COSEWIC
Assessment and Status Report

on the

Lumpfish
Cyclopterus lumpus

in Canada

THREATENED
2017

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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Lumpfish — Provided by authors.

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COSEWIC
Assessment Summary

Assessment Summary – November 2017

Common name
Lumpfish

Scientific name
Cyclopterus lumpus

Status
Threatened

Reason for designation
This marine fish species is broadly distributed across the Northwest Atlantic. Directed commercial fishery landings have declined sharply since 2005, in spite of high market demand. There have been declines in abundance of about 58% indicated in bottom trawl surveys over 19-20 years, conducted in the core part of its Canadian range (off southern Newfoundland). However, abundance appears to have remained stable across other parts of the Canadian range such as the northern Gulf of St. Lawrence, making recolonization possible.

Occurrence
Nunavut, Manitoba, Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, Newfoundland and Labrador, Atlantic Ocean

Status history
Designated Threatened in November 2017.

COSEWIC
Executive Summary

Lumpfish
Cyclopterus lumpus

Wildlife Species Description and Significance

Lumpfish is a member of the Cyclopteridae family and is the only species of the genus *Cyclopterus*. It is a thick, almost ball-shaped fish. The color is variable, often matching surroundings, especially in the young. Breeding males have a dark blue body, orange to red fins and belly, plus a metallic silver patch behind each pectoral fin. Their unusual appearance and wide distribution in the North Atlantic has led to the use of an unusually large number of common names including Lumpfish, henfish, lumpsucker, poule l'eau (Fr), grosse poule de mer (Fr), Lompe (Fr), Nipisa, Lepisuk, Qorkshuyoq (I).

Beginning in 1969, a fishery for roe was developed off Newfoundland when depletions in sturgeon (Acipenseridae) stocks coupled with an increase in world consumption of caviar created a market for a sturgeon caviar substitute. Canada was the leading exporter of Lumpfish roe during the 1980s and 1990s. Lumpfish (wild-sourced and hatchery reared) are being used to control sea lice at some Newfoundland and Labrador salmon aquaculture sites.

Distribution

Lumpfish are distributed demersally and pelagically in the North Atlantic Ocean. In the western Atlantic, they are occasionally caught up to 65ºN in Davis Strait but are more common further south with the highest estimates of abundance in waters surrounding the island of Newfoundland. Their Canadian extent of occurrence (EOO), from Davis Strait to the Gulf of Maine, is 5,280,226 km^2 and overall index of area of occupancy (IAO) is 106,136 km^2. Occasional records occur as far south as the mid-Atlantic Bight (37°N).

In the eastern Atlantic, they range from the Barents and White Seas south to Portugal and off Greenland, Iceland, Svalbard, Spitsbergen, in the North Sea, and rarely off Galicia, Spain and in the Mediterranean Sea (vagrant).

Habitat

Lumpfish are associated with diverse habitats, being found on the bottom and in the water column during different life stages and seasons. Females lay eggs in inshore nests established by males around rocky areas and in crevices, and the males guard the eggs. Young of the year inhabit near-surface waters often attached to or under floating seaweed. Adult Lumpfish are semi-pelagic, spending a greater portion of their time near the bottom in the winter months. At all stages, Lumpfish are often observed adhering to stones, lobster pots, seaweed or other objects by means of the pelvic adhesive disk, thereby making use of complex benthic structure to prevent drift in the currents.

There are clear temperature preferences that vary with stage; 4 to 12ºC for larvae and young of the year, and near bottom, from -1.9ºC to 12ºC for both juveniles and adults.

Biology

Most information describing Lumpfish biology, life history and population dynamics is based on research in the Northeast Atlantic. They display a high degree of sexual dimorphism with males being much smaller than females. Length at first maturity ranges from ~ 28 cm to over 40 cm for females. There are differing opinions regarding mortality related to reproduction with some arguing that Lumpfish are short lived and only spawn once, while others suggest multiple spawnings and a maximum age of about 12 years. Tagging results tend to support the latter perspective.

Generation time (*G*) was estimated to be 7 years and natural mortality (*M*) was approximated as 0.3 although both estimates are associated with considerable uncertainty.

Population Sizes and Trends

The different bottom trawl research surveys utilize different gears and cover different areas and depths so comparisons are not meaningful. Demersal survey data do indicate that the centre of mass in the Northwest Atlantic occurs around the island of Newfoundland and particularly off the south and west coasts (Northwest Atlantic Fisheries Organization (NAFO) Div. 3P and 4R) where the greatest proportion of the fishery takes place. Based on surveys in this area, there was a period of stability or some increase in abundance during 1995 to about 2005, after which there has been a precipitous decline as evidenced in both the spring survey data for Div. 3P (south coast) and the fall survey data for Div. 2+3KLNO (north-east coast and Labrador). Overall, there has been a decline in abundance of about 58% indicated in bottom trawl surveys over 19-20 years conducted in the core part of its Canadian range (off southern Newfoundland) However, abundance appears to have remained stable across other parts of the Canadian range such as the northern Gulf of St. Lawrence. In other areas, Lumpfish are only caught infrequently.

Threats and Limiting Factors

Key factors that may constitute threats to Lumpfish off Canada include fishing, change in habitat and seismic exploration. Young Lumpfish are a prey item for Thorny Skate, and sharks. Sperm Whales and seals prey upon adult Lumpfish. The effects of such predation are unknown.

Protection, Status and Ranks

The species has recently been listed by IUCN as NT (Near Threatened) (Appendix 1, Red List status of European marine fishes) for the Northeast Atlantic.

In Canada and the USA, Lumpfish are ranked as follows:

NatureServe Status

1. Global: GNR, Not Yet Ranked
2. National: Canada N4, (Apparently Secure, 06 May 2013)
   a. Ontario (SNA, Not Assessed)
   b. Quebec (S4, Apparently Secure; in Quebec, this species is not listed as “Threatened” under the “Loi sur les espèces menacées ou vulnérables” (RLRQ, c E-12.01) (LEMV) (Act respecting threatened or vulnerable species) (CQLR, c E-12.01).

      Also, this species is not included on the Liste des espèces susceptibles d’être désignées menacées ou vulnérables (list of wildlife species likely to be designated threatened or vulnerable). This list is produced according to the the “Loi sur les espèces menacées ou vulnérables” (RLRQ, c E-12.01) (LEMV) (Act respecting threatened or vulnerable species) (CQLR, c E-12.01).
3. National: United States: Rhode Island: SNR, Not Yet Ranked (southern limit).

In terms of fishery management, only occasional, rudimentary assessments of Lumpfish have been carried out in Canada and thus their population status is generally not well understood and the fishery is not managed based on changes in the population. There is no quota for the species but Conservation Harvesting Plans (CHPs) are in place. Management measures include vessel, gear and seasonal restrictions. Internationally, regulatory measures are in place for the Icelandic fishery. Some regulatory measures are also in place in Norway (season, mesh size, vessel size and individual Total Allowable Catch (TAC), Greenland (management plan and Marine Stewardship Certification since 2015, TAC, fishing season) and Denmark and Sweden (logbook, mesh size).

TECHNICAL SUMMARY

Cyclopterus lumpus

Lumpfish

Grosse poule de mer

Range of occurrence in Canada (province/territory/ocean): Nunavut, Manitoba, Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, Newfoundland and Labrador, Atlantic Ocean

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)	7 years but with uncertainty
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Yes (observed)
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Not Determined
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Declines in abundance of about 58% indicated in bottom trawl surveys over 19-20 years, conducted in the core part of its Canadian range (off southern Newfoundland) (inferred, three generations)
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[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.	Unknown
Are the causes of the decline a.clearly reversible and b.understood and c. ceased?	a. No b. No c. Unknown
Are there extreme fluctuations in number of mature individuals?	No

Extent and Occupancy Information

Estimated extent of occurrence	5,280,226 km^2
Index of area of occupancy (IAO) (Always report 2x2 grid value).	106,136 km^2
Is the population “severely fragmented” ie. 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)	>5 (directed and bycatch fisheries)
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?	No
Is there an [observed, inferred, or projected] decline in number of "locations"*?	No
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?	No
Are there extreme fluctuations in number of "locations"*?	No
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 Identified	
Total	

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Unknown

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

i. Overfishing
ii. Change in the habitat (no direct quantitative data)
iii. Seismic Exploration (no direct quantitative data)

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.	Unknown
Is immigration known or possible?	Uncertain
Would immigrants be adapted to survive in Canada?	Yes

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

Is there sufficient habitat for immigrants in Canada?	Yes
Are conditions deteriorating in Canada?[+]	Unknown but Unlikely
Are conditions for the source population deteriorating?[+]	Unknown but Unlikely
Is the Canadian population considered to be a sink?[+]	No
Is rescue from outside populations likely?	Unknown but unlikely

Data Sensitive Species

Is this a data sensitive species? No

Current Status

COSEWIC Status History: Designated Threatened in November 2017.

Status and Reasons for Designation:

Status: Threatened	**Alpha-numeric codes:** Meets criteria for Endangered, A2b, but designated Threatened, A2b, because the species is not at imminent risk of extirpation.
Reasons for designation: This marine fish species is broadly distributed across the Northwest Atlantic. Directed commercial fishery landings have declined sharply since 2005, in spite of high market demand. There have been declines in abundance of about 58% indicated in bottom trawl surveys over 19-20 years, conducted in the core part of its Canadian range (off southern Newfoundland). However, abundance appears to have remained stable across other parts of the Canadian range such as the northern Gulf of St. Lawrence, making recolonization possible.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Meets Endangered A2b, as the decline over three generations (21 years) is greater than 50%.
Criterion B (Small Distribution Range and Decline or Fluctuation): Does not apply because the extent of occurrence exceeds 20,000 km² and the index of area of occupancy is greater than 2,000 km².
Criterion C (Small and Declining Number of Mature Individuals): Not applicable. The number of mature individuals is likely greater than criterion thresholds.
Criterion D (Very Small or Restricted Population): Not applicable. The number of mature individuals is likely greater than criterion thresholds.
Criterion E (Quantitative Analysis): Not done.

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

PREFACE

Studies of Lumpfish in Canadian waters of the Northwest Atlantic have been limited, with many aspects of their life history and biology remaining unknown or, at best, uncertain. This report attempts to help rectify this situation by pulling together information from available literature (including from the Northeast Atlantic), and research surveys conducted by DFO in Atlantic Canada.

In support of this work, DFO held a Pre-COSEWIC Assessment for Lumpfish during which considerable Canadian data were presented and discussed. This information contributed significantly to this document and the writers are grateful to the many people who contributed to this report.

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
(2017)

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
Service canadien de la faune

Canada

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

COSEWIC Status Report

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Lumpfish, *Cyclopterus lumpus* (Linnaeus, 1758), etymology: *Cyclopterus:* Greek, kyklos = round + pteron = fin, is a member of the Cyclopteridae family (Scott and Scott 1988) and is the only species of the genus *Cyclopterus*, established on morphological grounds (Thorsteinsson 1981). Cox (1920a) proposed a variety, *Cyclopterus lumpus* var. *hudsonius* for a Hudson Bay population, but no subspecies or varieties are currently recognized (Davenport 1985).

The unusual appearance of Lumpfish (Figure 1), its wide distribution in the North Atlantic and marked sexual dimorphism has led to the use of an unusually large number of common names. These include Lumpfish, henfish, lumpsucker, poule l'eau (Fr), grosse poule de mer (Fr) (Scott and Scott 1988), Lompe (Fr), Nipisa, Lepisuk, Qorkshuyoq (I) (Coad and Reist 2004). Other common names can be found in Table 1 of Davenport (1985) and Table 2 of Johannesson (2006).

Morphological Description (from Davenport (1985) and Scott and Scott (1988))

The Lumpfish, largest of the Cyclopteridae, is a thick, almost ball-shaped fish (Figure 1). Its body is compressed anteriorly and posteriorly and somewhat polygonal in transverse section at the middle. The head is short and thick and the snout rounded and blunted. The mouth is terminal, opening slightly upwards. The teeth are simple, small, conical, and arranged in several rows anteriorly. The eye is moderate in size and gill openings large. The first dorsal fin is covered by thick skin, forming a high and long crest with large compressed tubercles on the front and top of the crest in adult fish. The height of this crest increases with age such that the back is humped in older specimens. As such, the depth of the body changes with growth stage; although it is much less than half the length in small young specimens, in large specimens it is nearly equal to half the whole length of the body.

