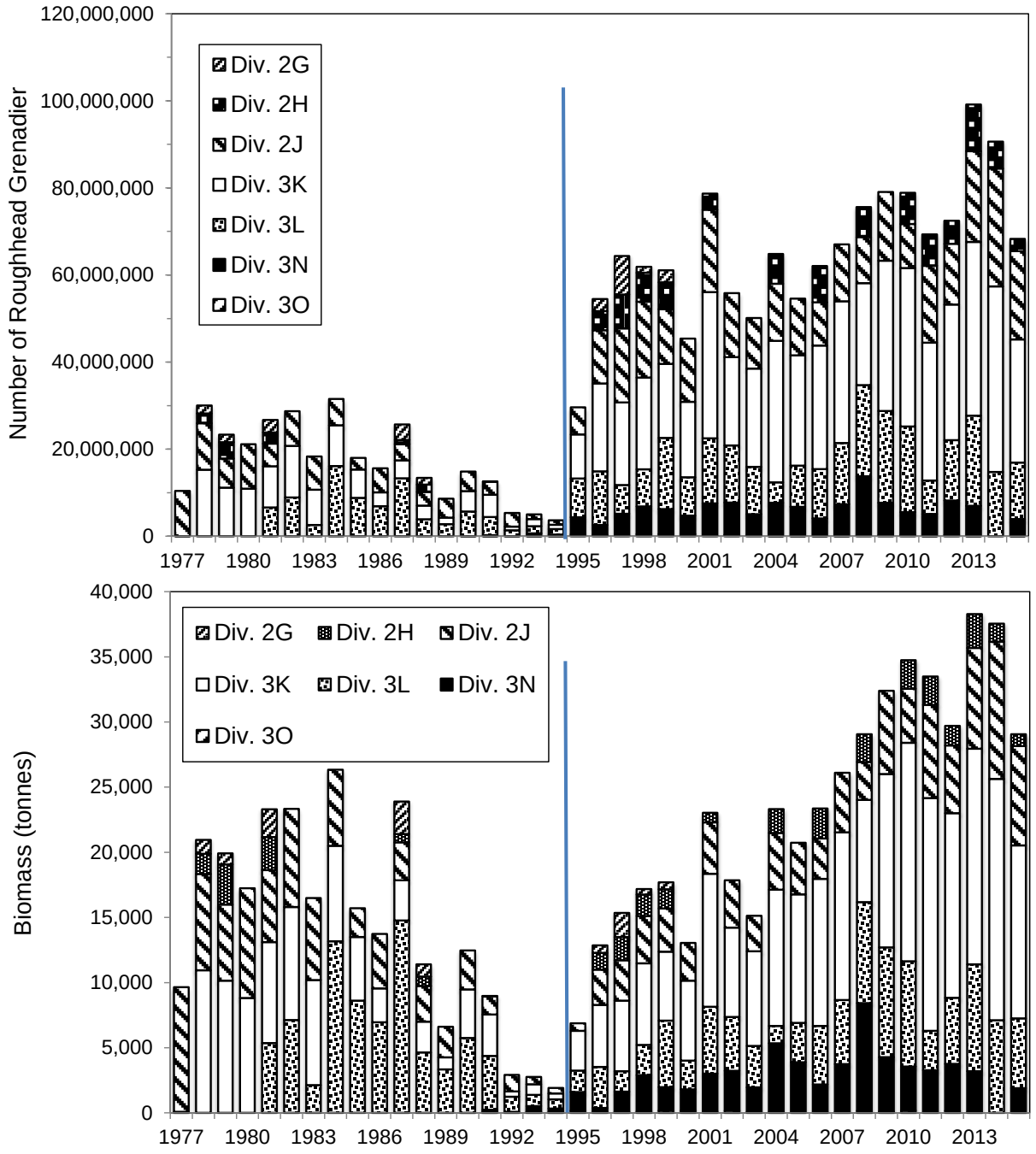

Figure 21. Abundance (upper panel) and biomass (tonnes; lower panel) indices for Roughhead Grenadier from DFO-NL fall research surveys in Div. 2GHJ3KLNO, 1977-2015. The thin vertical bar indicates a change in survey trawl from Engel to Campelen in 1995.

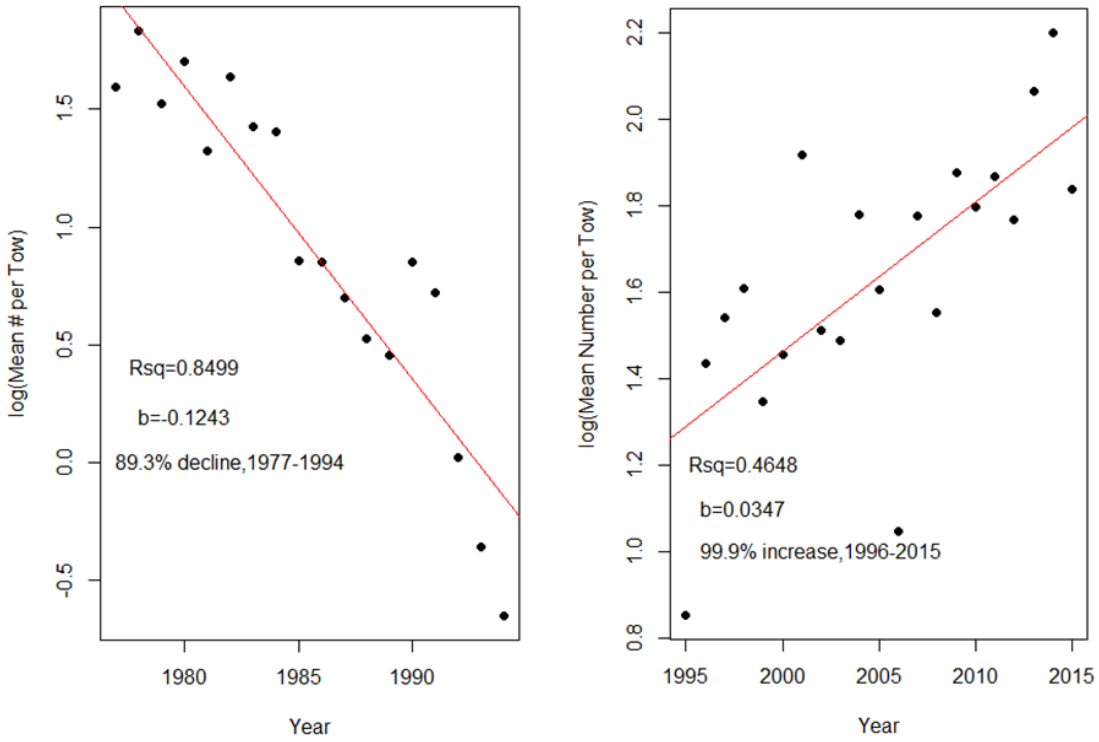

Figure 22. Stratified mean catch rates of Roughhead Grenadier (all sizes) in Divs. 2J3K from fall surveys during 1977-94 (left panel) and 1995-2015 (right panel). Regression lines are shown for loge catch rate versus year along with their slope, Rsq, and decline rate.

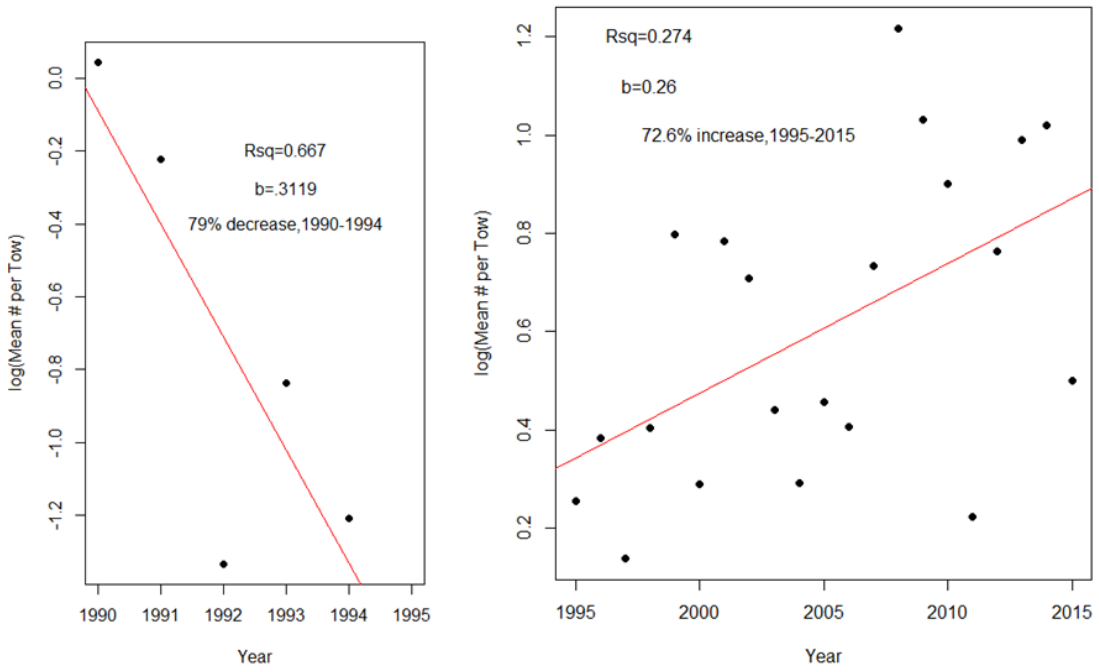

Figure 23. Stratified mean catch rates of Roughhead Grenadier (all sizes) in Divs. 3LNO from fall surveys during 1990-94 (left panel) and 1995-2015 (right panel). Regression lines are shown for loge catch rate versus year along with their slope, Rsq, and decline rate.

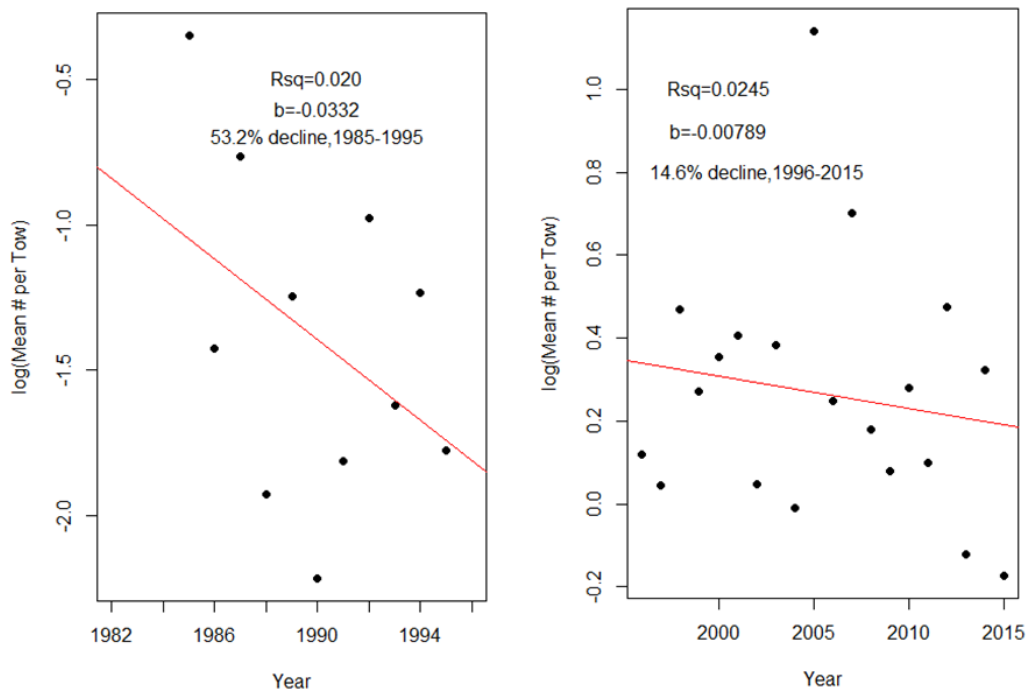

Figure 24. Stratified mean catch rates of Roughhead Grenadier (all sizes) in Divs. 3LNO from spring surveys during 1984-95 (left panel) and 1996-2015 (right panel). Regression lines are shown for loge catch rate versus year along with their slope, Rsq, and decline rate.

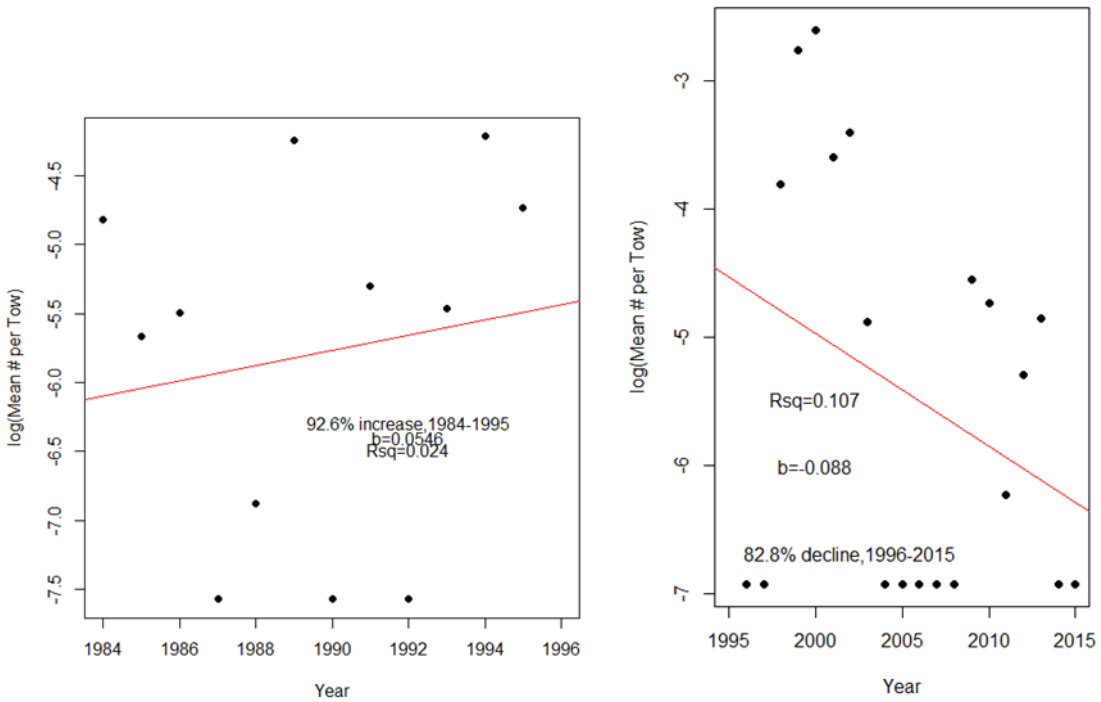

Figure 25. Stratified mean catch rates of Roughhead Grenadier (all sizes) in Subdiv. 3Ps for 1984-95 (left panel) and 1996-2015 (right panel). Regression lines are shown for loge catch rate versus year along with their slope, Rsq, and decline rate.

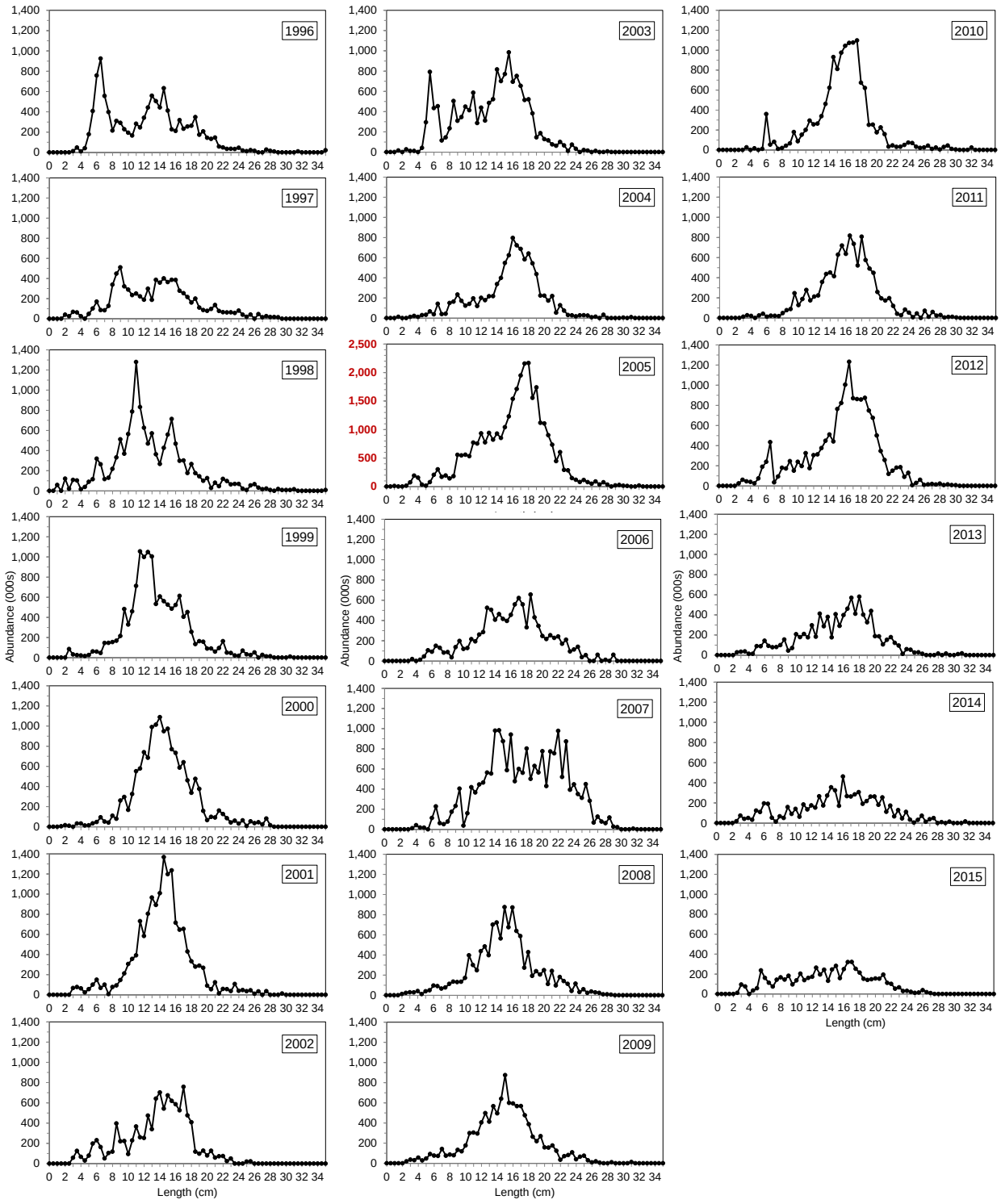

Figure 26. Roughhead Grenadier abundance-at-length (AFL in cm; sexes combined) from DFO-NL spring research surveys in Divs. 3LNOPs, 1996-2015. The 2005 Y-Axis is on a different scale.

