COSEWIC
Assessment and Status Report

on the

Roughhead Grenadier
Macrourus berglax

in Canada

NOT AT RISK
2018

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:

COSEWIC. 2018. COSEWIC assessment and status report on the Roughhead Grenadier *Macrourus berglax* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 38 pp. (http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

Previous report(s):

COSEWIC 2007. COSEWIC assessment and status report on the roughhead grenadier *Macrourus berglax* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 40 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

Production note:
COSEWIC would like to acknowledge Bruce Atkinson for writing the status report on Roughhead Grenadier (*Macrourus berglax*) in Canada, prepared under contract with Environment and Climate Change Canada. This report was overseen and edited by Alan Sinclair and Ross Claytor, Co-chairs of the COSEWIC Marine Fishes Specialist Subcommittee.

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le Grenadier berglax (*Macrourus berglax*) au Canada.

Cover illustration/photo:
Roughhead Grenadier (*Macrourus berglax*). Illustration by Gary Taylor. Reproduced with permission from DFO.

Catalogue No. CW69-14/525-2019E-PDF
ISBN 978-0-660-31339-9

COSEWIC
Assessment Summary

Assessment Summary – November 2018

Common name
Roughhead Grenadier

Scientific name
Macrourus berglax

Status
Not at Risk

Reason for designation
Millions of individuals of this deepwater fish species occur inside and outside Canadian waters. The primary threat to this species is bycatch in the Greenland Halibut fishery, which is under-reported and varies with fishing effort. However, these concerns have been reduced because a management plan exists for the Greenland Halibut fishery, most bycatch occurs outside the core range, the population index in the core area has increased since 1995, and reported bycatch has declined steadily since 2003. Thus, the threat from bycatch is unlikely to cause declines, as Canadian and international management is focused at recovery of Greenland Halibut.

Occurrence
Atlantic Ocean, Arctic Ocean (Newfoundland and Labrador, Nova Scotia, New Brunswick, Nunavut)

Status history
Designated Special Concern in April 2007. Status re-examined and designated Not at Risk in November 2018.

COSEWIC
Executive Summary

Roughhead Grenadier
Macrourus berglax

Wildlife Species Description and Significance

Roughhead Grenadier (*Macrourus berglax*, Lacépède 1802) is a member of the Macrouridae family (rattails). In Canada, it is commonly known as the Roughhead Grenadier, the onion eye, or smooth spined rattail.

The head shape and body of Roughhead Grenadiers are typical for the family Macrouridae. They have a large head and a moderately slender body, tapering uniformly to a pointed tail. The anal fin has a narrow dark edge. *Macrourus berglax* have been reported to reach greater than 91 cm in length (McMillan *et al.* 2012).

They can be distinguished from other grenadiers in the North Atlantic by a prominent and pointed snout that is equal to eye height and are almost or completely scaleless underneath. 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.

Distribution

Roughhead Grenadier are widely and continuously distributed throughout the Northwest Atlantic, both inside and outside Canada's Exclusive Economic Zone (EEZ) extending north into the Arctic Ocean (Baffin Bay). Population structure across this range is unknown. In the waters off Canada, Roughhead Grenadier are widely and continuously distributed along the slope of the continental shelf including Arctic waters of Baffin Bay and throughout the Northwest Atlantic to the Scotian Shelf in the south. They are also distributed between the Grand Bank and Flemish Cap in the area called Flemish Pass. Roughhead Grenadier distribution does not extend into the Laurentian Channel between Newfoundland and Nova Scotia, nor is it found in the Gulf of St. Lawrence. In the absence of any information to suggest local adaptation and genetic differentiation within this range, this report considers that Roughhead Grenadier comprise a single designatable unit (DU) in the waters off Atlantic Canada (including waters beyond the EEZ).

Habitat

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. It is predominant in depths ranging from 500 to 1500 m, although they inhabit depths from <200 m to 2700 m. Based on Fisheries and Oceans Canada (DFO) research surveys, Roughhead Grenadier are found in temperatures ranging from about -0.5º to 5.4º C in the Northwest Atlantic.

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

Roughhead Grenadiers are slow-growing, late-maturing, and have a long life cycle. In the Northwest Atlantic, mean length-at-age has been found to be similar for males and females under 10 years old. Male growth is slower than females after the age of 10 and the differences increase with age. The average anal fin length for mature females collected in the Grand Bank and Flemish Cap was 26.2 (66.7 cm total length) – 28.5 cm corresponding to an age of 13-16 years.

Population Sizes and Trends

The uncertainty associated with surveys used to examine abundance trends in a previous report has been reduced because surveys initiated since 1995 cover the depths with highest Roughhead Grenadier densities (500 to 1500 m). Even though Roughhead Grenadier occur deeper than 1500 m, there is no evidence that systematic trends, resulting from dispersal or migration between deep and shallow waters, that would disrupt major trend conclusions, occur. Hence, there is no systematic variation that would violate assumptions required for an appropriate index.

European Union (EU) survey trends beyond Canada’s EEZ declined, especially in the recent period, whereas DFO survey trends, mainly inside the EEZ increased. Mature abundance in the DFO Labrador Shelf – northern Grand Bank survey averaged approximately 13 million mature fish from 1995 – 2016, while mature abundance in the EU Flemish Cap survey averaged about 3.5 thousand fish. The Labrador Shelf – northern Grand Bank survey also covered a greater area where the species occurs than the surveys outside the EEZ.

Hence, it was concluded that the Labrador Shelf – northern Grand Bank survey was an appropriate index for Roughhead Grenadier, demonstrates an increasing trend in the core area of the species, and should receive the most weight in the designation decision.

Threats and Limiting Factors

The primary threat to this species is bycatch in the Greenland Halibut fishery, which is under-reported and varies with fishing effort. However, these concerns have been reduced because a management plan exists for the Greenland Halibut fishery, most bycatch occurs outside the core range, the population index in the core area has increased since 1995, and reported bycatch has declined steadily since 2003. Thus, the threat from bycatch is unlikely to cause declines, as Canadian and international management is focused on recovery of Greenland Halibut.

Protection, Status and Ranks

The species is not listed (not assessed) by IUCN, CITES or other international conservation organizations. Roughhead Grenadier was previously assessed by COSEWIC as Special Concern but was not listed under SARA.

NatureServe Status

Global Status: GNR – Not Yet Ranked
Rounded Global Status: GNR – Not Yet Ranked
National Status: NNR – Not Yet Ranked
Nunavut: SNR – Not Yet Ranked

TECHNICAL SUMMARY

Macrourus Berglax

Roughhead Grenadier

Grenadier berglax

Range of occurrence in Canada (province/territory/ocean): Atlantic Ocean, Arctic Ocean (Newfoundland and Labrador, Nova Scotia, New Brunswick, Nunavut)

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	17.7 years based on M = 0.15 and A_{1st} = 11 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	No
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	No
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	118% increase in the Labrador Shelf – northern Grand Bank survey since 1995. It was concluded that this survey covers the core of the population and should receive the most weight in designation. Areas outside this population core and Canada's EEZ cover a smaller segment of the population distribution and indicate declines of 18 – 75%.
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	No
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	No
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. NA b. NA c. NA
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	>3,000,000 km² (within Canadian EEZ including unsuitable habitat)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	32,004 km² (based on 2 km x 2 km grids over each data point)

Is the population “severely fragmented” i.e., is >50% of its total area of occupancy is in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	a. No b. No
Number of “locations”* (use plausible range to reflect uncertainty if appropriate)	The number of locations was not determined because Roughhead Grenadier do not occupy multiple discrete locations but rather form a nearly continuous distribution over more than 26 degrees of latitude (~2900 km) along the shelf waters of West Greenland, Canada and USA and there is not an identified threat that could reduce the mature abundance over a relatively short period of time.
Is there an [observed, inferred, or projected] decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	No
Is there an [observed, inferred, or projected] decline in number of subpopulations?	NA
Is there an [observed, inferred, or projected] decline in number of “locations”*?	NA
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	No
Are there extreme fluctuations in number of subpopulations?	NA
Are there extreme fluctuations in number of “locations”*?	NA
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	**N Mature Individuals**
None	
Total	

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Quantitative analysis not done

* See Definitions and Abbreviations on COSEWIC website and IUCN (Feb 2014) for more information on this term

Threats (actual or imminent, to populations or habitats, from highest impact to least)

i. Commercial fishery bycatch Was a threats calculator completed for this species and if so, by whom? No

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	Roughhead Grenadier comprise a single designatable unit (DU) in the waters off Atlantic Canada (including waters beyond the Canadian Economic Exclusion Zone (EEZ)). It has been suggested that Roughhead Grenadier in West Greenland, East Greenland and the Norwegian Sea comprise separate stock units.
Is immigration known or possible?	Yes
Would immigrants be adapted to survive in Canada?	Yes
Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?[+]	No
Are conditions for the source population deteriorating?[+]	Yes, Surveys in West Greenland show a decline
Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	Uncertain, there is a continuous distribution within the DU and migration rates between Roughhead Grenadier in West Greenland, East Greenland and the Norwegian Sea are unknown.

Data Sensitive Species

Is this a data sensitive species? No

Status History

COSEWIC Status History: Designated Special Concern in April 2007. Status re-examined and designated Not at Risk in November 2018.

[+] See Table 3 (Guidelines for modifying status assessment based on rescue effect)

Status and Reasons for Designation:

Status: Not at Risk	**Alpha-numeric codes:** Not applicable.
Reasons for designation: Millions of individuals of this deepwater fish species occur inside and outside Canadian waters. The primary threat to this species is bycatch in the Greenland Halibut fishery, which is under-reported and varies with fishing effort. However, these concerns have been reduced because a management plan exists for the Greenland Halibut fishery, most bycatch occurs outside the core range, the population index in the core area has increased since 1995, and reported bycatch has declined steadily since 2003. Thus, the threat from bycatch is unlikely to cause declines, as Canadian and international management is focused at recovery of Greenland Halibut.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Does not meet criterion because the survey which covers the major portion of the species distribution within Canadian waters indicates increased abundance of mature individuals from 1995 to 2016.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not meet criterion. EOO and IAO exceed criteria for Threatened.
Criterion C (Small and Declining Number of Mature Individuals): Does not meet criterion because the number of mature individuals >> exceeds the threshold.
Criterion D (Very Small or Restricted Population): Does not meet criterion because the number of mature individuals >> threshold.
Criterion E (Quantitative Analysis): Not done.

PREFACE

The survey index (1978 -1984) examined in the previous Status Report for Roughhead Grenadier (COSEWIC 2007) was considered inappropriate for the taxon even though it described a >90% decline. Because the maximum depth of that survey extended to 1000 m, Roughhead Grenadier trends in the survey area, resulting from distribution shifts or abundance declines could not be separated. This report presents new information from Canadian, European Union (EU), and West Greenland surveys which have been extended to cover depths to 1500 m. This extension to 1500 m is important for investigating abundance changes because the highest Roughhead Grenadier trawl survey densities are expected to occur between 500 – 1500 m. The surveys examined occur both inside and outside Canada's Exclusive Economic Zone (EEZ). The EEZ extends a distance of 200 nautical miles from the nearest point of the baselines of the territorial sea of Canada.