The pelvic fins are modified to 6 pairs of fleshy knobs surrounded by a circular flap of skin forming an adhesive disc (sucker). The sucker is slightly longer than wide and about 1/5-1/6 of the body length. It is the spherical shape, the presence of rows of tubercles and the sucker that make this species easily recognizable.

Lumpfish are sexually dimorphic: adult males are smaller in body size than females. Males and females also swim differently: the male relies primarily on a tail stroke, while the female relies mainly on her pectoral fins although the tail muscles are occasionally used for propulsion (Davenport and Kjørsvik 1986). The colour is variable, often matching surroundings, especially in the young. There can be tints of blue, bluish grey to greenish and yellowish or whitish below. The exception is with breeding males that have orange to red fins and belly, plus a metallic silver patch behind each pectoral fin.

Figure 1. Male and female Lumpfish colour difference during spawning. Photographs courtesy of Quebec Region of DFO.

Population Spatial Structure and Variability

Results of tagging studies of (primarily) mature females during inshore spawning (Bagge 1967; Schopka 1974; Blackwood 1982, 1983; Thorsteinsson 1983; Fréchet *et al.* 2006, 2012; Mitamura *et al.* 2007; Kennedy *et al.* 2014) have been interpreted as suggesting a strong homing behaviour from one year to the next. Mitamura *et al.* (2007) considered that such homing behaviour suggests that separate spawning stocks could be maintained, even if they mix on the oceanic feeding grounds, provided that adults return to the shore that they left as juveniles. However, Kennedy *et al.* (2014) cautioned that there have been no investigations into the possibility of natal homing, and the observed homing behaviour may be to where the fish had spawned previously rather than to where they were hatched. They suggested the juvenile stage may be a source of significant mixing between areas and, as such, at least for Icelandic waters, there was currently no evidence to support the rejection of the single population hypothesis but neither did their study offer unequivocal evidence for a single population. The same might be said for Lumpfish in Canadian waters based on tagging by both Blackwood (1982) and Fréchet *et al.* (2006). Blackwood (1982) documented an extensive inshore movement (~160 km) by a mature female Lumpfish over a period of 14 days. A more recent tagging experiment (Grant 2001) indicated that inshore, gravid females may move distances of 35-130 km within 6-17 days. Recovery patterns, however, led him to suggest that inshore movements by mature females were mainly localized on spawning grounds and long distance movements were likely by pre-spawning females homing to spawning grounds outside the study area. Blackwood (1982) did suggest that local stocks may exist as evidenced by the fact that a decline in catch per unit effort at Valleyfield, Newfoundland and Labrador (NL) had no observable effect on the fishery at Comfort Cove NL, less than 100 km away.

Tagging in offshore areas off Iceland (Schopka 1974; Kennedy *et al.* 2014) demonstrated that the site of tagging provided no indication of where these fish would be recaptured. They did not always migrate to the closest spawning area, but were sometimes recaptured hundreds of kilometres from the tagging site.

There is evidence that Lumpfish occur extensively in the oceanic realm in the north Atlantic (Wienerroither *et al.* 2013; ICES 2015). However, genetic studies by Skirnisdottir *et al.* (2013) found high polymorphism in genetic loci between Icelandic and Canadian populations as did Pampoulie *et al.* (2014) who examined samples from 16 different sites in the north Atlantic and Baltic Sea including three areas of the Northwest Atlantic (off Maine (18 specimens), southern Labrador (57 specimens), and West Greenland (93 specimens)). Using all loci, the overall genetic estimates revealed a highly significant F_{ST}[1] and a non-significant overall F_{IS}[2]. Of 120 pairwise F_{ST} comparisons, 65 were significantly different from zero, and 54 remained significant after Bonferroni correction. Pairwise F_{ST} values using neutral loci only were similar to those observed using all loci. Overall, the F-statistics revealed that, with or without outlier loci, the main differentiation occurred among samples from the Northwest Atlantic, the Northeast Atlantic, and the Baltic Sea, and these results were supported by Bayesian and hierarchical analysis of variance approaches (Pampoulie *et al.* 2014). Gene flow was limited among the detected groups and also between Greenland and Maine - Labrador. Although the pairwise F_{ST} for all loci as well as neutral loci only for Maine and Labrador were significantly different from zero, the values were less than those between Greenland and Maine – Labrador (Pampoulie *et al.* 2014).

Designatable Units

Lumpfish in the Northwest Atlantic is treated here as a single designatable unit (DU) based on results of the single genetic study (Pampoulie *et al.* 2014), also taking into consideration the largely continuous distribution in offshore areas coupled with the uncertainties in interpretation of tagging results as expressed by Kennedy *et al.* (2014).

Special Significance

Cyclopterus is a monotypic genus (Mecklenburg and Sheiko 2003).

In Canada, Lumpfish were not utilized or even considered important except as a minor food source and as lobster bait in a few Newfoundland outports prior to 1970 (Blackwood 1982). However, beginning in 1969, an important fishery for roe developed (Collins 1976; Blackwood 1982; Stevenson and Baird 1988) off Newfoundland when depletions in sturgeon (Acipenseridae) stocks coupled with an increase in world consumption of caviar created a market for a sturgeon caviar substitute (Blackwood 1982). Lumpfish caviar was originally an imitation of sturgeon caviar because the eggs are of similar size to those of sturgeon and they were dyed black to imitate the sturgeon roe. Subsequently, Lumpfish

[1] F_{ST} is the proportion of the total genetic variance contained in a subpopulation (the S subscript) relative to the total genetic variance (the T subscript). Values can range from 0 to 1. High F_{ST} implies a considerable degree of differentiation among populations.

[2] FIS (inbreeding coefficient) is the proportion of the variance in the subpopulation contained in an individual. High FIS implies a considerable degree of inbreeding.

caviar became a product in its own right, and between 3,000 and 4,000 tonnes of Lumpfish caviar are sold globally on an annual basis (Johannesson 2006). Canada was the leading exporter of Lumpfish roe during the 1980s and 1990s, that was subsequently processed to and sold as high value caviar in Europe (Johannesson 2006). The roe is extracted by cutting open the belly of the female and extracting the two sacs of eggs.

Recently, Lumpfish (wild-sourced and hatchery reared) are being used to control sea lice at some Newfoundland and Labrador aquaculture sites.

There are no indications of any ceremonial uses of Lumpfish in Canada and there is no ATK (Aboriginal Traditional Knowledge) information available (N. Jones pers. comm., 2015).

DISTRIBUTION

Global Range

Lumpfish are widely distributed both demersally and pelagically in the North Atlantic Ocean, with rare occurrences in Arctic Ocean waters of Hudson Bay and Hudson Strait (Figure 2). The rare occurrences in the Canadian Arctic Ocean may reflect low sampling effort. In the pelagic realm, Lumpfish are more widely distributed in offshore waters east of Canada, and west of Europe than depicted in Figure 2. A pelagic Mackerel survey (International Ecosystem Summer Survey in the Nordic Seas (IESSNS)) that covers offshore (as well as coastal) waters between Norway and Greenland regularly captures Lumpfish, indicating a nearly continuous distribution between Europe and Greenland with an established fishery in Iceland (ICES 2015). A pelagic salmon survey (Sheehan *et al.* 2012) off Canada indicated their presence east of the shelf break in offshore waters.

In the Northeast Atlantic, Lumpfish range widely from the Barents and White Seas south to Portugal and off Greenland, Iceland, Svalbard, Spitsbergen and the North Sea (Whitehead *et al.* 1986; Vasconcelos *et al.* 2004). Vagrants have recently been recorded in Galicia, Spain (Bañón *et al.* 2008) and in the Mediterranean Sea (Dulčić and Golani 2006).

In the Northwest Atlantic (Figure 3), Lumpfish have been occasionally caught in Davis Strait up to 65º N but are more common off Newfoundland and Labrador, New Brunswick and Nova Scotia, extending as far south as the Gulf of Maine and Georges Bank. Occasional records occur as far south as the mid-Atlantic Bight (37°N) (Stevenson and Baird 1988). USA surveys going back to 1963 show only 7 records of Lumpfish south of Georges Bank, mainly off Long Island NY, defining their southern limit on this side of the Atlantic.

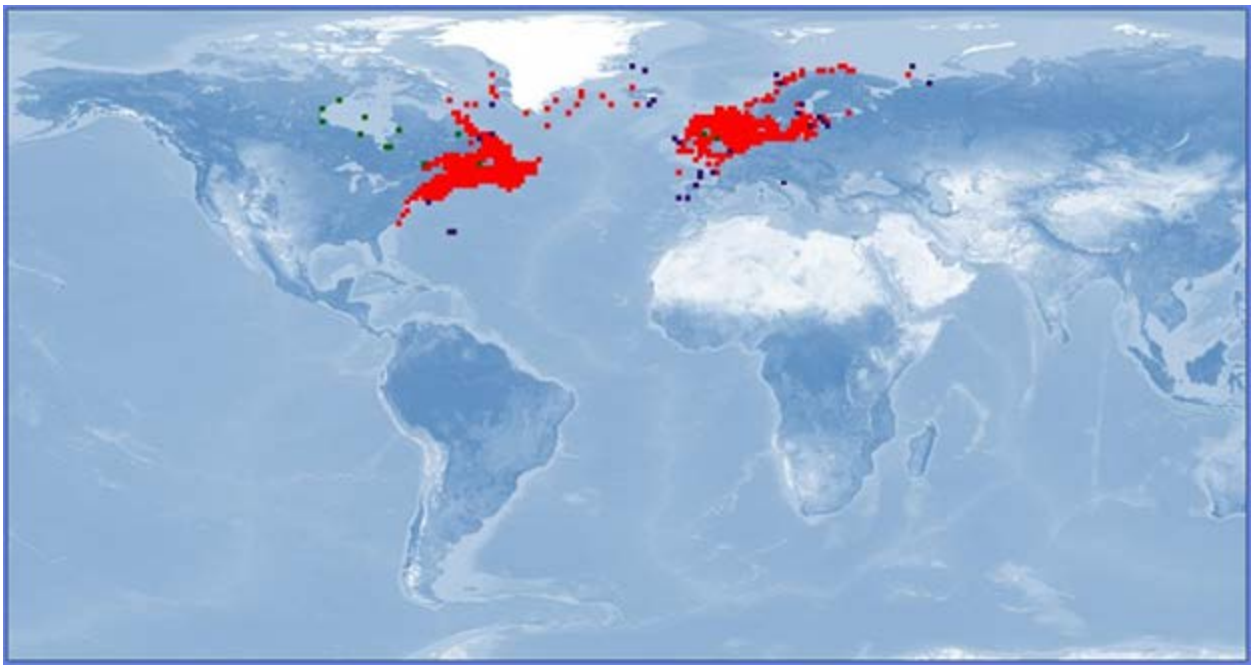

Figure 2. Global distribution of Lumpfish (red). Modified from: FishBase: http://www.fishbase.ca/Summary/SpeciesSummary.php?ID=62&AT=lumpfish#. Points appearing on land were removed.