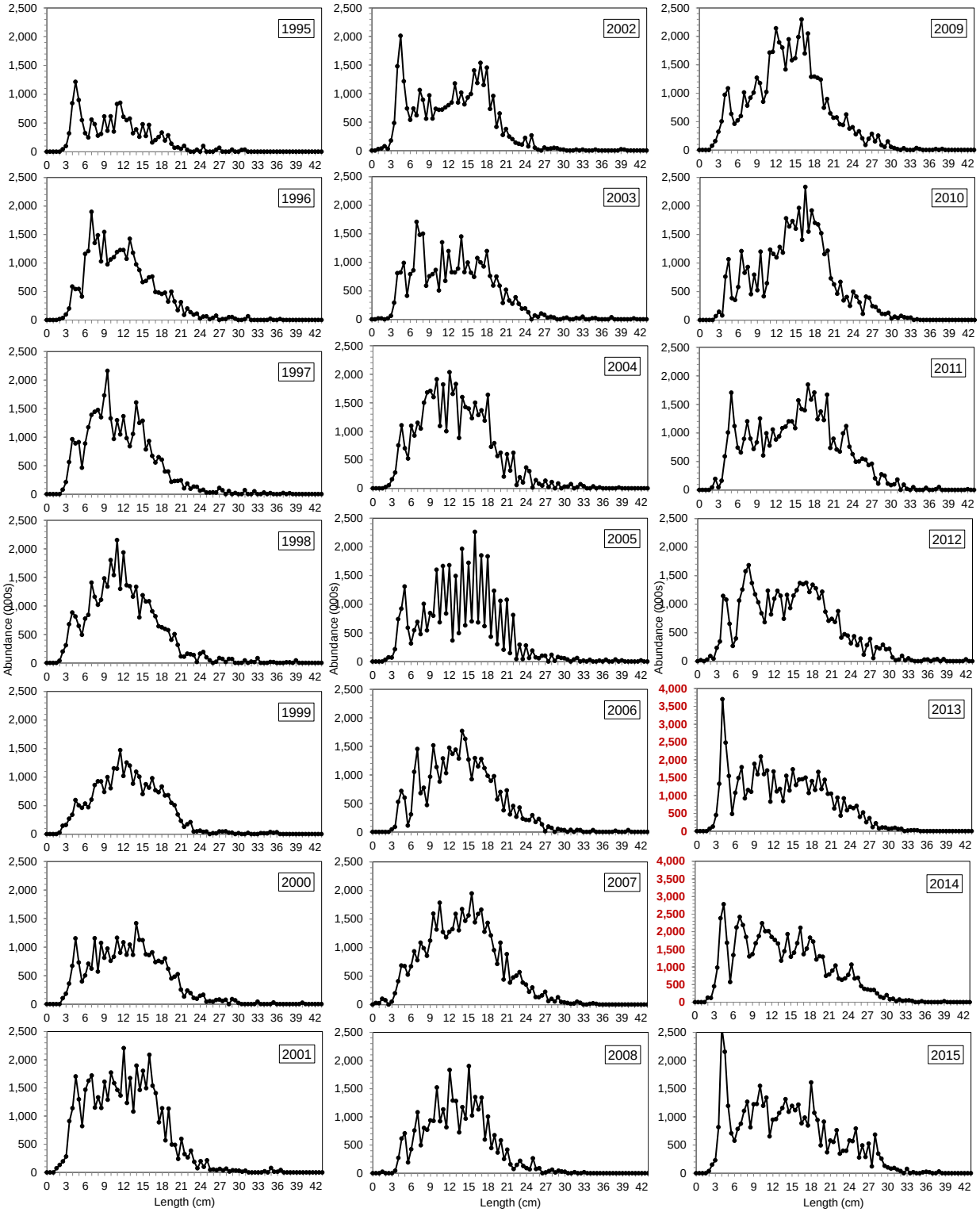

Figure 27. Roughhead Grenadier abundance-at-length (AFL in cm; sexes combined) from DFO-NL fall research surveys in Divs. 2J3K, 1995-2015. The 2013-14 Y-Axes are on a different scale.

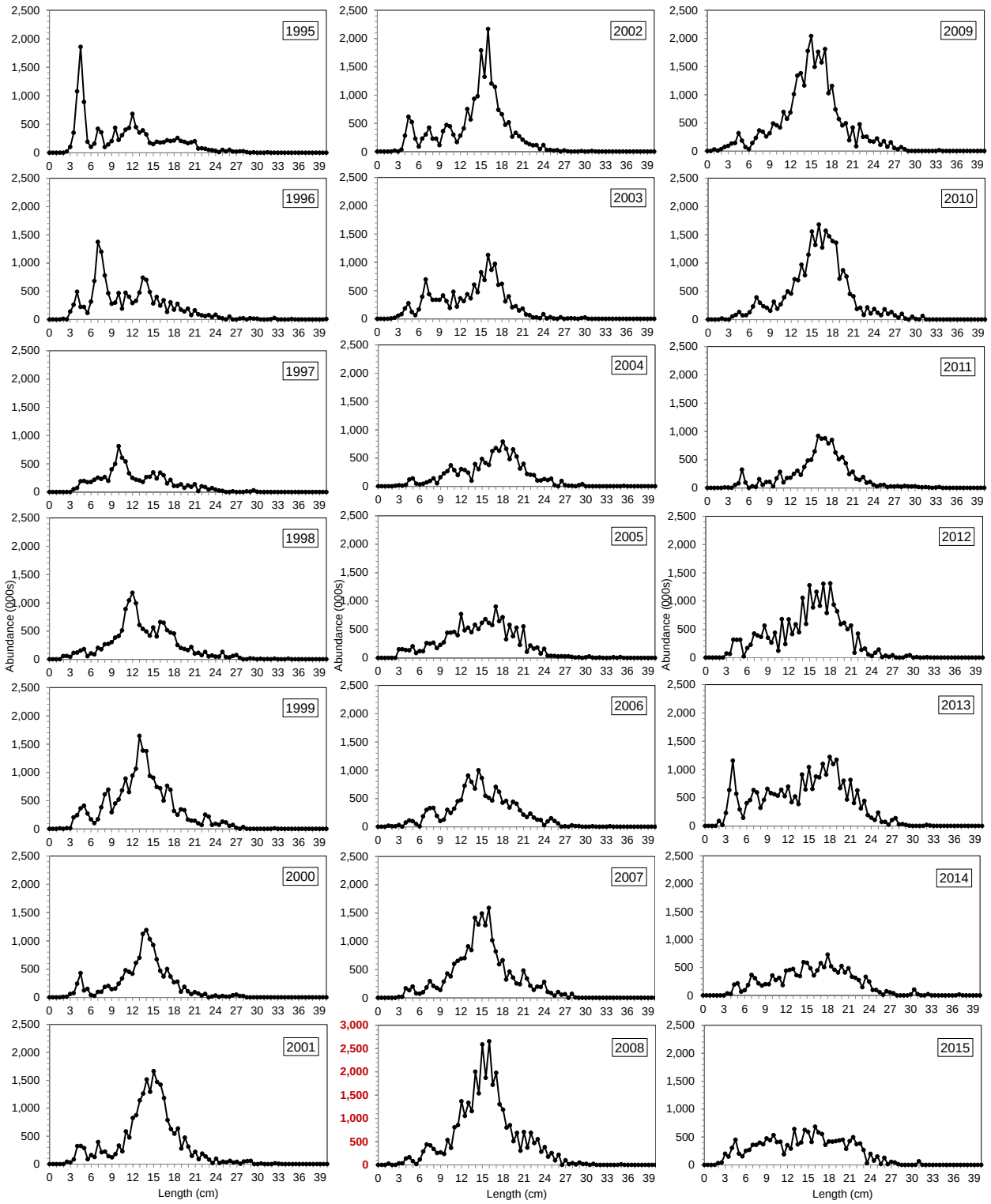

Figure 28. Roughhead Grenadier abundance-at-length (AFL in cm; sexes combined) from DFO-NL fall research surveys in Divs. 3LNO, 1995-2015. The 2008 Y-Axis is on a different scale.

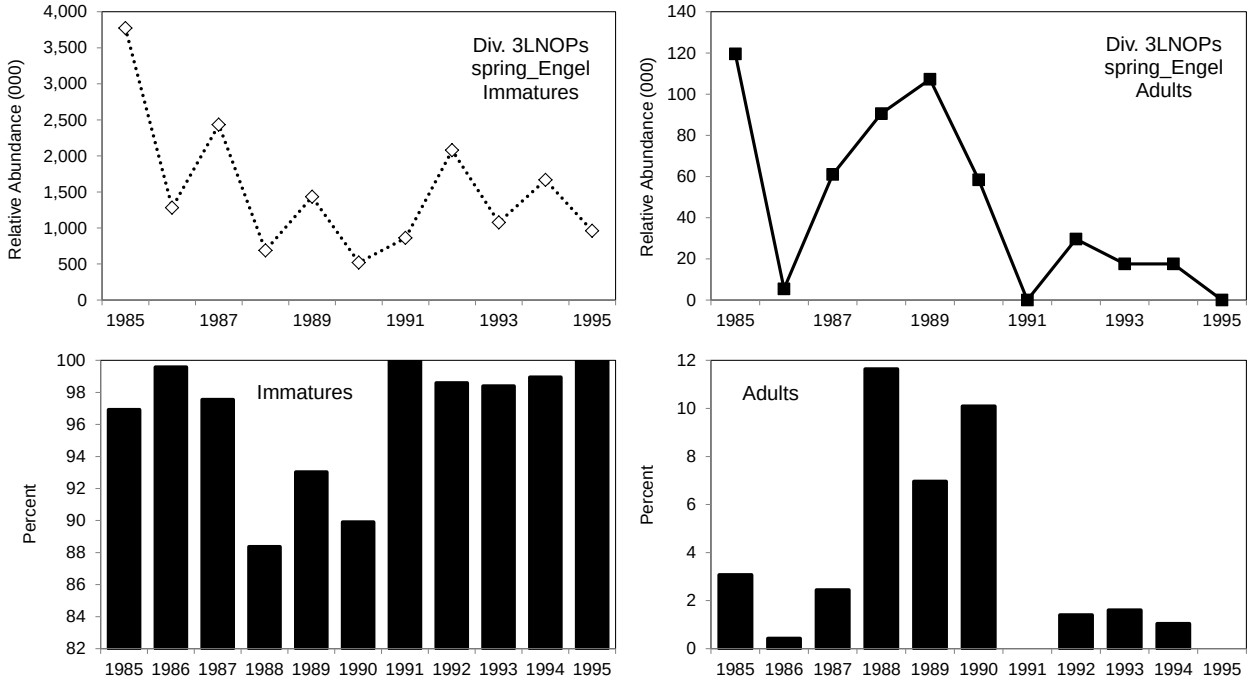

Figure 29. Relative abundance at length of immature (≤27.5 cm) and adult (>27.5 cm) Roughhead Grenadiers from DFO-NL spring Engel surveys in Divs. 3LNOPs, 1985-95.

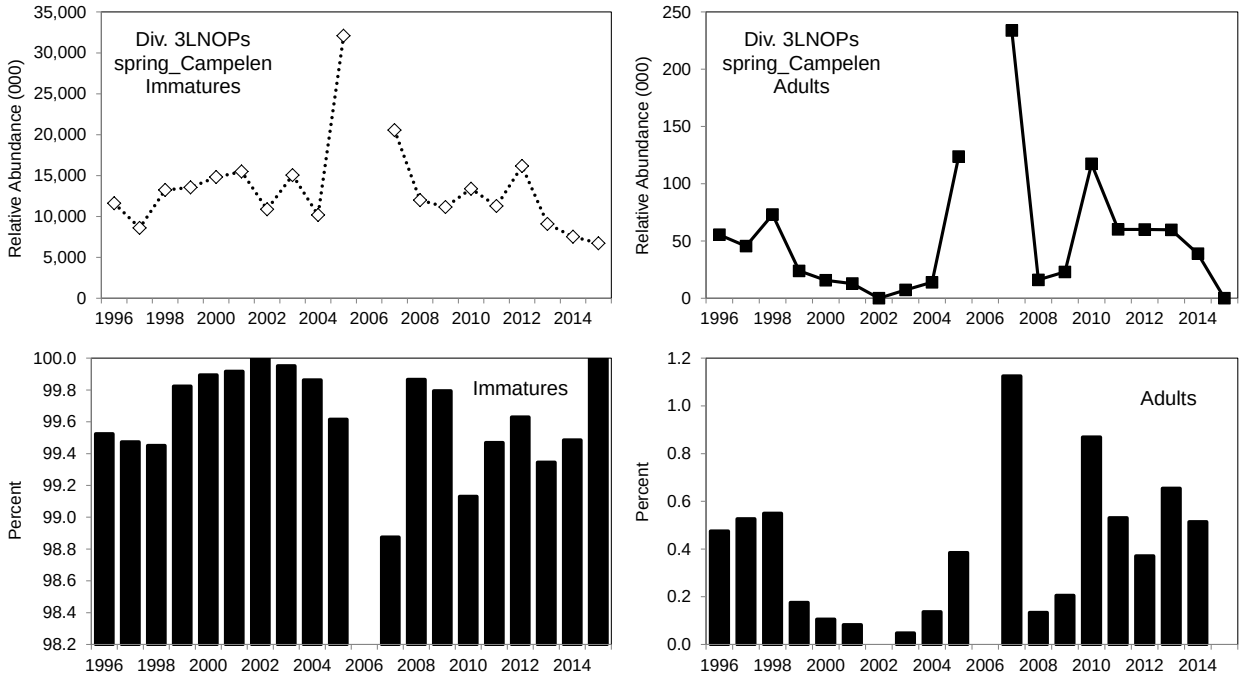

Figure 30. Relative abundance at length of immature (≤27.5 cm) and adult (>27.5 cm) Roughhead Grenadiers from DFO-NL spring Campelen surveys in Divs. 3LNOPs, 1996-2015.