Studies of Roughhead Grenadier in the Canadian EEZ of the Northwest Atlantic have been limited with many aspects of their life history and biology remaining unknown or, at best, uncertain. This report brings together information, from outside Canada's EEZ, in Northwest Atlantic Fisheries Organization (NAFO) and other publications produced since 2007. This information is considered to be reflective of the species biology within the Canadian EEZ due to the continuous Roughhead Grenadier distribution extending beyond Canada's EEZ.

This report also adds new information on the management plan for the Greenland Halibut fishery. This information is important because bycatch in the Greenland Halibut fishery was considered the main threat to Roughhead Grenadier in the previous report (COSEWIC 2007).

In support of this work, the Department of Fisheries and Oceans (DFO) held a Pre-COSEWIC Assessment meeting for Roughhead Grenadier during which Canadian data were presented and discussed. This information contributed extensively to this document.

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 (2018)

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 and Climate Change Canada
Canadian Wildlife Service
Environnement et Changement climatique Canada
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Canada

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

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Roughhead Grenadier

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Macrourus berglax, Lacépède 1802 is a member of the Macrouridae family (rattails) and is generally known as Roughhead Grenadier. In Canada, it is commonly known as the Roughhead Grenadier, the onion eye, or smooth spined rattail. The French refer to it as Grenadier Berglax (Scott and Scott 1988) and the Inuit, Ingminniset, meaning “it bellows when dying” (COSEWIC 2007).

Morphological Description

The head shape and body of Roughhead Grenadier is typical for the family Macrouridae. It has a large head and a moderately slender body, tapering uniformly to a pointed tail (Figure 1) (Bigelow and Schroeder 1953). It 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 (COSEWIC 2007).

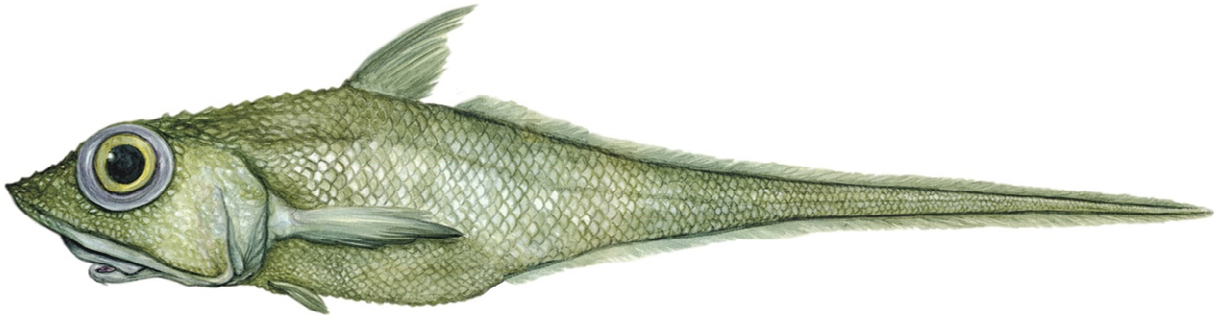

Figure 1. Roughhead Grenadier (*Macrourus berglax)*. Illustration by Gary Taylor. Reproduced with permission from DFO.

The mouth is small and located on the underside of the head. A short chin barbel is present. It has a tall truncate first dorsal fin and small, continuous second dorsal and anal fins (Encyclopedia of Life 2016). Gillrakers are reduced, and there are three to five irregular rows of pointed teeth in the upper jaw (Scott and Scott 1988). They are ash grey in colour but darker at the posterior of the body. The anal fin has a narrow dark edge. *Macrourus berglax* have been reported to reach greater than 91 cm in length (McMillan *et al.* 2012).

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 and Scott 1988).

Population Spatial Structure and Variability

Roughhead Grenadiers are widely and continuously distributed throughout the Northwest Atlantic, both inside and outside Canada's EEZ (Figure 2).

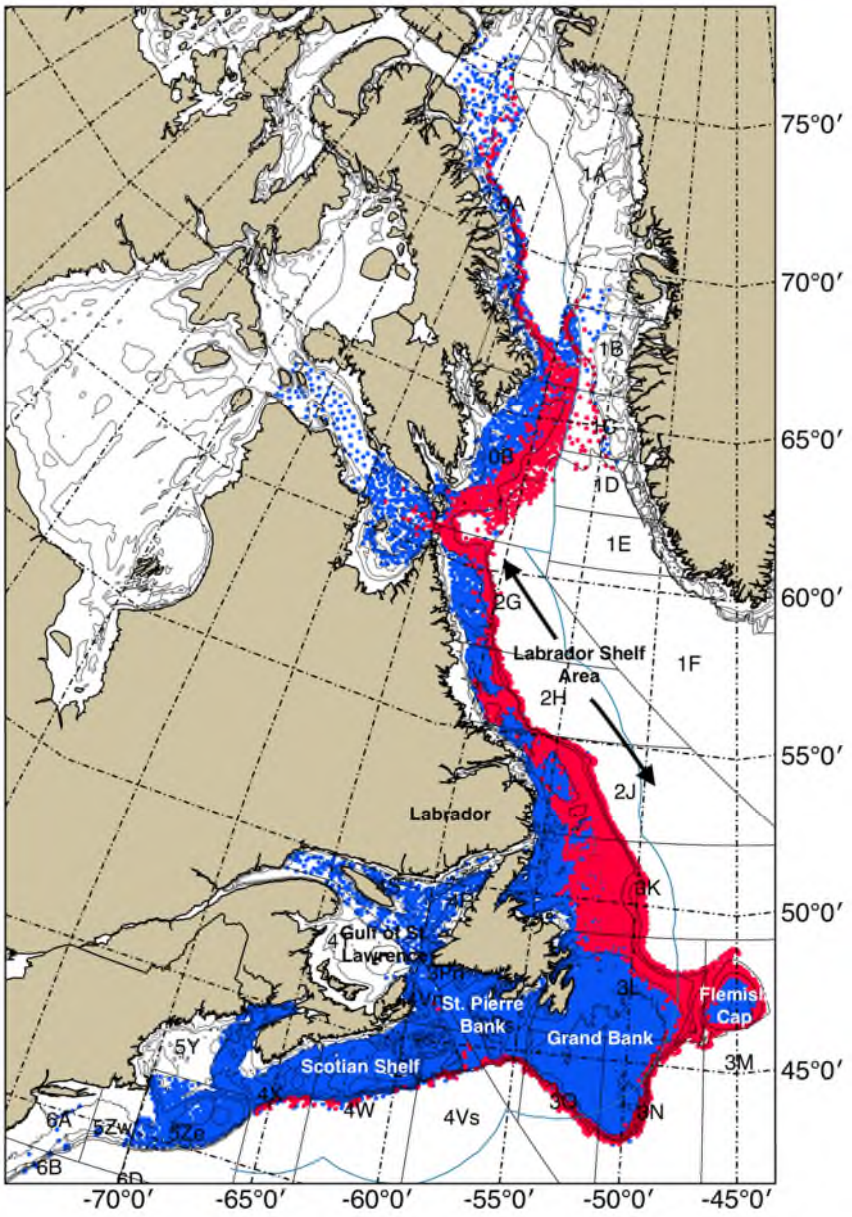

Figure 2. Distribution of Roughhead Grenadier in the Northwest Atlantic (based on DFO and Northern Shrimp Research foundation (NSRF) research survey data). Sets with zero catch in blue; sets with >0 catches in red. Note the figure also shows the NAFO Divisions and geographic areas mentioned in the text as well as Canada's EEZ line (blue). Canadian research survey data from Southern Gulf of St. Lawrence (NAFO Div. 4T) are not included in the figure. No catches of Roughhead Grenadier have been reported from the Gulf of St. Lawrence.

Designatable Units

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 and Nævdal 2001). However, in the waters off Canada, Roughhead Grenadier are distributed in temperate to Arctic waters of the North Atlantic and Arctic Oceans, from Baffin Bay through the Scotian Shelf and Georges Bank (Halliday *et al.* 2012a,b; Simpson *et al.* 2017) (Figure 2). Distribution also extends into United States waters as far south as Norfolk Canyon off the state of Virginia (Moore *et al.* 2003, Sosebee 2016). They are also distributed between the Grand Bank and Flemish Cap in the area called Flemish Pass. In the absence of any information to suggest local adaptation and genetic differentiation within this range, this report considers that Roughhead Grenadier comprise a single designatable unit (DU) in the waters off Atlantic Canada (including waters beyond the EEZ).

Special Significance

Macrourus berglax is the only species in this genus that is found in Atlantic Canada (Scott and Scott 1988), and indeed in the whole of the North Atlantic. Cohen *et al*. (1990) recognized three other species of Macrourus: *M. carinatus*, *M. holotrachys*, and *M. whitsoni*, all of which are only found in the southern hemisphere. Subsequently, McMillan *et al.* (2012) identified a fourth species, *M. caml*, also in the southern hemisphere.

Although Canadian interests have explored possible fisheries for Roughhead Grenadier, particularly following the Atlantic Cod (*Gadus morhua*) collapses during the early 1990s, the fish's tough scales caused problems with automated filleting equipment and investigations were abandoned. Today it is taken as bycatch rather than in any directed fishery. There have not been any specific management measures aimed at Roughhead Grenadier in place at any time to date.

DISTRIBUTION

Global Range

Roughhead Grenadier are distributed in temperate to Arctic waters including the North Atlantic, from Norfolk Canyon (about 37° N; off Virginia, USA) and Georges Bank north to Labrador, Davis Strait, Baffin Bay (Arctic Ocean), eastern and western Greenland, Iceland, and from the Irish Atlantic slope north to the Faeroe Islands, Norwegian coast, to Spitzbergen, and into the Barents Sea north to 82 ºN (Cohen *et al.* 1990) (Figure 3).