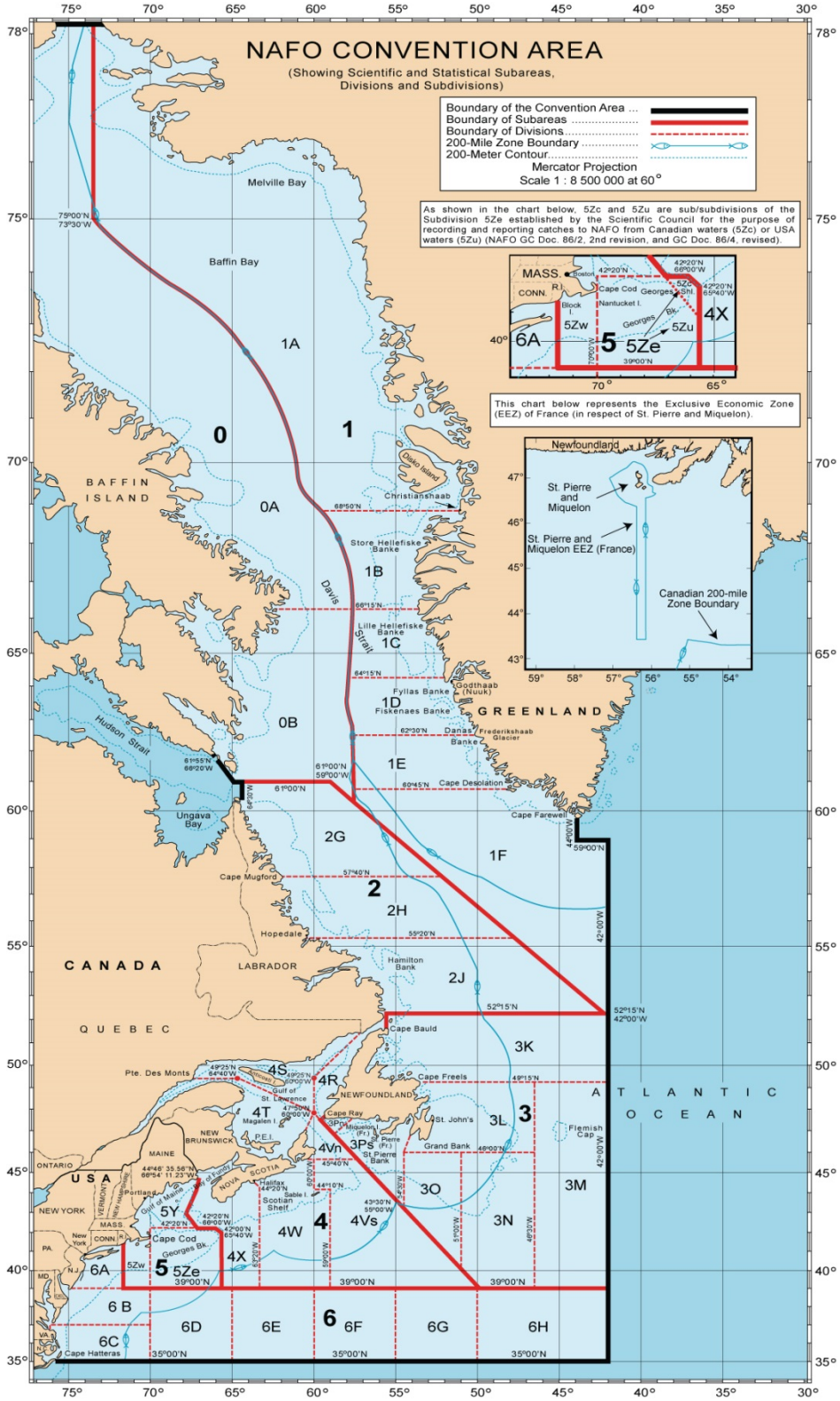

Figure 3. Map of NAFO Subareas and Divisions mentioned in the text (www.nafo.int/Portals/0/PDFs/GeneralInfo/NAFO-map-poster-8.5x11-web.pdf?ver=2016-07-26-112954-377).

Canadian Range

Based on demersal survey records, Lumpfish are only occasionally found in offshore waters of the Davis Strait as far north as 65º N (Figure 4). Of research survey sets (27 records) conducted during 2005-2014 from 58º N to 66º 15' N 0.8% contained Lumpfish, mainly single captures. Fishery observer data pertaining to the Greenland Halibut and Shrimp fisheries in Davis Strait contain records of Lumpfish. Two specimens were captured in each of Ungava Bay and Hudson Strait (Hudon 1990). In Hudson Bay, three juveniles and five postlarvae/juvenile specimens were reported by Cox (1920a). That paper includes a description of *C. lumpus* var. *hudsonius*, a specimen collected by Bell at Fort Churchill in 1885 but no longer considered a separate, valid species (Davenport 1985). Cox also recorded that "W.G. Walton collected some "fry" at Gray Goose Islands, on the east side of James Bay, September, 1919".

Lumpfish are increasingly encountered southward, taken regularly in DFO demersal research surveys on the Labrador Shelf, Grand Banks, Gulf of St. Lawrence, Scotian Shelf, Bay of Fundy and Gulf of Maine. Proportion of tows containing Lumpfish (Campelen survey 1995-2013) is 4.6% in Northwest Atlantic Fisheries Organization (NAFO) Div. 2GH (northern Labrador Shelf) (Figures 3 and 4), 12.6% in Div. 2J3KL (southern Labrador Shelf) and 35.3% in Div. 3P (southern Grand Bank). In the northern Gulf of St. Lawrence (Div. 4RS and part of 4T), based on DFO survey data, Dutil *et al.* (2009) indicated that Lumpfish, although regularly captured (caught in 15.4% of survey sets), did not constitute a significant portion of the fish biomass (0.15% of the total fish biomass) in the Gulf as a whole. However, Lumpfish is locally abundant enough to result in a small directed roe fishery along western Newfoundland (Div. 4R) and along the Quebec north shore (Div. 4S).

Although captured in the southern Gulf of St. Lawrence (Div. 4T) and on the Scotian Shelf/Bay of Fundy, percent occurrence and abundance there is low: 5% of DFO survey sets for the southern Gulf contained Lumpfish, 3% for the Scotian Shelf and most sets in those areas contained only a single specimen. Encounter rates on the Scotian Shelf were highest in eastern Div. 4V adjacent to the Laurentian Channel (near Div. 3P).

Density of sets that captured Lumpfish from DFO demersal surveys was used rather than mean number per tow to illustrate distribution (Figure 4) because different survey gears used in the different areas have different catchability and because different surveys cover different depths, some without Lumpfish. Overall, however, demersal survey data indicate that the centre of mass for the species in the Northwest Atlantic occurs around the island of Newfoundland and particularly off the south and west coast (Div. 3P and 4R).

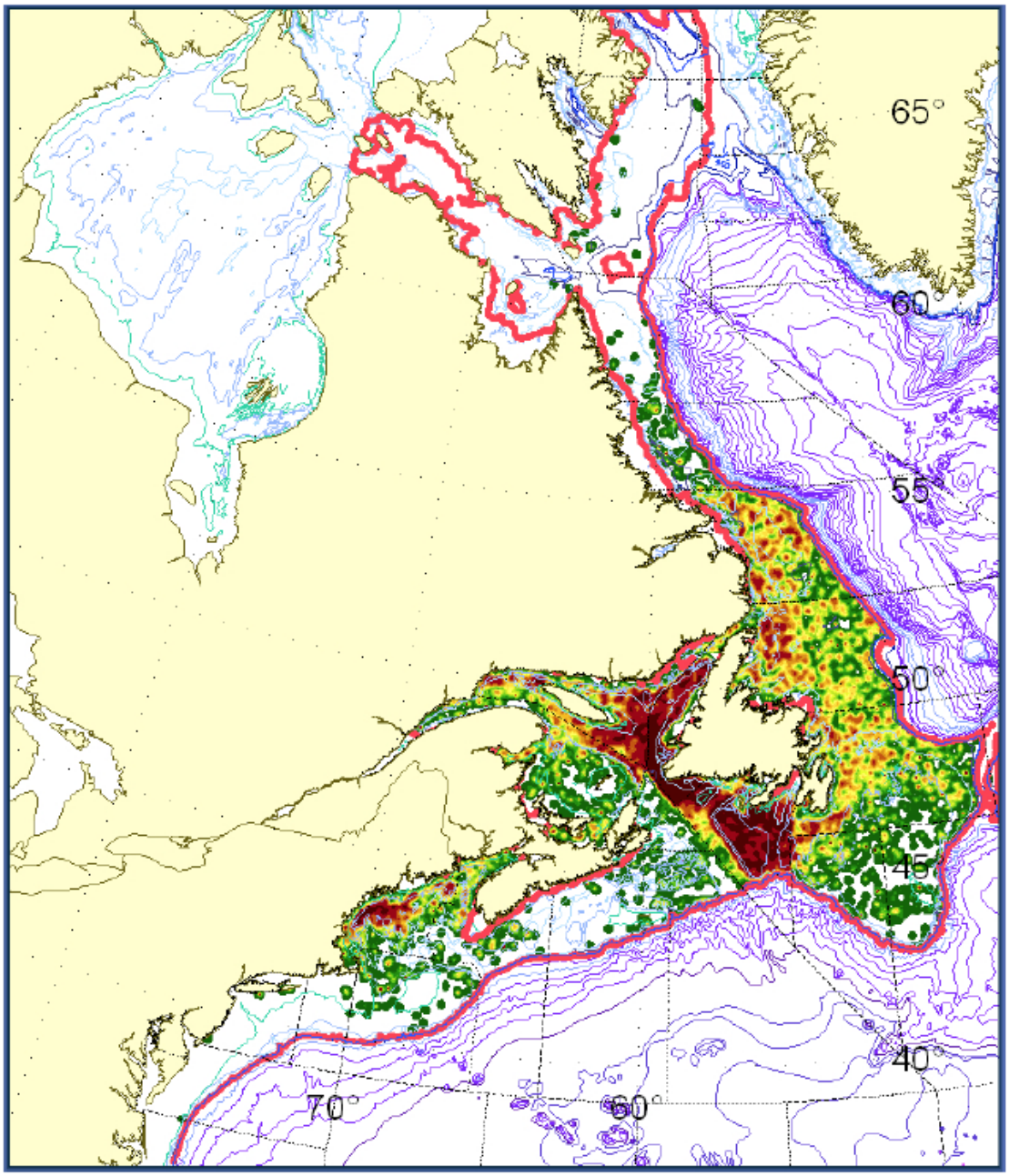

Figure 4. Density of Canadian and USA demersal survey sets from 1970 to 2014 that contained one or more Lumpfish specimens (proportion of sets in a given area containing Lumpfish). Red line represents extent of the demersal surveys. Dark brown areas represent where sets containing Lumpfish were most dense, green least dense, blank areas inside the red line indicate where no Lumpfish were captured.

As well, Lumpfish juveniles and adults up to 55 cm are commonly taken pelagically; as bycatch in the near surface Atlantic Salmon (*Salmo salar*) survey (Sheehan *et al.* 2012) and in pelagic trawl fisheries of the Labrador Shelf, Grand Banks and eastern Scotian Shelf. They are also taken in trawl and seine fisheries for Cod (*Gadus morhua*), Herring (*Clupea harengus*) and Mackerel (*Scomber scombrus*), and in the historical Canadian and Russian Capelin (*Mallotus villosus*) fisheries on the Grand Bank and Labrador Shelf, particularly in winter.

Where pelagic sampling was undertaken in the summer/fall, YOY (young of the year, < 17 cm) Lumpfish were generally caught in: Northeast Newfoundland and Labrador Shelf within 10 m of the surface, in Aug.-Sep. (Sheehan *et al.* 2012); northern Grand Banks, DFO IYGPT (International Young Gadoid Pelagic Trawl) pelagic larval surveys, within 3-64 m of the surface survey in Aug.-Sep. 1996-2000; southern Gulf of St. Lawrence, Scotian Shelf and Bay of Fundy (OBIS 2015). USA surveys in Gulf of Maine and to a lesser extent on Georges Bank have also captured larvae and post-larvae in surface waters (Jordan and Evermann 1896; Moring 2001).

Thus, Lumpfish are widespread in both the pelagic and the demersal realm in waters off eastern Canada.

Extent of Occurrence and Area of Occupancy

The extent of occurrence (EOO) for Lumpfish, 5,280,226 km^2, is derived from a minimum convex polygon (COSEWIC 2010) from trawl research survey data and other records of occurrence specified under **Search Effort**, including terrestrial areas. An overall index of area of occupancy (IAO) derived from 2x2 km grids placed over each observation point amounts to 106,136 km^2.

Design Weighted Area Occupied (DWAO) estimates (Perry and Smith 1994) were derived from DFO demersal survey data on regional basis as each region surveyed during different periods and seasons using different gears.