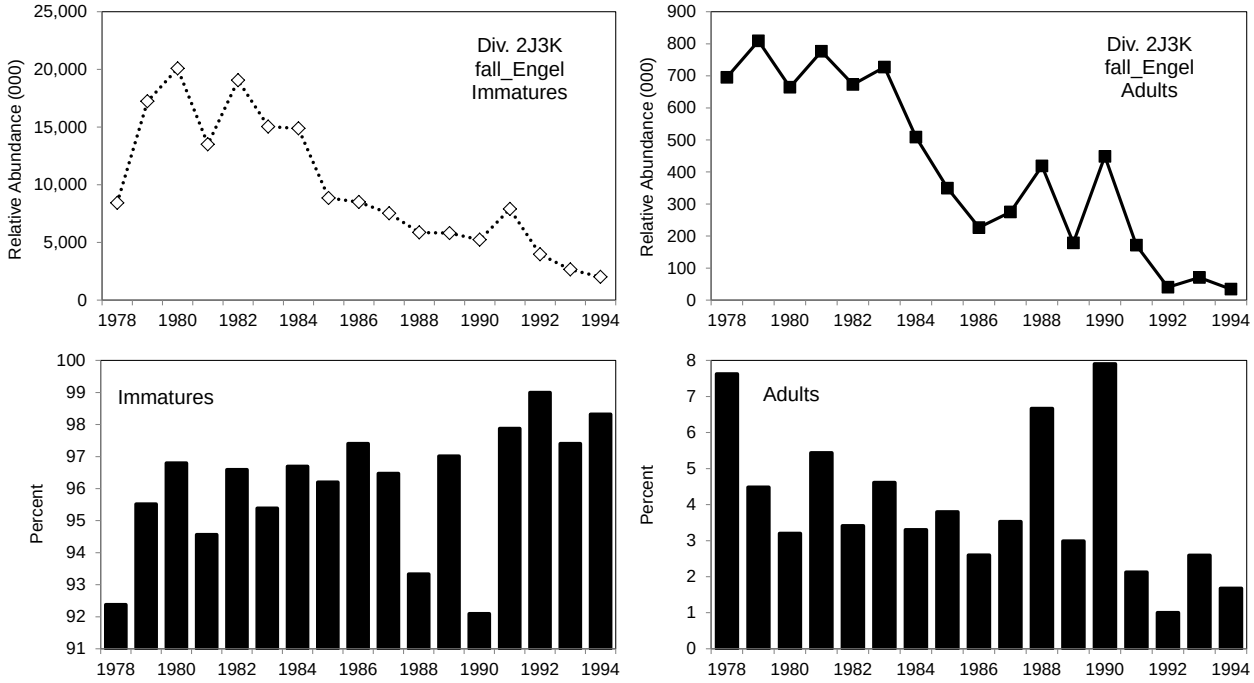

Figure 31. Relative abundance at length of immature (≤27.5 cm) and adult (>27.5 cm) Roughhead Grenadiers from DFO-NL fall Engel surveys in Divs. 2J3K, 1978-1994.

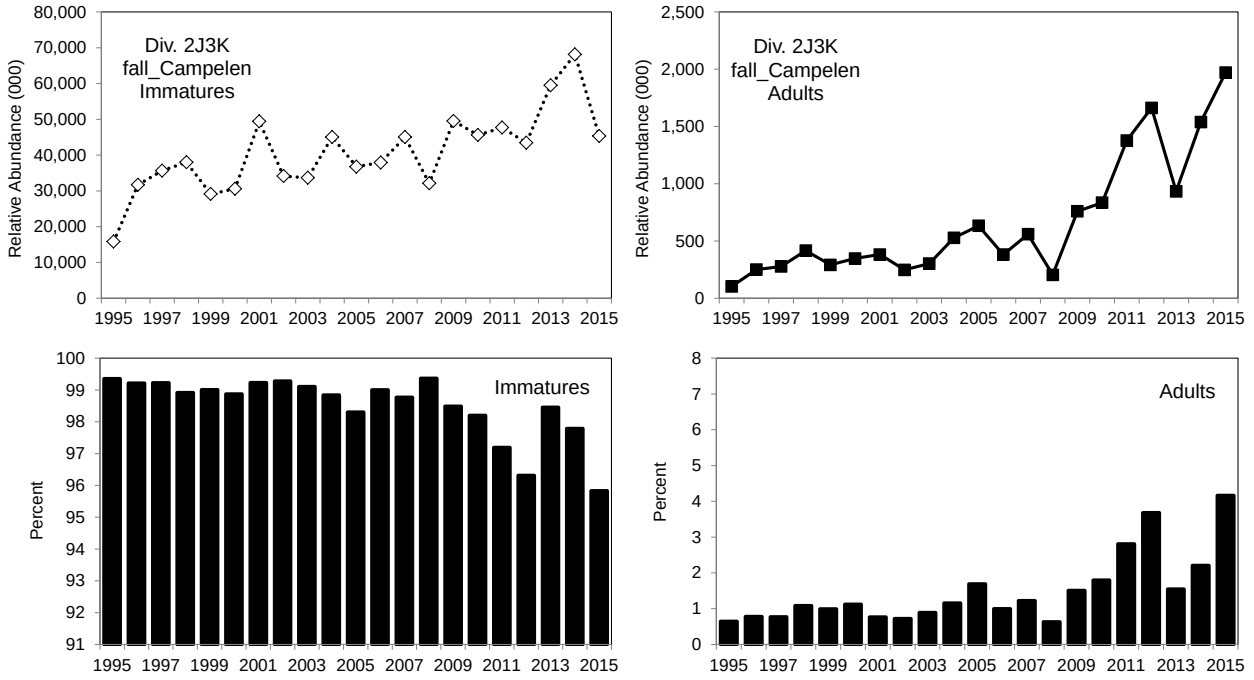

Figure 32. Relative abundance at length of immature (≤27.5 cm) and adult (>27.5 cm) Roughhead Grenadiers from DFO-NL fall Campelen surveys in Divs. 2J3K, 1995-2015.

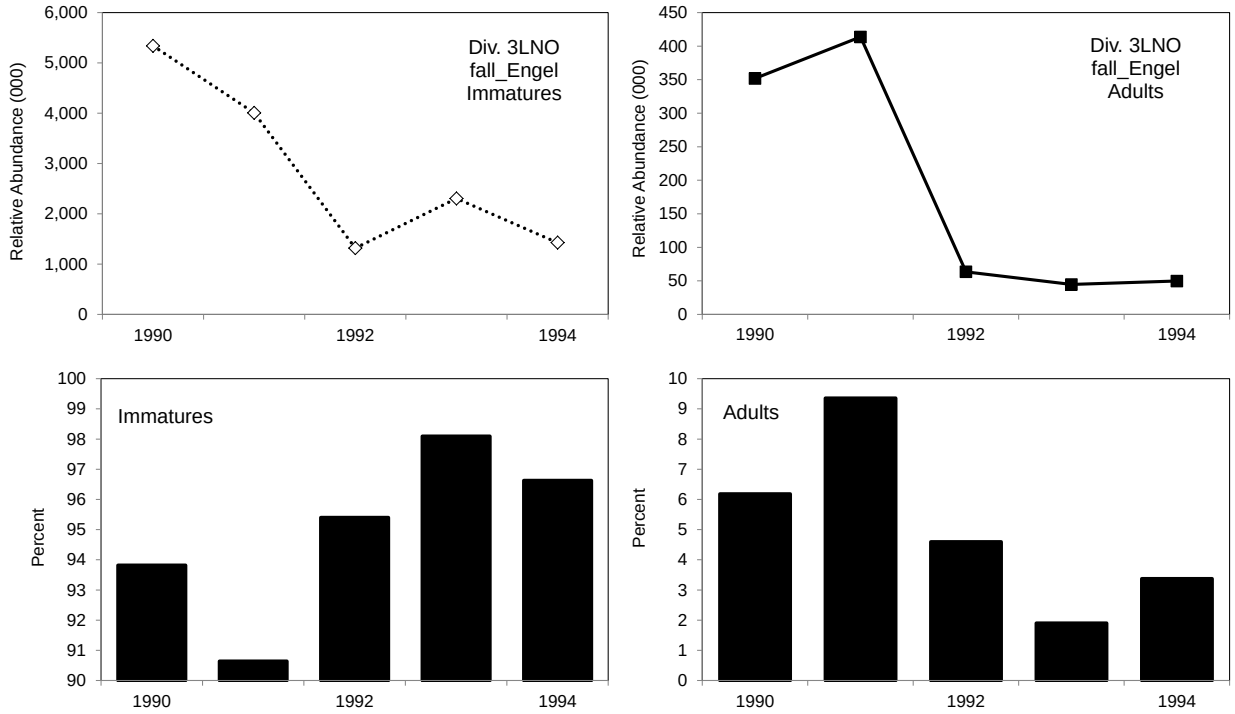

Figure 33. Relative abundance at length of immature (≤27.5 cm) and adult (>27.5 cm) Roughhead Grenadiers from DFO-NL fall Engel surveys in Divs. 3LNO, 1990-94.

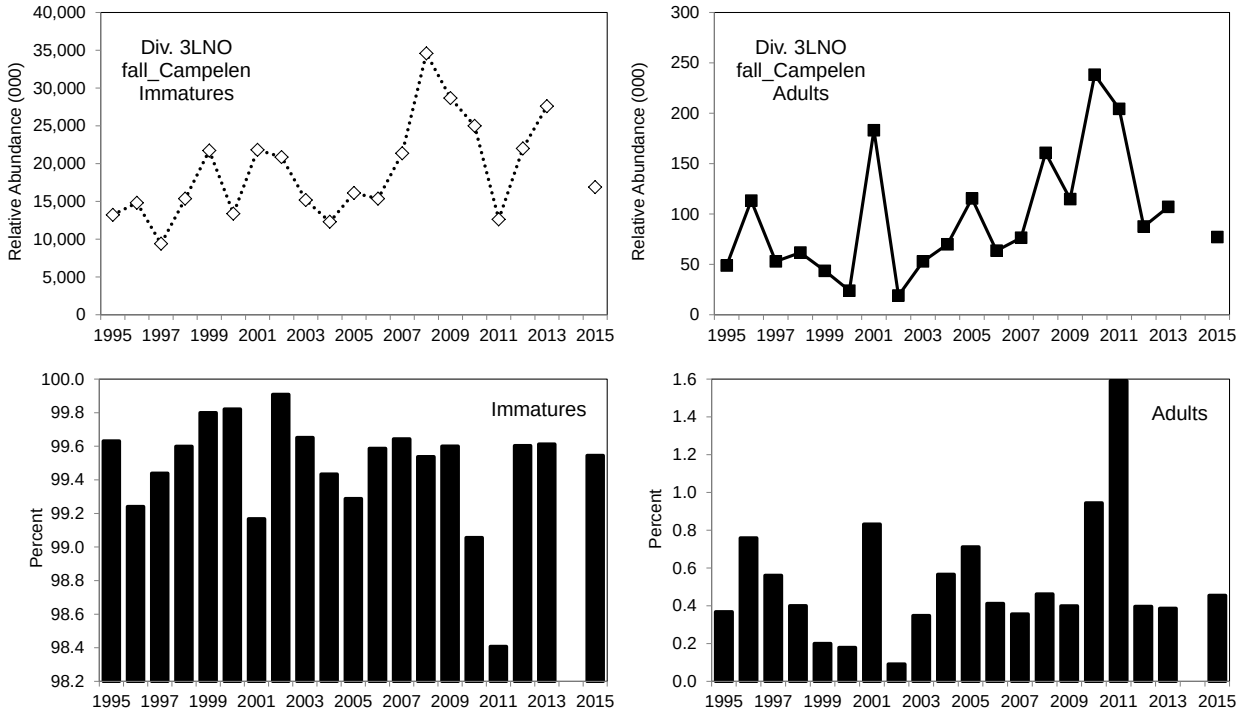

Figure 34. Relative abundance at length of immature (≤27.5 cm) and adult (>27.5 cm) Roughhead Grenadiers from DFO-NL fall Campelen surveys in Divs. 3LNO, 1995-2015.

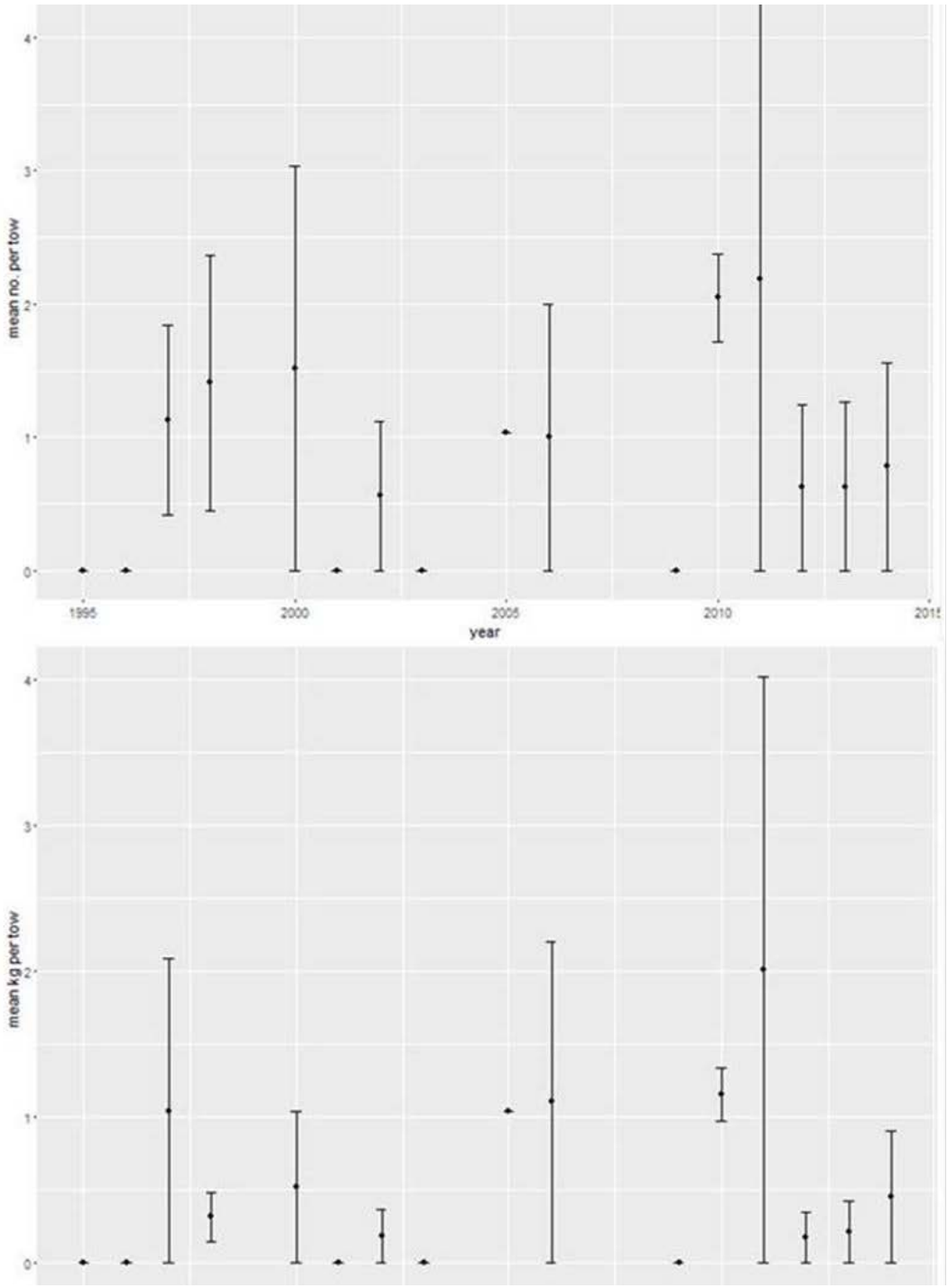

Figure 35. Mean numbers (top panel) and mean weights (kg; bottom panel) per tow of Roughhead Grenadier from DFO-MAR summer research survey in stratum 496, 1995-2014. Vertical bars represent one standard error.

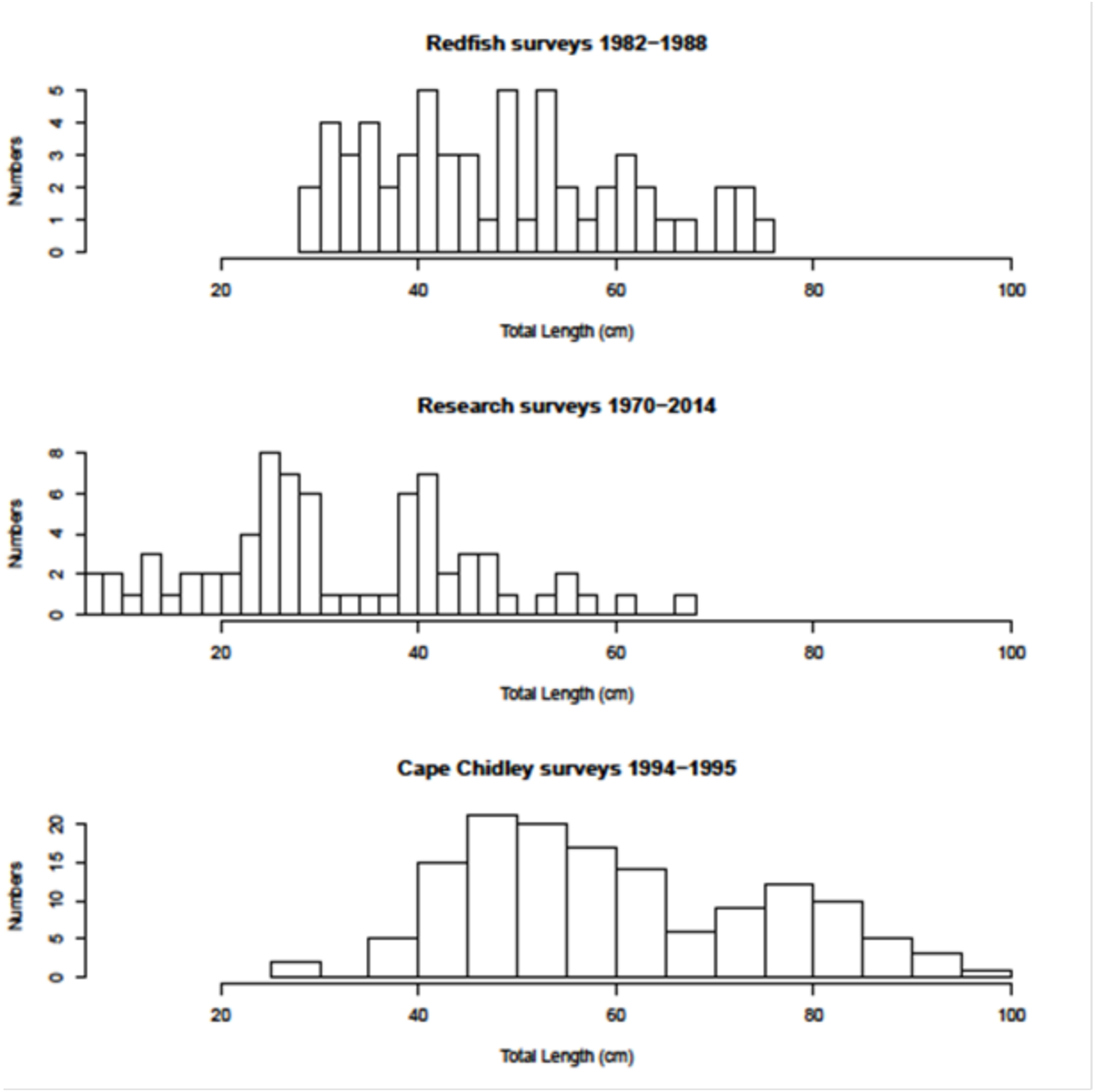

Figure 36. Total lengths (cm) of Roughhead Grenadier from DFO-MAR surveys. Top panel: redfish surveys, 1982-88; middle panel: Summer, 4VsW and Georges Bank research surveys, 1970-2014; bottom panel: Cape Chidley surveys, 1994-95.