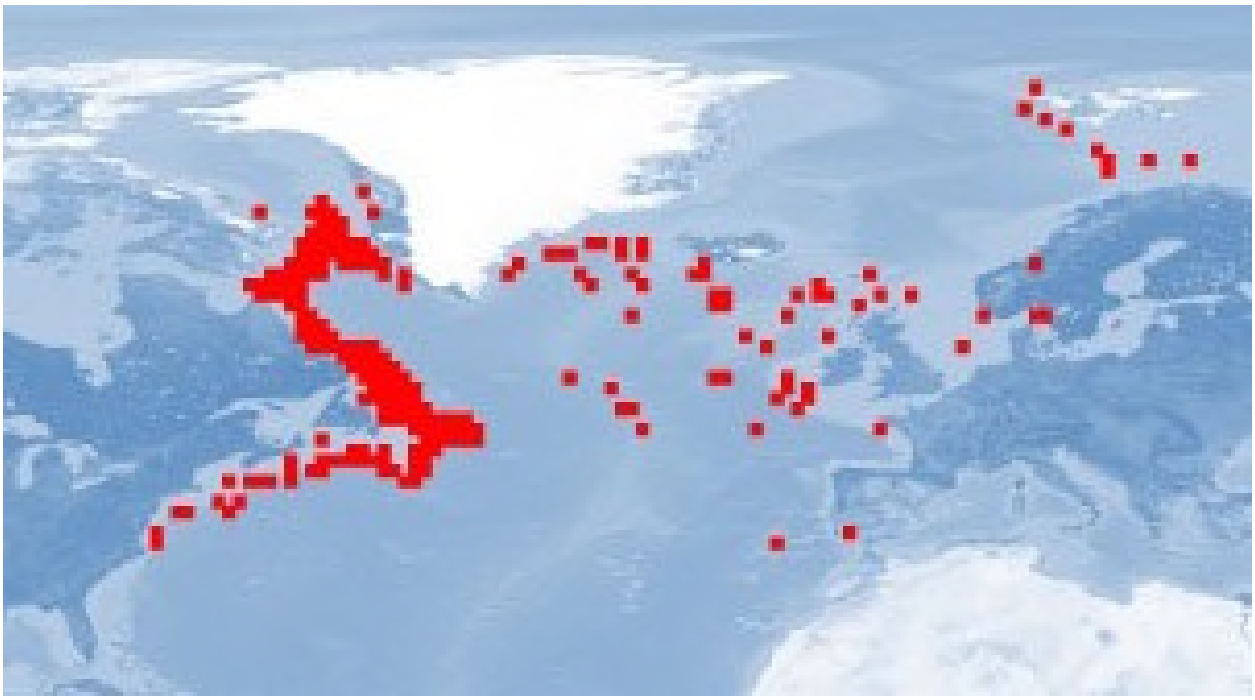

Figure 3. Distribution of Roughhead Grenadier based on known samples (AquaMaps 2008). Note this source does not include points in Baffin Bay seen in Figure 2.

Canadian Range

Inside the Canadian EEZ, Roughhead Grenadier are distributed along the continental slope and deep shelf of the Northwest Atlantic and Arctic (Baffin Bay) oceans (Figure 2). They have been observed off Baffin Island, Labrador, Newfoundland and the Grand Bank to the Scotian Shelf (Halliday *et al.* 2012a,b; Simpson *et al.* 2017). Roughhead distribution does not extend into the Laurentian Channel between Newfoundland and Nova Scotia (three specimens were reportedly caught in this area, but it is believed they were actually Common Grenadier (*Nezumia bairdii*) that were misidentified as Roughhead Grenadier), nor is it found in the Gulf of St. Lawrence (Atkinson and Power 1987; Gauthier 2016). Their distribution is continuous from inside to outside Canada's EEZ in areas where the continental slope is close to the EEZ.

Extent of Occurrence and Area of Occupancy

The extent of occurrence (EOO) for Roughhead Grenadier is 3,224,116 km^2, based on a minimum convex polygon (COSEWIC 2010) from trawl research survey data and other records of occurrence specified under **Search Effort**, including terrestrial areas. The overall index of area of occupancy (IAO) derived from 2x2 km grids placed over each observation point amounts to 32,004 km^2.

Search Effort

The primary source of information on the capture site of Roughhead Grenadier was data collected during DFO research surveys of five DFO Regions: Central and Arctic, Gulf, Maritimes, Newfoundland and Labrador (NL) and Québec (Halliday *et al.* 2012a,b; Simpson *et al.* 2017). These surveys cover most of the shelf and shelf edge of Atlantic Canada and all employ a stratified random design with stratification based on depth and latitude. Surveys of deeper waters where Roughhead Grenadiers are primarily located are only routinely surveyed by the Newfoundland and Labrador and Central and Arctic Regions, but in some areas this coverage is intermittent. Overall, the survey data do not cover the entire latitude or depth distribution.

Information from the USA indicated only 10 Roughhead Grenadier found throughout the entire time series of data. These surveys are mainly conducted to a depth of only 366 m so they would not be expected to capture many Roughhead Grenadier (Sosebee pers. comm. 2016). Moore *et al.* (2003) reported 17 specimens captured between Georges Bank and Cape Hatteras.

Research survey information was also available from surveys conducted outside Canada's EEZ by European Union and EU-Spain. Survey information from West Greenland waters is also available. Assessment information was available from the Northwest Atlantic Fisheries Organization (NAFO) research document series (González-Costas, 2016; Jørgensen *et al.* 2017; Román *et al.* 2017; Sânchez and González-Troncosco 2017).

HABITAT

Habitat Requirements

Roughhead Grenadier is a benthopelagic species that can be found in the deep waters of the subarctic along the continental slope, deep shelves, and as far south as the eastern United States and Spain. Gónzalez and Murua (2008) 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; Murua and De Cárdenas 2005; Halliday *et al.* 2012a,b). It has, however, been found in depths less than 200 m as well as up to 2700 m in the Northeast Atlantic (Wheeler 1969). In the trawl surveys off the Labrador Shelf densities tend to be highest at depths of about 500 – 1500 m (the maximum depth surveyed, see below). During a long-line survey in the NAFO Regulatory Area (NRA) of Div. 3LMN (Grand Bank and Flemish Cap) in depths of 708 – 3028 m, Murua and De Cárdenas (2005) found the highest catch rates of Roughhead Grenadier in 1000 – 1299 m depths although they were caught down to depths of 2199 m.

In spite of highest densities being found in the 500 – 1500 m range, some uncertainties remain in how Roughhead Grenadier use deeper waters. Garabana *et al.* (2016), studying female reproduction, suggested that the absence of higher numbers of

actively spawning females, could indicate that the areas/depths covered by the commercial catches and research surveys in Div. 3LMN (northern and southeastern Grand Bank / Flemish Cap) only correspond to nursery and/or recovering areas where only adolescent, recovering individuals, or skip spawners were available. They surmised that a spawning migration to adjacent waters, or to deeper waters may occur. This suggestion is supported by the presence of large individuals in deep waters off the Scotian Shelf as reported by Halliday *et al*. (2012b). Simpson *et al*. (2017) indicated only 0.5-1.6% of fish caught during the NL surveys were mature sizes.

Determining the depth range most likely occupied by Roughhead Grenadier is important because if there are systematic trends over time with Roughhead Grenadier moving up or down the slope, there will be increased uncertainties surrounding interpretation of survey abundance indices and any observed trends over time. However, if the proportion of the population beyond the coverage of surveys does not have any trend over time, the survey trends should reflect resource status. This would be applicable not only for the EU surveys, but also for those conducted by Canada.

For example, COSEWIC (2007) reported that there was evidence for movement of fish into deeper water as a result of the cooling of the shelf in the 1980s. Because the maximum depth of that survey extended to 1000 m, Roughhead Grenadier trends in the survey area resulting from distribution shifts or abundance declines could not be separated. Extension of the surveys from 1000 m to 1500 m reduces the likelihood that systematic trends of Roughhead Grenadier moving out of the survey area will occur and reduces uncertainties regarding interpretation of survey abundance trends over time.

Atkinson and Power (1987) reported that based on Canadian research surveys, Roughhead Grenadier were found in temperatures ranging from about -0.5º to 5.4º C in the Northwest Atlantic.

Habitat Trends

Where fishing occurs, bottom structure may be altered but any effects on Roughhead Grenadier habitat over time are unknown.

BIOLOGY

Roughhead Grenadier 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 and Scott 1988).

Little has been published on the biology and reproduction of Roughhead Grenadier including comparisons between east and west North Atlantic populations (Murua 2003).

Savvatimsky (1989, 1994) and Jørgensen (1996) have described age structure and growth of macrourids in the Northwest Atlantic based on age readings from scales. The age structure and growth parameters of the Roughhead Grenadier in the Northwest Atlantic have also been estimated based on otolith readings (Murua 2000, Murua *et al.* 2005, Gónzalez and Murua 2008). Validation of age estimates, derived from otolith readings was reported by Rodríguez-Marín *et al.* (2002).

Yanulov (1962), Geistdoerfer (1979), Eliassen and Falk-Petersen (1985), Savvatimsky (1989), Murua and Motos (2000), and Fossen *et al*. (2003) have carried out studies on the timing of spawning, egg diameter, egg and ovary development and fecundity of this species.

Older and larger fish are generally found at greater depths (Murua and De Cárdenas 2005).

Life Cycle and Reproduction

In the Northwest Atlantic, mean length-at-age has been found to be similar for males and females for ages under 10 years, after which male growth is slower, the differences increasing with age (Gónzalez and Murua 2008). In the Flemish Cap area, studies considering all ages have found that the average pre-anal fin length (AFL, L_{50}) for females was greater than for males: 16.1 cm for females versus 14.7 cm for males (Rodriguez-Marin *et al*. 1998; Gónzalez and Murua 2008; Murua *et al*. 2005). Savvatimsky (1989) also reported a greater mean length for females in Div. 3KLN (southern Labrador Shelf / north and southeast Grand Bank).

Studies in NAFO Division 3LMNO (Grand Bank and Flemish Cap) found that female average anal fin length (AFL, (L_{50})) at-maturity, varied from 26.2 to 28.5 cm. These AFL values correspond to average female age-at-maturity (A_{50}) between 13 – 16 years old, with age-at-first maturity (A_{1st}) of 11 years (Eliassen and Falk-Petersen 1985; Atkinson 1991; Murua and Motos 1997; Murua 2003). The AFL at-maturity (L_{50}) from these studies was approximately 27.5 cm, the same as that applied in COSEWIC (2007).

Fossen *et al*. (2003) reported males reached maturity at AFL (L_{50}), between 15.6 and 16.4 cm for samples collected off East Greenland.

Savvatimsky and Gorchinsky (2001) and Gónzalez and Murua (2008) concluded that there are some differences in mortality between sexes. Total mortality by sex, calculated from catch curves suggested both sexes are fully recruited at age 7 and total mortality is 0.38 for females, and 0.57 for males (Gónzalez and Murua 2008), and combined total mortality is 0.43. The authors did not differentiate between natural mortality (M) and fishing mortality (F).

Murua (2003) examining survey and commercial catches reported that the female proportion of Roughhead Grenadier in the Flemish Cap and Flemish Pass increased with age. The proportion of females in the studied region was 40–50% during the first 10–12

years of age (<20 cm AFL), increased to 73% at 13 years (~20 cm AFL), and was 80% at 14 years (~24 cm AFL). Above 14 years old, females made up 100% of the catches. It was not possible to determine if these changes resulted from differential mortalities, changes in distribution with males moving outside the survey area, or issues with age determinations.

A recent review of the reproductive biology of Roughhead Grenadier in Div. 3LMN (north and southeast Grand Bank / Flemish Cap) (Garabana *et al.* 2016) indicated a decrease in average female AFL from 27.8 cm during 2005 – 2011 to 25.6 cm during 2012 – 2015. There was a steady decrease in AFL beginning in 2009. The authors did not speculate on possible reasons for this observed decline. The average age-at-maturity varied between 13.1 and 15 years without trend.

Murua (2003) found fecundity ranged between 8,522 and 61,844 eggs and a relationship to AFL of

$$F_t = 1299.3 \times e^{(0.0842\ x\ L50)}$$

Roughhead Grenadier eggs are reported to be pelagic and have a hexagonal pattern membrane (Eliassen and Falk-Petersen 1985).

