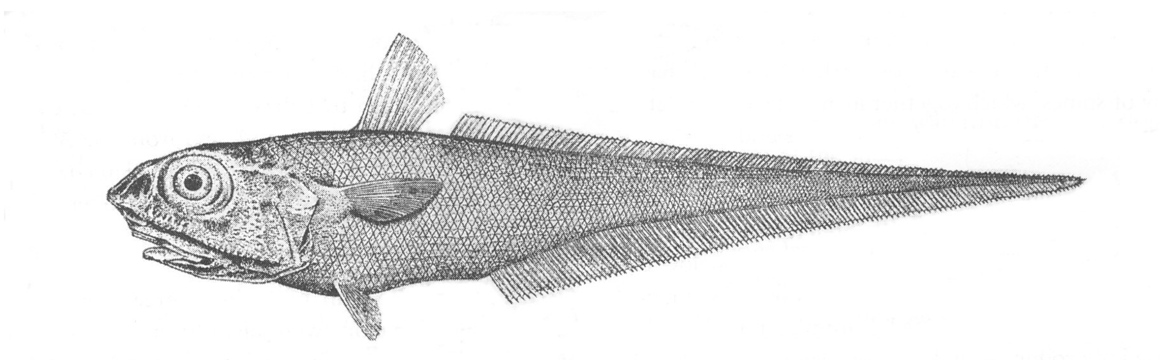
COSEWIC
Assessment and Status Report

on the

roughhead grenadier
Macrourus berglax

in Canada



SPECIAL CONCERN
2007

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
COMITÉ SUR LA SITUATION
DES ESPÈCES EN PÉRIL
AU CANADA

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Roughhead grenadier — Drawn by H.L.Todd and reproduced from Collette and Klein-MacPhee (2002) with permission from the Division of Fishes, National Museum of Natural History, Smithsonian Institution.

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COSEWIC
Assessment Summary

Assessment Summary – April 2007

Common name
Roughhead grenadier

Scientific name
Macrourus berglax

Status
Special Concern

Reason for designation
This species is widespread on the upper continental slope and deep continental shelf throughout the North Atlantic. Females mature at 13-15 years with a generation time of approximately 20 years. The species is distributed from Davis Strait in the north to Georges Bank in the south, occurring both inside and outside 200 n. miles, primarily in depths between 400 and 1500 m. Research vessel surveys have not consistently covered deep portions of the range and catch a low proportion (ca. 2%) of mature adults. Canadian survey index decline rates over 15 years (< one generation) of > 90% occurred in the 1980s and early 1990s, but the surveys only covered depths to 1000 m. This decline is probably due to a combination of distributional change and abundance decline: there is evidence for movement of fish into deeper water as a result of the cooling of the shelf in the 1980s, and reduction in population size due to fishing pressure is also a possible factor. The species is caught primarily as bycatch in the Greenland halibut fishery, which has experienced reduced Total Allowable Catch and greater restrictions on areas of operation since 2000. However, there are no catch limits or management plans for the species in Canadian waters, and catch reporting of foreign vessels is often unreliable. Survey indices (Canadian and European Union) for adults have been stable over the past decade. The species is of concern because of late maturation, lack of evidence of return of adults to shallower depths with return to environmental conditions prevailing prior to the 1980s, a probable decline in abundance in the 1980s and 1990s, and the lack of a management plan for directed and incidental harvest.

Occurrence
Atlantic Ocean

Status history
Special Concern in April 2007. Assessment based on a new status report.

COSEWIC
Executive Summary

roughhead grenadier
Macrourus berglax

Species information

The roughhead grenadier belongs to the family Macrouridae, which as a group are often referred to as rattails. It is distinguished from similar species in the North Atlantic by its fairly broad head exhibiting ridges with scute-like scales bearing strong spinules that provide it with its common name. In this report, roughhead grenadier are treated as a single designatable unit in Atlantic Canada (including the Flemish Cap and other waters beyond the 200-mile limit).

Distribution

The roughhead grenadier is found in temperate to arctic waters of the North Atlantic generally on or near the continental slope. In the waters off Canada, roughhead grenadier have been observed from the Davis Strait to Georges Bank, but are most commonly found along the slope of the Labrador and Northeast Newfoundland Shelves, the northeastern slope of the Grand Bank and off the Flemish Cap. The range of the roughhead grenadier in the Northwest Atlantic extends beyond the 200-mile limit and outside Canada's jurisdiction. As a straddling stock, it is assessed and managed by the Northwest Atlantic Fisheries Organization (NAFO).

Habitat

The roughhead grenadier is a benthopelagic species commonly occurring at depths between 400 and 1200 metres, although they may inhabit depths between 200 - 2000 m. In the waters off Newfoundland, densities tend to be highest at depths of about 500 – 1500 m. Their distribution extends beyond the offshore and northern limits of the annual monitoring surveys that are used to assess trends in marine fish abundance.

Biology

M. berglax has a low fecundity, slow growth rate, late maturation, and low population turnover rate. Females mature at approximately 13 to 15 years and reach a maximum age of 25 years. Generation time is calculated to be 19 years. Recent estimates of their instantaneous rate of total mortality, 0.34 for females and 0.71 for males, are rather high in light of what is known of life history and fishing pressure, and instantaneous rate of natural mortality is assumed to be 0.2. They are generally found in water temperatures between 2.0 and 5.4 ºC. Roughhead grenadiers are non-specialist predators. The food type consumed by this species is usually dependent on the size of the individual fish, but includes a wide variety of invertebrates and some fish.

Population sizes and trends

Catch rates of roughhead grenadier in the Canadian bottom-trawl surveys of the Grand Bank and Newfoundland Shelf were roughly stable in the 1970s, declined precipitously in the 1980s, and have been stable or increasing slightly since the early to mid-1990s. The declines in the 1980s amounted to 90 – 95% declines over 10 – 15 yr. The extent to which these declines in survey catch rates reflect declines in population abundance is unclear. Densities of roughhead grenadier are greatest along and beyond the offshore margin of the areas covered by these surveys. The decline in survey catch rates coincided with a shift in distribution to the deep strata along the offshore margin of the survey area. In the 1970s and 1980s, grenadier density declined to relatively low levels in the deepest waters sampled; in the 1990s and 2000s, density remained near peak levels in these deep waters. This strongly suggests that there has been a decline in availability of roughhead grenadiers to the survey, and that the declines in survey catch rates overestimate population declines.

The NAFO assessment focuses on recent population trends (since 1995). In addition to the Canadian surveys, it considers European surveys of the Flemish Cap and the southern Grand Bank, conducted since 1988 and 1997, respectively. The most recent NAFO assessment concluded that biomass in 2004 was the highest in the time series from 1995.

Minimum population estimates based on catches in the Canadian fall survey in recent years average 102 million for all sizes and 1.4 million for adult females. These are likely underestimates, since catchability is probably less than 100% and only part of the distribution is covered by the surveys.

Limiting factors and threats

M. berglax have been subject to commercial exploitation mostly as by-catch in the Greenland halibut fishery. Catches of roughhead grenadiers in this fishery increased between 1989 and 1990. Low fecundity, slow maturity, and long life limit the species' potential for recovery following a disturbance.

Special significance of the species

Macrourus berglax is the only species in the North Atlantic that belongs to this genus. There are only three other *Macrourus* species in the world; *M. carinatus*, *M. holotrachys*, and *M. whitsoni*, all from the southern hemisphere.

Existing protection or other status designations

The fishery for *M. berglax* is unregulated because it is mainly taken as incidental catch in fisheries targetting other species. The roughhead grenadier is not currently protected by any legislation or regulation and it has no status under any other species protection conventions.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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SPECIES INFORMATION

Name and classification

Macrourus berglax, Lacepede, 1801 is a member of the family Macrouridae (rattails), and is generally known as the roughhead grenadier. Synonyms are as follows: *Coryphaena rupestris* Fabricius, 1780; *Macrourus rupestris* Bloch, 1786; *Macrurus fabricii* Sundevall, 1842; *Macrourus holotrachys* Collett, 1896; *Coryphaenoides berglax* Collett, 1905. In Canada, it is commonly known as the roughhead grenadier, the onion eye, and smooth-spined rattail. The French refer to *M. berglax* as grenadier berglax and the Inuit, Ingminniset, meaning “it bellows when dying” (Leim & Scott 1966; Scott & Scott 1988; Cohen *et al*. 1973).

Description

The basic body and head shape of roughhead grenadiers are typical for the family Macrouridae (Bigelow & Schroeder 1953). They exhibit a large head and a moderately slender body, tapering uniformly to a pointed tail (Figure 1; Scott & Scott 1988).

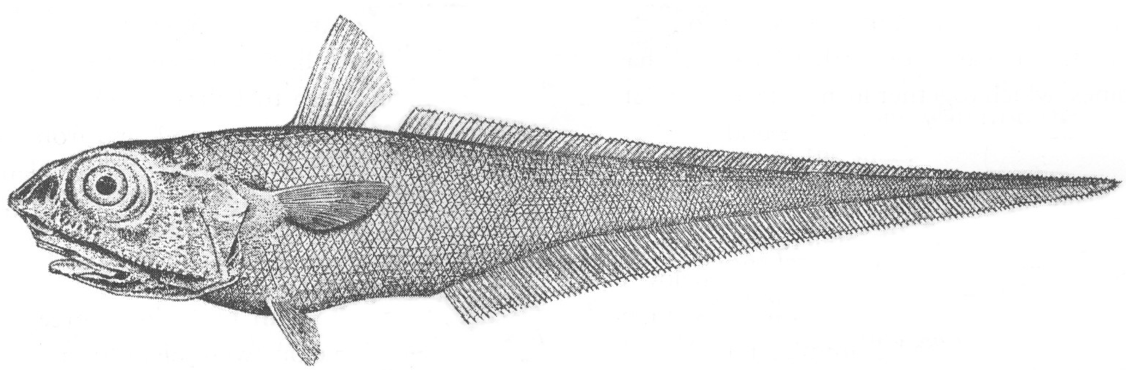

Figure 1. Illustration of *Macrourus berglax*. Drawn by H.L.Todd and reproduced from Collette and Klein-MacPhee (2002) with permission from the Division of Fishes, National Museum of Natural History, Smithsonian Institution.

The roughhead grenadier can grow up to 1 metre in length (Bigelow & Schroeder 1953; Collette & Klein-MacPhee 2002). The body is ash-grey in color with a darker chest, anal fin, and hind edges of the posterior scales (Scott & Scott 1988; Cohen *et al*. 1990). Their heads are broad and comprise approximately 25% of the total body length. A small chin barbel is present, gillrakers are reduced, and there are three to five irregular rows of pointed teeth in the upper jaw (Whitehead *et al*. 1986; Scott & Scott 1988; Cohen *et al.* 1990).

The roughhead grenadier’s distinguishing features also provide it with its common name. This fish has a fairly broad head exhibiting ridges with scute-like scales bearing strong spinules (Scott & Scott 1988). They can be distinguished from other grenadiers in the North Atlantic by a prominent and pointed snout that is equal to eye height and is almost or completely scaleless underneath (Whitehead *et al*. 1986).

Designatable units

Recent studies suggest some genetic differentiation in roughhead grenadier at large geographic scales in the North Atlantic, with grenadiers in West Greenland, East Greenland and the Norwegian Sea comprising separate stock units (Katsarou & Naevdal 2001). However, in the waters off Canada, roughhead grenadier show a continuous distribution along the slope of the continental shelf from the Davis Strait to the southern Grand Bank (D.W. Kulka, unpublished analyses). They are also distributed between the Grand Bank and Flemish Cap in the area called the Flemish Pass. In the absence of any information to suggest local adaptation and genetic differentiation within this range, the working hypothesis for this report is that roughhead grenadier comprise a single designatable unit (DU) in the waters off Atlantic Canada (including the Flemish Cap and other waters beyond the 200-mile limit).

DISTRIBUTION

Global range

The roughhead grenadier is found along the continental shelf and slope in temperate to arctic waters of the North Atlantic (Figure 2). In the western North Atlantic, they can be found from Davis Strait; off the Labrador and northeast Newfoundland Shelves; off the Grand Bank; off Nova Scotia on Banquereau, Sable Island, and Browns Banks; and on Georges Bank (Scott & Scott 1988). In the eastern North Atlantic, they can be found from the Irish Atlantic Slope and Faeroe Islands, Norwegian coast to Spitzbergen and into the Barents Sea (Cohen *et al*. 1990).