DWAO (A_t) was calculated in each year t as follows:

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

where Y_{ijk} is the number of fish caught in tow *i* at site j in stratum *k*, a_k is the area of the stratum *k* (km^2), N_k is the number of sites sampled in stratum *k*, n_j is the number of tows conducted at site *j*, and *S* is the number of strata. DWAO estimates for the oceanic realm (pelagic records beyond the shelf break) are not available although there is evidence that Lumpfish are widely pelagically distributed beyond the shelf edge (Sheehan *et al.* 2012).

Data were too sparse for Subarea 0, Hudson Strait, Hudson Bay and James Bay to calculate DWAO.

In Div. 2J3K (Labrador Shelf), DWAO increased from 1995 to 2005 then rapidly declined thereafter to about one third of the peak value in 2009 (Figure 5a). DWAO was relatively constant thereafter. In Div. 3LNOP (Grand Banks), the timing of the decline in DWAO was the same as in Div. 2J3K but the magnitude was greater, falling to about 10% of previous levels (Figure 5b). The decline was greatest in Subdiv. 3Pn (off the southwest coast of Newfoundland), an area with the highest proportion of DWAO during the 1990s, falling to near zero DWAO since 2010. The observed decreases were concurrent with an observed decrease in biomass and abundance (refer to **Population Sizes and Trends**). In both spring and fall, DWAO was consistently lowest in Div. 3LNO (Grand Bank) compared to other areas but also showed a similar decline pattern.

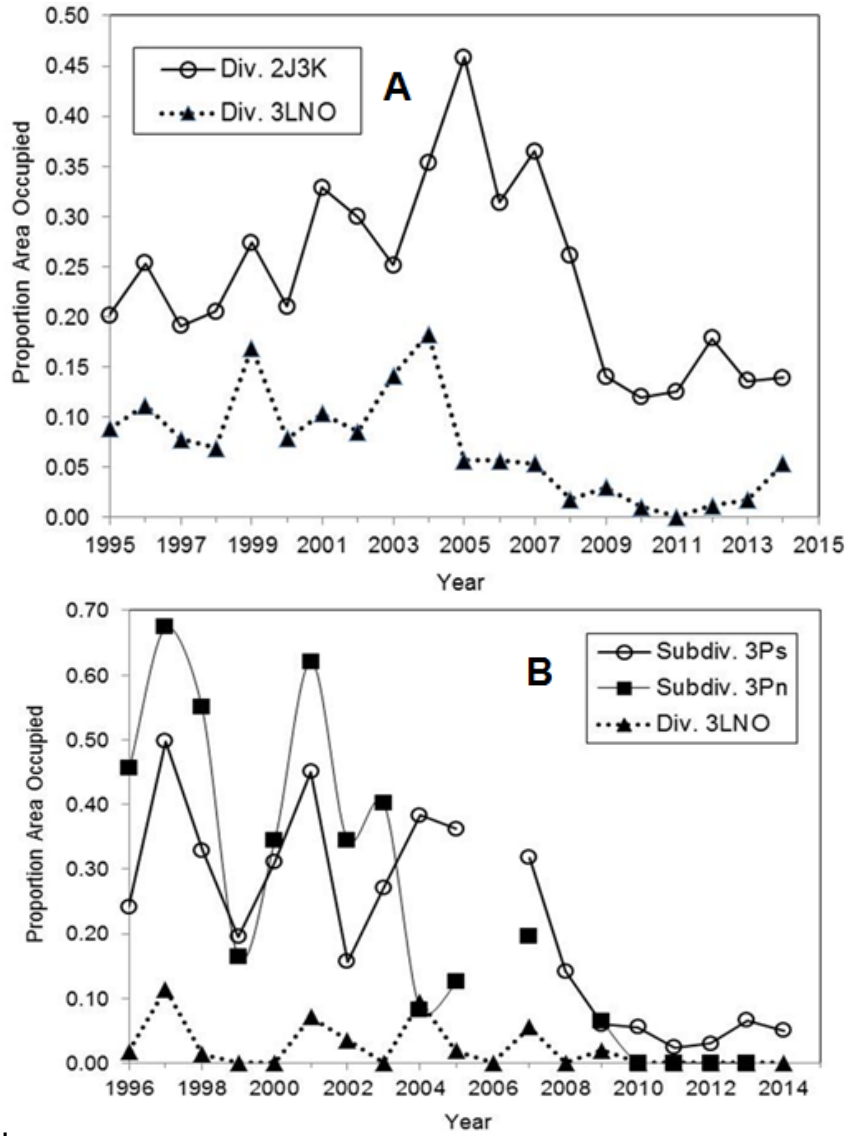

Figure 5. Design Weighted Area Occupied (DWAO) by Lumpfish as a proportion of the total survey footprint a) on the Labrador Shelf and Grand Banks, Div. 2J3KLNO based on fall survey data, and b) on the Grand Banks, Div. 3LNOP based on spring survey data. Source: Simpson *et al.* (2016).

In the northern Gulf of St. Lawrence, only the summer survey encompassed the entire northern Gulf (Div. 4RS) and included recent years (1990-2014, see Table 1). For that reason, it was used to examine long term trend in DWAO. However, summer is the time of year when a significant portion of the population is thought to be inshore/more pelagic and outside the survey footprint.

Based on the summer surveys, DWAO was low, < 20% of the survey area, varying from 3,000 to 27,000 km^2, with a modest increasing trend over the time series (1991 to 2014) (Figure 6). However, Simpson *et al.* (2016) indicated that the apparent increase between 1991-2003 and 2005-2014 coincided with a change in survey vessel and gear that may have affected catchability. Whether there was an actual change in DWAO in this area is unclear.

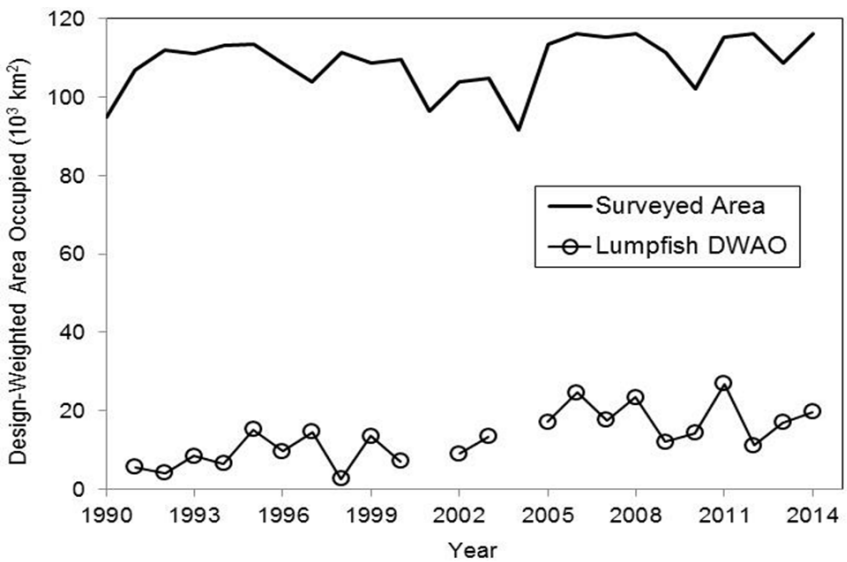

Figure 6. Design Weighted Area Occupied (DWAO) by Lumpfish in the northern Gulf, Div. 4RS based on the summer surveys. Source: Simpson *et al.* (2016).

Catches in the southern Gulf are sparse and there has been no perceptible change over the duration of the survey. Maps for all years of the survey are illustrated in Simpson *et al.* (2016).

DWAO estimates from the September survey in the southern Gulf (Div. 4T) are low, erratic and without trend (Figure 7). Abundance of Lumpfish in this area is correspondingly low. Values for mature fish, very low over the life of the survey, have been zero in many years since 1991.

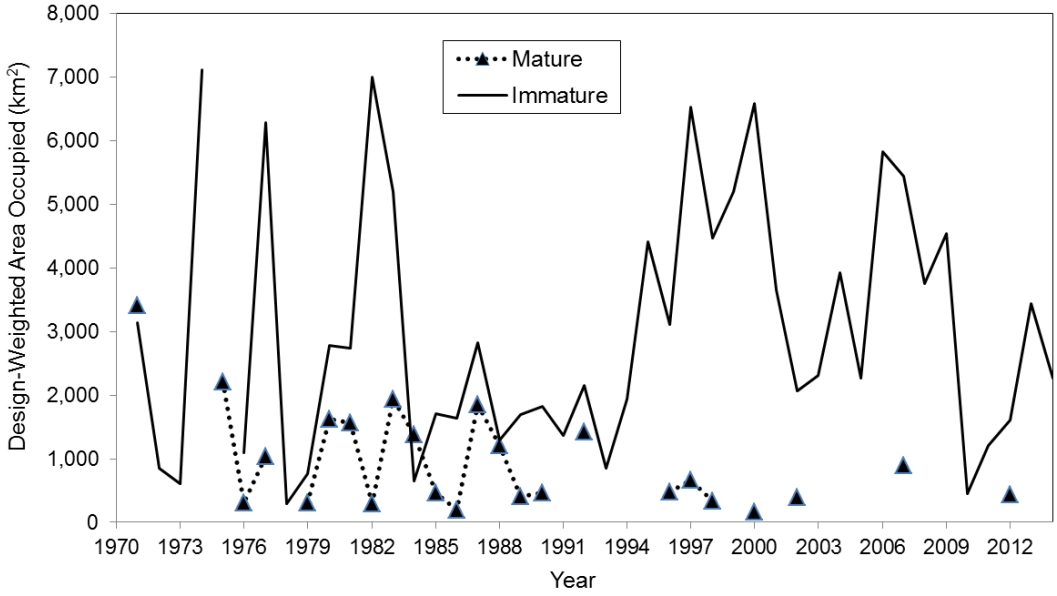

Figure 7. Design Weighted Area Occupied (DWAO) by Lumpfish in the southern Gulf of St. Lawrence, Div. 4T. Years with zero values are not plotted. Source: Simpson *et al.* (2016).

DWAO for Scotian Shelf/Bay of Fundy (Div. 4VWX5Y) surveys was estimated from three survey series: the summer Div. 4VWX surveys conducted from 1970 to date; March Div. 4VsW surveys conducted on the eastern half of the Scotian Shelf in 1986-2010; and Feb./Mar. surveys on Georges Bank (the portion of Subdiv. 5Ze within Canada) from 1986 to date. Lumpfish in this area are in low abundance and infrequently caught in all surveys, particularly in Div. 5Z.

Summer and winter DWAOs for the Scotian Shelf/Bay of Fundy (Figures 8 and 9) have fluctuated around the long-term mean. Values were lower in Div. 4VsW after 1997, but it is uncertain whether this reflects a decline. Values in Div. 5Z were zero since 2009, but zero values are not uncommon in the survey series as Lumpfish are uncommon in this area.