Geistdoerfer (1979) reported a well-defined spawning season lasting from the end of spring to the beginning of the summer in the Labrador Sea. Savvatimsky (1989) concluded that Roughhead Grenadier spawn during winter and early spring on the Grand Bank. Murua and Motos (2000) inferred that the spawning period extended from February through July in Div. 3LMN (north and southeast Grand Bank / Flemish Cap). However, Murua (2003), based on combined data from all months except January, concluded that this species may not have a well-defined spawning period in the Northwest Atlantic. Garabana *et al.* (2016) could not define a specific spawning season either but concluded that this could have been due to the very few spawning and spawning-capable females in their samples. An important finding of their work was the high prevalence of atresia (egg resorption) in the females. They tentatively concluded that Roughhead Grenadier have an ‘adolescent’ period with fish beginning maturation for the first time but undergoing high levels of atresia over multiple years before the first successful spawning. Such behaviour could mean that the average at-maturity and subsequent Spawning Stock Biomass (SSB) values are overestimated. This behaviour, in turn, could also affect the trends in SSB over time.

COSEWIC (2007) assumed a natural mortality of 0.2. Devine *et al.* (2012) indicated M ranged between 0.043–0.2 based on information from a variety of studies. González-Costas (2013, 2016) assumed an M of 0.1, reasoning that Roughhead Grenadier is a long-lived species inhabiting a stable deep-sea ecosystem. The International Council for the Exploration of the Sea (ICES) has applied this value in the assessment of some stocks of Roundnose Grenadier (*Coryphaenoides rupestris*). Roundnose and Roughhead Grenadier have similar biology and inhabit similar ecosystems.

Hoenig (1983) suggested that natural mortality can be estimated by

$$M = {}^{4.22}/_{t_{max}{}^{0.982}}$$

where t_{max} is the age at which ~1.5% of the population remains. Murua (2003) indicated the maximum age found was 28 years. Assuming t_{max} = 28, M = 0.16 based on the above. An M of 0.15, also the average of the estimates used by COSEWIC (2007) and González-Costas (2013, 2016), was used for this report.

Generation time is defined by COSEWIC as the average age of parents of the current cohort. It is greater than the age at sexual maturity and less than the age of the oldest breeding individuals. Generation time can be calculated as the age at first reproduction + 1/M, where M is the instantaneous rate of natural mortality (IUCN Standards and Petitions Subcommittee 2014) as per

$$G = A_{1st} + {}^{1}/_{M}$$

where G is generation time, A_{1st} is age at first reproduction and M is natural mortality. When age at first reproduction is unavailable, it is often approximated by the age at which 50% of the females mature.

COSEWIC (2007) assumed an age-at-maturity of 14 years (females) resulting in a generation time of 19 years. This age-at-maturity was based on an approximation using a length-age key and an average total length at-maturity of 66.7 cm as reported by Murua and Motos (2000).

Murua (2003) also reported an age-at-first maturity of 11 years (females). Based on M = 0.15 and age-at-first maturity = 11, generation time, in this report, was estimated to be 17.7 years. This is somewhat less than the 19-year generation time described previously (COSEWIC 2007).

Physiology and Adaptability

In the Northwest Atlantic, Roughhead Grenadier have been found in temperatures ranging from about -0.5° to 5.4°C with the largest concentrations in bottom temperatures of <4.0º (Atkinson and Power 1987).

Roughhead Grenadier, 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).

Dispersal and Migration

Katsarou and Nævdal (2001) found evidence that Roughhead Grenadier in the North Atlantic do not comprise a single panmictic population. 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 the Canadian population may be distinct from other populations in the North Atlantic. However, the estimated genetic distances between stock units were low and they concluded that the evolutionary significance of these genetic differences is uncertain and possibly low. There have been no specific studies of possible stock structure in the Northwest Atlantic.

Overall, the population structure of this species in the North Atlantic remains unclear, particularly in the Northwest Atlantic where Roughhead Grenadier is distributed throughout NAFO Subareas 0 through 6. For assessment purposes, NAFO Scientific Council treats the population of Subareas 2 and 3 as a single stock (NAFO 2010).

Interspecific Interactions

Roughhead Grenadiers are known as non-specialist predators and feed on a wide variety of invertebrates (Cohen *et al.* 1990). The food type consumed by this species is usually directly dependent on the size of the individual fish.

Savvatimsky (1989) found more than 20 food items belonging to different groups in the stomachs of Roughhead Grenadier. The occurrence of ophiura (26%) was the highest, polychaetes (19%) second, and gastropods and bivalves (11.7%, with bivalves occurring more often) third, followed by different crustaceans. Large Roughhead Grenadier preferred Capelin (*Mallotus villosus*) and American Sand Eel (*Ammodytes americanus*); the occurrence of fish in stomachs was 25.3% at total lengths of 71-80 cm Roughhead Grenadier but only 3.3% in the 31-40 cm specimens. The smaller fish fed mainly on *Calanus* sp. (a copepod), amphipods, polychaetes and small ophiuroids. Eliassen and 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.

Immature and postspawning Roughhead Grenadier were the most intensive feeders but the intensity of feeding decreased in prespawning fishes (Savvatimsky 1989). The decrease in intensity of feeding during spawning was also typical of Roughhead Grenadier near the coast of Norway in winter 1982-84 (Savvatimsky 1985).

Scott and Scott (1988) noted that Roughhead Grenadier are “no doubt’ prey of larger animals but details in the literature are scarce. Hammill and Stenson (2000) recorded Macrouridae in the diet of Harp Seals (*Phoca groenlandica*), Hooded Seals (*Cystophora cristata*), Grey Seals (*Halichoerus grypus*) and Harbour Seals (*Phoca vitulina*) combined in Atlantic Canada but did not describe the specific species. Rodriguez-Marin *et al.* (1995) noted a higher presence of species such as *Roughhead Grenadier* in the diet of Greenland Halibut (*Reinhardtius hippoglossoides*) as depth increased. They also noted that the wide distribution of the Roughhead Grenadier makes it ideal prey for large sized Greenland Halibut.

Khan *et al.* (1980) reported the presence of trypanosome blood parasites in four of 41 Roughhead Grenadier samples from Div. 3NO (southern portion of Grand Bank). He also reported infections in samples from Ungava Bay as well as northern and southern Labrador (Khan 1986). The latter study also reported hemogregarine parasites in samples from northern and southern Labrador and piroplasm parasites in samples from southern Labrador. Khan (2009) found that a coccidian, *Goussia caseosa*, with an infection rate of 91%, caused lesions in the swim bladder of fish sampled from Davis Strait to the Grand Bank. He speculated that because the swim bladder was filled with a creamy mass that inhibited gaseous exchange, upward migration was limited and infected fish were restricted to feeding only on benthic prey.

Garabana *et al.* (2016) found that almost one-quarter of females, sampled from the commercial fishery as well as research surveys in Div. 3LMN (north and southeast Grand Bank / Flemish Cap), contained parasites or had signs of having parasites. They concluded the potential damage caused to the gonad could be high and reduce fecundity, and indicated that more work is required before the impacts on reproductive potential could be evaluated.

Edinger *et al.* (2007) reported Roughhead Grenadier were most abundant in sets defined by large gorgonians and antipatharians at 200–400 m depths, but at 400–600 m and 600–1000 m depths they were most abundant in soft coral sets. These conclusions were based on data from fall DFO trawl surveys (2003 – 2005) and the 2005 Northern Shrimp Research foundation (NSRF) trawl survey of northern Labrador and the Davis Strait, covering the area north of latitude 58°N (NAFO Div. 2G and 0B) and totalling 1614 sets.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Population size and trends of Roughhead Grenadier were based on offshore demersal trawl surveys conducted by DFO, the European Union (EU) and EU-Spain, and Greenland. Only Canadian surveys conducted by the Newfoundland and Labrador Region (NL) (excluding Div. 3P (off south coast of Newfoundland)) were examined in detail because of limited annual data or no catches elsewhere (Figure 2). COSEWIC (2007) described trends in the data up to 2005. For this report, survey data from

1995/1996 through 2016 were examined. This corresponds to the period when the Campelen gear was used. Differences between surveys exist regarding depths surveyed and seasons (hence catchabilities) so two Canadian survey series were developed (Table 1).

Table 1. A summary of Fisheries and Oceans research survey data used for analysis showing gears and seasons fished. NL is DFO, Newfoundland Region.

Region	NAFO Area	Years	Season	Max. Depth (m)	Gear
NL	2HJ3KL (Labrador Shelf and northern Grand Bank)	1995-2016	Fall	1500	Campelen 1800 shrimp trawl
NL	3LNO (Grand Bank)	1996-2016	Spring	730	Campelen 1800 shrimp trawl

The fall surveys in Div. 2HJ3KL were sampled to 1500 m. Although these surveys include Div. 3NO, in most years the maximum depth surveyed in these divisions was only 731 m, so they were excluded from the analyses. The spring surveys in 3LNO were only conducted to a maximum depth of 731 m in all three divisions.

Not all NAFO Divisions were covered in all years, nor were all strata (Power *et al.* 2015, 2016). COSEWIC (2007) incorporated a multiplicative model to estimate values for missing strata. A similar exercise was carried out with the survey data above but, except for some differences in the inter-annual variation, the overall trends remained the same (see e.g., Figure 4). Also, in more recent years, the filling of missing strata has become increasingly uncertain due to the greater gaps in surveyed strata, especially in the deeper waters. Therefore, unlike COSEWIC (2007), abundance estimates and trends were examined based on the data as collected without accounting for missing strata.