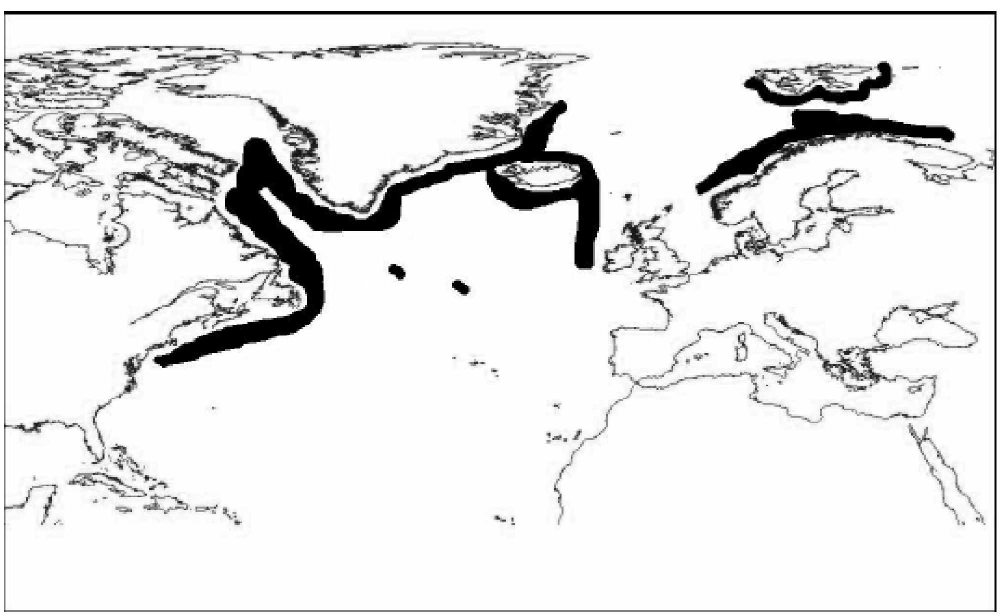

Figure 2. Global distribution of *Macrourus berglax* (Adapted from Cohen *et al*. 1990).

Canadian range

Macrourus berglax is distributed along the continental slope and deep shelf in the North Atlantic. They have been observed off Newfoundland and the Grand Bank to off Nova Scotia on the Banquereau, Sable Island, Browns Bank and Georges Bank (Figure 3).

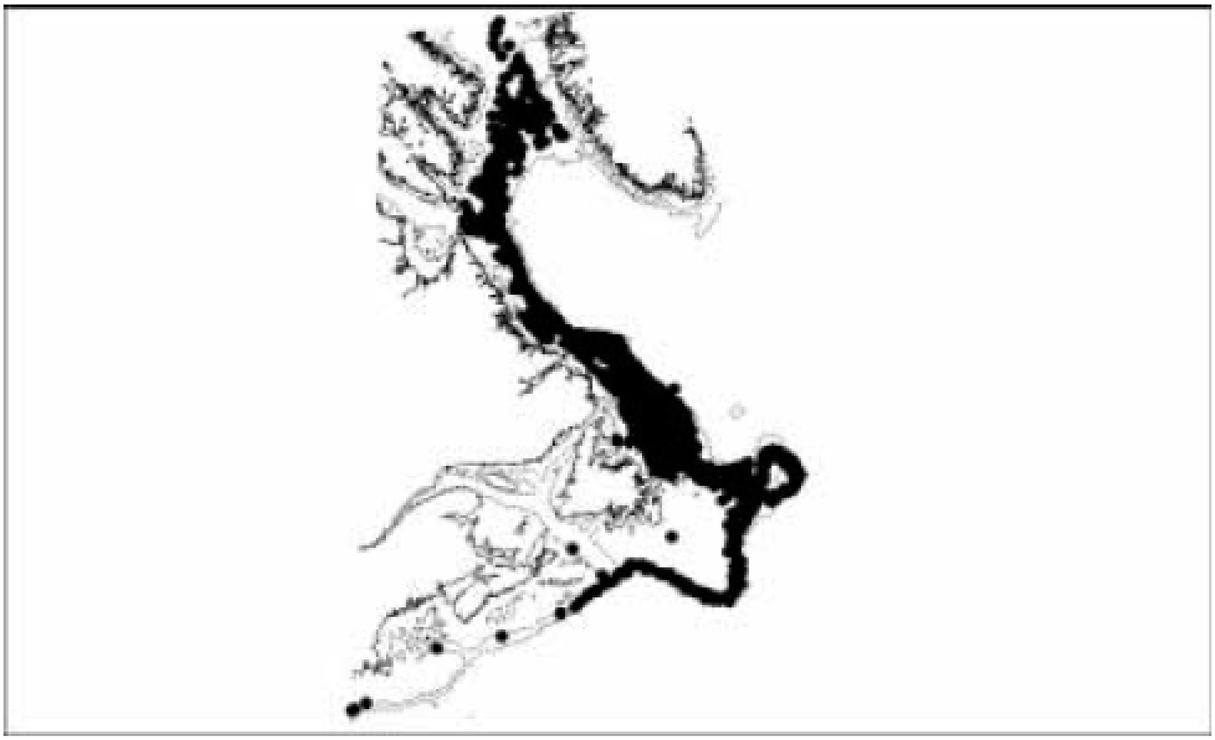

Figure 3. Canadian distribution of *Macrourus berglax,* derived from the ECNASAP database.

HABITAT

Habitat requirements

The roughhead grenadier is a benthopelagic species that can be found in the deep waters of the subarctic along the continental slope and on deep shelves. Murua *et al*. (2005) concluded that it is predominant in depths ranging from 400 to 1200 m, although they may inhabit depths between 200-2000 m (Snelgrove and Haedrich, 1985; de Cardenas *et al*., 1996). It has, however, been found in depths up to 2700 m (Wheeler, 1969). In the trawl surveys off Newfoundland, densities tend to be highest at depths of about 500 – 1500 m (see below). In recent years, Murua (2003) obtained the largest biomass index values between 1000 and 1200 m.

Protection/ownership

In 1977, under the Extension of Jurisdiction, Canada declared its jurisdiction over fishery resources out to 200 nautical miles. However, in the waters off Newfoundland and Labrador (Northwest Atlantic Fisheries Organization [NAFO] Divisions 2 and 3), the distribution of roughhead grenadier extends beyond the 200-mile limit. Thus, as a straddling stock, it is assessed and managed by NAFO (the Northwest Atlantic Fisheries Organization, the regional fisheries management organisation responsible for managing fisheries in international waters in the Northwest Atlantic).

BIOLOGY

General

M. berglax is a member of the family Macrouridae (grenadiers or rattails). This family of fishes is one of the most widespread families occurring on the continental slope of the North Atlantic and along the mid-Atlantic ridge. Roughhead grenadiers are slow-growing, late-maturing, and have a long life cycle (Scott & Scott 1988).

Reproduction

Age determination by scales and otoliths proves to be difficult in this species due to the very indistinct annuli but females have been aged up to 25 years (Cohen *et al.* 1990). This problem is common to many deep-sea fishes and is probably related to their generally low metabolic rates (Smith & Hessler 1974).

Like other members of the Macrouridae, the roughhead grenadier is slow-growing, late-maturing, and has a long life cycle (Scott & Scott 1988). At 7 to 9 years of age females begin to grow faster than males (Murua 2001), and this growth difference increases with age. Murua & Motos (2000) found female roughhead grenadiers in the Northwest Atlantic to mature at 66.7cm (L_{50}), which corresponds to approximately 13-14 years according to their length-age key. Eliassen & Falk-Petersen (1985) found females to mature at 15 years of age in the Northeast Atlantic using direct observations.

Generation time was estimated as female age at maturity plus 1/*M*, where *M* is the instantaneous rate of natural mortality. Based on catches in the Spanish 3NO survey, González Costas & Murua (2005) reported values of 0.34 for females and 0.71 for males for *Z*, the instantaneous rate of total mortality, rather high in light of current knowledge of life history and fishing pressure. These estimates of *Z* are based on catch curve analysis and will be overestimates if old fish are under-represented in the survey catch due to a tendency to be distributed in waters deeper than those surveyed. Assuming that *Z* is greater than *M* due to fishing mortality, a value of 0.2 was assumed for female *M*, yielding an estimate of 19 yr for generation time.

Savvitimsky & Gorchinsky (2001) found the number of females was close to 50% of the population before 9-10 years of age. At age 12 and older, only females were found. This is a result of females having a longer lifespan than males (Savvatimsky 1994; Murua 2000). The commercial catch at present usually includes ages between 5 and 10, with a peak at 6 years of age (Savvitimsky & Gorchinsky 2001; Junquera *et al*. 2001).

M. berglax is a sexually dimorphic species; females grow larger and as discussed above live longer than males. The males also have two large, intrinsic, drumming muscles on the forward part of their swim bladder (Cohen *et al*. 1973).

M. berglax spawning occurs in winter and early spring and may even extend over an entire year (Eliassen & Falk-Peterson 1985; Scott & Scott 1988; Murua & Motos 2000). One female is estimated to produce 25,000 large eggs, which are laid over a lengthy spawning period and represent a relatively low fecundity for fish of this type (Cohen *et al*. 1973). Whether the species is itero- or semelparous is unknown. Roughhead grenadier eggs are reported to be pelagic and have a hexagonal pattern membrane (Eliassen & Falk-Peterson 1985). The exact locations of spawning grounds are not certain but they are thought to lie on the southern and southeastern slopes of the Grand Bank (Scott & Scott 1988).

Survival

Zaferman (1992) directly observed grenadiers with a submersible on the North Atlantic Ridge and found their movements directly related to the velocity and orientation of the current. Although the observations were not made on roughhead grenadier, it is generally agreed that they are very slow-moving creatures making them easy potential prey for larger predatory fishes inhabiting the same area. They have been found in the stomach contents of cod and other predatory fish.

Other important sources of mortality are anthropogenic. Roughhead grenadiers are one of two grenadiers to be commercially exploited in the western North Atlantic and they are a significant component of the by-catch in the Greenland halibut fishery (Duran *et al*. 1997).

Physiology

The roughhead grenadier is generally found in water temperatures between 2.0 and 5.4 ºC but specimens have been retrieved from temperatures slightly below 0 ºC in the Norwegian and Barents seas (Scott & Scott 1988; Cohen *et al*.1990; Murua & Motos 2000).

Rattails, like some other deep-sea fish, are known to have specialized swim bladders that function at great depths, and therefore great pressures, in the ocean. The wall of the swim bladder is impermeable to gases. The presence of certain lipids resists the outward diffusion of oxygen (Wittenberg *et al*. 1980).

Movements/dispersal

Katsarou & Naevdal (2001) found evidence that roughhead grenadier in the North Atlantic do not comprise a single panmictic stock. Instead, there appear to be at least three stock units (West Greenland, East Greenland and Norwegian Sea) each with their own gene pools. An implication of this study is that Canadian populations may be distinct from other populations in the North Atlantic. However, the estimated genetic distances between stock units were low and Katsarou & Naevdal (2001) concluded that the evolutionary significance of these genetic differences is uncertain and possibly low.

Nutrition and interspecific interactions

Roughhead grenadiers are known as non-specialist predators and feed on a wide variety of invertebrates (Cohen *et al*. 1973; Cohen *et al*. 1990). The food type consumed by this species is usually directly dependent on the size of the individual fish. Smaller fish feed on small bivalves, starfish, shrimps and polychaetes, which are essentially benthic prey. Larger individuals tend to eat active benthopelagic organisms such as larger bivalves, shrimp, small fish, and squid (Eliassen & Jobling 1985; Scott & Scott 1988). Eliassen & Jobling (1985) found that crustaceans are the most widely consumed prey organisms but fish may make up a considerable portion by weight in the diet of mature females during the summer months in Norwegian waters.

Behaviour/adaptability

The combination of low fecundity, slow growth rates, late maturity, and long population turnover times makes these fish highly vulnerable to population disturbance. Therefore, they are presumed to have low adaptability to sudden change.

POPULATION SIZES AND TRENDS

Data and methods

Data are from 1) stratified-random bottom trawl surveys conducted annually by the Canadian Department of Fisheries and Oceans, 2) the Spanish survey in NAFO Divisions 3NO (Figure 4) and 3) the EU survey of the Flemish Cap, NAFO Division 3M (Figure 4). Analyses of the Canadian data are restricted to surveys of the Grand Bank and the Labrador and NE Newfoundland Shelves. Although reported from areas as far south as Georges Bank and the Gulf of Maine, roughhead grenadier are rarely captured in surveys of areas south of the Grand Bank. This may reflect the relatively shallow depths (mostly < 400 m) sampled by these surveys. For example, a July survey of the Scotian Shelf and Bay of Fundy has been conducted annually since 1970. Additional deepwater strata (200-400 fathoms) were added to this survey in 1995. Only three specimens have been captured in the strata sampled since 1970 (one in each of 1995, 1998 and 2002) whereas over 50 individuals were captured in the deepwater strata between 1997 and 2002.