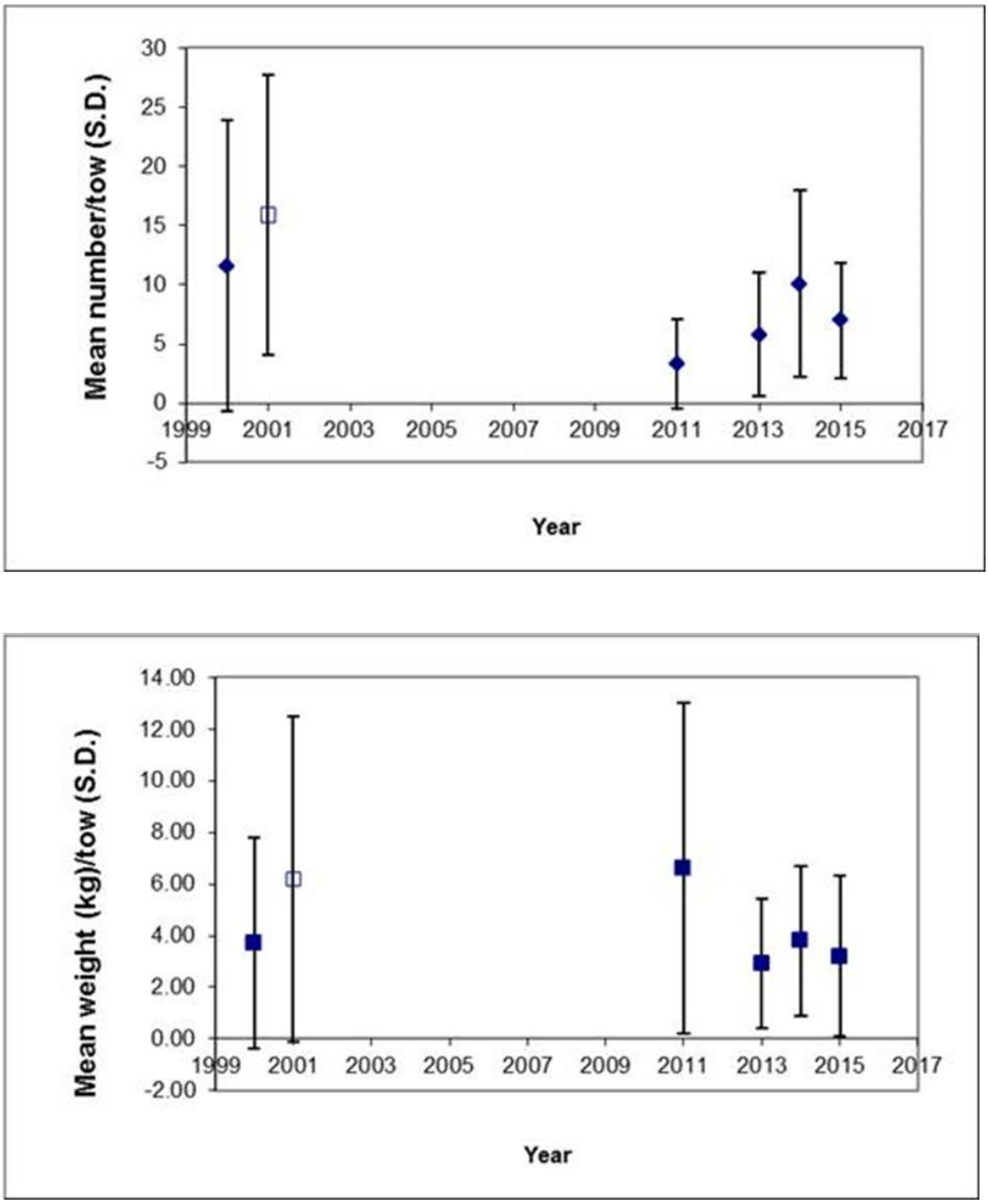

Figure 37. Mean numbers (upper panel) and mean weights (kg; lower panel) per tow (±1SD) of Roughhead Grenadier from DFO-C&A surveys in Div. 0B (2000, 2001, 2011, 2013-15).

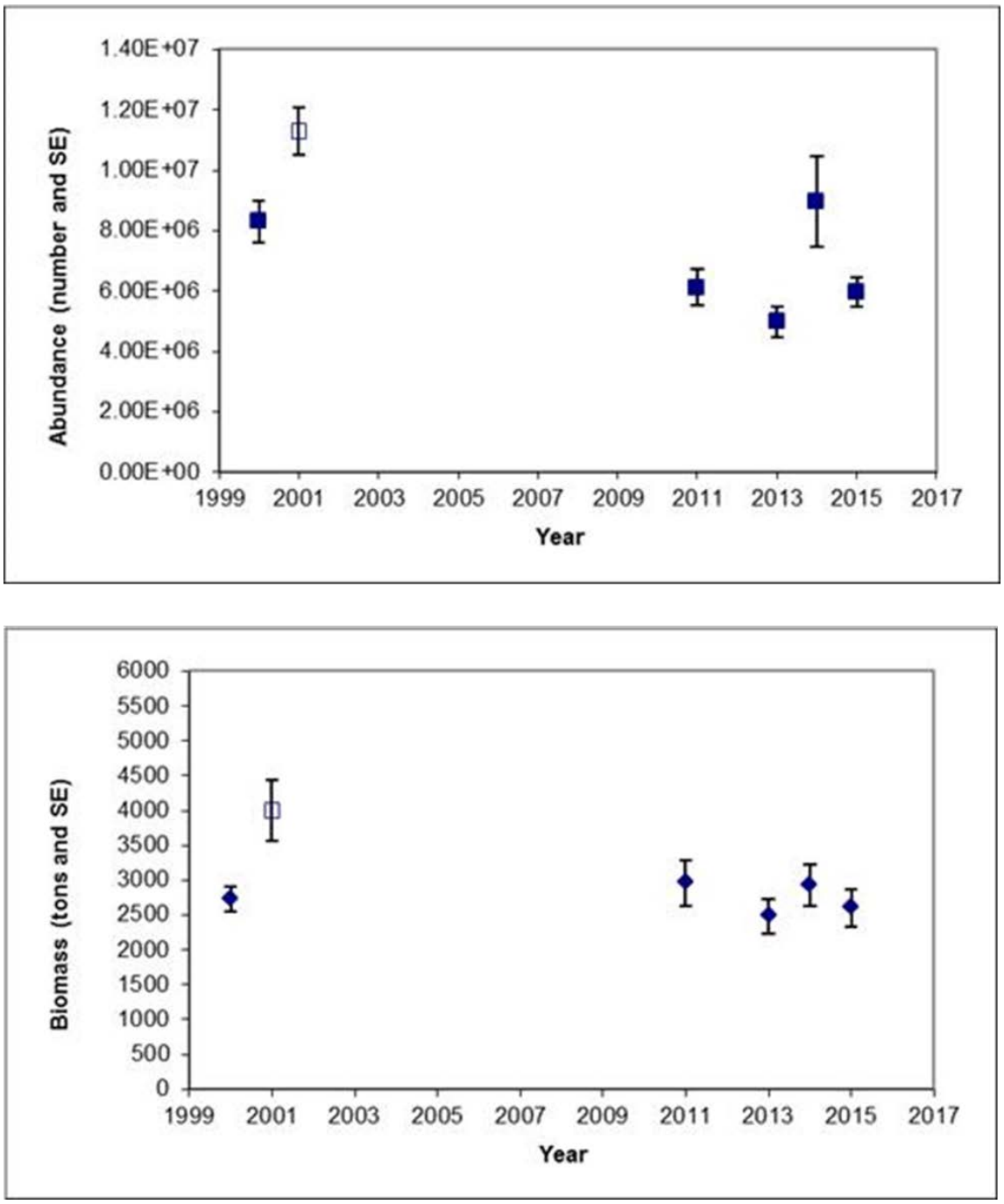

Figure 38. Abundance (±1SE; upper panel) and biomass (tons ±1SE; lower panel) indices for Roughhead Grenadier from DFO-C&A surveys in Div. 0B (2000, 2001, 2011, 2013-15).

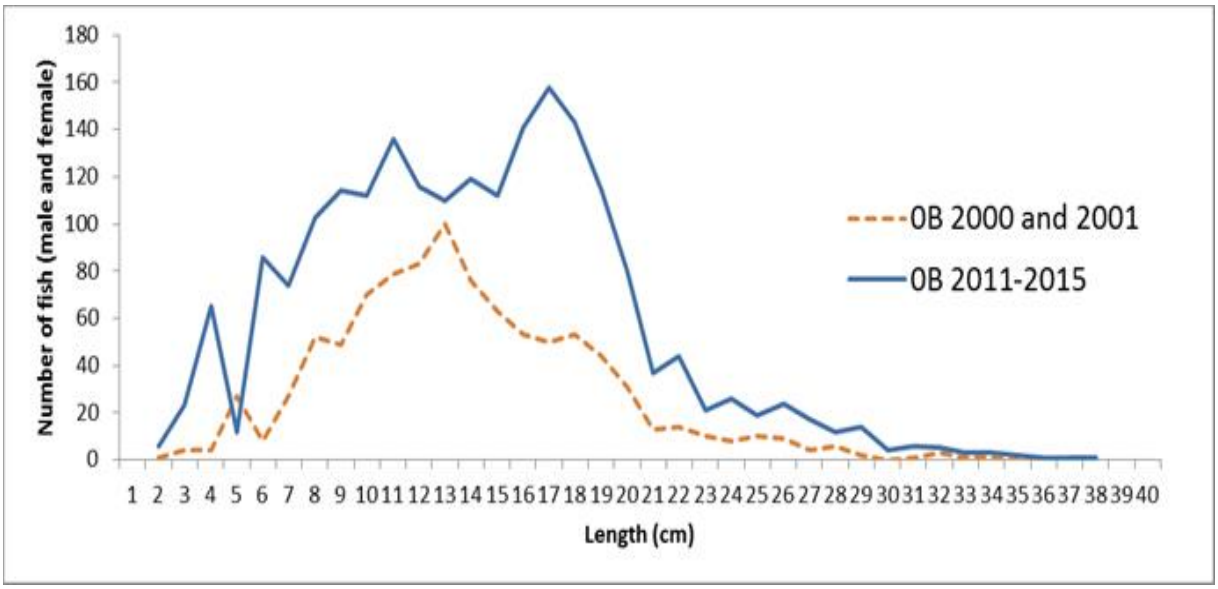

Figure 39. Roughhead Grenadier abundance-at-length (AFL in cm; sexes combined) from DFO-C&A surveys in Div. 0B (2000, 2001, 2011, 2013-15).

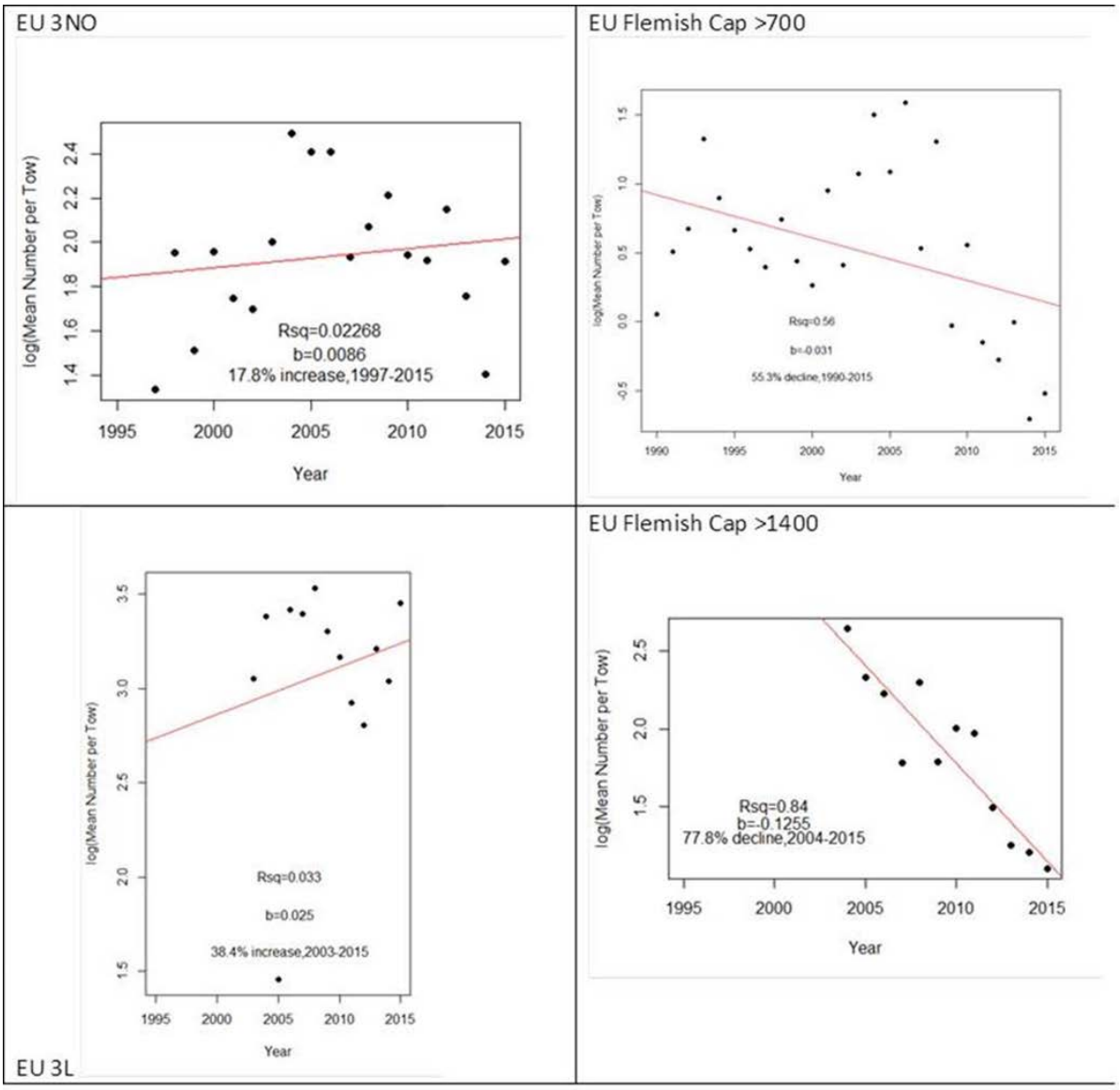

Figure 40. Stratified mean catch rates of Roughhead Grenadier (all sizes) in EU-Spain surveys in Divs. 3NO, 3L, and 3M (>700 m; >1400 m). Regression lines are shown for loge catch rate versus year along with their slope, Rsq, and decline rate.