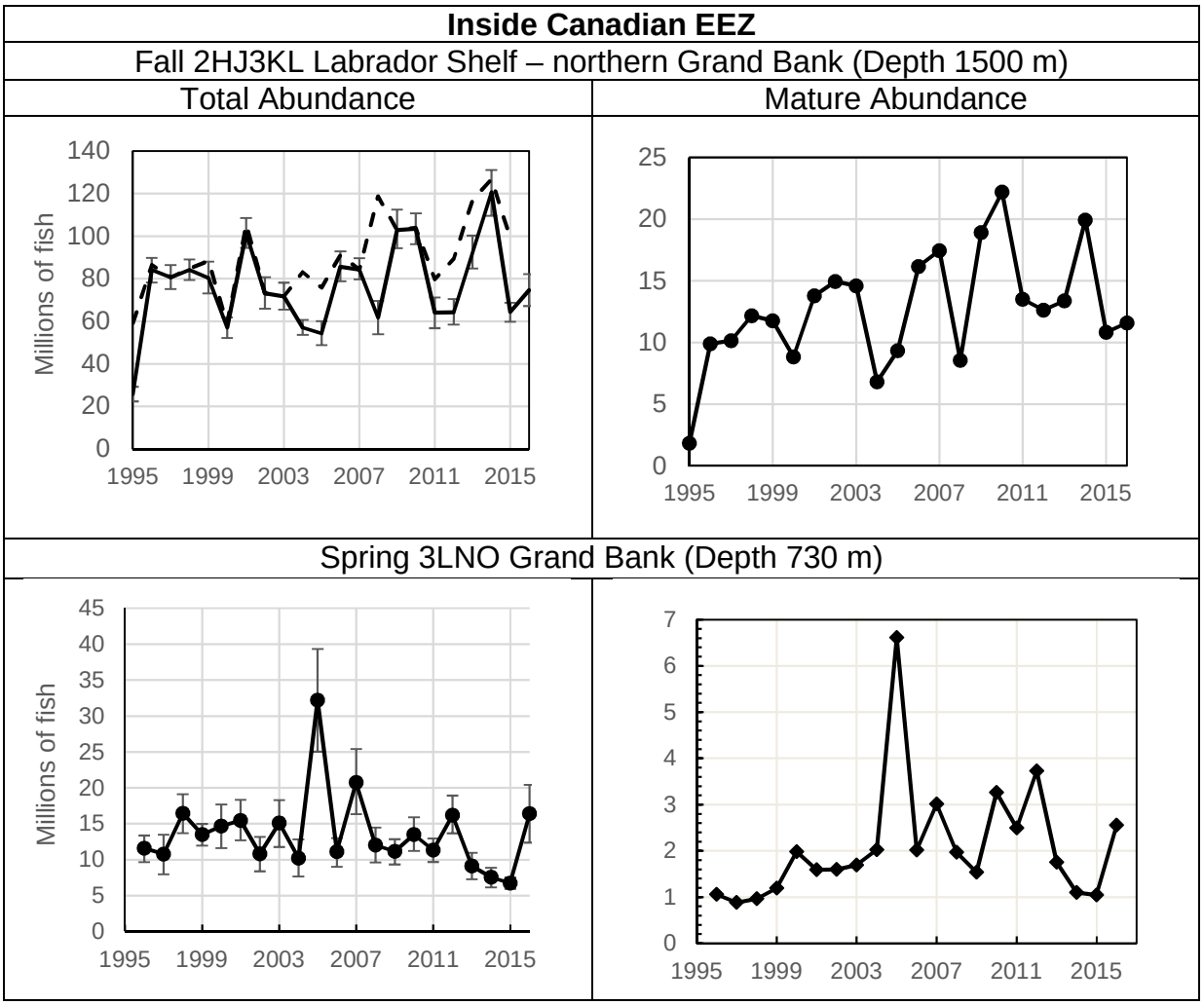

Figure 4. Total and mature abundance from surveys inside the Canadian EEZ. Note scale is in millions of fish. Scales differ on abundance axes depending on minimum and maximum values for each survey. Solid line is based on the actual survey data; dashed line includes strata with estimated values for Total Abundance (Fall 2HJ3KL Labrador Shelf – northern Grand Bank). Confidence intervals are 95% for Total Abundance estimates.

Outside Canadian EEZ surveys are conducted by the European Union (EU) and EU-Spain, and Greenland. The European survey areas (Figure 2, Table 2) comprise a relatively small proportion of the North Atlantic distribution for Roughhead Grenadier.

Table 2. Summary of the EU and Greenland surveys outside Canada's EEZ that contain information regarding Roughhead Grenadier.

Country	NAFO Area	Years	Season	Max. Depth (m)	Gear
EU-Spain	3L (northern Grand Bank)	2003-2004; 2006-2016	Summer	1500	Campelen
EU	3M (Flemish Cap)	2004 - 2016	Summer	1500	Padreira – Campelen
EU-Spain	3NO (southern Grand Bank)	1997 - 2016	Spring	1500	Campelen
Greenland	1CD (West Greenland)	1997 - 2016	Summer	1500	Alfredo III

Mean numbers / tow at length from EU-Spanish surveys outside 200-miles in Div. 3NO (southern Grand Bank) were obtained from (González-Troncoso *et a*l. 2010, 2015, 2017), and mean numbers / tow at length from their surveys outside Canada's EEZ in Div. 3L (northern Grand Bank) are from Román *et al*. (2017). EU survey abundance information at age from Flemish Cap surveys is from Sánchez and González-Troncoso (2017). These indices have been corrected for vessel and gear changes as described by González-Costas and Murua (2005). Table 2 summarizes the surveys and indicates survey years as well as depth coverage.

Abundance of mature individuals (sexes combined) was determined by extracting then adding together male and female AFL L_{50} estimates (≥27.5 cm for females; ≥16.0 cm for males) based on information from the various EU surveys (**Life Cycle and Reproduction** section above). For the EU survey in Div. 3M only unsexed age information was available. Based on an A_{50} for females of 14 years and an estimated A_{50} for males with AFL L_{50} of ~16 cm at ~8 years (Rodríguez-Marín *et al.* 1998; Fossen *et al.* 2003; Murua *et al.* 2005), mature adults were estimated as ages 11 and over. This corresponds to the A_{1st} described by Murua (2003).

Abundance estimates from Greenland surveys off West Greenland (NAFO Div. 1CD) conducted from 1997 through 2016 were extracted from Jørgensen (2017). Only total abundance information was available from these surveys.

For assessment purposes, NAFO Scientific Council considers Roughhead Grenadier in SA2+3 (Labrador Shelf Area / Grand Bank) to represent a single stock and carries out assessments of this resource every 3 years. The most recent of these was done in June, 2016 (González-Costas 2016, NAFO 2016) and the results presented below.

Abundance Fluctuations and Trends

Newfoundland and Labrador Surveys

Total abundance results from the NL fall surveys in Div. 2HJ3KL (Labrador Shelf and northern Grand Bank) (Figure 4) indicate considerable inter-annual variability primarily due to lower coverage of the deeper strata (e.g., 2008, 2011, 2012, 2013, 2015 and 2016) but overall there is an increasing trend.

Abundance of mature individuals (Figure 4) also indicates an overall increasing trend from 1995 – 2015, again with considerable inter-annual variability.

The NL spring survey data from Div. 3LNO (Grand Bank) also indicate considerable variability between years but no overall trend (Figure 4). This decline is related to reduced abundance in the strata between 366 m and 731 m. Whether this trend reflects a real decline or simply a shift in distribution to deeper water is unknown. The highest proportion of the annual overall abundance estimates were from Div. 3L (northern Grand Bank). In 2015, six strata in Div. 3L (northern Grand Bank) that made up 36% of the 2014 estimate of abundance for that division were not surveyed. Overall, it is considered that depth coverage has been too limited and inconsistent among years to allow determination of abundance trend estimates with sufficient confidence.

Abundance of mature individuals based on spring survey data (Figure 4) shows no overall trend with time, again with considerable inter-annual fluctuations. The high values in 2005 and 2007 are also reflected in the total abundance estimates and are related to abnormally high catches in single sets.

The Change in Abundance ($CA_{\%}$) was estimated from the slope of the linear regression of $\log_e$ abundance (N_t) versus time (t, in years). The resulting regression equation is

$$lnN_t = \propto + \beta \times t$$

The percentage CA ($CA_{\%}$) over years is then calculated as

$$CA_{\%} = (1 - e^{(\beta \times years - 1)}) \times 100$$

Over the 21/22-year survey period for mature adults only, the change in abundance is positive for both the fall survey data and the spring data (Figure 5). In addition, with the influential 1995 point removed from the fall survey the change in abundance remains positive (Figure 5). Note that the 21/22-year periods are slightly greater than 1 generation (17.7 years).

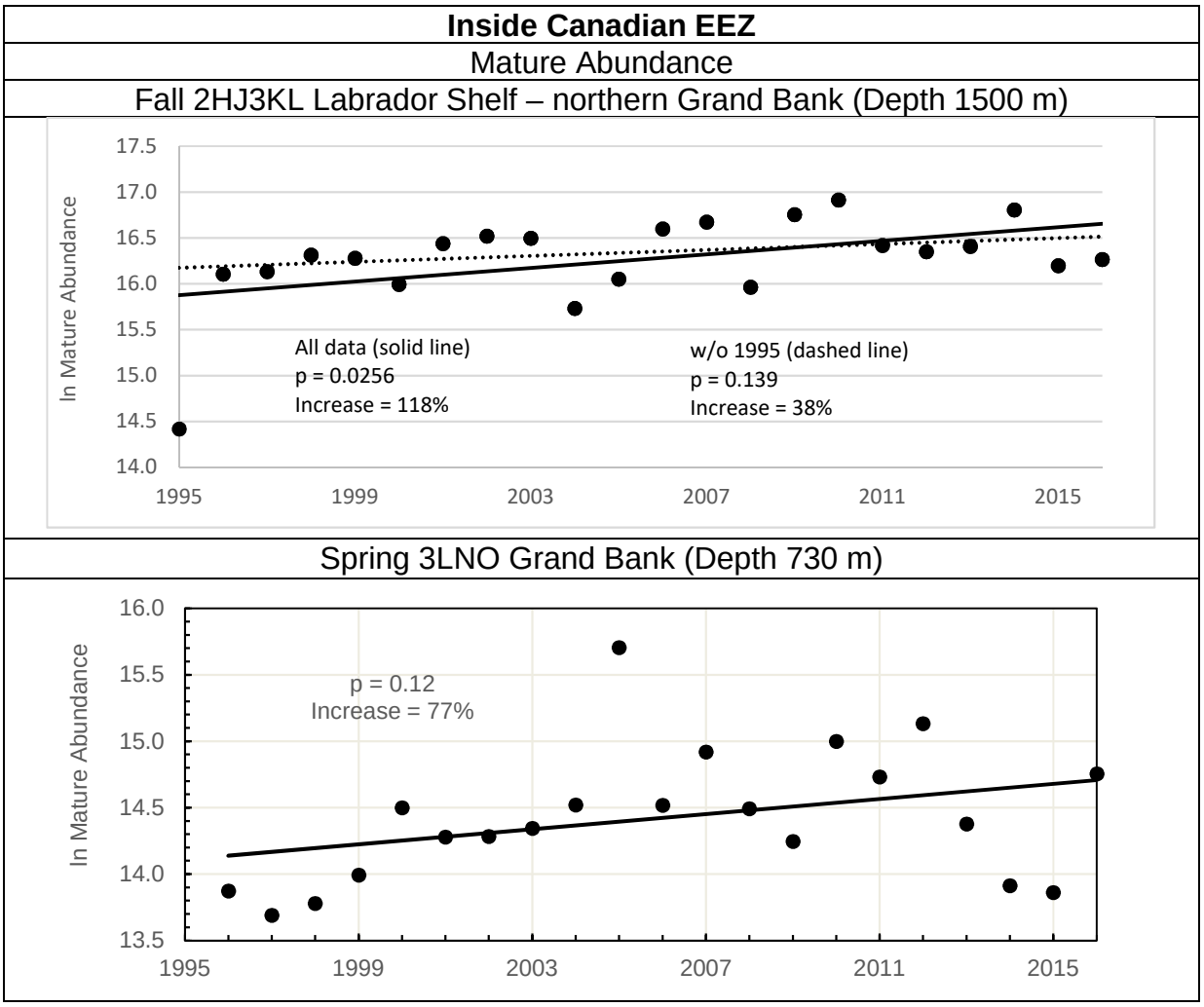

Figure 5. Change in abundance of mature Roughhead Grenadier based on NL Region fall surveys in Div. 2HJ3KL (Labrador Shelf – northern Grand Bank) and 3LNO (Grand Bank).

European Surveys

The surveys conducted by the European Union are only done in the areas outside Canada's 200-mile EEZ. This area is a relatively small proportion of the overall distribution area of the species compared to the area inside the Canadian EEZ (Figure 2). The area in Div. 3L (northern Grand Bank) is often referred to as the 'nose' while the area in Div. 3NO (southern Grand Bank) is called the 'tail'. As such, changes in abundance may only represent changes in local density that may not be representative of overall abundance changes.