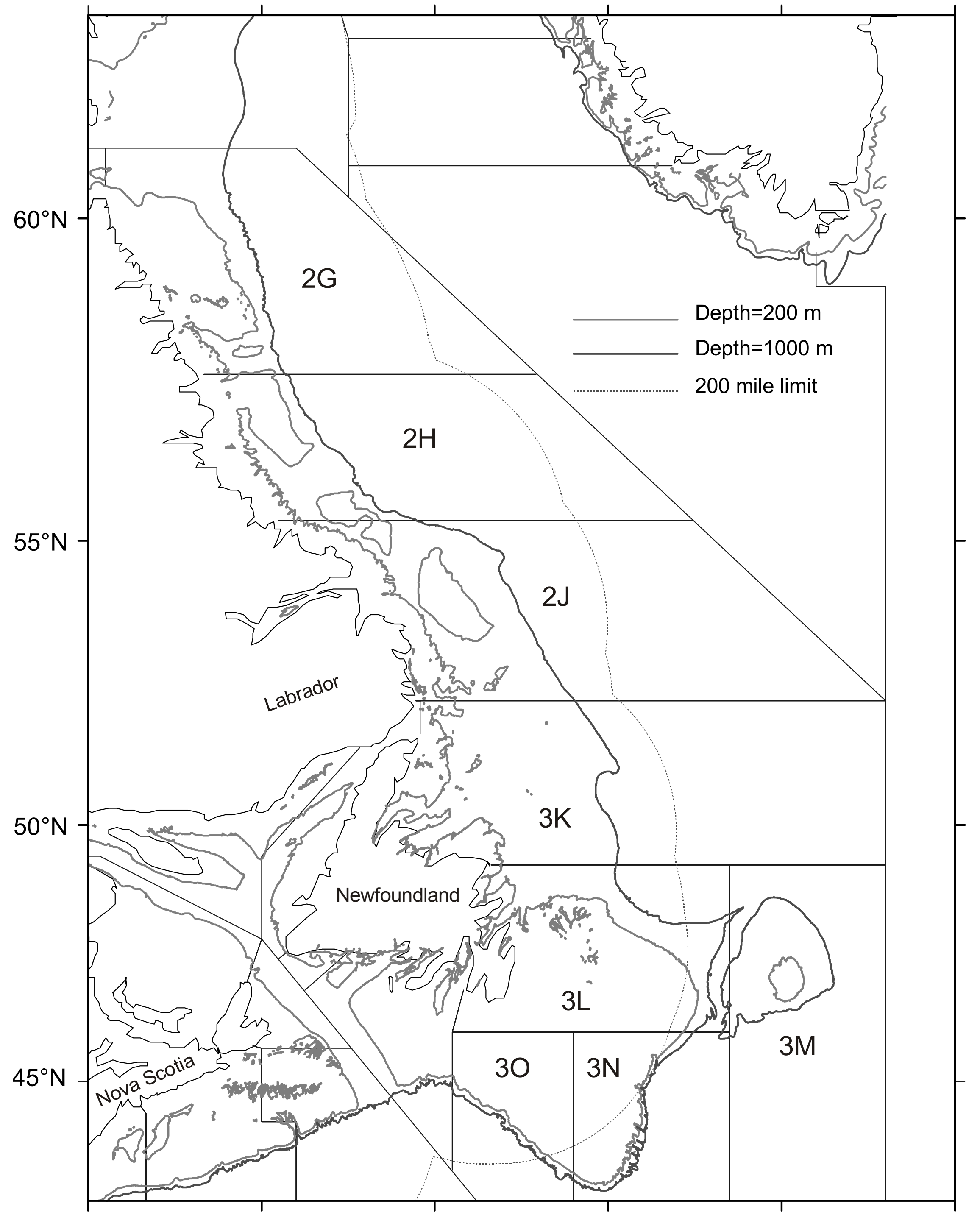

Figure 4. Northwest Atlantic Fisheries Organization (NAFO) divisions referred to in this report.

Canadian Surveys

Two surveys are considered here: a spring (April – June) survey of the Grand Bank (NAFO Divisions 3LNO, Fig. 4) and a fall (mostly October – December) survey of the Labrador and NE Newfoundland Shelves (NAFO Divisions 2J3K). The fall survey was extended to include the northern Grand Bank (3L) in 1981 and the southern Grand Bank (3NO) in 1990. It also occasionally covered the Flemish Cap (3M) and northern areas off Labrador (2GH). Stratum coverage within each division has been variable from year to year. Additional deepwater strata were added to the surveys in the mid-1990s.

Survey catch rates provide an index of trends in abundance if catchability to the survey gear and the proportion of the population available to the survey do not change from year to year. The gear used in the fall Newfoundland surveys changed from an Engels trawl to a Campelen trawl in 1995. The spring Newfoundland surveys used a Yankee 41.5 trawl from 1971 to 1982, the Engels trawl from 1985 to 1995, and the Campelen trawl since 1996. A change in survey vessel also occurred in the fall survey in 1995 and in the spring survey in 1985. No estimates of relative fishing efficiency between these trawls and vessels are available for grenadiers. Thus, the Yankee, Engels and Campelen surveys are treated here as separate time series.

Indices for consistently sampled subsets of strata were constructed in order to reduce the likelihood that the proportion of the population covered by the survey varied from year to year (and to avoid other biases that result from changes in the area surveyed). Three indices were calculated using the fall data: 1) 2J3K, starting in 1978; 2) 2J3KL, starting in 1981; and 3) 2J3KLNO including the new deep strata, starting in 1996. Two indices were calculated using the spring data: 1) an index starting in 1971 but restricted to shallow strata with depths mostly less than 350 m; 2) an index starting in 1996 but including depths down to about 700 m. Indices were calculated up to 2002, 2003 or 2005, depending on data availability. Details are given in Appendix A. Note that the fall index covers a much greater portion of the roughhead grenadier distribution, including strata in the 750-1000 m range even in the early years.

Roughhead grenadier occur in relatively deep waters, along and beyond the offshore margin of the area covered by these surveys. Thus, shifts in the distribution of these grenadiers may result in changes in availability to the surveys, so that changes in catch rates in the surveys may not accurately reflect changes in population abundance. To investigate this possibility, interannual variation in geographic distribution and bathymetric pattern was examined for the fall surveys. Grenadier density as a function of depth was examined using Generalized Additive Models (see Swain & Benoît 2006 for details on the methods). The proportion of fish occurring in the deepwater (751-1000 m) strata was also calculated for each year.

Adult catch rate indices were also calculated for the fall survey. These consisted of catch rates of fish with a pre-anal fin length (AFL) over 275 mm. This corresponds approximately to the length at maturity for females. Males mature at a considerably smaller size and few males reach an AFL of 275 mm. Only 1% of the fish over 275 mm AFL were males. Thus, these indices reflect catch rates of adult females.

To assess rates of change, $\log_e$ of the stratified mean catch rate was regressed against year. Percent change was calculated as $100 \cdot (1-e^{-b\Delta t})$, where b is the regression slope and Δt the change in time (years). In two cases, the stratified mean catch rate was 0. In these cases, zeros were replaced by half the minimum non-zero mean catch rate before calculating the $\log_e$ catch rate.

European Surveys

Biomass indices for the Spanish 3NO survey and the EU Flemish Cap (3M) survey are taken with permission from González Costas & Murua (2005). These indices are corrected for vessel and gear changes as described by González Costas & Murua (2005). The 3NO survey fishes waters down to 1500 m whereas the 3M survey is restricted to depths <720 m. The 3M and 3NO surveys have been conducted annually since 1988 and 1995, respectively. However, the 1995 and 1996 3NO surveys are not considered representative because the deeper strata were not surveyed, and they have been omitted from analyses presented here.

Trends in survey catch rates

Canadian Fall Surveys

Catch rates in the fall survey declined sharply from 1978 to 1994 in the 2J3K area (Fig. 5a). The linear trend in $\log_e$ catch rates over this time period was highly significant (R^2=0.84, P<0.0001, Fig. 5b), and corresponded to an 88% decline over 16 yr. Catch rates after 1994 are not directly comparable to the earlier catch rates because of the change in gear in 1995. Catch rates were stable or slightly increasing over the 1995 – 2005 period. The linear trend in $\log_e$ catch rates was positive but non-significant (R^2=0.19, P=0.18, Fig. 5b).

Similar trends are evident in the 2J3KL indices (Fig. 5c,d). Catch rates declined sharply over the 1981 – 1994 period, corresponding to a 92% decline in 13 yr. Catch rates were stable after 1994, with a positive but non-significant trend in $\log_e$ catch rates over the 1995 – 2003 period.

Catch rates were substantially (about 1.7 times) higher in the index expanded to include the deep strata added in 1996 (Fig. 5c), reflecting the relatively high densities of grenadier in these deep strata. This index has been roughly stable since 1996, with no significant trend in $\log_e$ catch rates (Fig. 5d).

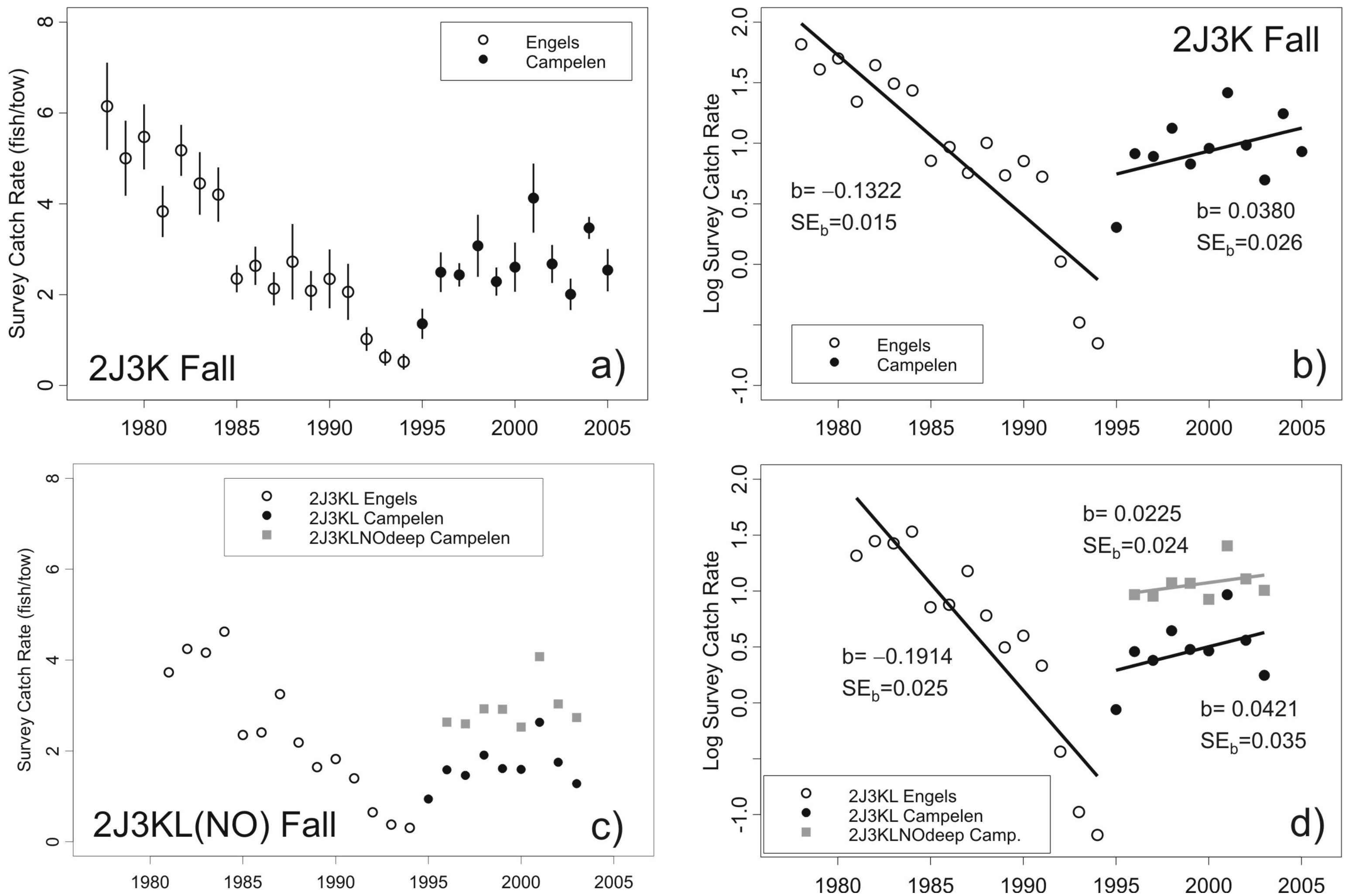

Figure 5. Stratified mean catch rates of roughhead grenadier (all sizes) in fall surveys of the Labrador and NE Newfoundland Shelves and the Grand Bank. Regression lines are shown for $\log_e$ catch rate versus year in panels **b)** and **d)**, along with their slope *b* and its standard error. Vertical lines in panel **a)** are ±2SE. Different symbols denote different areas and/or gears.

Canadian Spring Surveys

Catch rates in the spring survey are much lower than those in the fall survey (Fig. 6), reflecting the lack of coverage of deep waters in the spring survey. Catch rates in the spring survey were stable over the 1971 – 1982 period, declined sharply over the 1985 – 1995 period, and have been stable or increasing since 1996. The decline in the 1985 – 1995 period was highly significant (R^2=0.85, P<0.0001) and corresponded to a 99% decline over 10 yr. However, most of the decline appeared to occur between 1989 and 1992.