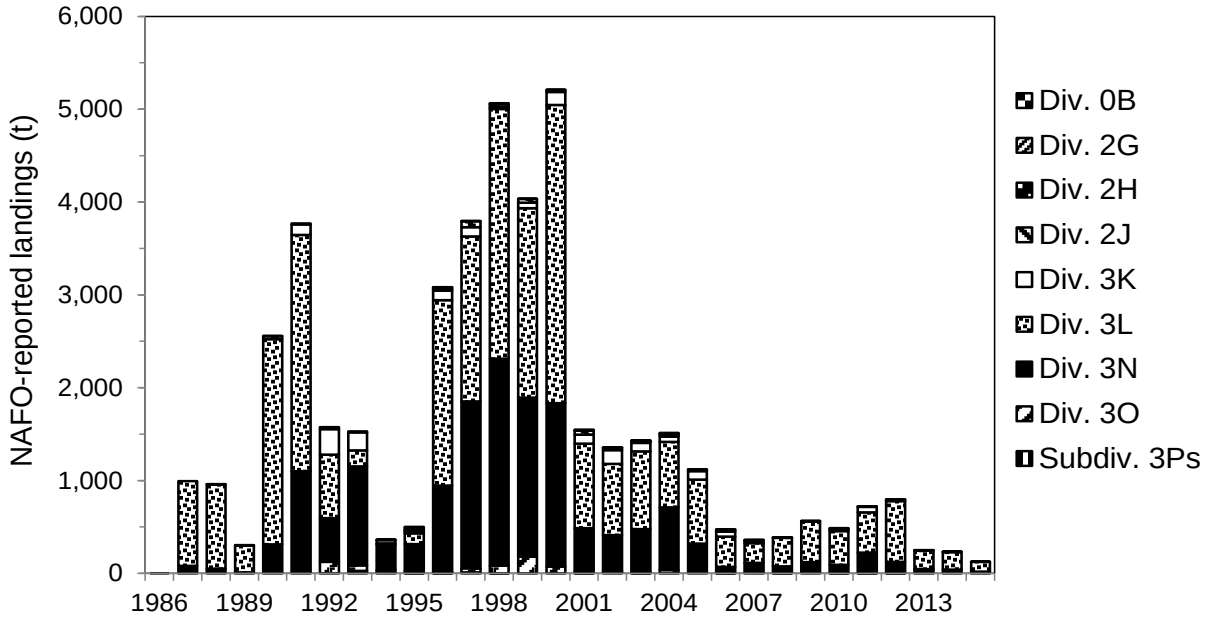

Figure 41. NAFO-reported landings (tonnes) of Roughhead Grenadier by Division in Divs 0B2GHJ3KLNOPs, 1986-2015 (STATLANT-21A). Data do not include discards. Note that NAFO landings for EU-Spain in 1992-95 are not included, because they were reported as Roundnose Grenadier (see text for details).

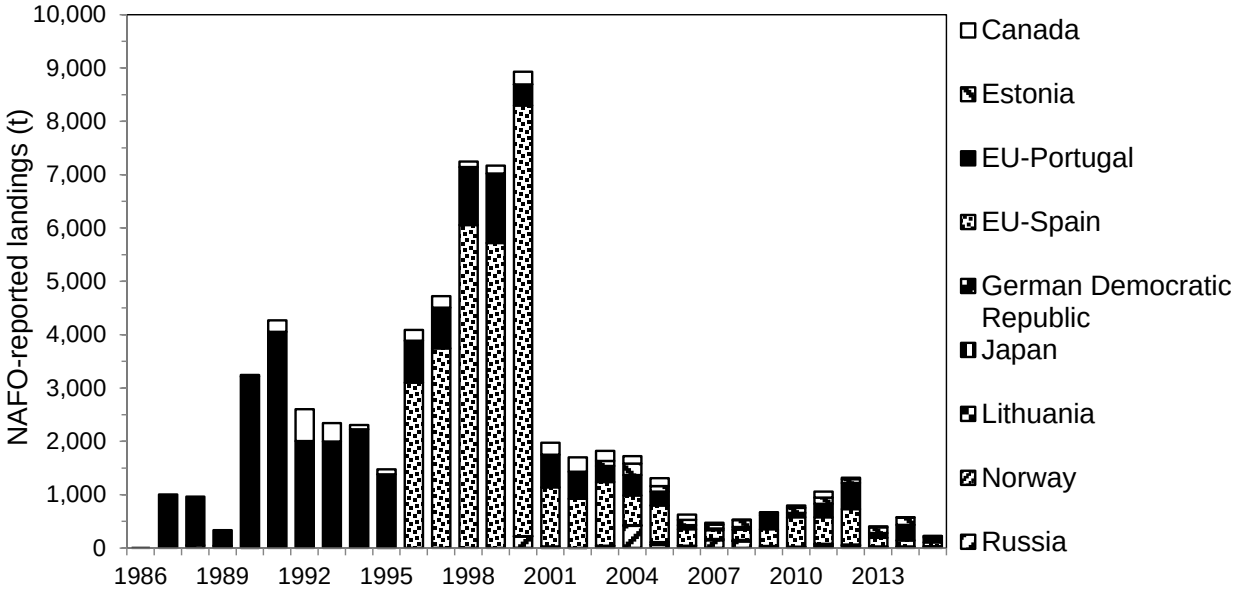

Figure 42. NAFO-reported landings (tonnes) of Roughhead Grenadier by member country in Divs. 0B2GHJ3KLNOPs, 1986-2015 (STATLANT-21A). Data do not include discards. Note that NAFO landings for EU-Spain in 1992-95 are not included, because they were reported as Roundnose Grenadier (see text for details).

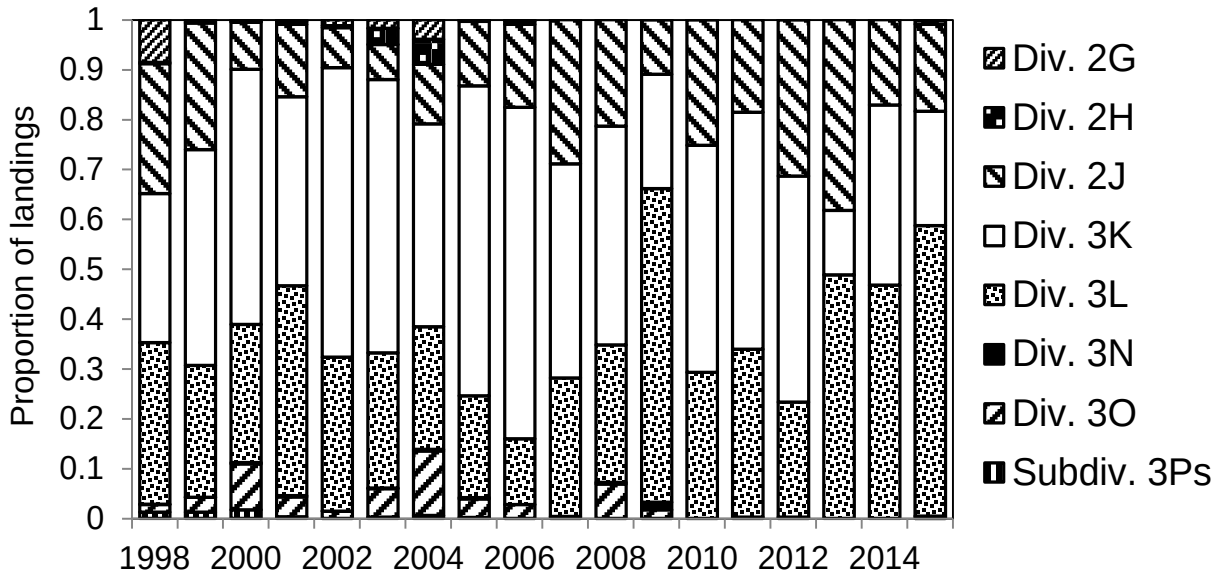

Figure 43. Proportion of DFO-NL ZIFF-reported Roughhead Grenadier landings taken by Canada inside the 200-mile limit in Divs. 2GHJ3KLNOPs, 1998-2015. Data do not include discards.

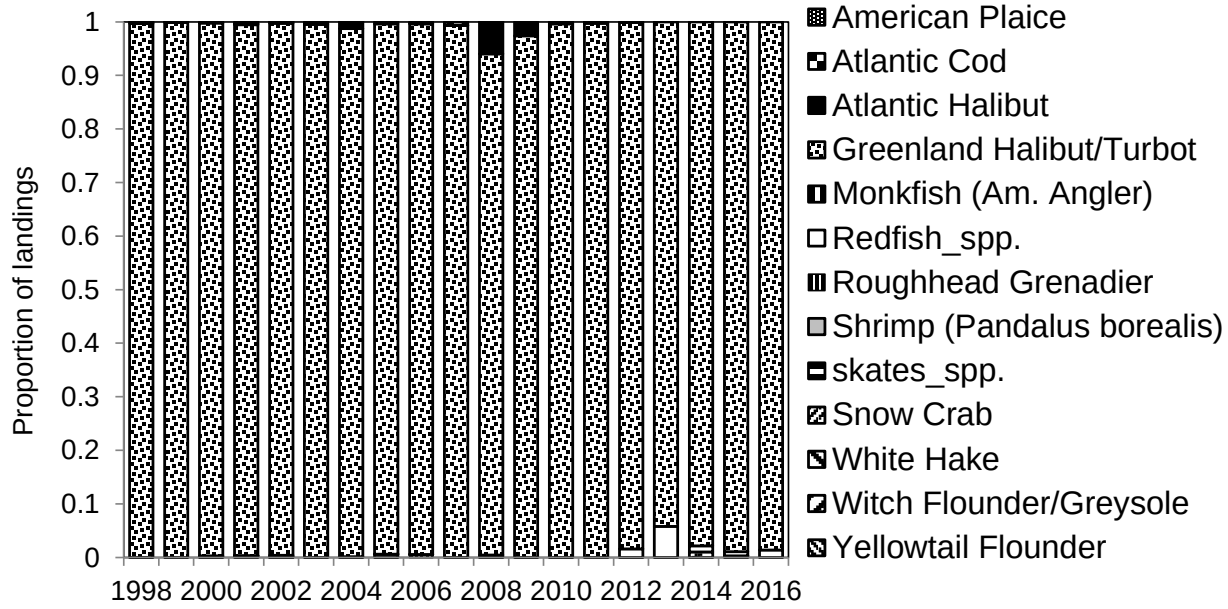

Figure 44. Proportion of DFO-NL ZIFF-reported Roughhead Grenadier landings by directed species in Canada's EEZ of Divs. 0B2GHJ3KLNOPs, 1998-2016. Data do not include discards, and are preliminary for 2016.

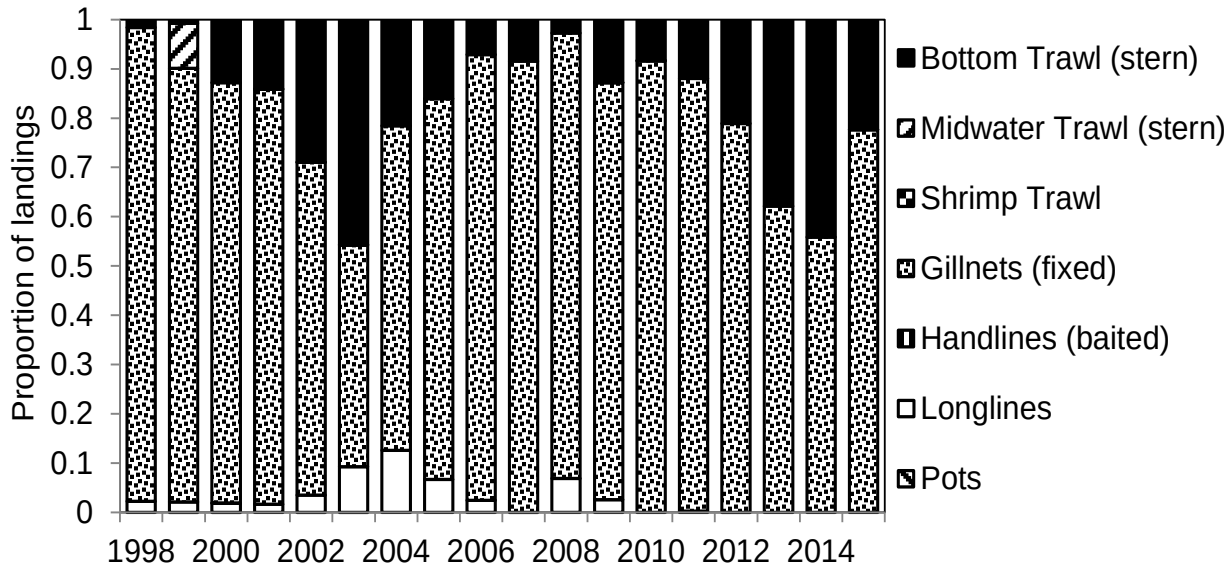

Figure 45. Proportion of DFO-NL ZIFF-reported Roughhead Grenadier landings by gear type in Canada's EEZ of Divs. 0B2GHJ3KLNOPs, 1998-2015. Data do not include discards.

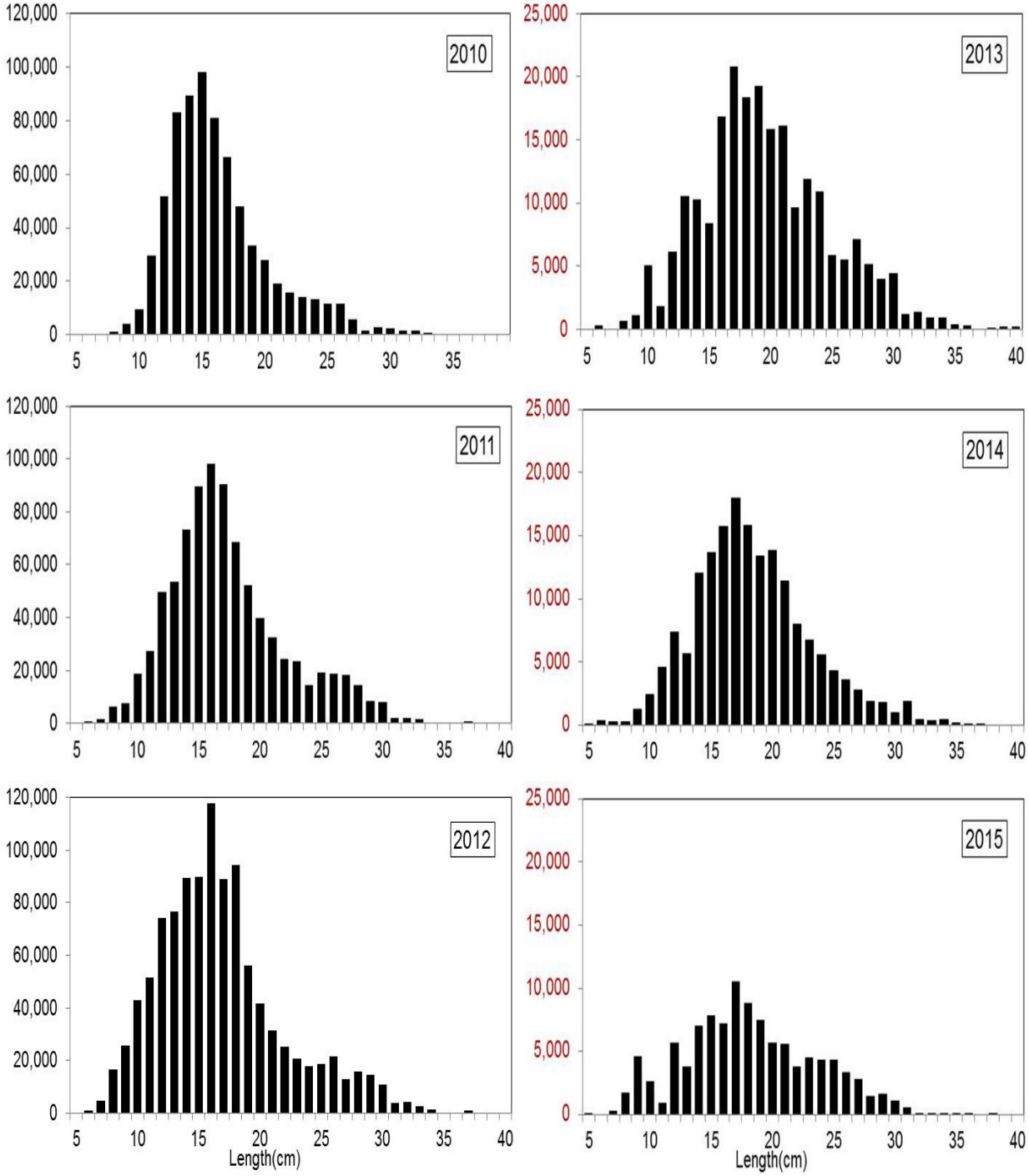

Figure 46. Roughhead Grenadier commercial length distributions (AFL; sexes combined) in Divs. 3LMNO from Greenland Halibut trawl fisheries conducted by EU-Spain using 130 mm mesh, 2010-15. Note that Y-axis values are different between the left and right panels.