In Div. 3L (northern Grand Bank), total (immature + mature) mean numbers / tow declined from 2008 to 2012 but subsequently appear to have increased although there is considerable inter-annual variability (Figure 6). Mature mean numbers / tow decreased to 2012 then stabilized, showed an increase in 2015 but declined again to the 2014 level in 2016 (Figure 6).

Based on surveys to 1500 m on Flemish Cap (Div. 3M), declines in total and mature survey abundance occurred from 2004 to 2011 (Figure 6)

In Div. 3NO (southern Grand Bank), the trend in total (mature + immature) mean numbers / tow indicates a slight increase followed by a subsequent gradual decline (Figure 6). The mature mean numbers / tow also suggests a gradual increase from 1995 through 2012 followed by a decrease (Figure 6). There is considerable inter-annual variability within both series.

Linear regressions of ln transformed mature abundance indices versus time shows a 41% decline for Div. 3L (northern Grand Bank). There is a 75% decrease in Div. 3M (Flemish Cap) over 12 years. In 3NO (southern Grand Bank) the overall trend is an 18% decline. The decline from 2004-2016 (12 years) is 65% (Figure 7).

Greenland Surveys

Stratified random surveys for Greenland Halibut and Roundnose Grenadier have been conducted by Greenland in Div. 1CD (off West Greenland) at depths between 400 and 1500 m since 1997. Jørgensen (2016) reported that while Roughhead Grenadier were caught throughout the survey area, their numbers were generally low. Total abundance was estimated to be about 10 million individuals, which was among the lowest in the time series (Figure 8). Densities in numbers per km^2 were fairly evenly distributed at depths > 600 m.

Linear regressions of the ln transformed total abundance index versus time shows a 50% decline (Figure 8).

NAFO Assessment – survey and trend interpretation

The most recent Roughhead Grenadier assessment of Roughhead Grenadier in SA 2+3 (Labrador Shelf Area and Grand Bank) by NAFO Scientific Council occurred in 2016 and involved three different analyses: an Extended Survivors Analysis (XSA), a Stock-Production Model Incorporating Covariates (ASPIC) and qualitative evaluation based on survey and fishery information (González-Costas 2016). It was concluded that the results from XSA and ASPIC were not representative of the status of the stock. Instead, biomass indices from the surveys with depth coverage to 1500 m were considered the best information to monitor trends in species status because they cover the depth distribution of Roughhead Grenadier fairly well (NAFO 2016). The assessment did not comment on the possible impacts of distribution extending deeper than the surveyed areas as had been suggested by COSEWIC (2007) and Garabana *et al*. (2016) and documented by Murua and De Cárdenas (2005).

Overall the NAFO assessment concluded that the survey indices suggest a stable or declining stock in recent years and fishing mortality indices (based on survey Catch/Biomass ratios and catch curves using survey and commercial catch-at-age data) have remained at low levels since 2005 (NAFO 2016).

The next full NAFO assessment of Roughhead Grenadier is scheduled for 2019 (NAFO 2017).

Summary - Abundance Fluctuations and Trends

The uncertainty associated with surveys used to examine abundance trends in the previous report (COSEWIC 2007) has been reduced because surveys since 1995 cover the depths of highest densities. Even though Roughhead Grenadier occur deeper than 1500 m, there is no evidence that systematic trends, resulting from dispersal or migration between deep and shallow waters, that would disrupt major conclusions on trends, occur. Hence, there is no systematic variation that would violate assumptions required for an appropriate index.

Survey results beyond Canada's EEZ in Div. 1CD, Div. 3L Div. 3M and Div. 3NO all suggest gradual declines, especially in the recent period (Div. 3NO), whereas DFO survey results mainly inside the EEZ suggest stability or moderate increases (Figures 5, 7, 8, Table 3). However, mature abundance in the Labrador Shelf – northern Grand Bank survey (2H3JKL) averages approximately 13 million mature fish from 1995 - 2016 (Figure 4, Table 3). Mature abundance in the EU Flemish Cap (3M) survey averages about 3.5 thousand fish (Figure 6, Table 3). The Labrador Shelf – northern Grand Bank survey (2H3JKL) covers a greater area than the surveys outside the EEZ (Figure 2).

Table 3. Summary of trends in abundance of Roughhead Grenadier over time from the different surveys carried out in the NAFO area (DU is Northwest Atlantic (NWA)).

Survey	NAFO Divisions	Years	Average Number of mature fish or number/tow) over years	% Change	Years N	Adjusted R^2	P-value	Slope	Intercept
Newfoundland & Labrador Fall fishery	2HJ3KL South Labrador Shelf / northern Grand Bank	1995-2016	12.69 millions of fish (1995-2016), 13.21 millions of fish (1996-2016)	+117.5 +38.3	21 20	0.1896 0.0647	0.0256 0.139	0.0371 0.0162	-58.05 -16.16
Newfoundland & Labrador Spring Survey	3LNO Grand Bank	1996 - 2016	2.10 millions of fish	+76.6	20	0.0771	0.119	0.0284	-42.63
EU 3L	3L NRA northern Grand Bank outside Canada's EEZ	2003 – 2016, 2005 missing	9.68 numbers/tow	-41.3	13	0.2418	0.050	-0.041	+84.54
EU 3M	3M Flemish Cap	2004 - 2016	3.5 thousands of fish	-74.7	12	0.8623	<0.001	238.6	-0.12

Survey	NAFO Divisions	Years	Average Number of mature fish or number/tow) over years	% Change	Years N	Adjusted R^2	P-value	Slope	Intercept
EU 3NO	3NO NRA southern Grand Bank outside Canada's EEZ	1997-2016	2.97 number/tow (1997-2016) 3..17 number/tow (2004-2016)	-17.9 -64.5	19 12	-0.024 0.7507	0.468 <0.001	-0.014 -0.086	21.85 174.78
Greenland 1CD	1CD West Greenland outside Canada's EEZ	1997-2016	Total abundance 10.71 millions of fish	-50.1	19	0.222	0.021	-0.037	75.67

Survey trend uncertainties remaining include the consideration that depth coverage in the DFO 3LNO (Grand Bank) survey has been too limited and inconsistent among years to allow determination of abundance estimate trends with any confidence (Figure 4). Abundance trends as mean number / tow were only available for the EU survey in 3L (northern Grand Bank) and EU 3NO (southern Grand Bank) surveys. As a result, it was not possible to convert these to mature abundance estimates (Figures 6, 7), as it was for Labrador Shelf – northern Grand Bank (2H3JKL) and the EU Flemish Cap (3M) surveys (Figures 4, 5, 6, 7). Finally, the 1995 point for the Labrador Shelf – northern Grand Bank survey (2H3JKL) was an influential point in defining the increase in abundance from 1996 – 2016. Without this point the increase in abundance was 38% (Figure 5, Table 2).

With consideration for these changes in survey depth and uncertainties it was concluded that the Labrador Shelf – northern Grand Bank (2H3JKL) survey was an appropriate index for Roughhead Grenadier, demonstrates an increasing trend in the core area of the populations, and should receive the most weight in the designation decision.

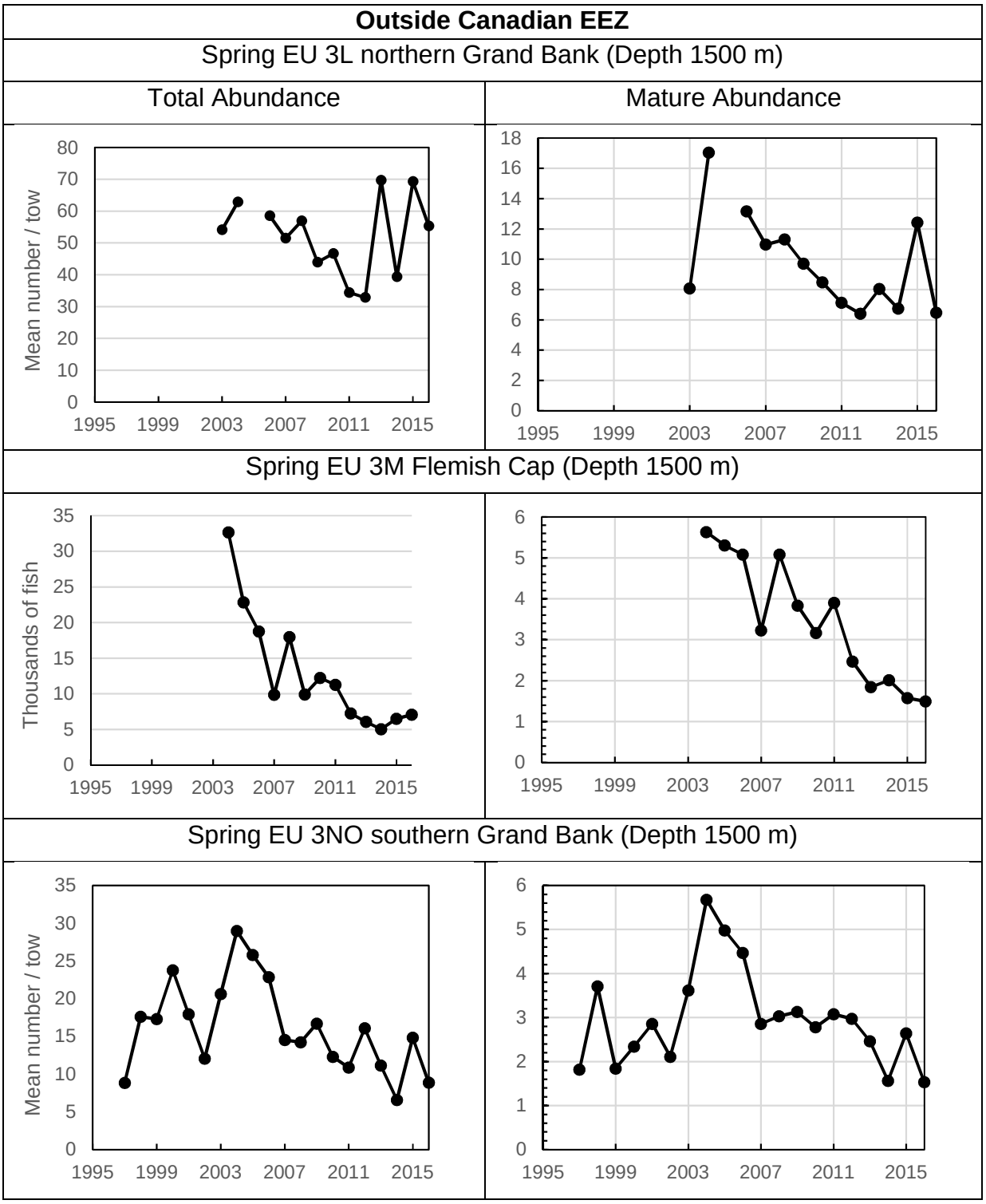

Figure 6. Total and mature abundance from surveys outside the Canadian EEZ. Note scales are in millions of fish, thousands of fish, and mean numbers / tow depending on the data available for each survey. Scales differ on abundance axes depending on minimum and maximum values for each survey.