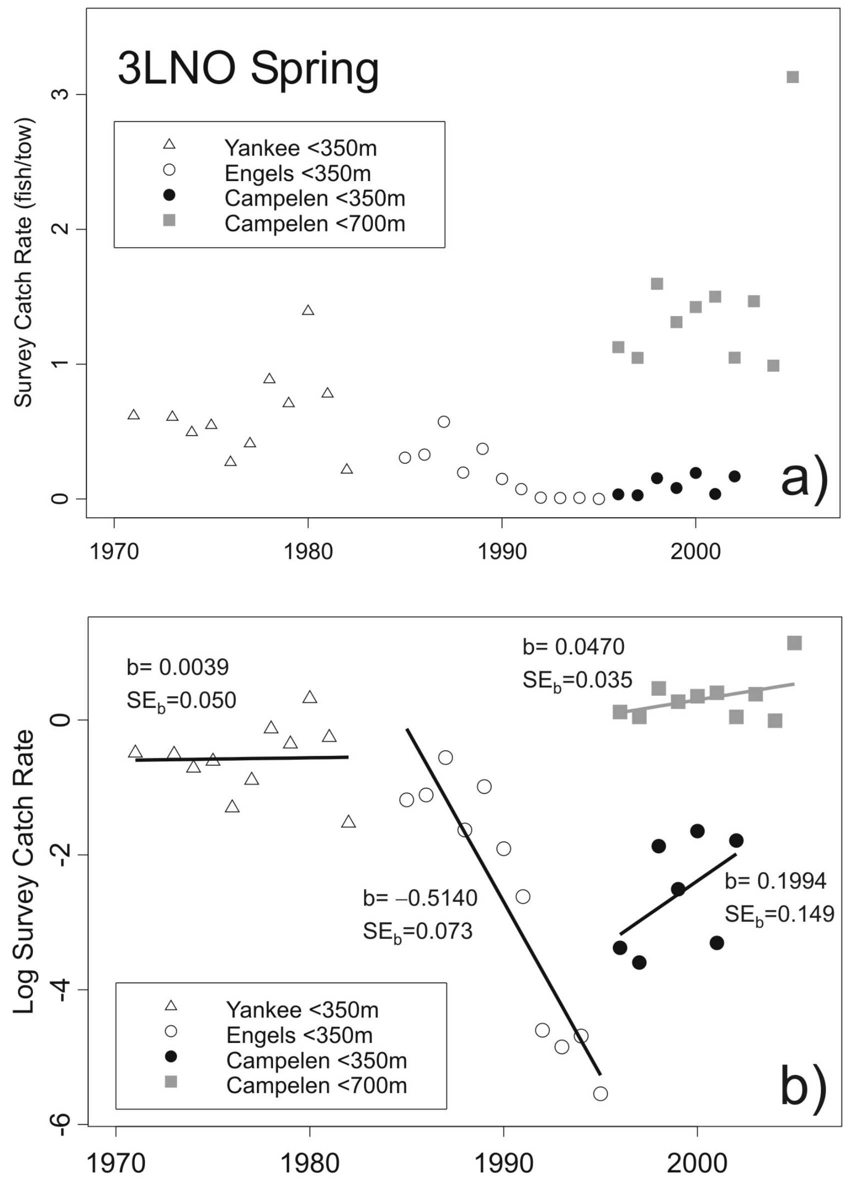

Figure 6. Stratified mean catch rates of roughhead grenadier (all sizes) in spring surveys of the Grand Bank. Regression lines are shown for $\log_e$ catch rate versus year in panel **b)**. Different symbols denote different areas and/or gears.

Mean catch rates in the shallow strata sampled since 1971 have been very low since the early 1990s. However, mean catch rates are more than an order of magnitude greater including the deeper strata sampled since 1996.

Adult Catch Rates

The roughhead grenadier caught during the surveys are almost entirely juveniles (Fig. 7). Sizes corresponding to mature females comprise less than 3% of the grenadier caught.

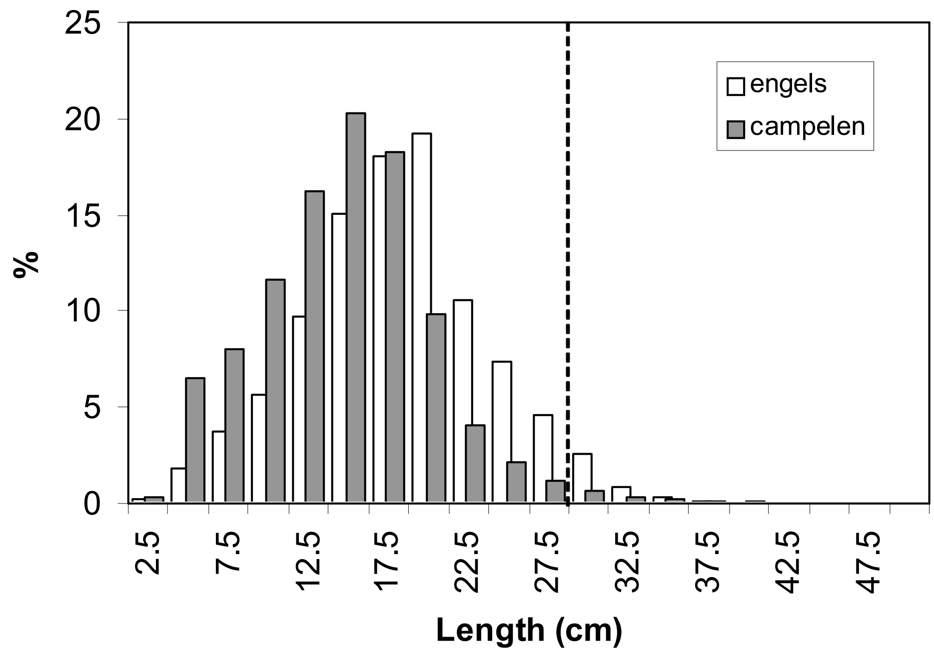

Figure 7. Length distribution of roughhead grenadier catches in the fall surveys of the Labrador and NE Newfoundland Shelves and the Grand Bank. Lengths are pre-anal fin length (AFL). Distributions are shown separately for the Engels trawl used prior to 1994 and for the Campelen trawl used since 1995. The dashed line denotes the approximate length at maturity for females.

Adult catch rates declined sharply in the fall survey of 2J3K between 1978 and 1994 (Fig. 8a). The linear regression of $\log_e$ catch rates versus time was highly significant over this period (R^2=0.66, P<0.0001, Fig. 8b), and corresponded to a 95% decline over 16 yr. Adult catch rates in 2J3K also tended to decline between 1995 and 2003, but the decline was not significant (R^2=0.34, P=0.1).

Similar patterns are evident extending the analysis to include 3L. The decline in catch rate was highly significant over the 1981 – 1994 period (96% decline over 13 yr.) but was non-significant over the 1995 – 2003 period (Fig. 8c,d). Adult catch rates were substantially higher extending the analysis to include the deepwater strata sampled since 1996. Catch rates were stable over the 1996 – 2003 period when these deepwater strata are included in the analysis (Fig. 8d).

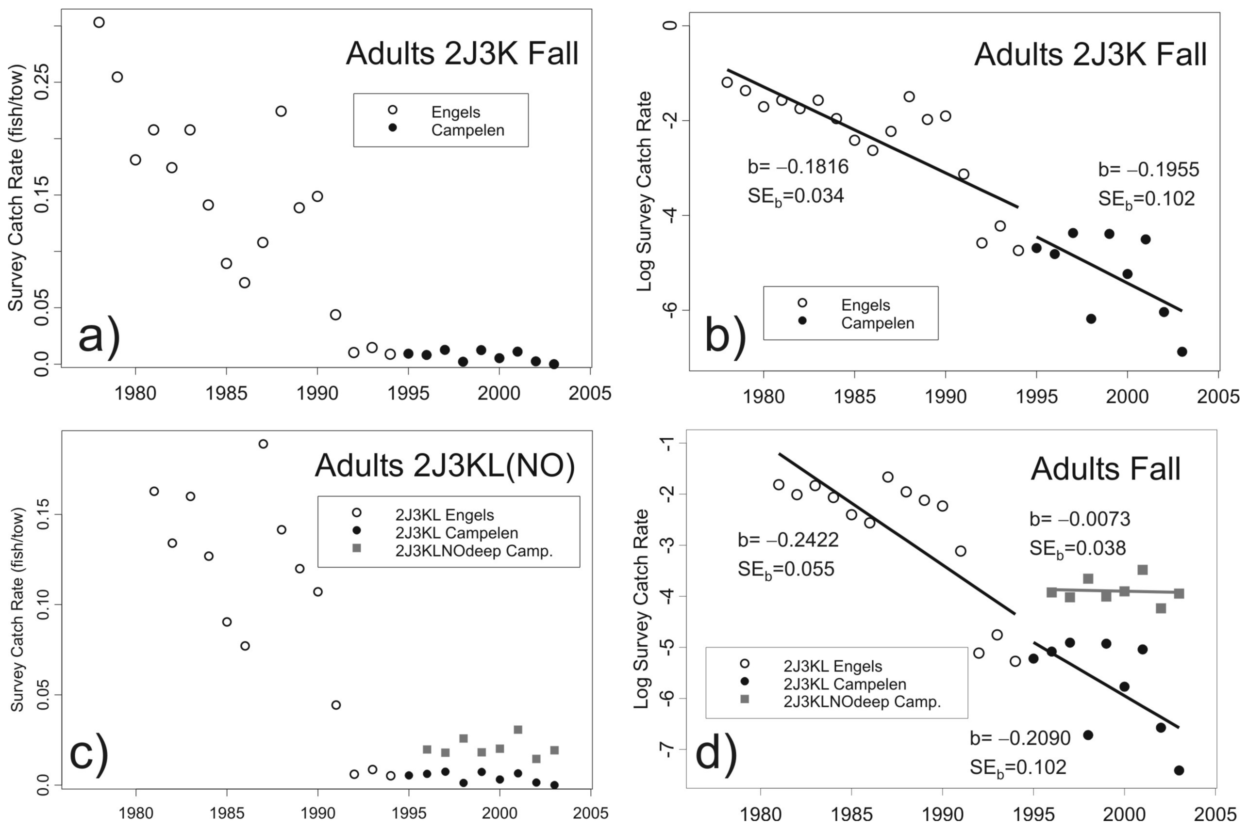

Figure 8. Stratified mean catch rates of adult female roughhead grenadier in fall surveys of the Labrador and NE Newfoundland Shelves and the Grand Bank. Regression lines are shown for $\log_e$ catch rate versus year in panels **b)** and **d)**, along with their slope b and its standard error. Different symbols denote different areas and/or gears.

<u>European Surveys</u>

Biomass in the Flemish Cap survey varied without a long-term trend over the 1988-2004 period, with highest biomasses in 2004 and 1993 (Fig. 9a). Biomass in this survey has increased in recent years. The linear regression of $\log_e$ biomass versus time was positive but non-significant for this survey (R^2=0.12, P=0.18, Fig. 9b).

Biomass in the Spanish 3NO survey tended to increase over the 1997-2004 period (Fig. 9c). The linear regression of $\log_e$ biomass in this survey versus time was positive over this brief period, approaching statistical significance (R^2=0.47, P=0.06, Fig. 9d).