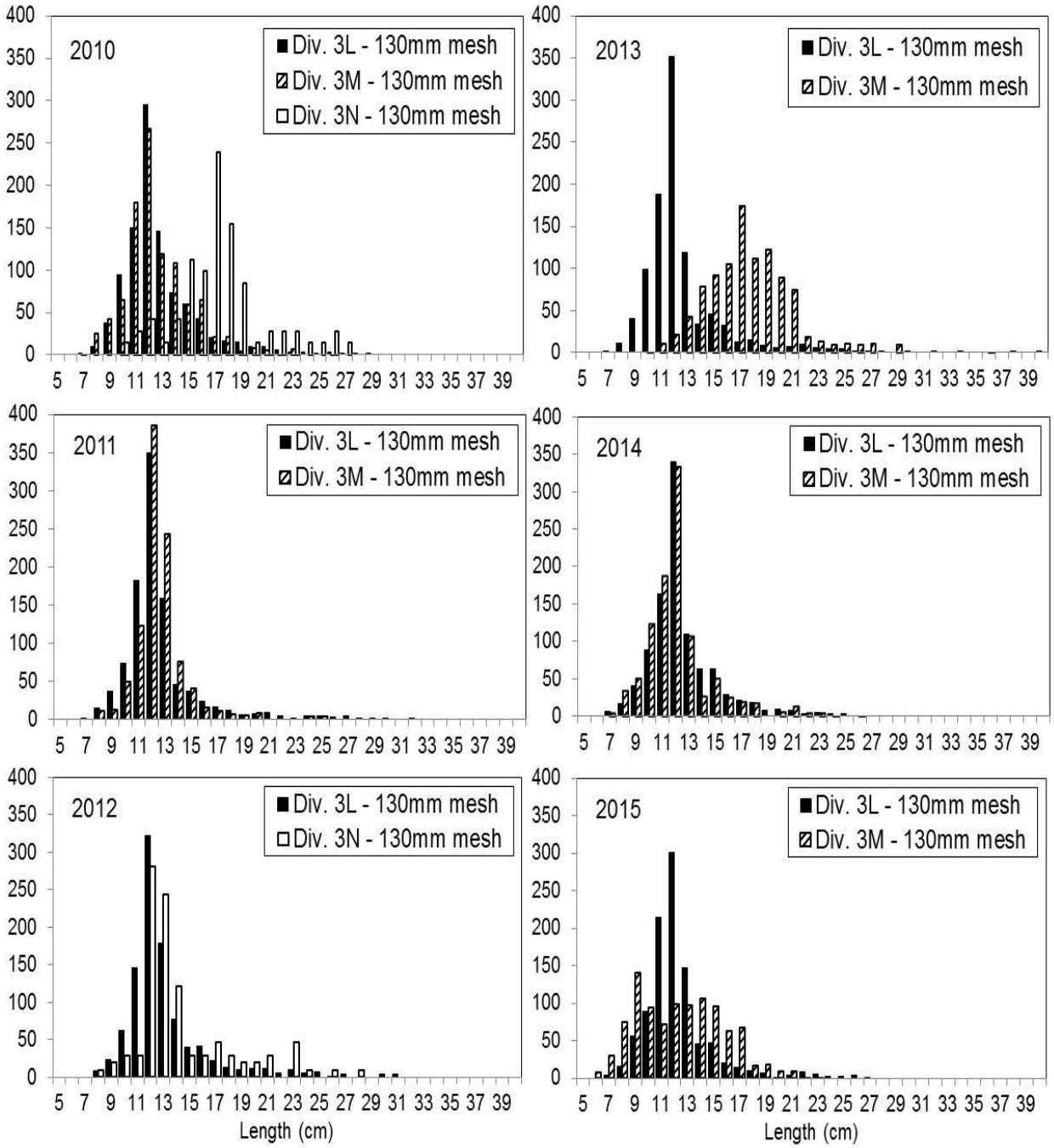

Figure 47. Roughhead Grenadier commercial length distributions (AFL; sexes combined) in Divs. 3LMN from Greenland Halibut trawl fisheries conducted by EU-Portugal using 130 mm mesh, 2010-15.

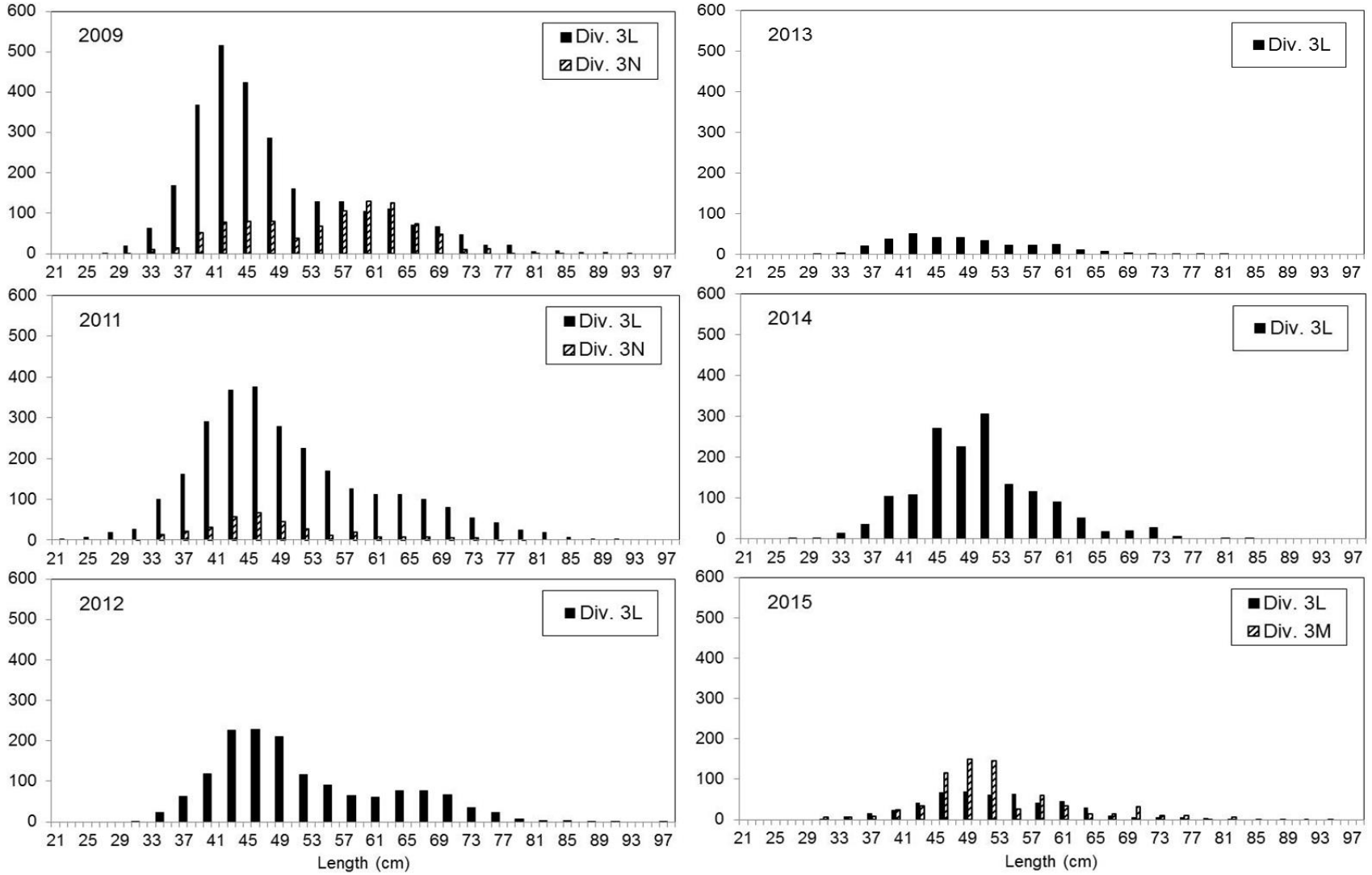

Figure 48. Roughhead Grenadier commercial length distributions (TL; sexes combined) in Divs. 3LMN from Greenland Halibut trawl fisheries conducted by Russia, 2009-15.

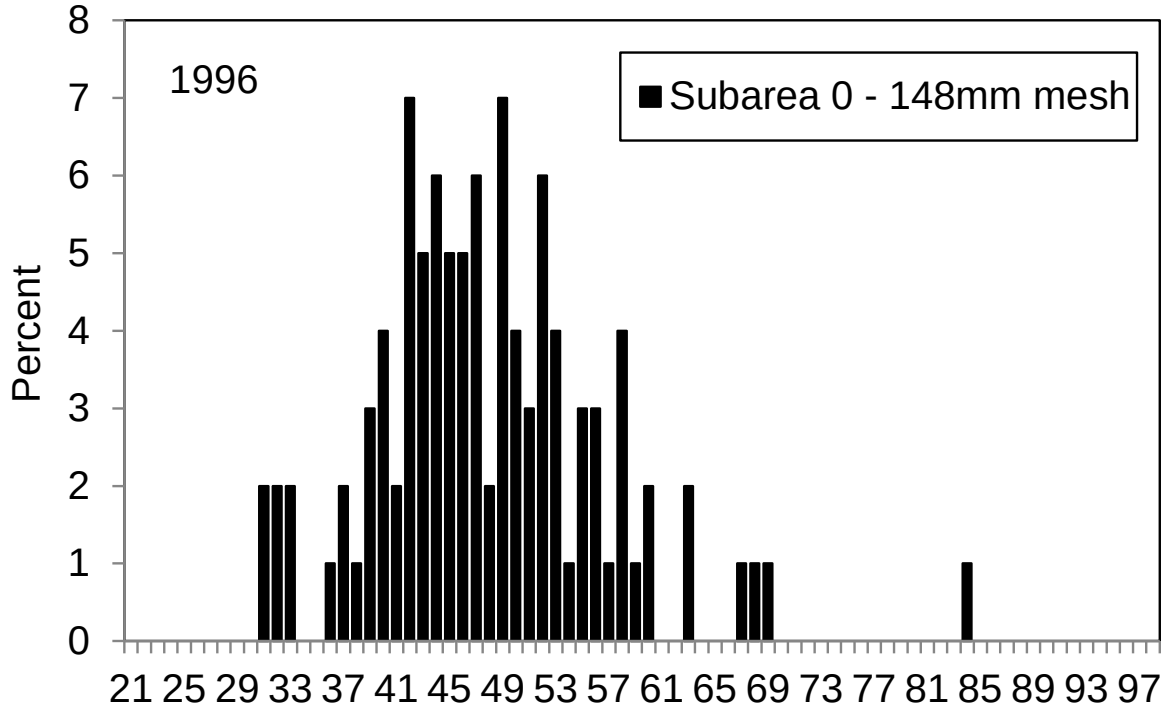

Figure 49. Roughhead Grenadier commercial length distributions (TL; sexes combined) in Subarea 0 from Greenland Halibut trawl fisheries conducted by Canada using 148 mm mesh in 1996. Data are from Canadian At-Sea Fisheries Observers – NL Region.

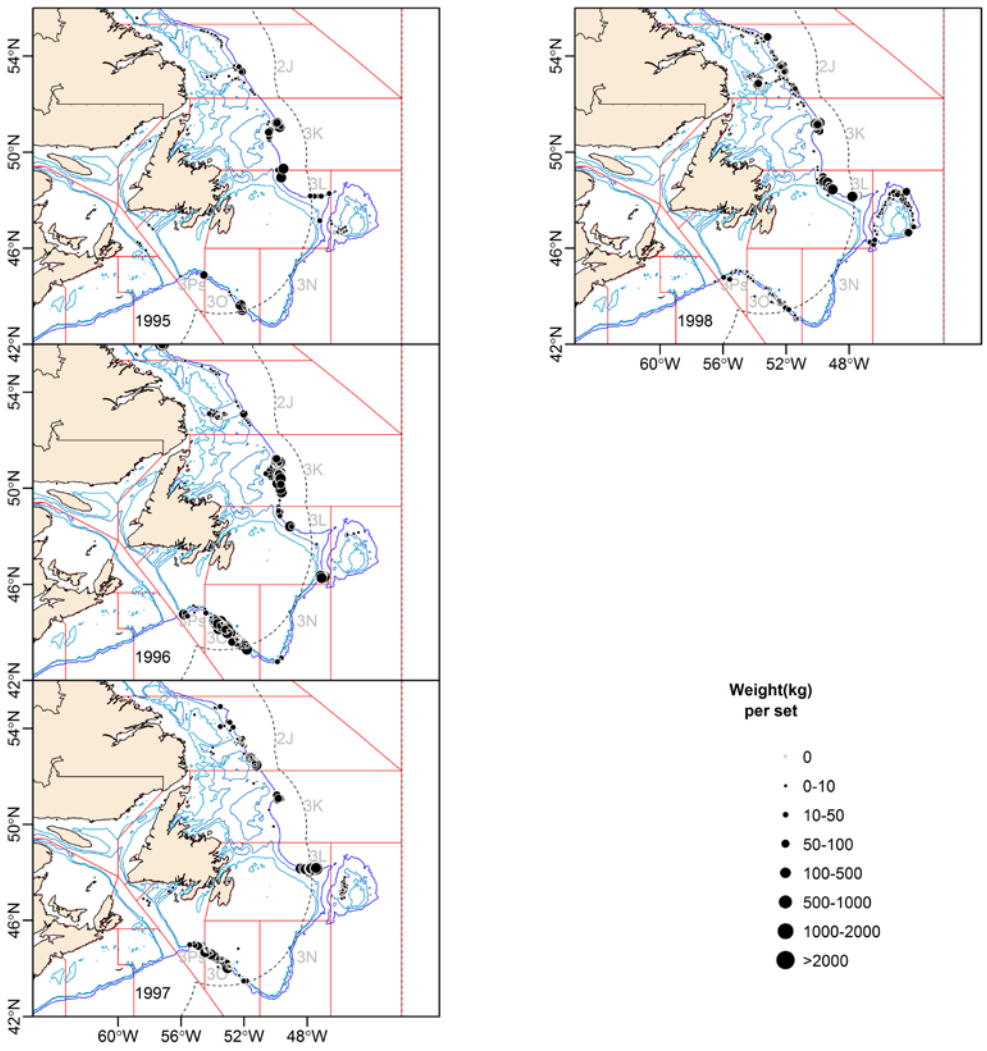

Figure 50a. Distribution (total weight in kg per tow) of Roughhead Grenadier in Divs. 2J3KLNOPs commercial catches, 1995-98. Data are from Canadian At-Sea Fisheries Observers – NL Region.

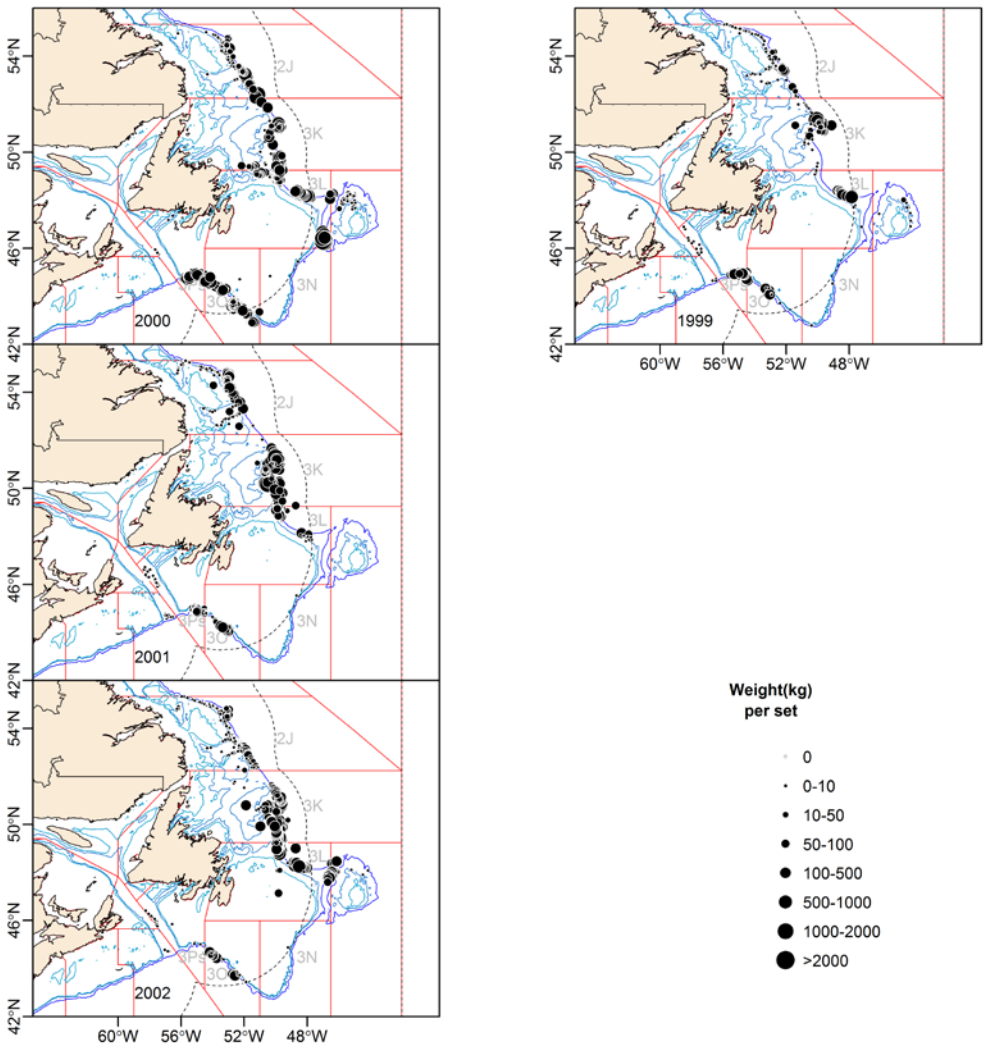

Figure 50b. Distribution (total weight in kg per tow) of Roughhead Grenadier in Divs. 2J3KLNOPs commercial catches, 1999-2002. Data are from Canadian At-Sea Fisheries Observers – NL Region.