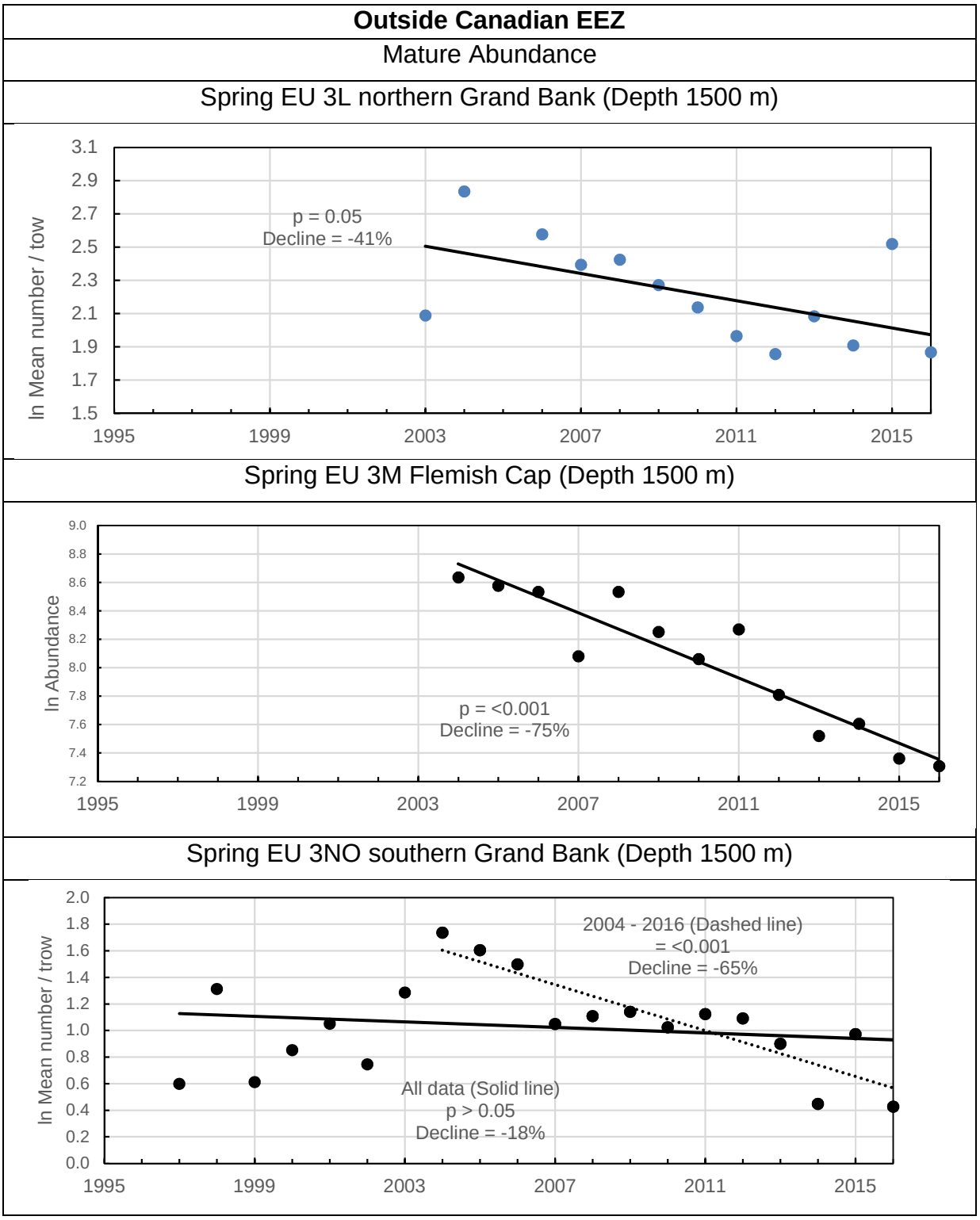

Figure 7. Percent decline of mature Roughhead Grenadier based on EU surveys outside Canada's EEZ in Div. 3L, 3NO and 3M.

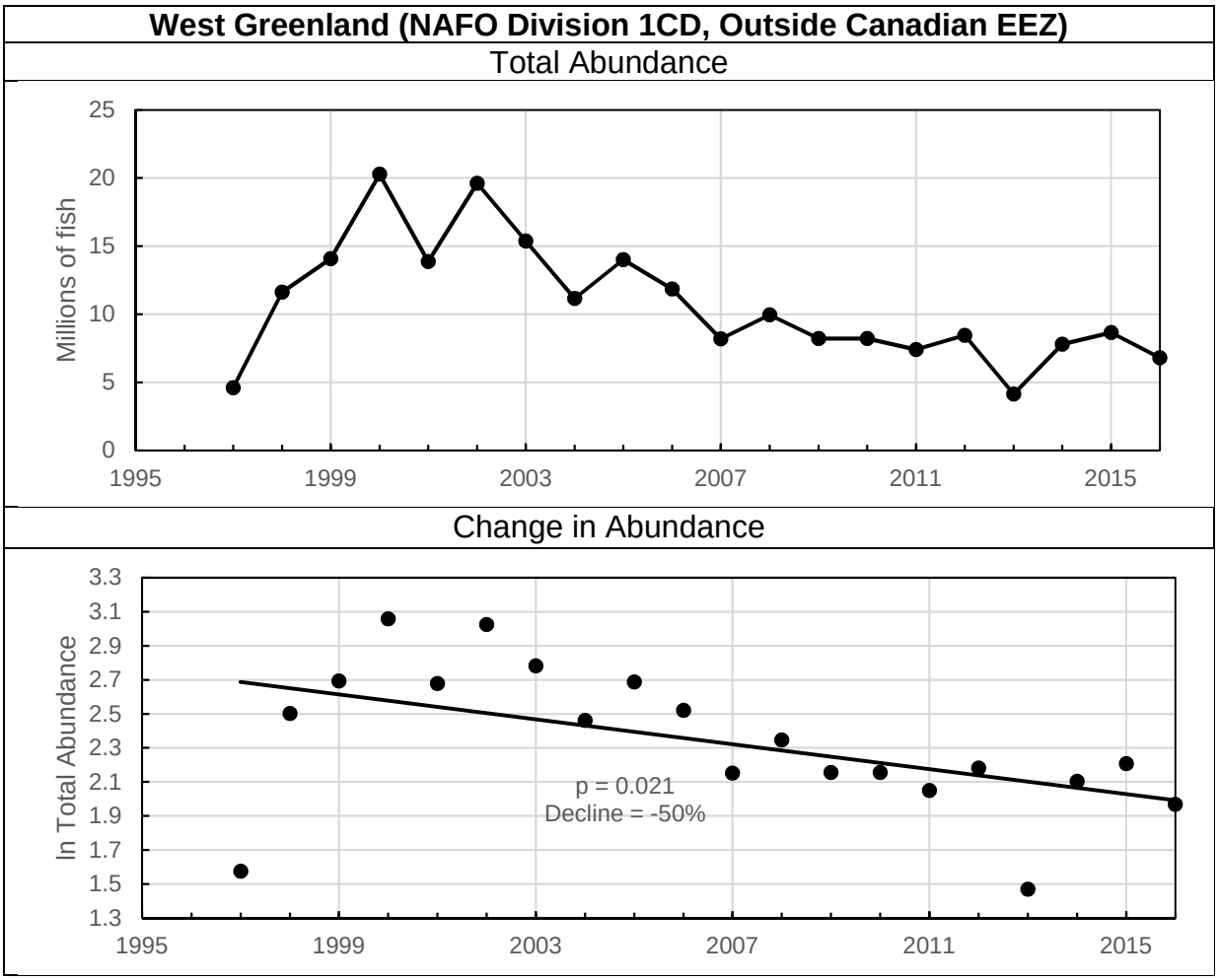

Figure 8. Trend in abundance (millions of fish) of Roughhead Grenadier based on Greenland surveys in NAFO Div. 1CD (West Greenland) (Top). Percent decline of Roughhead Grenadier based on Greenland surveys outside Canada's EEZ in Div. 1CD (Bottom).

Rescue Effect

Roughhead Grenadier distribution is contiguous with areas adjacent to Canadian waters, most specifically West Greenland, the 'nose' of the Grand Bank in Div. 3L and Flemish Cap, and the 'tail' of the Grand Bank (Div. 3NO) (Figure 2). Distribution is also likely continuous throughout deeper Canadian and USA waters in the south. Possible rescue from West Greenland and USA is considered to be limited. Rescue from the nose, tail and Flemish Cap is possible although considering the continuous distribution extending beyond Canada's EEZ, it is believed that any declines would be applicable to the entire area and not limited to just Canadian waters thus possibly limiting recovery from outside Canada's EEZ. Additionally, current survey information suggests possible declines outside the EEZ but not inside.

THREATS AND LIMITING FACTORS

Threats to Roughhead Grenadier such as pollution, shipping and oil/gas development may be possible but are undocumented. Similarly, climate change may impact the species. Bottom temperature information is available from the various DFO surveys, but these data were not examined to determine if there have been any trends over time.

As noted above, parasitic infections may increase mortality and decrease reproductive potential but possible impacts at the population level are unknown.

At present, there are no directed fisheries for Roughhead Grenadier and they are mainly taken as bycatch in the Greenland Halibut fisheries. Hence, the primary threat to Roughhead Grenadier is considered to be commercial fishery bycatch. Roughhead Grenadier is vulnerable to over-fishing because of its life-history traits including relatively long-life span, late maturity, possible atresia, barotrauma (injury due to rapid pressure changes), slow growth rates, and long population turnover time. These traits can work together to make recovery following population reduction difficult.

The Greenland Halibut fishery began as a gillnet fishery during the 1960s in deep inshore bays of coastal Newfoundland, and trawlers from Eastern Europe and the USSR entered the fishery on the Grand Bank in the 1970s. This non-Canadian effort was mostly removed from Canadian waters when the 200-mile limit came into effect in 1977 and the current trawl fishery outside Canadian waters started in 1990 along the outer edge of the Grand Bank and in Flemish Pass (Div. 3LMNO). The non-Canadian fishery outside Canadian waters (Grand Bank – 3LMNO) is estimated to have made up about 75% of the overall Roughhead Grenadier bycatch since 1990 (NAFO 2016).

Past catches have been shown to be under-reported. For example, Durán *et al.* (1997) reported discard rates of Roughhead Grenadier ranged between about 40% to 75% in the Spanish Greenland halibut fishery during 1991 – 1994 and those discards are not included in reported bycatch statistics (Figure 9). Furthermore, annual At-Sea Fisheries Observer coverage of the Canadian Greenland Halibut fishery is ≤5%, thereby resulting in at least 95% of Canadian Roughhead Grenadier discards remaining unreported and absent in commercial fisheries statistics (Miri 2017). Mortality of discards is expected to be high due to barotrauma.