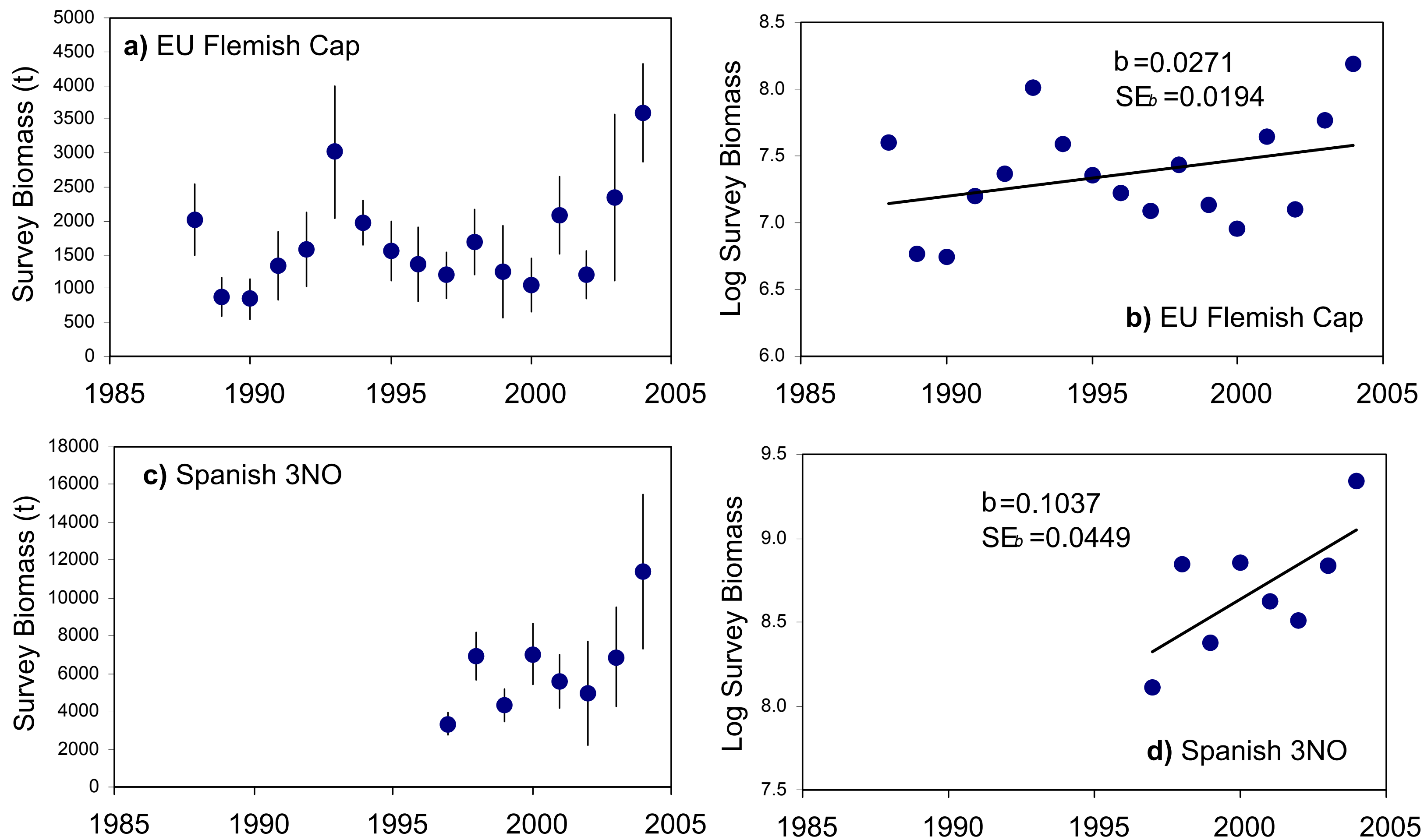

Figure 9. Biomass of roughhead grenadier in European surveys of the 3NO and Flemish Cap (3M) areas. Regression lines are shown for $\log_e$ biomass versus year in panels **b)** and **d)**, along with their slope b and its standard error. Vertical lines in panels **a)** and **c)** are ±2SD. Data are from González & Murua (2005).

Changes in distribution

In the late 1970s and early 1980s, roughhead grenadier were widely distributed over the Labrador and NE Newfoundland Shelves during the fall survey (Fig. 10). By the early 1990s, these fish were largely restricted to the offshore margin of the shelf. This restricted distribution along the offshore margin of the survey area persisted throughout the remainder of the 1990s and the early 2000s (Fig. 11).

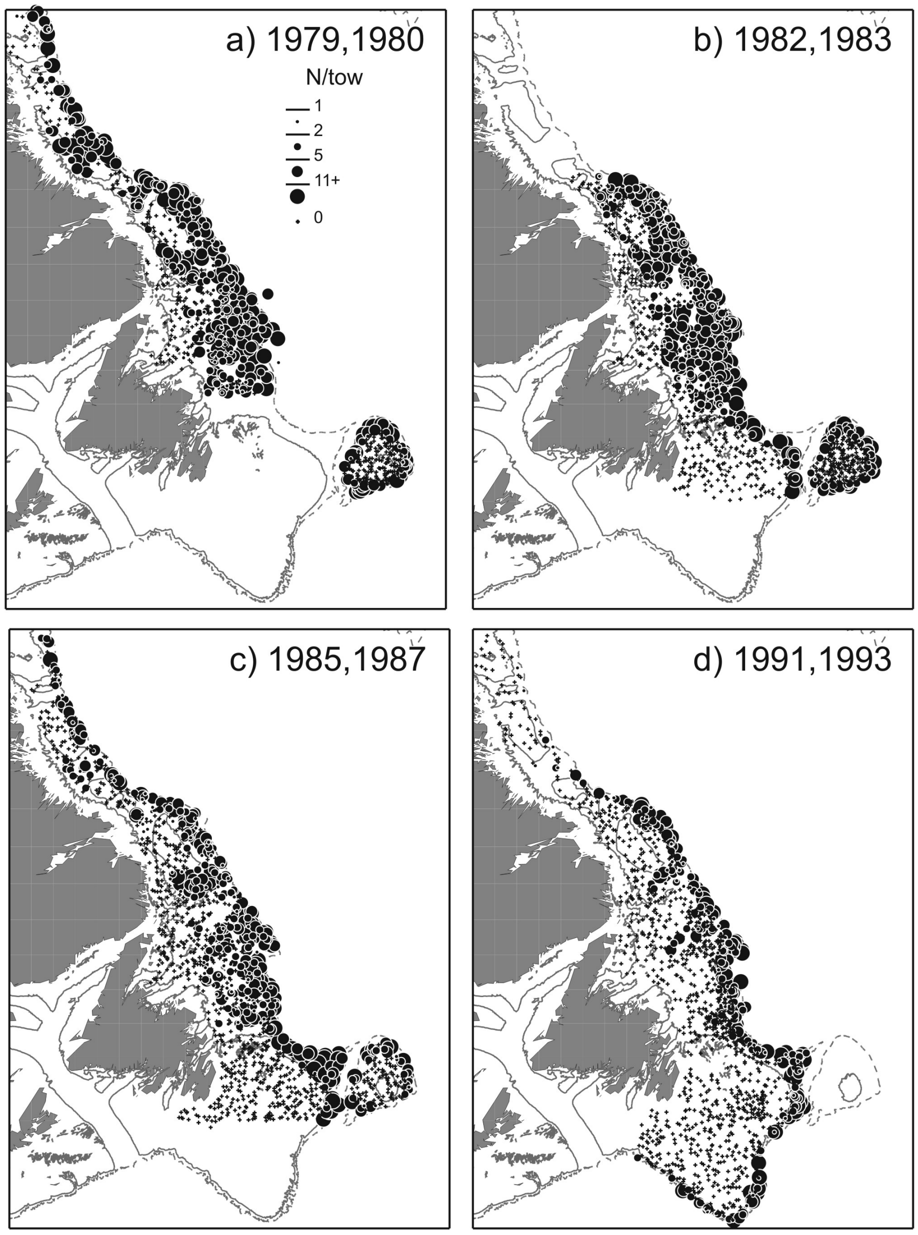

Figure 10. Geographic distribution of roughhead grenadier catches in the fall survey of the Labrador and NE Newfoundland Shelves and the Grand Bank for selected years between 1978 and 1994 (Engels surveys). Circle size is proportional to catch. Cutpoints are the 10th, 25th, 50th, and 75th percentiles of the non-zero catches. Crosses indicate zero catches. The 200 and 1000 m depth contours are denoted by solid and dashed lines, respectively.

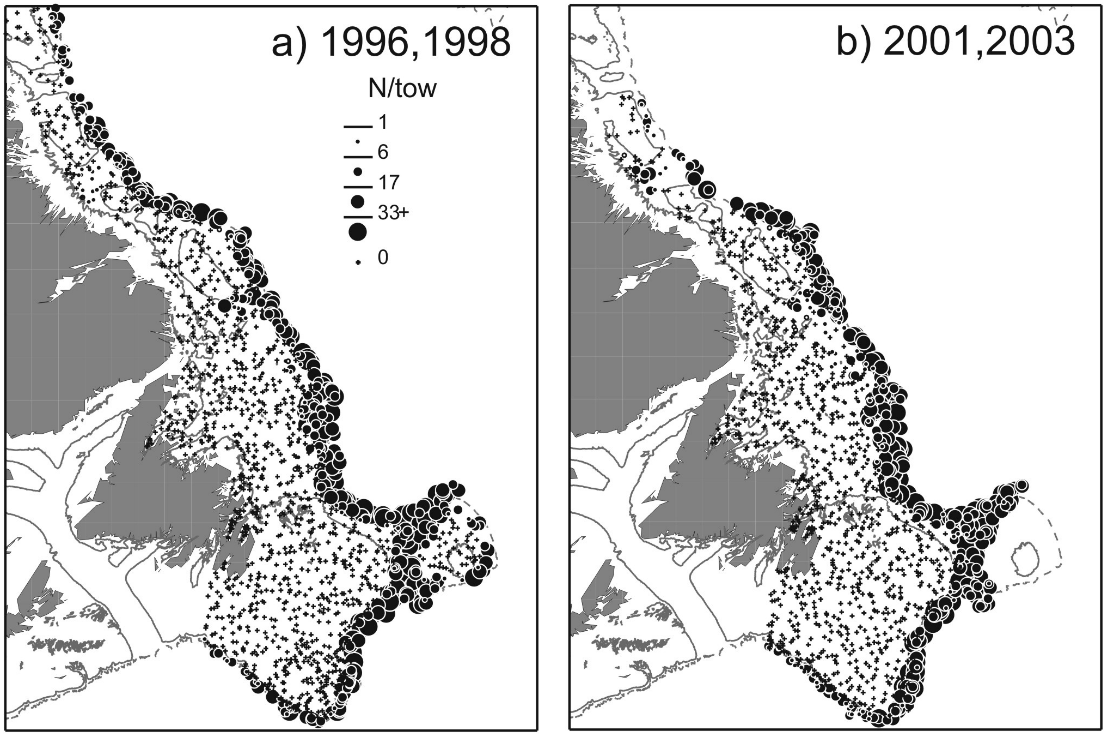

Figure 11. Geographic distribution of roughhead grenadier catches in the fall survey of the Labrador and NE Newfoundland Shelves and the Grand Bank for selected years between 1995 and 2000 (Campelen surveys). See Figure 10 caption for further details.

Figure 12 shows the proportion of the 2J3K survey catch occurring in the deep strata (751-1000 m) consistently sampled since 1978. The shift in distribution into deep waters along the offshore margin of the survey area is reflected in changes in this proportion. A small proportion (about 10%) of the survey catch occurred in these deepwater strata from the late 1970s to the mid-1980s. This proportion began to increase in the late1980s, reaching 50-60% by the mid-1990s.

Changes in the distribution of roughhead grenadier with respect to depth are described further in Figure 13. The analyses presented in this figure are based on all available tows (Fig. 10-11), not just the subsets used to construct the standardized catch-rate indices presented above. Grenadier density was strongly related to depth in all years. In the 1978 – 1983 period, peak densities occurred at depths of about 750 m, with density decreasing substantially at greater depths. In the 1984 – 1989 period, peak densities occurred at slightly shallower depths (600 – 700 m), but density again decreased at greater depths. In later periods, densities dropped sharply to levels near 0 in waters shallower than 500 m. In contrast, densities declined little following peaks at 700 – 1000 m, and remained at high values in the deepest waters sampled.

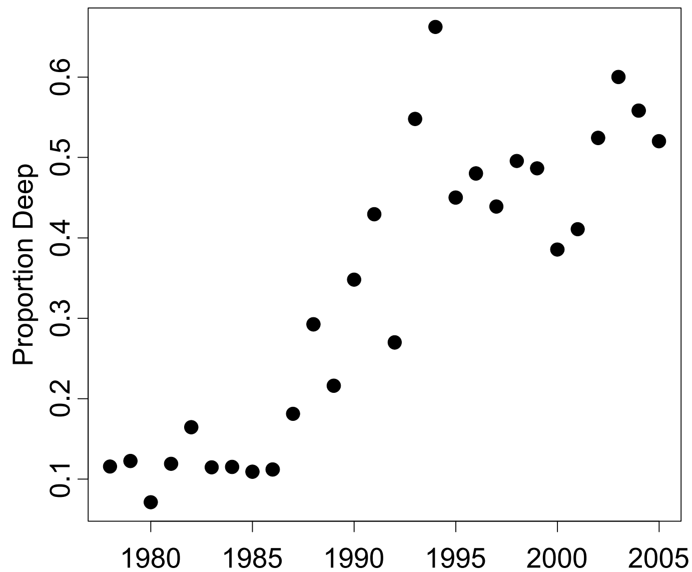

Figure 12. Proportion of roughhead grenadier caught in deep strata (751-1000 m) during the fall surveys of 2J3K.