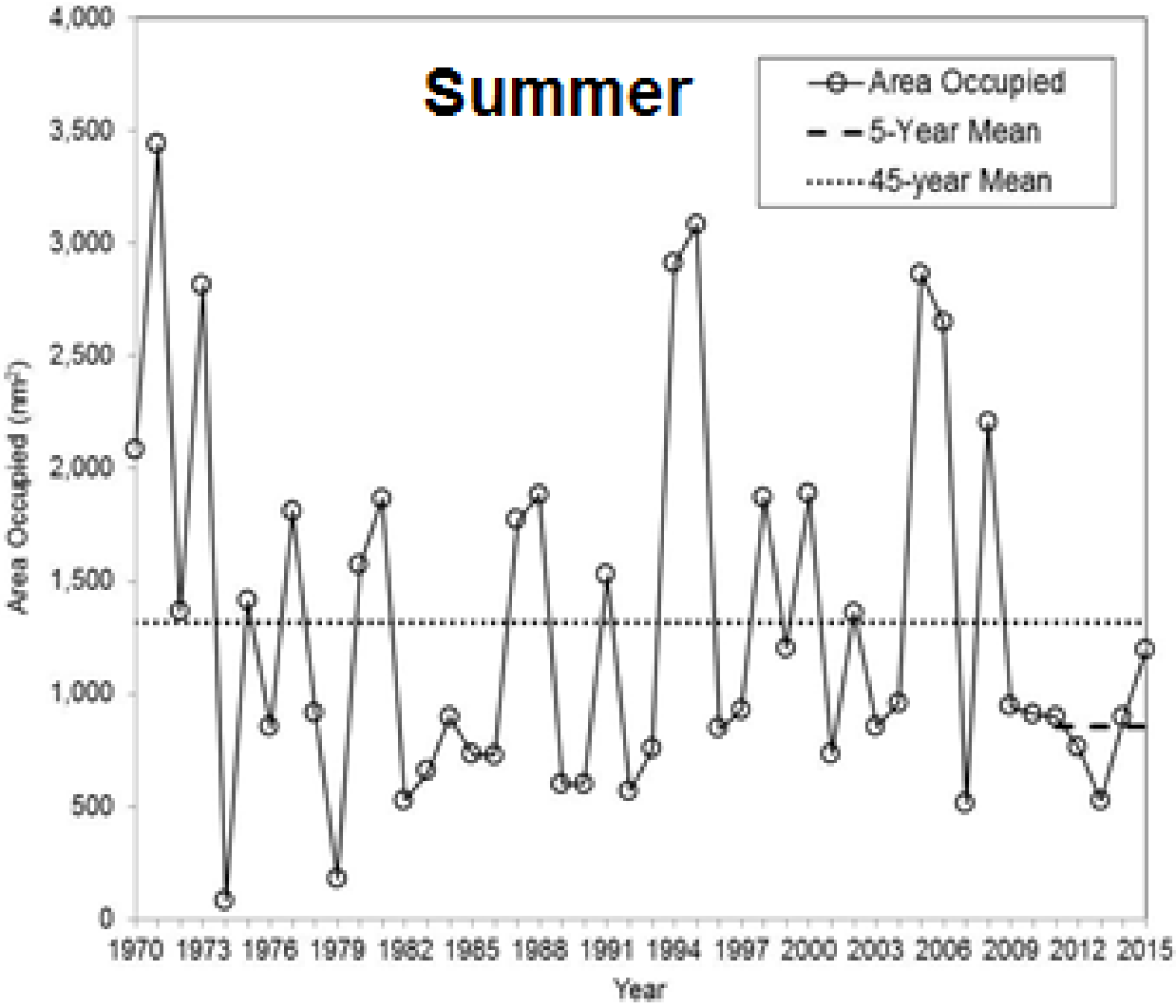

Figure 8. Design Weighted Area Occupied (DWAO) for Lumpfish in summer (4VWX). Source: Simpson *et al.* (2016).

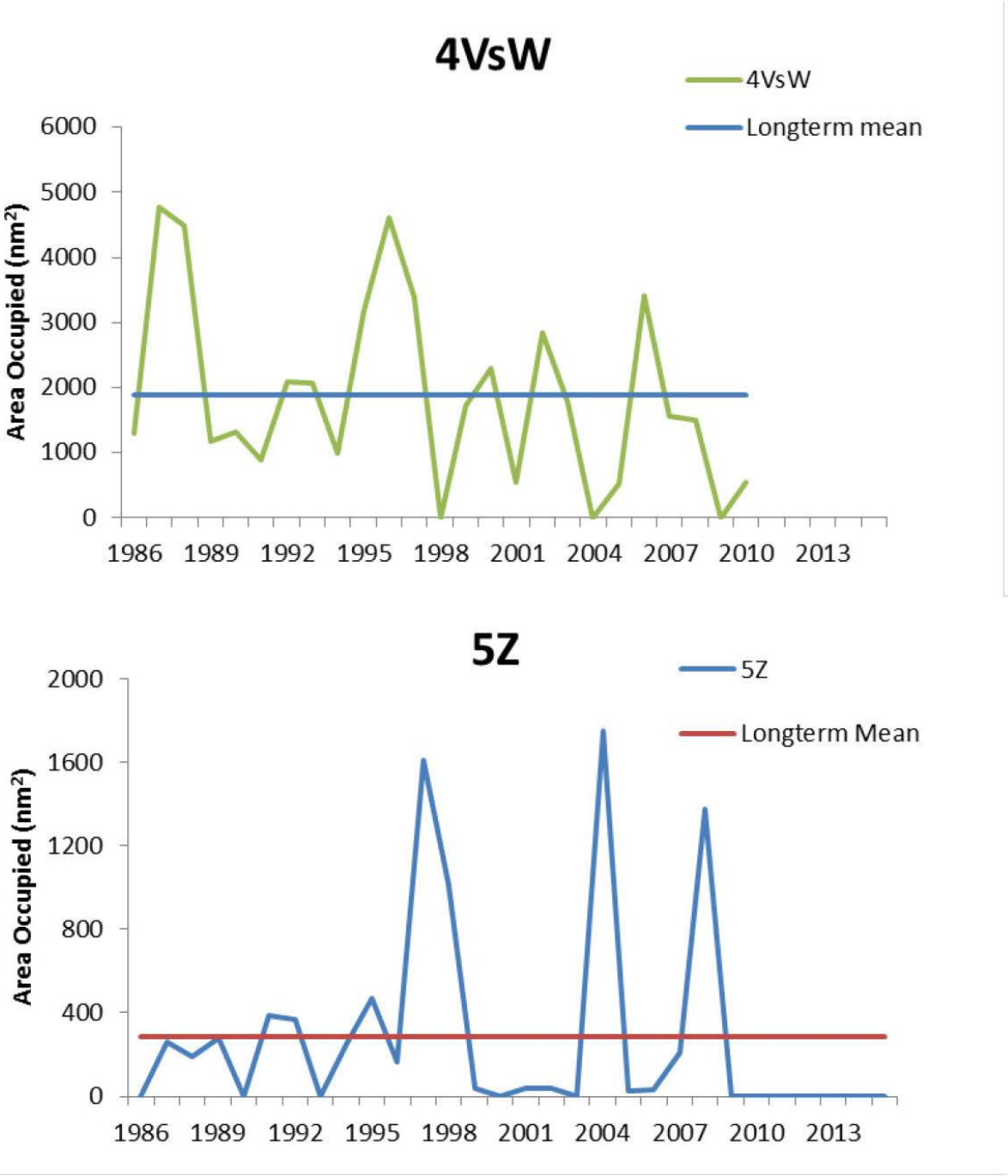

Figure 9. Design Weighted Area Occupied (DWAO) for Lumpfish: upper panel Div. 4VsW, eastern Scotian Shelf, and lower panel Div. 5Z Bay of Fundy/Gulf of Maine). Source: Simpson *et al.* (2016).

Simpson *et al.* (2016) provides maps illustrating changes in distribution of Lumpfish throughout its Canadian range corresponding to the changes in DWAO described above.

Search Effort

Individual nearshore studies have found Lumpfish inshore in various parts of Canada (Cox 1920b; Goulet 1985; Goulet *et al.* 1986; Methven *et al.* 2001; McAlpine 2013), and offshore (Fischer and Haedrich 2000). Observer fishery data from 1983 to 2015 held by Newfoundland and Labrador (NL) and Quebec Regions provides information on the coastal distribution of the species where it is fished, particularly where they are concentrated in the spring to lay eggs.

Records contained in OBIS (2015), results from a 2008-2009 salmon gillnet survey (Sheehan *et al.* 2012) and Newfoundland and Labrador Region IYGPT pelagic trawl records (1990s) were used to examine the distribution of planktonic juveniles and larvae. Underlying sources of information indicated in the OBIS records are derived from: Fishbase, Electronic Atlas of Ichthyoplankton on the Scotian Shelf of North America, BioChem: Sameoto zooplankton collection (OBIS Canada), BioChem: Fish, Eggs and Larvae in the Gulf of St. Lawrence, Atlantic Reference Centre Museum of Canadian Atlantic Organisms - Invertebrates and Fishes Data, DFO Quebec Region MLI museum collection.

Sources of information on capture locations of juveniles and adults, also contained in OBIS (2015): Canadian Museum of Nature - Fish Collection, Arctic Marine Fish Museum Specimens, ECNASAP - East Coast North America Strategic Assessment (derived from DFO surveys), Nova Scotia Museum of Natural History - Marine Birds, Mammals, and Fishes, Bay of Fundy Species List and DFO Quebec Region MLI museum collection.

The New Brunswick Museum collection also provided locations and dates (1886 to 2010) of captures in and around coves and estuaries of the Bay of Fundy (Div. 4X) and Northumberland Strait (Div. 4T). Most of those records were collected from individual field projects examining various aspects of Lumpfish life history. As well, the salmon gillnet surveys in 2008-2009 plus fishery observer records provided further information on juvenile and adult Lumpfish in the pelagic realm (Sheehan *et al.* 2012).

For offshore shelf waters, the primary sources of information on the capture location of older juvenile and adult Lumpfish are the DFO research surveys of five DFO Regions: Central and Arctic, Quebec, Gulf, Newfoundland and Labrador and Maritimes. Those surveys cover most of the shelf waters of Atlantic Canada and all employed a stratified random design with stratification based on depth and latitude.

HABITAT

Habitat Requirements

Although Lumpfish have been described as a bottom dwelling fish (benthic or epibenthic) by some authors (Blackwood 1982; Coad and Reist 2004; Gascoigne *et al.* 2014), it is more commonly thought to be a semi-pelagic, epipelagic or bentho-pelagic species (Bagge 1967; Schopka 1974; Blacker 1983; Davenport 1985; Eriksen *et al.* 2014; Froese and Pauly 2014; Kennedy *et al.* 2015). Data storage tags placed on Lumpfish off Iceland confirmed that adults exhibit diel vertical movements in the water column (Kennedy *et al.* 2015). Thus, Lumpfish inhabit both benthic and pelagic habitats and have specific habitat requirements for different parts of their life cycle; egg stages in crevices, larval and post-larval juvenile stages near surface and later stages both pelagic and demersal.

Diver observations nearshore (< 10 m bottom depth) indicate that females lay eggs in nests established by males around rocky areas and in crevices and the males guard those eggs (Goulet 1985; Goulet *et al.* 1986; Goulet and Green 1988). Thus, there is a requirement for uneven or rocky topography for nesting. There are no visual observations beyond the reported diving depths (> 10 m), but it is likely that reproduction/nesting/egg laying may also occur further offshore in rocky areas because mature adults are regularly captured demersally in offshore surveys during months when nesting has been observed inshore.

Once hatched, young of the year (YOY, 1-12 cm) become pelagic and are observed at the surface, often attached to or under floating seaweed (Cox and Anderson 1922; Sæmundsson 1926, 1949; Andriyashev 1964, Bagge 1964; Schopka 1974; Blacker 1983; Daborn and Gregory 1983; Vandendriessche *et al.* 2007; Sheehan *et al.* 2012), where they feed on plankton, primarily copepods, amphipods, isopods, and smaller juvenile Lumpfish (Faber 1976; Daborn and Gregory 1983; Ingólfsson and Kristjánsson 2002). Thus, young of the year appear to inhabit near surface habitat to access planktonic prey (Vandendriessche *et al.* (2007).

Bagge (1964) and Schopka (1974) concluded that adults remain pelagic before spring spawning when a gradual switch to demersal habit was thought to occur. Canadian fishery bycatch records indicate their presence pelagically as adults although there is a distinct seasonal pattern in catch rates of adult Lumpfish taken as bycatch in the Newfoundland redfish (*Sebastes* spp.) fishery employing midwater trawls. Lumpfish were absent from midwater trawl catches during June-August, while the highest bycatch rates occurred in February-March (Figure 10, left panel). This suggests that adult Lumpfish are semi-pelagic, spending a greater portion of their time near the bottom in the winter months. As well, Rusyaev and Orlov (2014) reported that a significant part of the adult Lumpfish diet comprises Northern Comb Jelly (*Bolinopsusinfundibulum*), a further indication that adults as well as juveniles spend a portion of their time up in the water column to access their prey. A gillnet Atlantic Salmon survey off Newfoundland and Labrador within 10 m of the surface regularly captured Lumpfish in the size range of 5-45 cm TL, confirming that adults also spend time in the water column (Sheehan *et al.* 2012). For female Lumpfish, Kennedy *et al.* (2015) described a diel pattern in vertical behaviour and also noted that they spent greater amounts of time exhibiting surface behaviour in April compared with March.