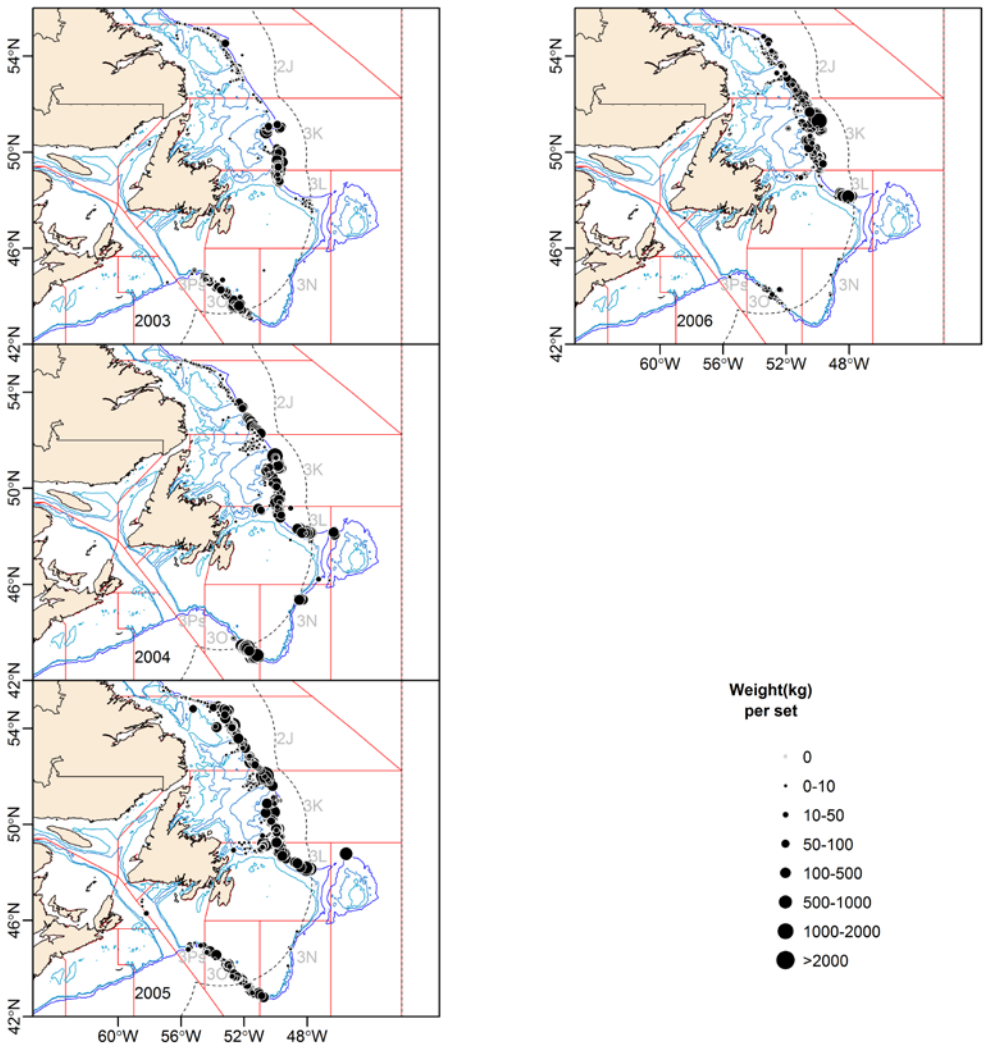

Figure 50c. Distribution (total weight in kg per tow) of Roughhead Grenadier in Divs. 2J3KLNOPs commercial catches, 2003-06. Data are from Canadian At-Sea Fisheries Observers – NL Region.

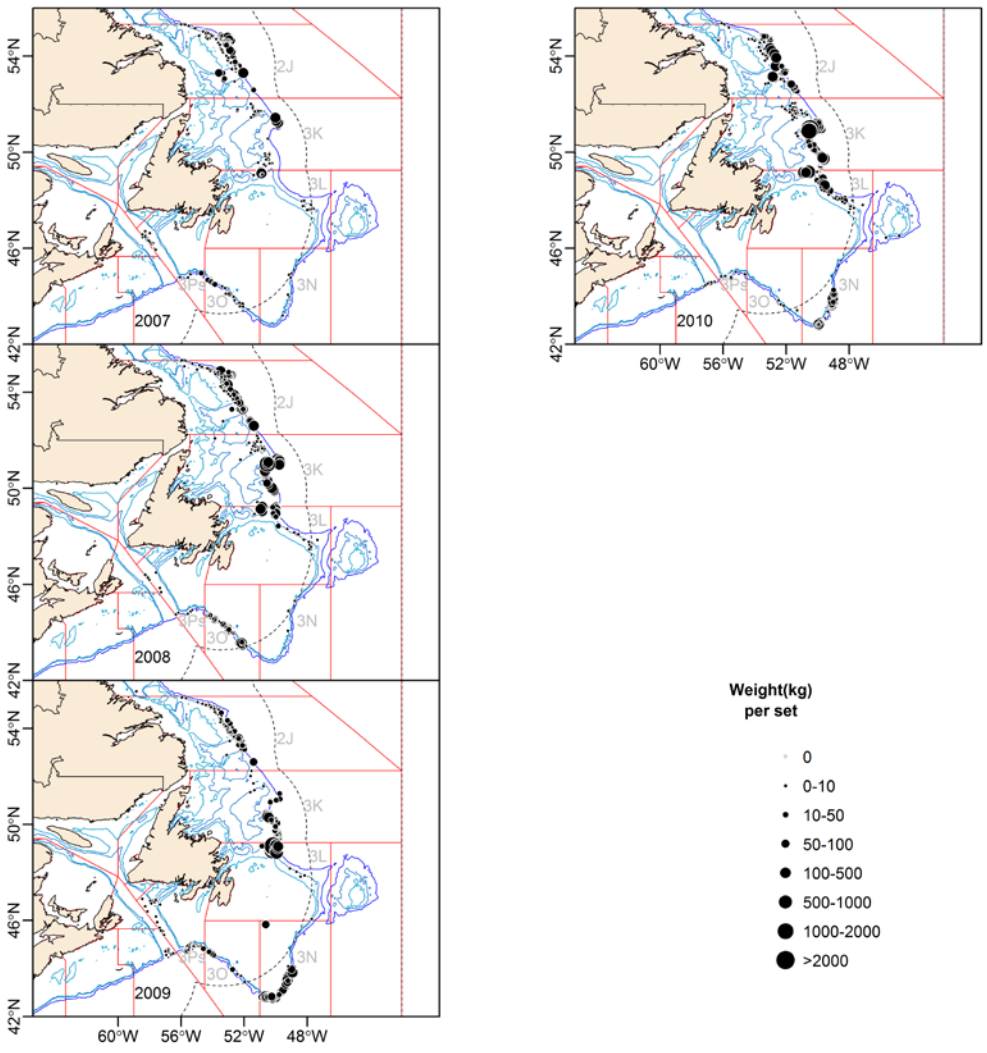

Figure 50d. Distribution (total weight in kg per tow) of Roughhead Grenadier in Divs. 2J3KLNOPs commercial catches, 2007-10. Data are from Canadian At-Sea Fisheries Observers – NL Region.

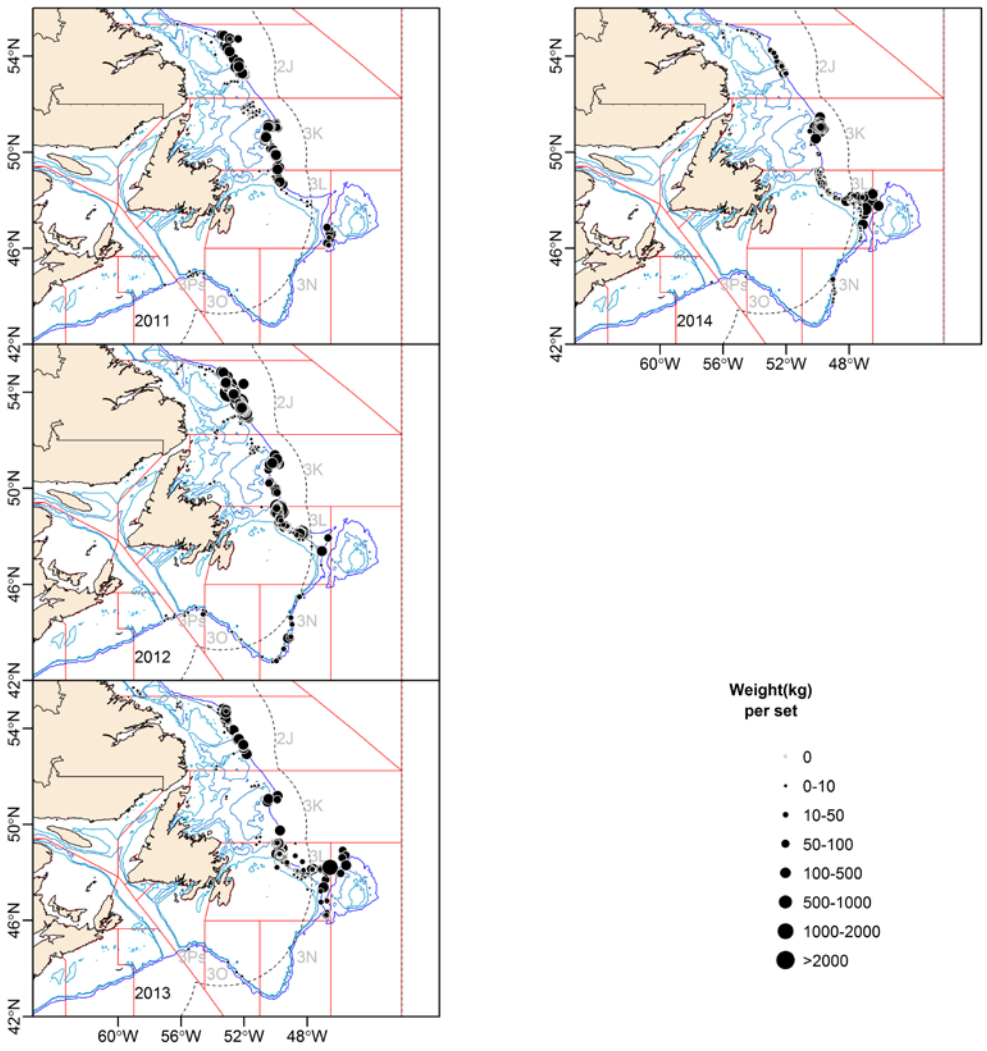

Figure 50e. Distribution (total weight in kg per tow) of Roughhead Grenadier in Divs. 2J3KLNOPs commercial catches, 2011-14. Data are from Canadian At-Sea Fisheries Observers – NL Region.

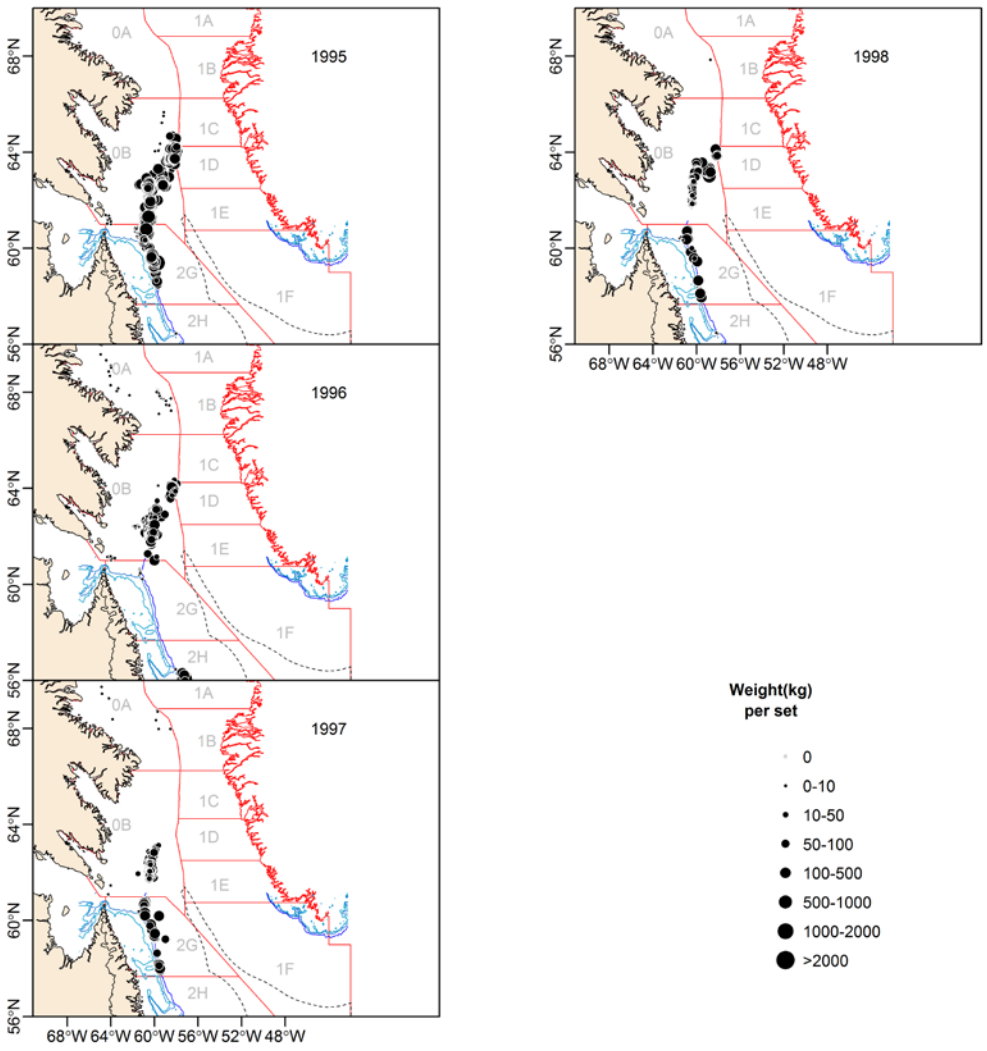

Figure 51a. Distribution (total weight in kg per tow) of Roughhead Grenadier in Subarea 0 and Divs. 2GH commercial catches, 1995-98. Data are from Canadian At-Sea Fisheries Observers – NL Region.

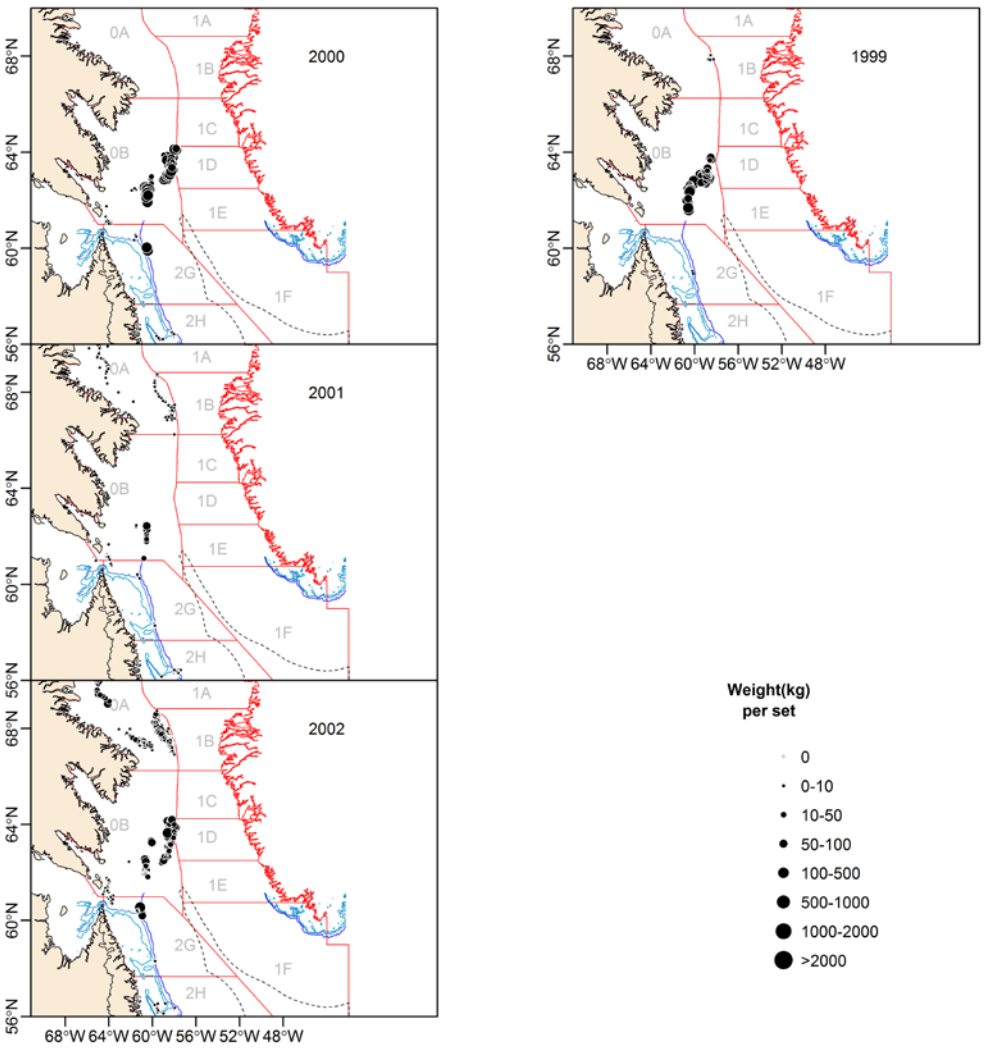

Figure 51b. Distribution (total weight in kg per tow) of Roughhead Grenadier in Subarea 0 and Divs. 2GH commercial catches, 1999-2002. Data are from Canadian At-Sea Fisheries Observers – NL Region.