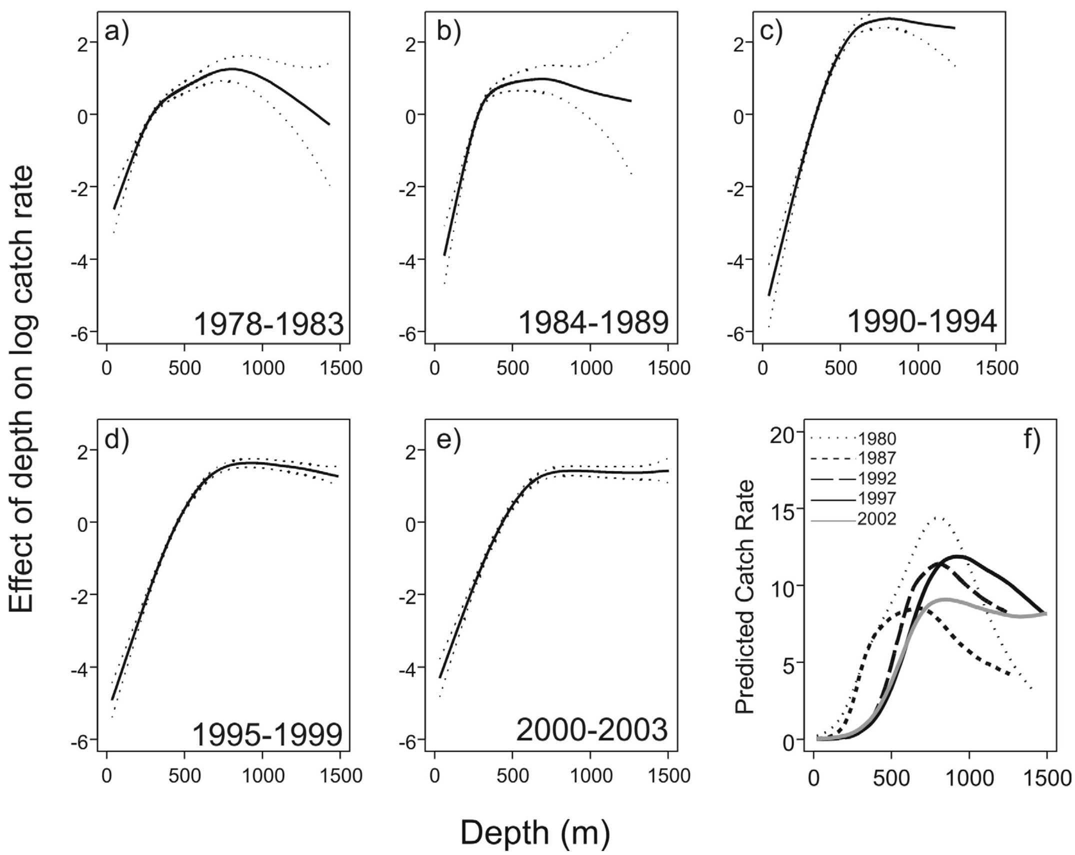

Figure 13. Effect of depth on the local density of roughhead grenadiers in fall surveys off Newfoundland and Labrador. Panels a) - d): effect of depth (on a $\log_e$ scale) on grenadier density in 5 time periods. Solid line shows the predicted relationship, and the dotted lines are ±2SE. Note that models included an effect of year not shown in these panels. Panel f): predicted density for a selected year in each decade. Campelen catch rates adjusted to be similar to Engels catch rates.

Coverage in the fall survey was extended into deeper waters in 1995. Maximum depths sampled were under 1275 m in the 1984 – 1994 period and over 1475 m in the 1995 – 2003 period (but 1432 m in the 1978 – 1983 period). The 95th percentile of sampled depths was about 600 m in the three periods before 1995 and 1200 m in the two later periods. However, the changes described in Figure 13 do not just reflect this change in depths sampled. The change was evident in the 1990 – 1994 period, preceding the extension of the survey into deeper waters.

Population size

A minimum estimate of population size can be obtained by expanding the mean survey catch per tow to the survey area (i.e., by multiplying by the survey area divided by the area swept by a standard tow). This estimate is an underestimate because 1) catchability to the survey gear is likely substantially less than 100%, and 2) a substantial portion of the roughhead grenadier population likely occurs outside of the area surveyed. Minimum estimates based on the fall survey of NAFO Divisions 2GHJ3KLMNO averaged 101.91 million for the 1996 – 2005 period (D. Power, DFO St. John's, pers. comm.). This estimate was obtained by calculating the average survey abundance within each division over all years sampled in 1996-2005 and then summing over divisions. About 1.4% of the roughhead grenadiers caught by the Campelen trawl during these surveys correspond to adult females, based on their size. This yields a minimum estimate of about 1.43 million adult females in the area covered by this survey in recent years.

A deepwater longline survey was conducted in the 3LMN area in April – May 1996 between depths of 700 and 3000 m (Murua and de Cárdenas 2005). Roughhead grenadier were the most common species caught in this survey, comprising 34% of the catch by weight (compared to 5% for Greenland halibut). At depths below 1150 m, roughhead grenadier was the predominant species in the catch (>90% by weight).

Summary of population trends

Catch rates of roughhead grenadier in the bottom-trawl surveys of the Grand Bank and Newfoundland Shelf were roughly stable in the 1970s, declined precipitously in the 1980s, and have been generally stable since the early to mid-1990s, though some surveys have shown increases in catch rates in recent years. The declines in the 1980s amounted to 90 – 95% declines over 10 – 15 yr. (less than one generation). Declines in adult females in the surveys were 95-96% over 13 - 15 yr, although the surveys take a very low proportion of adult females.

The extent to which these declines in survey catch rates reflect declines in population abundance is unclear. Densities of roughhead grenadier are greatest along and beyond the offshore margin of the areas covered by these surveys. The surveys used here do not cover all of the latitudinal range of roughhead grenadier in the northwest Atlantic. Thus, catch rates of this species are likely to be affected by changes in availability to these surveys.

The decline in survey catch rates coincided with a shift in distribution to the deep strata along the offshore margin of the survey area (R^2=0.70, P<0.0001). Many other species showed similar offshore shifts in distribution at about the same time (e.g., Gomes *et al*. 1995). The strong cooling of shelf waters in the 1980s has been implicated as a cause of these changes in distribution (e.g., Rose *et al*. 1994, Gomes *et al*. 1995), though density-dependence (Atkinson *et al*. 1997) or local depletion by fisheries (e.g., Hutchings 1996) could also be involved.

Distribution of roughhead grenadier failed to shift back into shallower waters when these waters warmed in the late 1990s. Other Northwest Atlantic fishes have shown similar patterns of distribution change. For example, thorny skate in the southern Gulf of St. Lawrence shifted into warm deep waters coincident with the cooling of the Magdalen Shallows in the early 1990s but failed to move back into shallower water when the Shallows warmed in recent years (Swain & Benoît 2006). One possibility is that fish distribution shows a high degree of 'conservatism' (cf. Corten 2002), with distribution changing quickly in response to an environmental stimulus but slow to return to its original pattern once the stimulus has been removed.

While local depletion by fisheries may contribute to the apparent shift in distribution, no known increases in grenadier catch coincided with these declines, and trawl fishing activity has tended to be greatest along the shelf edge (Kulka and Pitcher 2001) where grenadier density has not been depleted. Furthermore, the decline in grenadier density in shallower waters coincides with increases in density in deep waters (Fig. 13). This confirms that the change in distribution does not just reflect local depletion but must at least partly involve a true shift in distribution of individual grenadiers. In the 1970s and 1980s, grenadier density declined to relatively low levels in the deepest waters sampled; in the 1990s and 2000s, density remained near peak levels in these deep waters. This strongly suggests that there has been a decline in availability of roughhead grenadiers to the survey, and that the declines in survey catch rates overestimate population declines. However, the extent of this overestimation cannot be determined.

Summary of NAFO assessment

The most recent NAFO assessment (González-Costas and Murua 2005) focuses on recent trends (1990s and 2000s). They consider the Canadian fall 2J3K survey and the Spanish 3NO survey to be the most reliable surveys for monitoring population trends due to their coverage of deep waters. Their biomass indices from these surveys, starting in 1995 and 1997 respectively, both show increasing trends reaching maximum levels in 2004, the last year reported. The biomass increase is substantial (three- or fourfold from 1997 or 1995 to 2004 based on the point estimates). Fishery catch divided by survey biomass (an index of exploitation rate) declines substantially over the same period. Catches of 3-year-old fish in the 2004 EU Flemish Cap and Spanish 3NO surveys suggest that the 2001 year-class is strong. The assessment concluded that stock biomass "is the highest in the time series from 1995" but noted that "immature fish constituted 92% of the catch in weight in 2004" (NAFO 2005).

AREA OCCUPIED

The area occupied by roughhead grenadier was estimated based on catches in the Canadian fall survey of NAFO Divisions 2GHJ3KLMNO. The method is outlined in Appendix B. Because this survey does not cover all grounds inhabited by this species in the waters off Atlantic and Arctic Canada, the values reported here will be underestimates.

Estimates are based on the surveys in 1996-1999, a period with wide survey coverage in the 2GHJ3KLMNO area. The area covered by these surveys varied by about 10% from year to year (Table 1) and no attempt was made to adjust for this variation. The area occupied by roughhead grenadier within the survey area varied between 119,500 and 129,100 km^2 (Table 1).

The analysis was repeated for adult females. All fish longer than 275 mm AFL were assumed to be adult females. The area covered by this analysis was reduced by about 15% due to the omission of tows with no length frequencies. The estimated area occupied by adult females was 13,300 – 21,550 km^2 (Table 1).

Table 1. Area occupied (1000s km^2) by roughhead grenadier (all sizes or adult female sizes) in the fall survey of NAFO Divisions 2GHJ3KLMNO in selected years with broad survey coverage.

	All sizes		Adult females	
Year	**Surveyed**	**Occupied**	**Surveyed**	**Occupied**
1996	634.4	129.1	495.0	13.8
1997	562.8	119.5	496.2	13.3
1998	594.0	124.1	504.2	21.6
1999	572.1	121.1	474.5	15.7

In order to examine trends in area occupied, an analysis was conducted using a subset of “index” strata that were sampled in most years in the fall survey of areas 2J and 3K. Strata selection and summary data for these strata were kindly provided by M. Koen-Alonso and F. Mowbray (DFO St. John’s, pers. comm.). The area covered by this set of index strata varied little from year to year except for an increase in area in 1996 associated with the addition of deepwater (>1000 m) strata to the survey (Fig. 14). Area occupied within this subset of strata declined steadily throughout the1980s and early 1990s but has been roughly stable since 1995 (Fig. 14).

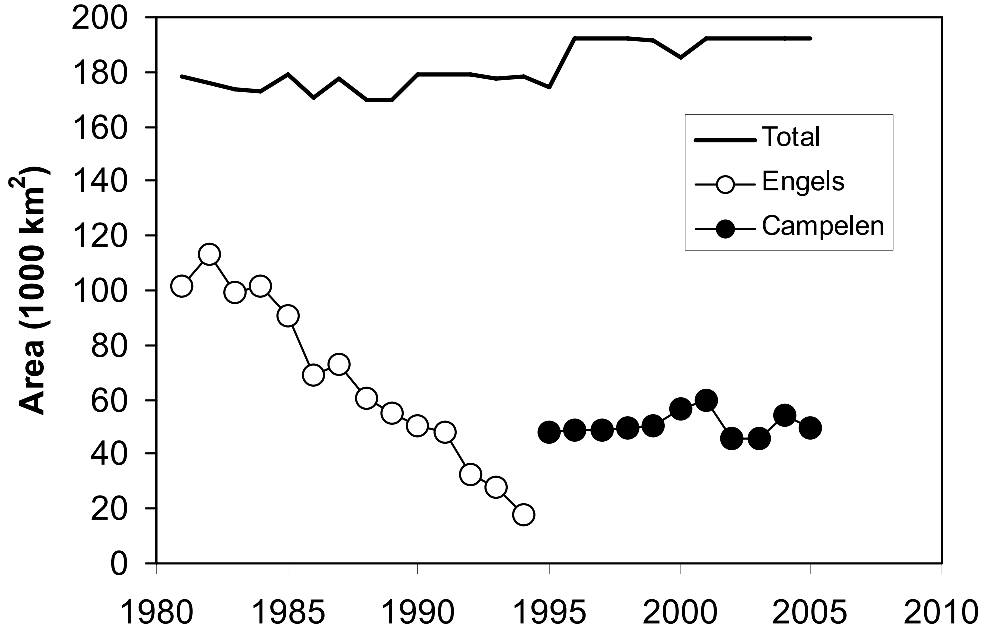

Figure 14. Area occupied by roughhead grenadier within a subset of index strata in the fall survey of NAFO Divisions 2J and 3K. The line shows the total area surveyed each year, circles show the area occupied by grenadiers (open circles – years fished by the Engels trawl, closed circles – years fished by the Campelen trawl).

LIMITING FACTORS AND THREATS

M. berglax is susceptible to mortality caused by humans because of its life-history traits. These include the characters already mentioned: long life span, late maturity, slow growth rates, and long population turnover time, which make recovery subsequent to a reduction in the population probably difficult for this species.

Of the nine species of grenadiers found in the Canadian Atlantic region, only two are commercially exploited (Cohen *et al.*1990). These are the roundnose grenadier (*Coryphaenoides rupestris*) and the roughhead grenadier. They are fished almost entirely by the Portuguese and Spanish in the Northwest Atlantic. The liver is prized for canning and for production of medicinal oil.

Roughhead grenadier is an unregulated species mainly taken as by-catch in the Greenland halibut fishery (Murua 2001). Duran *et al.* (1997) found that roughhead grenadier was one of the most important by-catch species in the Spanish Greenland halibut fishery from 1991 to 1994 in NAFO Divisions 3LMNO. Between these years the annual yield was between 29 and 48 kg/hr for large vessels. This same study found that the roughhead and roundnose grenadiers were the dominant species discarded. Little is known about the sex and age of commercial catches; however, in 2002 only about 4% of the catch in abundance and 20% in weight was above the female age at maturity (Murua 2003).