A distinct seasonal pattern is also observed in Newfoundland demersal trawl research survey catches (Figure 10, right panel), similar to the redfish midwater fishery. This suggests that Lumpfish largely distribute outside of the survey area (offshore shelf > 30 m) during the summer months, while breeding and they may be mainly distributed near shore at depths < 30 m.

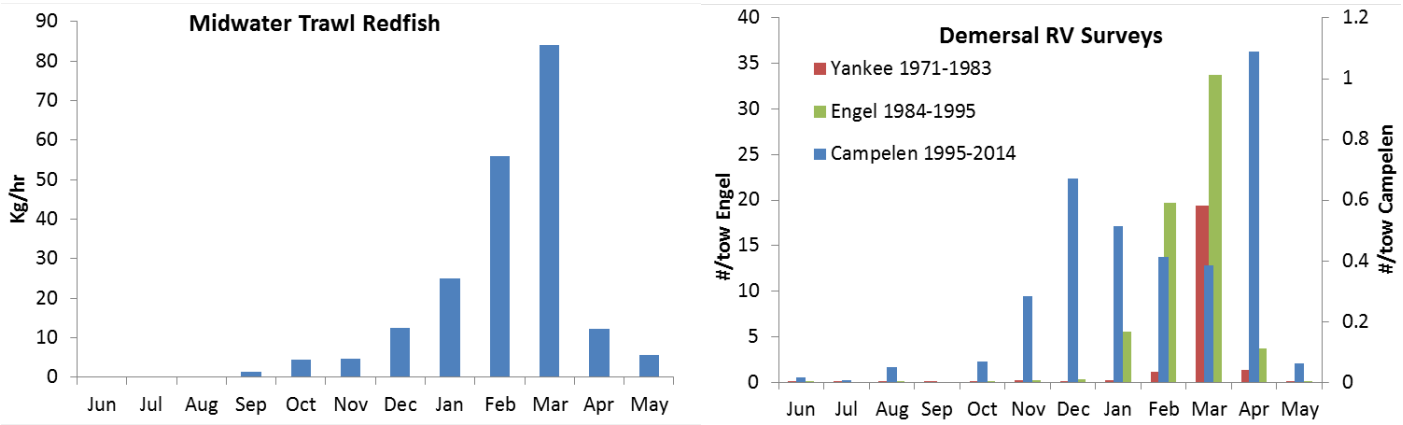

Figure 10. Bycatch rate of Lumpfish in the midwater trawl fishery directed for redfish by month (left panel) and catch rates of Lumpfish during the NL spring and fall demersal research surveys by month (right panel).

That Lumpfish occur on all types of benthic structure suggests that when on bottom, they are adaptable to a wide range of benthos (Keen and Piper 1990). Bottom types range from primarily mud or muddy sand in the Davis Strait and Labrador Shelf (SA 0, Div. 2GHJ3K), northern Gulf of St. Lawrence (Div. 4RS) and St. Pierre Bank/Laurentian Channel (Div. 3P) to sand and gravel on the Grand Bank (Div. 3LNO), Scotian Shelf (Div. 4VWX) and southern Gulf of St. Lawrence (Div. 4T). Locations covered mainly by sand tend to have lower densities of Lumpfish (e.g., offshore Grand Bank, central Scotian Shelf and the southern Gulf of St. Lawrence, Figure 4), suggesting a higher preference for muddy habitat, although this may be confounded by thermal preferences (see below).

At all stages, Lumpfish are often observed adhering to stones, lobster pots, seaweed or other objects by means of the pelvic adhesive disk. Lumpfish make use of complex benthic structure and floating seaweed to preventing drift in the currents.

Although Fischer and Haedrich (2000) indicated that Lumpfish “occupy equally all temperatures” in a bay off Newfoundland, there are clear thermal preferences that vary with life stage. Collins (1976) stated that in Newfoundland waters, spawning inshore occurred when temperature exceeded 4ºC, although he did not provide any supporting data. Benfey and Methven (1986) successfully hatched and reared larvae in water temperatures as high as 12ºC in the laboratory, although the egg masses were collected from a location where temperature was 3ºC. Near surface records of larvae and YOY (< 5 cm) occurred where temperatures ranged from 4 to 12ºC, but were concentrated mainly at 7-8ºC (OBIS records).

When demersal, juveniles and adults are found in bottom temperatures ranging from -1.9ºC to 12ºC and are largely absent from areas where water temperatures exceeded 12ºC (OBIS 2015; DFO survey and USA records). Thus it appears that 12ºC represents the upper thermal preference for the species. At the northern extent of their distribution (Lat. > 60ºN), Lumpfish were found in the full range of available temperatures, from -1º to 4ºC. At the southern extent, highest concentrations were recorded between -1.0º and 2.0ºC (Figure 11).

Cumulative frequency distributions of temperature in waters surrounding Newfoundland, where Lumpfish reach their highest abundance, indicate that they are selecting the cooler available temperatures. This preference was observed in all areas of Canada examined (see Simpson *et al.* 2016).

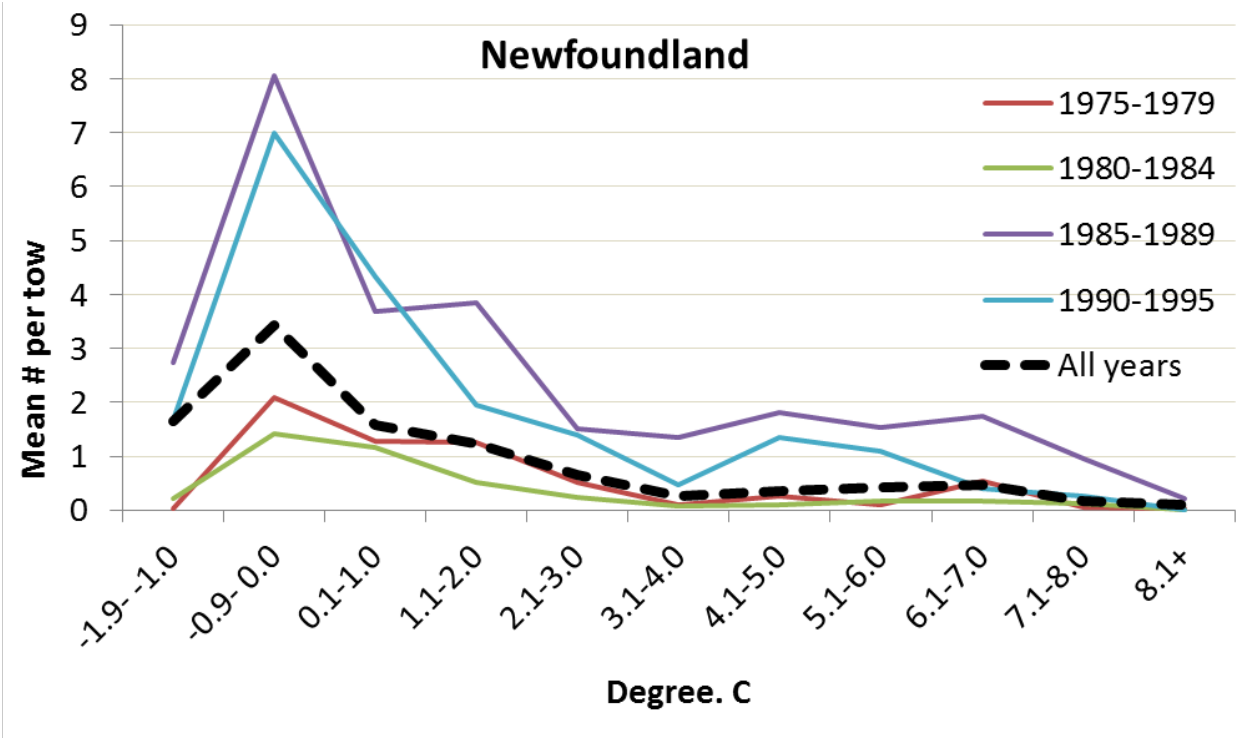

Figure 11. Lumpfish density (mean number per tow) by temperature interval from DFO demersal survey records in Div. 2HJ3KLNOP illustrating thermal preference for Lumpfish.

Habitat Trends

Where fishing occurs, bottom structure may be altered but the effect on Lumpfish nesting habitat, although unknown, would likely be minor given minimal overlap with the mainly offshore fishery footprint (Kulka and Pitcher 2001, marine atlases). In terms of the Lumpfish directed fishery, the effect of deploying demersal gillnets in the vicinity of nest sites to capture adults in the roe fishery is unknown.

The climate of the Earth has entered a period of rapid change, with potential negative consequences for the oceans, their ecosystems, and living marine resources (Reid and Valdes 2011). In Canadian waters, particularly off Newfoundland and Labrador Shelf, a warming trend has been observed since the mid-1990s (Figure 12). Colbourne *et al.* (2014) reported that since 1981, five of the warmest years on record have occurred since 2005 (based on the Atlantic composite climate index). Since highest concentrations of adult Lumpfish are observed where water temperatures are coldest, -1.0 to 2.0ºC, it is possible that this warming trend may have affected population growth, although there is no direct evidence of this. Lumpfish, unlike many demersal species off Canada that underwent dramatic population declines in the late 1980s-early 1990s, did not start to decline until the early 2000s, more in synchrony with the warming trend and well after the period of cooling in the 1980s and 1990s.

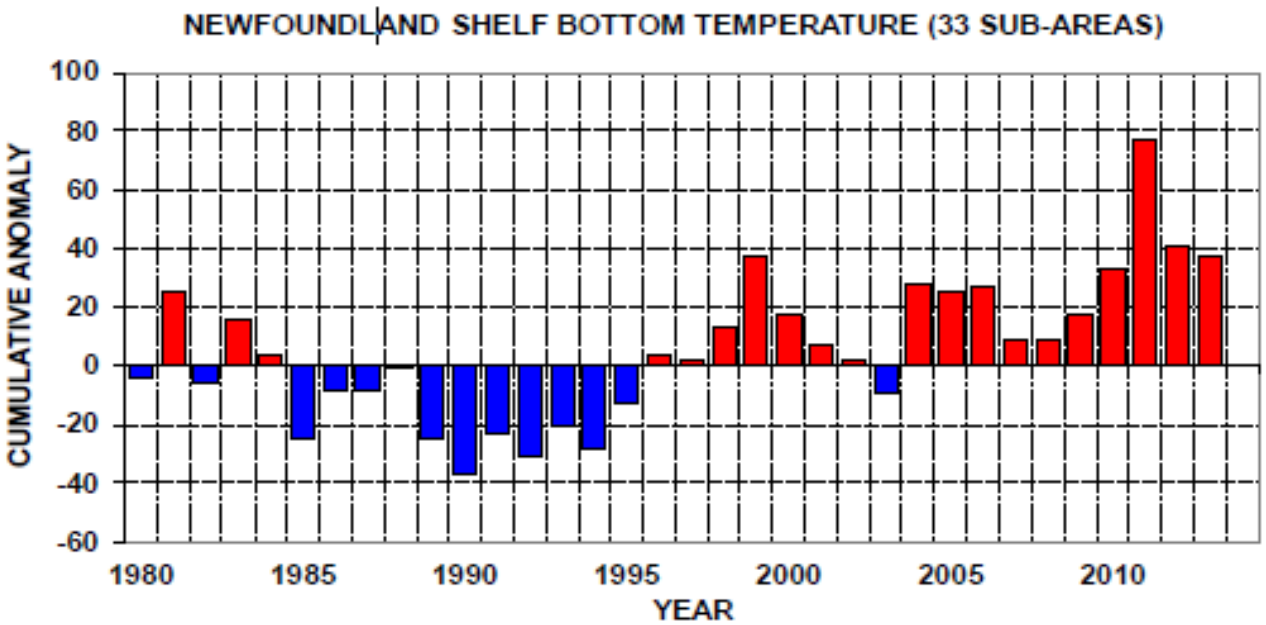

Figure 12. Cumulative bottom temperature anomalies on the Newfoundland Shelf from Colbourne *et al.* (2014) based on temperature values above or below normal as determined from Fig. 22 of Colbourne *et al.* (2014).