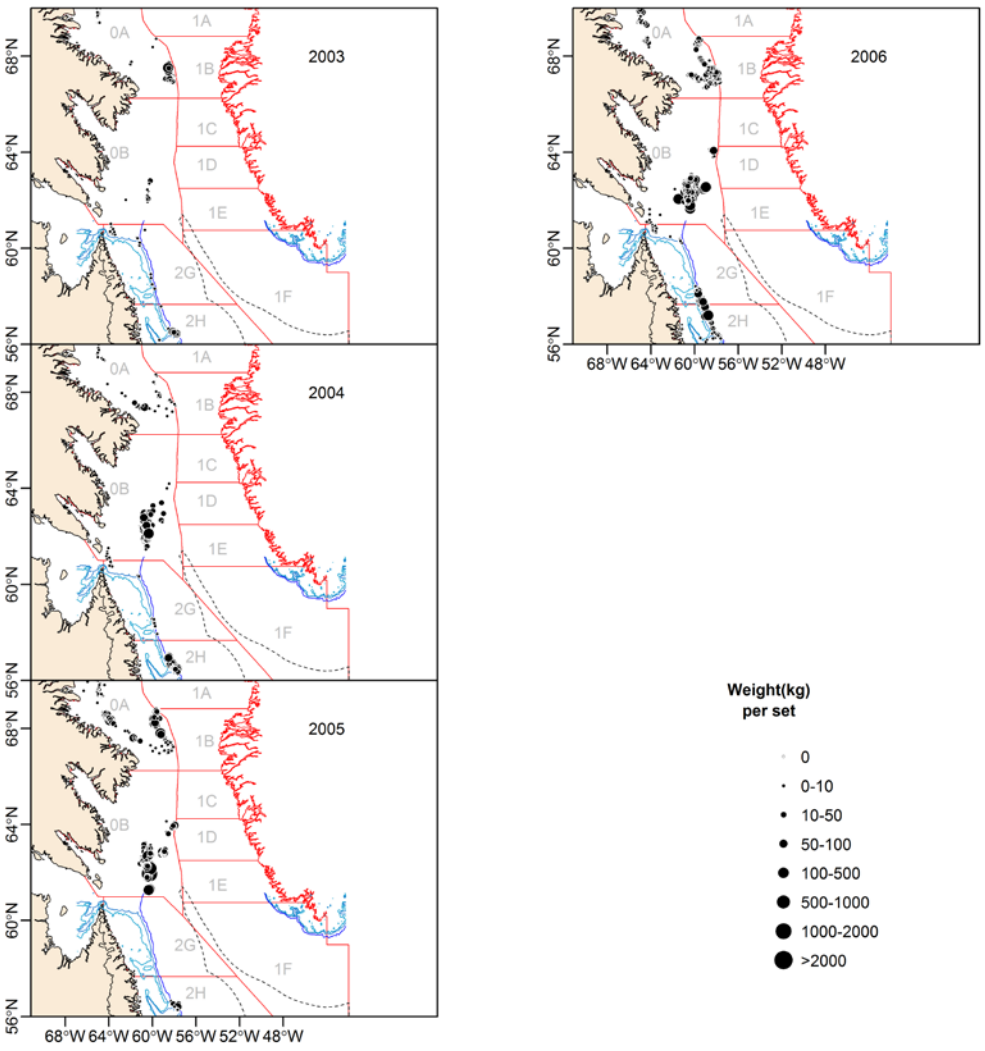

Figure 51c. Distribution (total weight in kg per tow) of Roughhead Grenadier in Subarea 0 and Divs. 2GH commercial catches, 2003-06. Data are from Canadian At-Sea Fisheries Observers – NL Region.

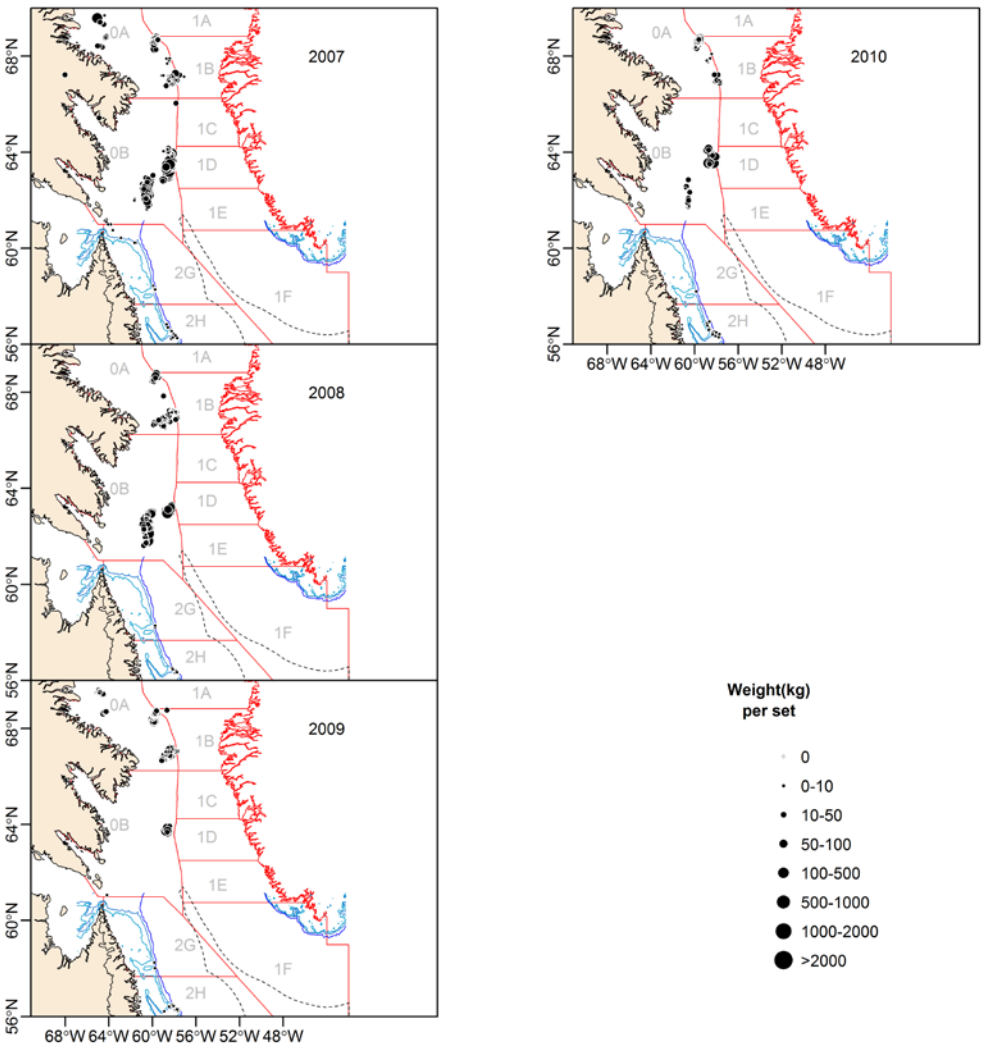

Figure 51d. Distribution (total weight in kg per tow) of Roughhead Grenadier in Subarea 0 and Divs. 2GH commercial catches, 2007-10. Data are from Canadian At-Sea Fisheries Observers – NL Region.

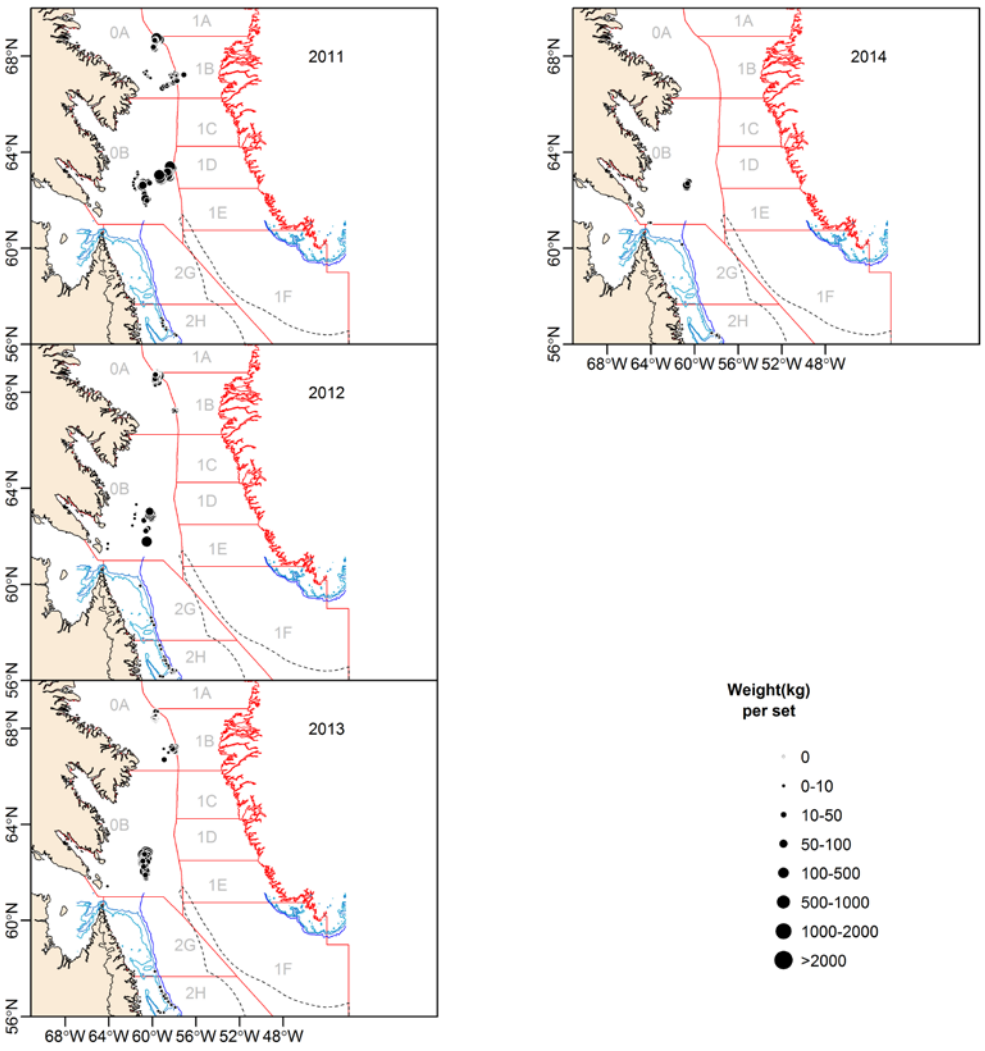

Figure 51e. Distribution (total weight in kg per tow) of Roughhead Grenadier in Subarea 0 and Divs. 2GH commercial catches, 2011-14. Data are from Canadian At-Sea Fisheries Observers – NL Region.

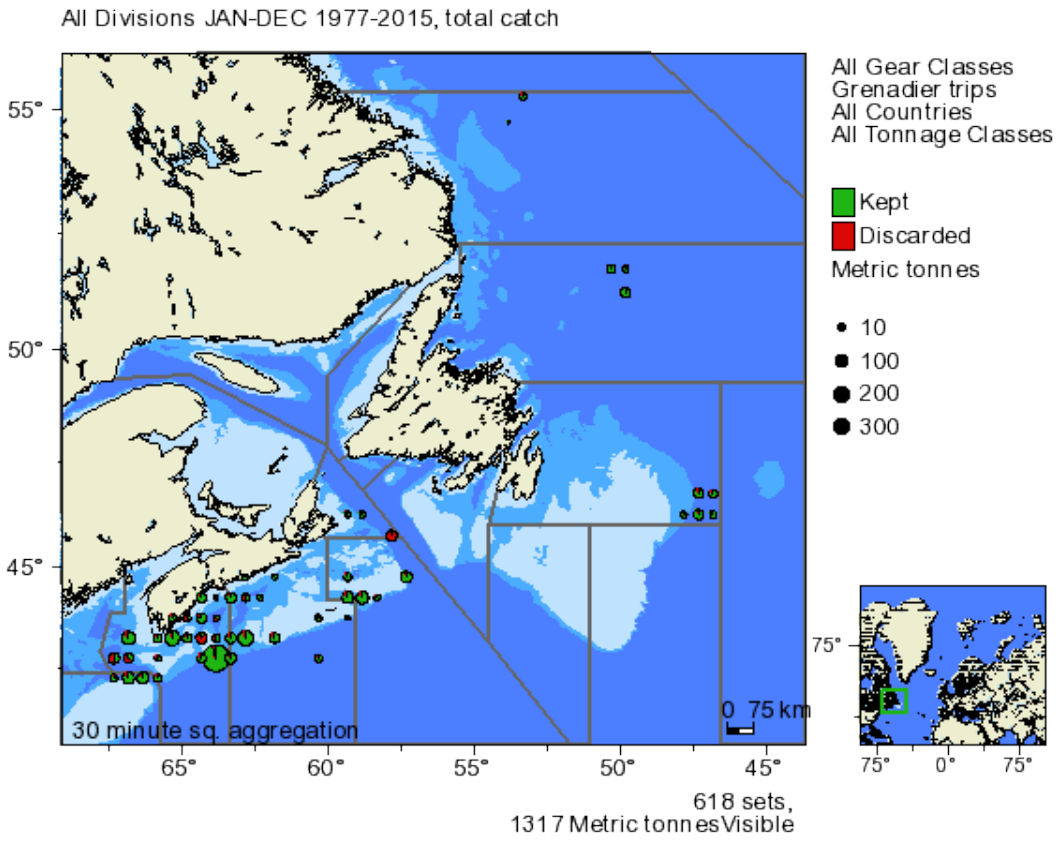

Figure 52. Distribution (kept and discards in t) of Roughhead Grenadier in grenadier-directed Maritime fisheries, 1977-2015. Data are from Canadian At-Sea Fisheries Observers - Maritimes Region.

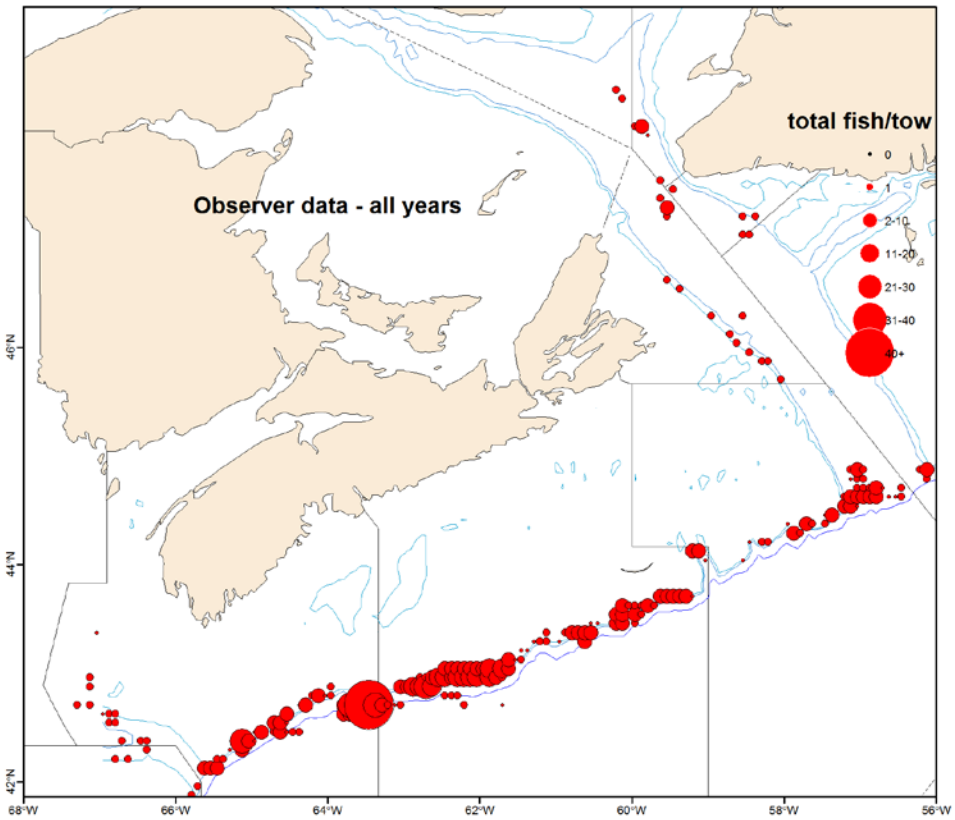

Figure 53. Distribution (total number of fish per tow) of Roughhead Grenadier in all Maritime fisheries, 1980-2015. Data are from Canadian At-Sea Fisheries Observers - Maritimes Region.