The revised catch history from 1987 to 2004 is presented in Table 2 (González-Costas & Murua 2005). Catches reported in this table are corrected for misreporting of roughhead grenadiers as roundnose grenadiers by Spain in 1992-1996. Catches increased sharply between 1989 and 1990. Estimated catches fluctuated between about 3000 and 4500 t from 1990 to 2004, except for catches near 7000 t in 1992, 1998 and 1999.

Table 2. Revised roughhead grenadier catches from Subareas 2 and 3 (from González Costas and Murua 2005).

Year	NAFO subdivision									Total
	2G	2H	2J	3K	3L	3M	3N	3O	Other	
1987					912	7	82			1001
1988		1			907		52			960
1989		2		3	289	28	11			333
1990		1	32		2211	688	312			3244
1991[a]			12	113	2543	497	1093	10		4268
1992			23	274	2582	2961	760	125		6725
1993			10	193	996	1428	1680	61	27	4395
1994	1		2	35	585	2301	1062	28	9	4023
1995	22	6	16	16	1199	1625	1074	20	4	3982
1996					1945	888	1300	2		4135
1997	36	5	63	100	1774	922	1797	43		4740
1998					2766	2190	2230	84	92[c]	7270
1999[b]				61	2037	3127	1705	180	49[c]	7160
2000[b]				139	1382	2109	888	38		4767
2001[b]				97	1465	753	754	48		3117
2002[b]				147	1905	869	700	36		3657
2003[b]	1	4	16	91	1342[c]	886	1201[c]	443[c]		3984[c]
2004[b]	4	8	19	58	1310	844	897	42		3182

[a] Catch could not be well estimated; based on revised data, estimate is 8000 – 14000 t mixed roundnose and roughhead grenadier.
[b] Provisional
[c] In 2003, STACFIS could not precisely estimate the catch.

Catches for years prior to 1987 have not been reported in recent assessments of roughhead grenadier. The main fisheries catching this species in earlier years would have been the fisheries for roundnose grenadier and Greenland halibut (D. Power and D. Kulka, pers. comm.). Roundnose grenadier catches dropped sharply in 1979 (D. Power, pers. comm.), following the extension of jurisdiction by Canada in 1977. If this reflects a drop in effort, the by-catch of roughhead grenadier in this fishery would have been much lower in the 1980s than in the 1967 – 1978 period. Catches of Greenland halibut in NAFO Sub-area 2 and Divisions 3KLMNO rose sharply in the 1960s, fluctuated between about 30,000 – 40,000 t in the 1970s and early 1980s, declined to about 20,000 t in the mid- to late 1980s, increased to 50,000 – 60,000 t in 1990-1994, and then declined to lower levels (Healey and Mahé 2005). Estimated fishing mortality of Greenland halibut also declined throughout the 1980s before increasing sharply in the early 1990s (Healey and Mahé 2005).

In summary, the sharp decline in survey catch rates in the 1980s – early 1990s began at a time when catches and effort in the main fisheries with by-catch of roughhead grenadiers were lower than in earlier and later periods. This suggests that the declining catch rates of roughhead grenadier in the research surveys in the 1980s were not initiated by increased by-catch in fisheries. Based on estimated fishing mortality (Healey and Mahé 2005), effort in the Greenland halibut fishery increased sharply in the early 1990s and may have contributed to declines in roughhead grenadier at that time. Fishing mortality of Greenland halibut in NAFO Sub-area 2 and Divisions 3KLMNO declined to lower levels in the mid-1990s but has since returned to record high levels (Healey and Mahé 2005); that fishing may have contributed to latter part of the decline. Population modelling and a detailed analysis of fishery observer data are needed to assess the impact of fishery removals on roughhead grenadier more fully. Such analyses are beyond the scope of this report.

SPECIAL SIGNIFICANCE OF THE SPECIES

Macrourus berglax is the only species belonging to this genus that is found in Atlantic Canada (Scott & Scott, 1988), and indeed in the whole of the North Atlantic. Cohen *et al*. (1990) recognize three other species of *Macrourus*: *M. carinatus*, *M. holotrachys*, and *M. whitsoni*, all of which are found only at higher latitudes in the southern hemisphere. The decline of the roundnose grenadier fishery increased the economic significance of the roughhead grenadier, making it today the primary grenadier species fished in the western North Atlantic, though it is taken mainly as by-catch rather than in a directed fishery.

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Roughhead grenadier is an unregulated species now taken mainly as by-catch (Murua 2000). The roughhead grenadier is not protected by any legislation or regulation and has no status under any other species protection conventions.

TECHNICAL SUMMARY

Macrourus berglax **Lacépède, 1801**
roughhead grenadier — grenadier berglax
Range of Occurrence in Canada: Atlantic Ocean

Extent and Area Information		
	• Extent of occurrence (EO)(km²) minimum estimate, based on surveys covering part of the distribution	> 120,000 km^2; Continental shelf and slopes of the North Atlantic Ocean
	• Specify trend in EO	Unknown
	• Are there extreme fluctuations in EO?	No
	• Area of occupancy (AO) (km²) minimum estimate, based on surveys covering part of the distribution	> 120,000 km^2 for all sizes; > 13,000-22,000 km^2 for adult females
	• Specify trend in AO	Unknown: change in distribution 1980s and early 1990s, stable since 1995
	• Are there extreme fluctuations in AO?	No
	• Number of known or inferred current locations	Continuous distribution
	• Specify trend in #	Continuous distribution
	• Are there extreme fluctuations in number of locations?	No
	• Specify trend in area, extent or quality of habitat	Unknown
Population Information		
	• Generation time (average age of parents in the population)	19 years
	• Number of mature individuals minimum estimate, based on surveys covering part of the distribution	Minimum estimate > 1.4 million (adult females)
	• Total population trend:	Unknown
	• % decline over 15 years (< 1 generation)	Survey catch rates for adult females declined by 95-96% over 13 - 15 yr, in the 1980s – early 1990s, stable over past 10 yr, but survey declines reflect some combination of population declines and distribution changes
	• Are there extreme fluctuations in number of mature individuals?	Unlikely
	• Is the total population severely fragmented?	No
	• Specify trend in number of populations	Single continuous population
	• Are there extreme fluctuations in number of populations?	No
	• List populations with number of mature individuals in each: N/A	
Threats (actual or imminent threats to populations or habitats) By-catch in fisheries in combination with conservative life-history traits		
Rescue Effect (immigration from an outside source)		
	• Status of outside population(s)? Unknown	
	• Is immigration known or possible?	Possible
	• Would immigrants be adapted to survive in Canada?	Probably
	• Is there sufficient habitat for immigrants in Canada	Yes
	• Is rescue from outside population likely?	Unknown

Current Status
COSEWIC: Special Concern (2007)

Status and Reasons for Designation

Status: Special Concern	**Alpha-numeric code**:
Reasons for Designation: This species is widespread on the upper continental slope and deep continental shelf throughout the North Atlantic. Females mature at 13-15 years with a generation time of approximately 20 years. The species is distributed from Davis Strait in the north to Georges Bank in the south, occurring both inside and outside 200 n. miles, primarily in depths between 400 and 1500 m. Research vessel surveys have not consistently covered deep portions of the range and catch a low proportion (ca. 2%) of mature adults. Canadian survey index decline rates over 15 years (< one generation) of > 90% occurred in the 1980s and early 1990s, but the surveys only covered depths to 1000 m. This decline is probably due to a combination of distributional change and abundance decline: there is evidence for movement of fish into deeper water as a result of the cooling of the shelf in the 1980s, and reduction in population size due to fishing pressure is also a possible factor. The species is caught primarily as bycatch in the Greenland halibut fishery, which has experienced reduced Total Allowable Catch and greater restrictions on areas of operation since 2000. However, there are no catch limits or management plans for the species in Canadian waters, and catch reporting of foreign vessels is often unreliable. Survey indices (Canadian and European Union) for adults have been stable over the past decade. The species is of concern because of late maturation, lack of evidence of return of adults to shallower depths with return to environmental conditions prevailing prior to the 1980s, a probable decline in abundance in the 1980s and 1990s, and the lack of a management plan for directed and incidental harvest.	
Applicability of Criteria	
Criterion A: Although the survey index for adults declined > 90% over less than one generation in the 1980s and early 1990s, exceeding the criterion threshold for Endangered status, it is not considered to have tracked abundance accurately during this period because it was influenced both by distribution changes and abundance changes. Accordingly it is not considered "an index of abundance appropriate for the taxon" as required in the definition for Criterion A-b. **Criterion B**: Does not apply because extent of occurrence exceeds 20,000 km² and the area of occupancy is greater than 2,000 km². **Criterion C**: Does not apply because the estimated population size exceeds 10,000 individuals. **Criterion D**: Does not apply because the number of mature individuals exceeds 1,000 and area of occupancy is grater than 20 km². **Criterion E**: Not undertaken.	

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D.P. Swain

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Appendix A. Construction of abundance indices

Overview

The survey data used in this report are from the DFO fall survey of NAFO divisions 2GHJ3KLMNO and the spring survey of divisions 3LNO. The area covered by these surveys has varied considerably over time. In order to construct consistent time series of relative abundance indices, subsets of consistently sampled strata were used (i.e., strata sampled in most years). For each survey, two or three time series were constructed, a long time series covering a smaller area, and shorter time series covering a larger area.

In constructing times series of abundance indices from these data, it is important to note that the stratification scheme for these surveys was revised substantially between 1992 and 1993 (Bishop 1994). Stratum boundaries were extensively revised, resulting in substantial changes to stratum areas (and thus to the weighting factors used to calculate stratified means). A number of stratum codes were dropped and new codes were added, without any substantial change to the total area covered. This needs to be kept in mind when selecting strata for inclusion in consistent time series (e.g., a new code appearing in 1993 should be included if it covers an area included in the analysis under a different code prior to 1993). Additional deepwater strata were added to the surveys in 1996.

For strata sampled in most years but missed in a few years, predicted values were used for the missed years. These were obtained from a statistical model with year and stratum terms. Both year and stratum were used as factors or class variables in these models (as opposed to continuous covariates as in the models in Devine *et al*. 2006). A generalized linear model was used, with a log link and Poisson error, allowing for overdispersion. This model assumes that distribution does not change between years. In order to minimize effects of distribution change, models were restricted to the year with missing data and the preceding and following year or two. Narrower year ranges were used during periods of distribution change. Models that included a year×stratum interaction (which reflects changes in distribution) were examined to ensure that the importance of this term was small relative to the stratum term.

The following indices were constructed:

1. Fall 2J3K, 1978-2003
   Strata: 2J: 201-219, 222-224, 227-231, 234-240, 3K: 617, 620-642, 645-647, 650-652

2. Fall 2J3KL, 1981-2003
   Strata: 2J: 201-219, 222-224, 227-231, 234-240, 3K: 617, 620-642, 645-647, 650-652, 3L: 328, 341-350, 363-372, 384-392

3. Fall 2J3KLNO, 1996-2003
   Strata 2J: 201:240, 3K: 617-631, 633-654, 3L: 328, 341-350, 363-372, 384-392, 729-736, 3N: 357-362, 373-383, 723-728, 3O: 329-340, 351-356, 717-722
4. Spring 3LNO shallow, 1971-2002: strata 347-354, 359-366, 368-392

5. Spring 3LNO deep, 1996-2005: strata 328:366, 368-392, 717-736
   (This index was provided by M. Koen-Alonso and F. Mowbray, DFO, St. John's).

Predicted values for missed strata

Statistical models were fit to the following subsets of data in order to obtain predicted values for missed strata. Unless otherwise noted, data were the tow-by-tow catch rates (as opposed to stratum means).

A. Fall data, all sizes

1978-2003 2J3K index

1. 1977-1982, 2J strata 201:219, 222:224, 227:231, 234:240. Used for missed strata in 2J in 1978-1982.

2. 1979-1983, 3K strata 617, 620:642, 645:647, 650:652. Used for missed strata in 3K in 1979-1983.

3. 1983-1985, 2J strata 201:219, 222:224, 227:231, 234:240. Used for missed strata in 2J in 1984.

4. 1985-1987, 3K strata 617, 620:642, 645:647, 650:652. Used for missed strata in 3K in 1986.

5. 1987-1990, 3K strata 617, 620:642, 645:647, 650:652. Used for missed strata in 3K in 1988 and 1989.

6. 1988-1990, 2J strata 201:219, 222:224, 227:231, 234:240. Used for missed stratum 236 in 2J in 1989.

7. 1995-1997, 2J strata 201:219, 222:224, 227:231, 234:240. Used for missed strata in 2J in 1995.

8. 1999-2001 3K strata 617, 620:642, 645:647, 650:652. Used for missed stratum 650 in 3K in 2000.

1981-2003 2J3KL index

9. 1981-1984 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed strata in 3L in 1981-1983.

10. 1985-1987 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed stratum 388 in 3L in 1986.