BIOLOGY

Davenport (1985) produced a comprehensive review of literature describing Lumpfish biology, drawing on work by a number of European and North American researchers. Cox (1920b) and Cox and Anderson (1922) provided some of the earliest information regarding Lumpfish in Canadian waters, but overall the biology of Lumpfish is not well known, especially in Canadian waters.

Life Cycle and Reproduction

Lumpfish display a high degree of sexual dimorphism with males being much smaller than females at maturity (Figure 13) and differing in colouration (Figure 1) and behaviour during the breeding season (Thorsteinsson 1983; Goulet 1985). The fins, tail and sucker of males are relatively bigger and stronger than in females such that the dimorphism extends to the buoyancy mechanisms (Davenport and Kjørsvik 1986).

Fish measurements (n=4677) from DFO surveys in Div. 2J3KLNOPs, 1979-2014, indicate that the sex ratio was 43/56, males to females since 1995. During 1979-1995, the ratio was 30/70. This is generally consistent with Hoenig and Hewitt (2005), who indicated the proportion of males ranged from 12% to 54% during 1979 to 1994 in that same area.

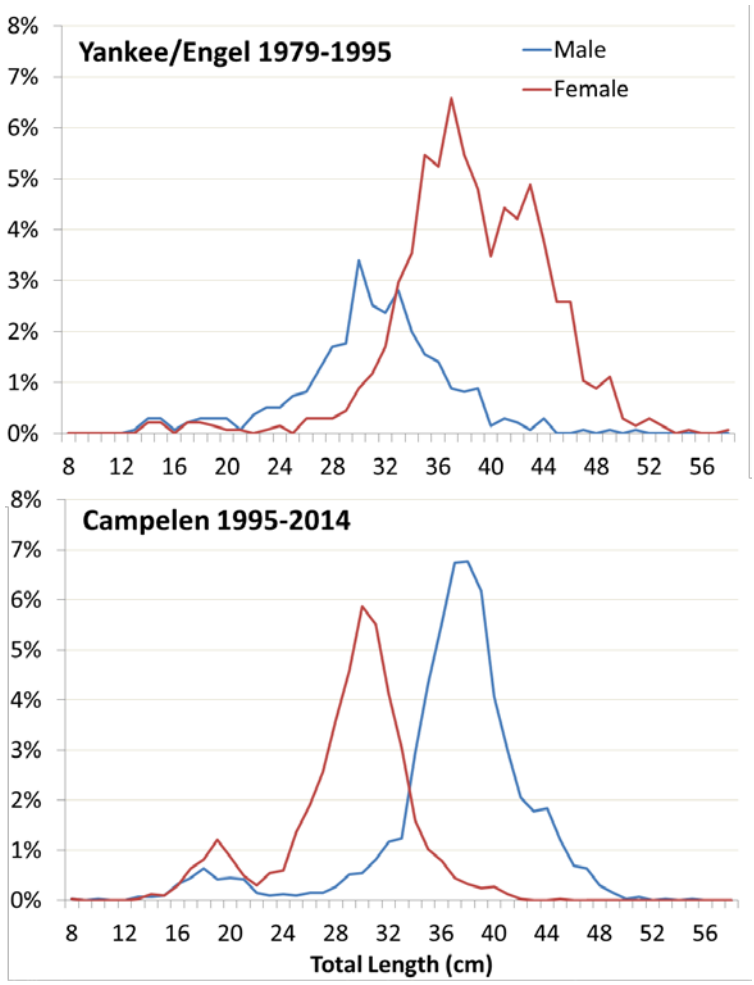

Figure 13. Length distribution of Common Lumpfish from DFO-NL spring and fall surveys in Div. 2J3KLNOPs, 1979-2014.

The smaller mesh used with the Campelen trawl would be expected to capture a greater proportion of the smaller males. Also, females > 40 cm made up a greater proportion of the catch pre-1996. Whether the increase in proportion of males in recent years is also the result of a fishery targeting females is unclear. A size difference between males and females is also observed in the northern Gulf of St. Lawrence (Simpson *et al.* 2016). However, sex ratio in that area is close to 1:1.

Adult Lumpfish appear to remain offshore from late summer to early spring, then in early spring both males and females move inshore to reproduce (Collins 1976; Davenport 1985; Goulet *et al.* 1986), although DFO surveys indicate the presence of substantial numbers Lumpfish offshore in all months. Goulet (1985) reported that males appear inshore before females and establish nest sites. Females migrate inshore asynchronously, making it possible for males to court and spawn with several females during the spawning period. Additional eggs acquired from multiple (batch) spawnings are deposited adjacent to previously spawned eggs (Goulet and Green 1988).

Females leave the nest site immediately after spawning, while males remain, aerating the eggs and defending the nest against predators (Goulet *et al.* 1986; Goulet and Green 1988). The incubation period is influenced by ambient water temperature, and may last for 1-2 months (Collins 1976, Goulet *et al.* 1986). Whether spawning and nesting occurs further offshore (beyond the depth ranges studied) is unknown given lack of observations at other depths.

There have been no published studies examining maturity ogives for Lumpfish, although there have been numerous reports on mean lengths and estimated ages at first spawning. Studies seem to agree that first spawning is more related to length than age because the length of first spawning can cover a wide range of ages (Davenport 1985). Bagge (1964) suggested that in the North Sea females first spawn at 41 cm and males at 31 cm. Thorsteinsson (1983) reported the mean lengths of females at first spawning in Icelandic waters ranged from 37-40.5 cm, while the mean length for males was 28 cm. In Greenland waters, the comparable lengths were 28 cm for males and 38 cm for females (Hedeholm *et al.* 2014). Based on commercial sampling from Newfoundland waters, Blackwood (1981, 1982) found that the smallest females caught were 34-39 cm, while in the Cartwright area of Labrador, the smallest caught was only 25 cm. He considered there to be a geographic cline with smaller fish being mature in more northern areas. However, there were no specific analyses of maturity to support these suggested sizes at maturity.

Simpson *et al.* (2016) assigned unsexed maturity to length frequency data from Canadian research surveys using length of the fish (≥34 cm adult, <34 cm juvenile) based on information from Davenport (1985) and Stevenson and Baird (1988)[3].

Albert *et al.* (2002) described previous studies that indicated age at maturity ranged from about 3 through 5-10 years for females and about 4-7 years for males. However, they examined otolith age estimates together with length frequencies (from spawning grounds in the North Sea, Iceland, and coastal waters of both south and north Norway) and found that males may spawn for the first time at age 2–3, and females at age 3–4. Hedeholm *et al.* (2014), using the same ageing technique, obtained similar results for Lumpfish off eastern and western Greenland.

Thorsteinsson (1981) described an early study indicating that Lumpfish off Iceland became sexually mature at age 5-6 and indicated that a Canadian study reached a similar conclusion. Although the origin of the Canadian study was obscure, it was probably from the work of Cox, although the information is not contained in Cox (1920b) or Cox and Anderson (1922). Grant (2001) reported the only other age determination work for the Northwest Atlantic based on otolith samples taken from Torbay, NL. While noting that age determination of Lumpfish was problematic, age at first maturity for females was estimated to be 5.6 years corresponding to a mean length of ~ 36.5 cm.

[3] Empirical estimates of L_{50}'s of 28 cm for females and 22 cm for males based on data collected during DFO research surveys in NAFO SA2+3KLNOP were available. However, it was recommended that these estimates not be used as the criteria for maturity stage designation has not been verified (DFO pre-COSEWIC Meeting on Lumpfish, Nov. 17-18, 2015).

There are differing opinions regarding mortality related to reproduction. Sigurðsson and Magnússon (2013) commented that Lumpfish are short lived and only spawn once. The source of this perspective was not provided, and the perspective is doubtful. A number of studies have demonstrated that a proportion of Lumpfish will spawn at least twice (Bagge 1967; Schopka 1974; Blackwood 1983; Fréchet *et al.* 2006; Kasper *et al.* 2014), although the overall number of times they may spawn over their lifetime remains unclear. Kennedy *et al.* (2014) caution that tag loss, as reported by several authors, is suspected to be an issue during tagging studies and complicates the estimation of post-spawning mortality.

Bagge (1967) reported a statistically significant difference in tag returns from males (13.2%) and females (8.8%) that he attributed to higher female mortality during spawning. However, this is contradicted by age determination work that has suggested the presence of females up to age 13 but no males beyond age 9 (Thorsteinsson 1983). Thorsteinsson (1983) also reported that reproductive life spans are quite variable. He suggested that from the analysis of otolith patterns, one could infer that some fish spawn only once, but others may spawn as many as 11 times, and he concluded that mortality in adult fish is more size dependent than age dependent. Within cohorts, mean length increased with age until a certain length interval (approx. 42-44 cm) was reached, after which mean length fell with age, suggesting death of the larger fish. He postulated that the reproductive process (including gonad production, spawning migration and associated prolonged starvation) becomes progressively costlier to the fish with increasing size and eventually large fish do not recover from spawning.

Cox (1920b) suggested there is rapid growth during the first summer of life, with the young sometimes doubling the average length in a month. According to Davenport (1985), it appears that most of the growth in length occurs before maturity. Hedeholm *et al.* (2014) concluded that male maximum size was reached by age three, as almost no somatic growth was seen from age three to four. No females older than four years were available to examine, but they theorized that similar mean size-at-age at age three and four indicated that this was also the case for females. Females were, on average, 8.8 and 10.3 cm larger than males at ages three and four. Kasper *et al.* (2014), however, argued that Lumpfish continue to grow, albeit at a slower rate, after reaching maturity as verified by both the Norwegian and Icelandic tagging studies of mature fish. They suggested the observed scarcity of fish between 10 and 18 cm, combined with the 17–30 cm growth observed during 528 days following tagging, suggests a period of rapid growth prior to maturity at age 3 or 4.

Thorsteinsson (1983) found that the weight of gonads/total weight did not vary with size for females caught on spawning grounds around Iceland.

For the most part, only linear length-weight relationships for Lumpfish have been described for mature females (e.g., Blackwood 1982; Gregory and Daborn 1982; Stevenson and Baird 1988), although this may be due to the fact that the length range of samples was generally small (~ 35-55 cm).

Length/weight data were available from Cox (1920b), DFO RV surveys off Newfoundland and Labrador (Div. 2GHJ3KLNOP), in the northern (nGSL) (Div. 4RS) and southern Gulf of St. Lawrence (sSGL) (Div. 4T) and Scotian Shelf (Div. 4VWX5Z). Additionally, data were provided from sampling Lumpfish off West Greenland[4]. The unsexed relationships for the recent surveys are quite similar and somewhat different from the historic data collected by Cox (1920b).

Generation time (*G*) 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. For Lumpfish, the generation time was estimated to be 7 years. Natural mortality (*M*) was approximated as 0.3 (Appendix 1). Both estimates are associated with considerable uncertainty.

Physiology and Adaptability

According to Collins (1976), spawning occurs when temperatures exceed ~4ºC but Goulet *et al.* (1986) observed spawning between temperatures of -1ºC - +7ºC. Based on European studies, hatching and growth of juveniles is related to temperature with mean weights and lengths showing a significant, stepwise increase with increasing temperature for most samples (Nytrø 2013). Fish reared at 4ºC displayed the lowest growth rate overall. This was in agreement with Ingólfsson and Kristjánsson (2002) who found that juveniles grew very little if at all during the first winter in waters around Iceland due to the cold water temperatures. Eriksen *et al.* (2014) reported that in the Barents Sea, while Lumpfish were found in temperatures from 0º to 11ºC, the largest concentrations were found in waters of 5º to 7ºC (60% of juveniles) and 4º to 7ºC (70% of adults). This contrasts with findings in the Northwest Atlantic where, although the range was similar, highest concentrations of demersal juveniles and adults were observed in much colder conditions, < 2ºC (see Figure 11), suggesting different local adaptations, although near surface YOY were observed mainly in 6º to 7ºC.