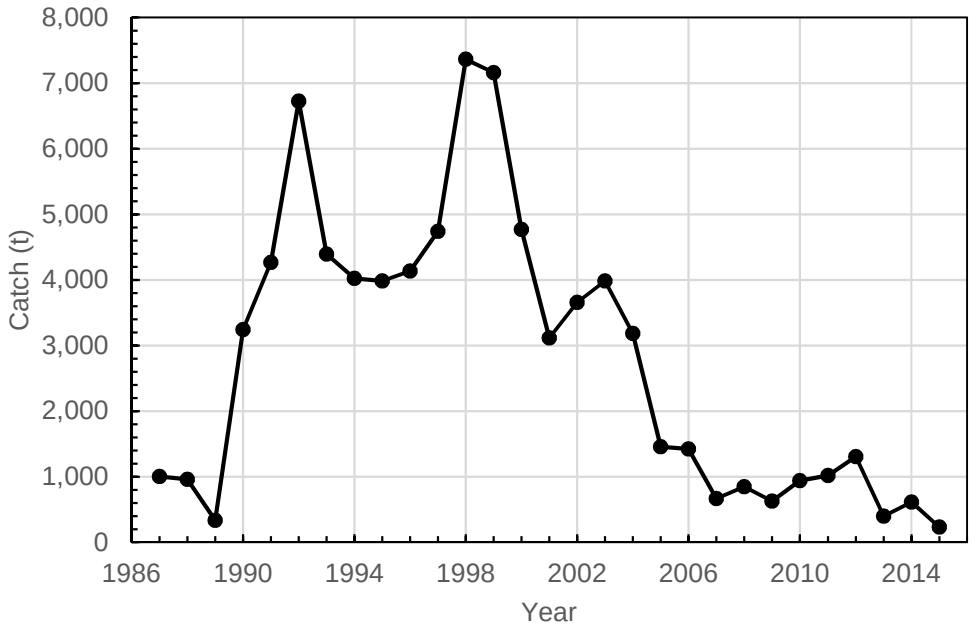

Figure 9. Reported commercial catches of Roughhead Grenadier.

Survey information from outside Canada's EEZ shows general declines in both total and mature abundance (Figure 7, Table 3) that correspond to the areas of highest bycatch since 1990 and are consistent with hypotheses that overall removals in these areas are too high. On the other hand, increases indicated in the DFO survey data for the Labrador Shelf and Grand Bank (Figure 5, Table 3) indicate there are no serious issues in Canadian waters.

Uncertainty in by-catch F estimates

There are three sources of uncertainty in F estimates of the NAFO assessment methodologies and hence conclusions. Firstly, the assumed M = 0.1 is thought to be too low. The value used in this report (0.15) is better supported by broad scale analyses of marine species by Hoenig (1983), compared to the estimates provided in González-Costas (2013, 2016). Secondly, the NAFO assessment did not contemplate the possible under-reporting of catches (i.e., unreported discards) and how these amounts may change over time. Thirdly, the catch curve analyses in the NAFO assessment document included two ages in the ascending portion of the catch curves (ages 6 and 7).

The inclusion of ascending ages in catch curve analysis leads to an underestimate of total mortality (Z). Smith *et al.* (2012) recommended that the youngest age used should be the age of maximum catch + 1. For these analyses, that would be age 9. They also recommended that linear regressions should not be used, and the best estimator of catch curve Z is the bias corrected Chapman-Robson method. Using the approach recommended by Smith *et al.* (2012) and appropriate starting age (9 in this case) results in higher estimates of Z within each of the age ranges examined (9 – 13 and 9 – 16)

(Table 4). These higher estimates of Z and F create concern because they are >M (see e.g., Gabriel and Mace 1999, Sainsbury 2008, Zhou *et al.* 2012).

Table 4. Estimates of total mortality (Z) and fishing mortality (F) assuming natural mortality (M) = 0.15 from catch curve analyses using catch-at-age information used by González-Costas (2016) but based on methodology recommended by Smith *et al.* (2012) (LR – linear regression; CRBC – Chapman-Robson bias corrected).

Survey / Age	NAFO (LR)		LR		LR		CRBC		CRBC	
	6-13		9-13		9-16		9-13		9-16	
	Z	F	Z	F	Z	F	Z	F	Z	F
EU – 3NO	0.21	0.06	0.30	0.15	0.36	0.21	0.53	0.38	0.41	0.26
EU – 3M 1400	0.13	-0.02	0.20	0.05	0.23	0.08	0.48	0.33	0.35	0.20
CAN 2J3K	0.24	0.09	0.34	0.19	0.41	0.26	0.54	0.39	0.44	0.29
Catch	0.19	0.04	0.33	0.18	0.37	0.22	0.55	0.40	0.43	0.28

However, there are important contradictions regardless of the method or ages used. Whereas the Canadian survey results suggest an abundance increase over time (Figure 5), the estimated Zs are higher than the EU Flemish Cap (3M) and southern Grand Bank (3NO) surveys, which declined since 2004 (Figure 7). Resolution of these contradictions requires detailed analyses of the survey catch-at-age matrices, which were not available at the time of this report.

There is no doubt that an overall decline in bycatch occurred as the fishery for Greenland Halibut was brought under control of quota management outside Canada's 200-mile limit in the mid-1990s. Nevertheless, until these uncertainties are resolved it is considered that greater weight should be given to trends in the survey estimates in designation decisions.

Number of Locations

The number of locations was not determined because Roughhead Grenadier do not occupy multiple discrete locations but rather form a nearly continuous distribution over more than 26 degrees of latitude (~2900 km) along the shelf waters of West Greenland, Canada, and USA and there is not an identified threat that could reduce the mature abundance over a relatively short period of time.

Threat Summary

The rationale for Special Concern (COSEWIC 2007) was a probable decline in abundance in the 1980s and 1990s, and the lack of a management plan for directed and incidental harvest. Currently, most of the by-catch occurs outside the core area of the population (Labrador Shelf – northern Grand Bank, 2HJ3KL), the population index in the core area has increased since 1995, there is a steady decline in reported by-catch since 2003, and a management plan exists for the Greenland Halibut fishery. Hence, the threat of Roughhead Grenadier by-catch has been reduced and managed with demonstrable effectiveness.

In conclusion, the potential threat from bycatch is not likely to lead to mature abundance declines, as Canadian and international management is focused on recovery of Greenland Halibut.

PROTECTION, STATUS AND RANKS

Legal and Non-Legal Protection and Status

IUCN Redlist Status – Not Evaluated

CITES – Not Evaluated

NatureServe Status
Global Status: GNR – Not Yet Ranked
Rounded Global Status: GNR – Not Yet Ranked
National Status: NNR – Not Yet Ranked
Nunavut: SNR – Not Yet Ranked

There are no specific Canadian, Greenlandic or NAFO regulations aimed at Roughhead Grenadier. It is only protected indirectly through regulations for Greenland Halibut and other fisheries that take Roughhead Grenadier as bycatch.

Habitat Protection and Ownership

Although a number of closed/protected areas including Marine Protected Areas can be found throughout the Canadian Atlantic, none are specifically designed to protect Roughhead Grenadier. With the exception of the Gully and an area off the southwest edge of the Grand Bank (Div. 3O), the degree of protection attributable to many of these areas is likely minor as they are mainly inshore. There is a voluntary closure of a small area off the northern tip of Labrador to shrimp fishing to protect corals and there are also some specific areas closed to fishing in the NAFO Regulatory Area (NAFO 2018). These deepwater closures should afford some protection to Roughhead Grenadier although this cannot be quantified.

More recently, DFO has enacted some additional closures that may aid in the protection of Roughhead Grenadier. The Northeast Newfoundland Slope Closure (DFO 2018), the Davis Strait Conservation Area (DFO 2017a) and Disko Fan Conservation Area (DFO 2017b) are aimed at protecting cold-water corals, sea pens and sponges but are in areas inhabited by Roughhead Grenadier. These areas are closed to all bottom contact fishing activities and as such should serve as refugia for Roughhead Grenadier.

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

Gratitude is extended to the following who provided contacts, information and/or advice relevant to the completion this status report.

COSEWIC Secretariat

- Julie Beaulieu, Neil Jones, Bev McBride, Sonia Schnobb

Department of Fisheries and Oceans

- National Headquarters - Christie Whelan (now with Pacific Region)
- Central and Arctic Region - Margaret Treble
- Gulf Region – Hugues Benoit, Doug Swain
- Maritimes Region - Daphne Themelis
- Newfoundland and Labrador Region – John Brattey, Roanne Collins, Sue Forsey, Danny Ings, Barry McCallum, Jim Meade, Luiz Mello, Carolyn Miri, Erika Parrill, Rick Rideout, Mark Simpson
- Québec Region - Johanne Gauthier

Other

- Dave Kulka, Scientist Emeritus, DFO, NL Region
- Tom Dooley, Newfoundland and Labrador Department of Fisheries and Aquaculture
- Lynda Orman, Nunavut Department of Environment
- Robert Anderson, Canadian Museum of Nature
- Noel Alfonso, Canadian Museum of Nature
- Stéphanie Tessier, Canadian Museum of Nature
- Sean Blaney, Atlantic Canada Conservation Data Centre (NS, NB, PEI)
- Cathy Sosebee, NOAA National Marine Fisheries Service, Woods Hole, MA, USA
- Bruce Chapman, head of CAPP (Canadian Association of Prawn Producers)
- Fernando González-Costas, Instituto Español de Oceanografía, Vigo, Spain
- Ricardo Alpoim, Instituto Español de Oceanografía, Vigo, Spain
- Distribution information was also provided by N. Alfonso and S. Tessier of the Canadian Museum of Nature.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

Bruce Atkinson is a retired fisheries biologist with more than 40 years' experience primarily related to the biology, life history and assessment of groundfish, but also with experience related to pelagic fishes and shellfish. His extended career with Department of Fisheries and Oceans Canada (DFO) also included management positions within Science culminating in the position of Regional Director of Science and Oceans sectors in Newfoundland and Labrador. He participated in the Northwest Atlantic Fisheries Organization (NAFO) for many years and was the Head of the Canadian Delegation to the Scientific Council from 2000-2004. Since retirement in 2005, he has maintained a keen interest in fisheries. He served on an Expert Panel that reviewed the performance of NEAFC (North East Atlantic Fisheries Commission) in relation to its mandated responsibilities, participated in regional groundfish assessments carried out by DFO in Newfoundland and Labrador as rapporteur, served as a reviewer of fisheries related proposals for European Union Framework Programme (FP7) and Horizon 2000 funding, chaired an Expert Panel that prepared a report on the Impacts of EU Framework Programmes (2000-2010) and Prospects for Research and Innovation in Fisheries and Aquaculture, served on an Expert Panel charged with developing an Outreach Strategy to better familiarize the EU public with Framework Programme benefits (2011-2012), served as a member of the Assessment Team for assessment of the Ocean Choice International Yellowtail Flounder Trawl Fishery against the MSC Principles and Criteria serving as lead for assessment of Principle 1 as well as being a member of the team conducting the subsequent annual audits and the 2014/2015 reassessment of this fishery, served as Chair of an Expert Panel that conducted a review of the methods of catch estimation of NAFO stocks by the NAFO Scientific Council as well as carrying out other fisheries related work under contract including 4 MSC peer reviews of fisheries as well as the conduct of 15 MSC CoC audits. He is currently a member of the COSEWIC (Committee on the Status of Endangered Wildlife in Canada) Marine Fishes Specialist Subcommittee.

COLLECTIONS EXAMINED

No specimens were examined.