11. 1992-1994 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed stratum 348 in 3L in 1993.

1996-2003 2J3KLNO (deep) index

12. 1996-1998 2J3KLNO strata 201:240, 328:392, 617:631, 633:654, 717:736. Used for missed strata in 3O in 1996.

13. 2000-2002 2J3KLNO strata 201:240, 328:392, 617:631, 633:654, 717:736. Used for missed stratum 650 in 2000.

B. Spring data, all sizes

1971-2002 3LNO shallow index (1972, 1983, 1984 omitted)

14. Missed strata where roughhead grenadier have never been caught were filled with 0 (347-349, 351-354, 359, 360, 364, 371 373, 376, 384).

15. 1971-1974 3LNO strata 347:354, 359:366, 368:392. Used for missed strata in 1971 and 1973.

16. 1974-1977 3LNO strata 347:354, 359:366, 368:392. Used for missed strata in 1976.

17. 1977-1979 3LNO strata 347:354, 359:366, 368:392. Used for missed stratum 368 in 1978.

18. 1990-1992 3LNO strata 347:354, 359:366, 368:392. Used for missed strata in 1991.

1996-2005 3LNO deep index

Used time series provided by Mariano Koen-Alonso and Fran Mowbray (DFO St. John’s).

C. Fall data, adult females

1978-2003 2J3K index

19. 1977-1981, 2J strata 201:219, 222:224, 227:231, 234:240. Used for missed strata in 2J in 1978-1980.

20. 1978-1981, 3K strata 617, 620:642, 645:647, 650:652. Used for missed strata in 3K in 1978-1979.

21. 1981-1984, 2J3K strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652. Used for missed strata in 2J3K in 1982-1984.

22. 1985-1987, 3K strata 617, 620:642, 645:647, 650:652. Used for missed strata in 3K in 1986.

23. 1987-1991, 2J3K strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652. Used for missed strata in 2J3K in 1988-1990, except for stratum 647.

24. 1995-1997, 2J strata 201:219, 222:224, 227:231, 234:240. Used for missed strata in 2J in 1995.

25. 1999-2002, 2J3K strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652. Used for missed strata in 2J3K in 2000.

26. Predicted values for stratum 647 in 1988-1990 were clearly unreasonable (too large) using model 23. In 1990, there were tows in this stratum but no length frequencies were taken. A prediction for the mean catch rate of adult females in this stratum in 1990 was obtained by multiplying the mean total catch rate in 647 in 1990 by the average proportion mature (>275 mm AFL) in this stratum in 1985-1992. Predictions for stratum 647 in 1988 and 1989 were obtained by running the model on stratum means (including the prediction for 647 in 1990 given above) for 1987-1992.

1981-2003 2J3KL index

27. 1981-1984, 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed strata in 3L in 1981-1983.

28. 1985-1987, 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed stratum 388 in 1986.

29. 1987-1992, 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed strata in 1988-1990.

30. 1992-1994, 2J3KL strata 201:219, 222:224, 227:231, 234:240, 617, 620:642, 645:647, 650:652, 328, 341:350, 363:372, 384:392. Used for missed stratum 348 in 1993.

1996-2003 2J3KLNO (deep) index

31. 1996-1998 2J3KLNO strata 201:240, 328:392, 617:631, 633:654, 717:736. Used for missed strata in 3O in 1996.

32. 2000-2002 2J3KLNO strata 201:240, 328:392, 617:631, 633:654, 717:736. Used for missed strata in 2000-2002.

Additional time series

Mark Simpson and Dave Kulka (DFO St. John's) have developed time series of abundance and biomass indices that control for variation in the area sampled by either deleting missed strata from the time series or combining them with adjacent strata in a similar depth zone. Trends are similar to those described in Figures 5 and 6, except that the decline in the 1980s and early 1990s is slightly steeper in these indices (Fig. A1). This may reflect the exclusion of deep strata (>750 m) from these indices for years before 1996. Deep strata (750-1000 m) are included in the index in Figure 5a.

Mariano Koen-Alonso and Fran Mowbray (DFO St. John's) have also developed abundance and biomass indices from these surveys. Their indices are based on a subset of core strata sampled in most years. Because not all core strata are sampled in all years, the area covered by their index varies slightly from year to year. Also their indices include deepwater strata sampled only since 1996. The time series based on their index is shown in Figure A2. Their spring abundance index (1996-2005) is used in Figure 6 of this report.

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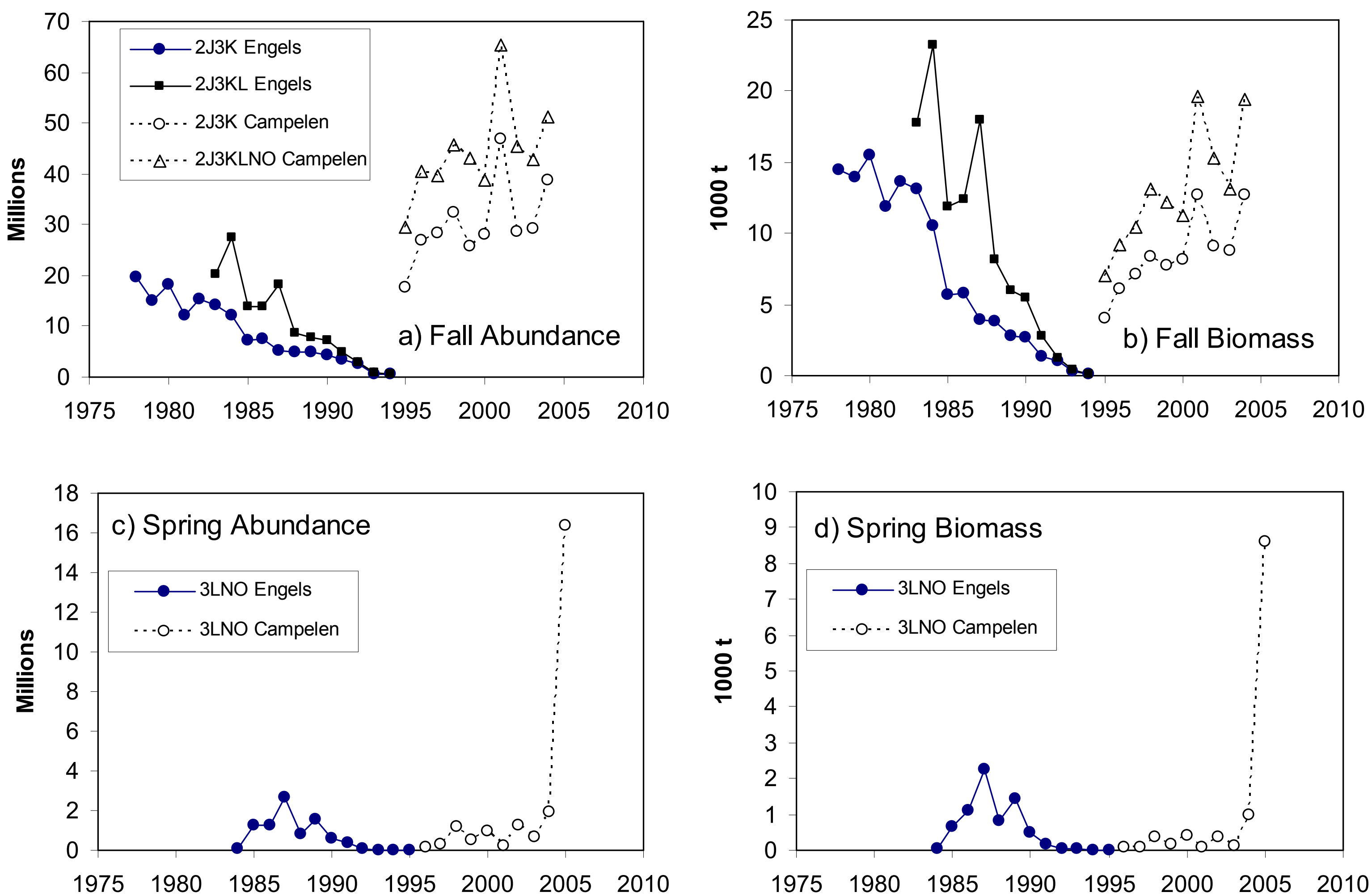

Figure A1. Abundance and biomass indices for roughhead grenadier from the fall and spring bottom-trawl surveys of NAFO divisions 2J3KLNO, supplied by Mark Simpson and Dave Kulka (DFO, St. John's). Engels indices exclude strata with depths >750 m.

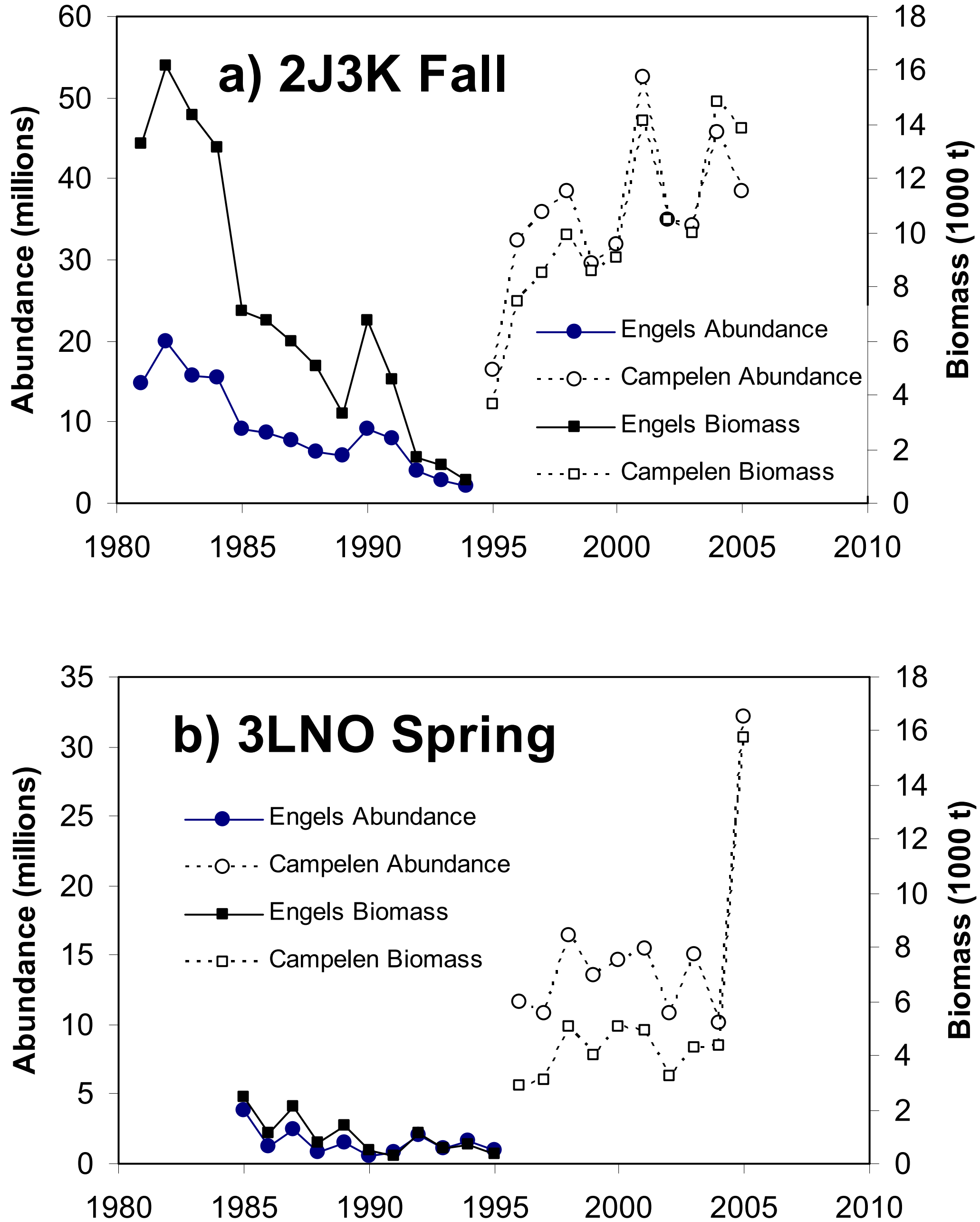

Figure A2. Abundance and biomass indices for roughhead grenadier from the fall and spring bottom-trawl surveys of NAFO divisions 2J3KLNO, supplied by Mariano Koen-Alonso and Fran Mowbray (DFO, St. John's). Results for core strata with more than 2 sets. Note that deepwater strata are added to the core strata in 1996.

Appendix B. Calculation of area occupied

Area occupied in year t (At) was calculated from the survey data based on the survey design:

$$A_t = \sum_{k=1}^{S} \sum_{j=1}^{n_k} \frac{a_k}{n_k} I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_{jk} > 0 \\ 0 \text{ otherwise} \end{cases}$$

where a_k is the area of the stratum *k*, *S* is the number of strata sampled, n_k is the number of tows made in stratum *k* in year *t*, and Y_{jk} is the catch in tow *j* in stratum *k* in year *t*.