Dispersal and Migration

During their first year, juveniles < 5 cm can be found in shallow waters, in tidepools or estuaries (Squires 1967; Moring 1989, 2001; Moring and Moring 1991; Methven *et al.* 2001) and extensively in near surface offshore waters, often attached to floating seaweeds (Daborn and Gregory 1983; Moring 2001; Ingólfsson and Kristjánsson 2002; Kasper *et al.* 2014). Larval records from the Bay of Fundy, Scotian Shelf, Gulf of St. Lawrence and Grand Banks indicate that they are widely distributed in those areas near the surface in spring. During this period, they are prone to drifting with surface currents leading to significant dispersion during early stages. It has been suggested that in their second year, Lumpfish begin an independent pelagic mode of life no longer associated with seaweed (Ingólfsson and Kristjánsson 2002).

[4] The data were provided by R. Hedeholm and S.L. Post of the Greenland Institute of Natural Resources to A. Fréchet (DFO, Québec Region (retired)) who then provided them to J. Gauthier, DFO, Québec Region.

Lumpfish, even though lacking a swim bladder, are neutrally buoyant allowing them to easily move vertically in the water column or drift with the currents (Davenport and Kjørsvik 1986). In addition, Lumpfish have a sucker that it can use to adhere to rocks and other objects to avoid being swept along in currents.

In spite of their morphology, Kennedy *et al.* (2014) reported that Lumpfish showed extensive movements around Iceland, with fish tagged in coastal areas being recaptured up to 587 km from their tagging site. Fish tagged offshore showed no clear pattern of where they would be recaptured. Although limited tagging has been conducted in Canadian waters (Blackwood 1982, 1983; Fréchet *et al.* 2006), these studies have all been carried out on the spawning grounds with all recoveries being from spawning grounds near the tagging site. This observation could be interpreted in two ways; that migrating fish return to specific sites or that they do not migrate. Blackwood (1983) described an extensive inshore movement of ~160 km in 14 days and Grant (2001) reported that some of his tag returns provided evidence of linear inshore movements by females of ~50 to ~130 km in 12 to 17 days. Overall, migration patterns of adults in Canadian waters are not known, but there is evidence elsewhere that they do undertake substantial movements, thus supporting a single DU hypothesis.

Interspecific Interactions

Templeman *et al.* (1976) found that Lumpfish is a common intermediate host of the larvae of the copepod, *Lernaeocera branchialis*, around Newfoundland and neighbouring areas. They found large numbers of these larvae on the gills of samples from inshore Newfoundland areas during the latter half of June to the first half of August, whereas only minor infections were found during any month in offshore areas. They concluded that infection of the final host, Atlantic Cod (*Gadus morhua*), apparently occurred mainly inshore. Lumpfish are hosts for both the protozoan *Cryptobia dahli* (Khan 1991) and the nematode *Anisakis simplex* (McLelland *et al.* 1990) and also a preferred host of the ectoparasitic copepod *Caligus elongates*, also known as “sea lice” (Øines *et al.* 2006; Øines and Heuch 2007; Heuch *et al.* 2007). The protozoans *Cryptobia dahli* and *Trichodina domerguei* are known to infest Lumpfish stomachs and urinary bladders, respectively (Margolis and Arthur 1979). There is no information on the possible impacts of these infestations on Lumpfish.

Mullins *et al.* (1994) reported the presence of an intranuclear rnicrosporidian that resulted in abnormal kidneys and chronic mortalities in Lumpfish raised in captivity, but did not identify the species. Freeman *et al.* (2013) also found an intranuclear microsporidian in wild Lumpfish caught around Iceland during spawning that caused kidney enlargements. They proposed the name *Nucleospora cyclopteri*.

Both benthic and pelagic species have been reported as part of the Lumpfish diet. Davenport (1985) summarized that Lumpfish mainly subsist on large planktonic organisms living in surface/mid-waters (medusa, ctenophores, euphausiids, etc.), but also occasionally browse on benthic organisms, particularly those dwelling upon seaweed. Bowman *et al.* (2000) reported polychaetes as well as copepods and Ascidiacea (sea squirts) in their diet off the USA. Rusyaev and Orlov (2014) indicated that a significant part of the adult diet comprises northern comb jelly in the Barents Sea. Daborn and Gregory (1983) studied post-larval fish < 55 mm in length, and found that they feed on near surface plankton, eating copepods (associated with drifting seaweed) then shifting to amphipods as they grow.

Young Lumpfish were noted as a prey item for Thorny Skate (*Amblyraja radiata*) (Templeman 1982). Davenport (1985) documented reports of Lumpfish being preyed upon by sharks and Sperm Whales (*Physeter microcephalus*). Thorsteinsson (1983) reported that seals, Greenland Sharks (*Somniosus microcephalus*) and Sperm Whales all prey on adult Lumpfish around Iceland. In the Northwest Atlantic, Lumpfish have been reported in the stomachs of Porbeagle Sharks (*Lamna nasus*) (Joyce *et al.* 2002), Harp Seals (*Pagophilus groenlandicus*) (Hammill and Stenson 1997, 2000; Stenson *et al.* 2009) and Grey Seals (*Halichoerus grypus*) (Benoît and Bowen 1990).

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

Fisheries and Oceans Canada (DFO) offshore demersal research trawl surveys form the basis for determining population size and trends for Lumpfish. There are no time series of inshore or pelagic surveys available to measure changes in population size. The DFO surveys are administered separately by five regions: 1) Newfoundland and Labrador (NL); 2) Quebec; 3) Gulf; 4) Maritimes; and 5) Central and Arctic. There are differences in survey trawl gears (with different catchabilities), survey seasons and years surveyed in different areas throughout the range of Lumpfish (Table 1).

There is a degree of consistency in that all regions use demersal trawl gear and a stratified random survey design based on depth and latitude (Doubleday 1981; Brodie 2005). Estimates of survey abundance are calculated using the method of areal expansion whereby the average number of Lumpfish caught per tow within each stratum is multiplied by the number of trawlable units for the respective stratum (see e.g., Smith and Somerton 1981). The strata estimates are then summed over the entire survey area (Bishop 1994; Kulka *et al.* 2006). These population abundance estimates can be either left unadjusted for gear and spatial changes or adjusted if relevant comparative trawling information is available.

Table 1. A summary of Fisheries and Oceans research surveys by region showing gears used and seasons fished.

Region	Area	Years	Season	Gear
C&A	SA0	1999-2001, 2004-2012	Fall	Alfredo III otter trawl, Cosmos 2000, Campelen 1800 shrimp
NL	3LNOPs	1971-1983	Winter/ Spring	Yankee-41.5
NL	3LNOPs	1984-1996	Spring	Engel 145 Hi-Lift
NL	3LNOPs	1996-2015	Spring	Campelen 1800 shrimp
NL	2HJ3K	1977-1980	Fall	Engel 145 Hi-Lift
NL	2HJ3KL	1981-1988	Fall	Engel 145 Hi-Lift
NL	2HJ3KLNO	1989-1994	Fall	Engel 145 Hi-Lift
NL	2HJ3KLNO	1995-2014	Fall	Campelen 1800 shrimp
Que	4RS3Pn	1978-1994	January	Engel 145 Hi-Lift
Que	4RS T(partial)	1984-1990	August	Western IIA
Que	3Pn 4RS T(partial)	1990-2005	August	URI Shrimp Trawl
Que	4RS T(partial)	2004-2015	August	Campelen 1800 shrimp
Gulf	4T	1971-1985	September	Yankee 36
Gulf	4T	1986-2015	September	Western IIA
Mar	4VWX	1970-1981	Summer	Yankee 36
Mar	4VWX	1982-2015	Summer	Western IIA
Mar	4VsW	1986-2010	Spring	Western IIA
Mar	5Z	1986-2015	Winter	Western IIA
Mar	4VWX	1978-1984	Fall	Western IIA
Mar	4VWX (deep)	1982-1988	Summer	Western IIA

Note: Not all NAFO Divisions were sampled in all years. Refer to Simpson *et al.* (2016) for details. For C&A, DFO/Greenland deep water multi-species surveys - Alfredo trawl gear from 1999-2001, then 2004, 2006, 2008, then 2010-present; DFO/Greenland shrimp surveys - Cosmos trawl gear from 2006-2013; NSRF shrimp surveys - Campelen gear from 2005-present.

Survey details are summarized in a variety of documents: for all regions up to 2006 (Kulka *et al.* 2006), Maritimes (Simon *et al.* 2012; Claytor *et al.* 2014), Gulf and Quebec (Swain *et al.* 2012; Bourdages et. al. 2016), Newfoundland and Labrador (Simpson *et al.* 2012) and most recently for all regions to 2014 (Simpson *et al.* 2016), as well as in various COSEWIC reports that have used these data sources for other species (e.g., Thorny Skate (*Amblyraja radiata*), Atlantic Cod (*Gadus morhua*), redfish (*Sebastes* spp.).

The type of survey gear greatly influences the proportions of the size of fish captured as well as overall catchability at any size and this confounds comparative analyses or combination of the data among regional surveys that use different gears (Benoít and Swain 2003).

Davenport (1985) indicated that Lumpfish are semi-pelagic, spending much of their adult lives in the pelagic zone and Fahay (2007) suggested they are primarily pelagic except during reproduction. However, neither author provided supporting evidence and available evidence indicates otherwise. Juvenile and adult Lumpfish are captured extensively in demersal surveys by NL Region of DFO during all months of the year in all parts of their range and they are also taken regularly in demersal commercial fishing gears. As well, a part of their diet comprises demersal prey (polychaetes, sea squirts and molluscs) and this indicates that a significant portion of their time during all months and particularly in the winter is spent on or near the bottom. Furthermore, a study off Iceland utilizing data storage tags (Kennedy *et al.* 2015) indicated that adult Lumpfish spent a significant amount of time on or near bottom.

Simpson *et al.* (2016) considered that the semi-pelagic nature of adults, coupled with annual spring spawning migrations, renders standard bottom trawl surveys inappropriate to evaluate population size or trends in abundance and biomass for Lumpfish.

DFO surveys are generally spatially and temporally consistent, sampling the same area at the same time of year, day and night. Thus, if there are no temporal changes in behaviour of a sampled species that affect availability to the gear over time, such as a systematic shift between a demersal and pelagic habitat over the period of the survey, then that same portion of the population being sampled/measured by the survey from one year to the next should appropriately reflect relative changes in biomass and abundance of the population. This is the same assumption used for all species for which DFO surveys form the basis for determining population trends. For example, DFO regularly uses the survey indices as a measure of biomass and abundance to assess other semi-pelagic/migratory species such as Pollock (*Pollachius virens*), redfish (*Sebastes* spp.), Atlantic Cod (*Gadus morhua*) and Dogfish (*Squalus acanthias*), among others. There is no evidence that Lumpfish, within the survey window, have systematically shifted their distribution over time, horizontally or vertically that could result in a trending pattern unrelated to changes in population biomass and abundance.

Demersal surveys are used in other areas to evaluate Lumpfish populations such as off Iceland (Gascoigne *et al.* 2014; Kennedy *et al.* 2015). In the Barents Sea, bottom trawl (along with pelagic) survey indices are considered to be indicative of Lumpfish distribution (Wienerroither *et al.* 2013; Eriksen *et al.* 2014). Kennedy *et al.* (2015) concluded that because Lumpfish frequently exhibit demersal behaviour, the use of demersal surveys to monitor changes in abundance is warranted.

Catchability (q) of most demersal fish in the surveys is thought to be <1 because fish escape the passing nets, may be well off bottom above the gear or outside the survey area. It is these latter points (Lumpfish are semi-pelagic, inshore spawning) that confound estimation of abundance, all or part of the population being inaccessible to the survey gear at certain times. Catchability has not been estimated for Lumpfish but survey abundance estimates presented here are considered minimum estimates of population size.

Abundance Fluctuations and Trends

Davis Strait

Abundance estimates were not generated for Lumpfish in NAFO SA 0 because of the low abundance resulting in small annual sample sizes (Simpson *et al.* 2016).

Newfoundland and Labrador

The demersal surveys conducted by NL Region of DFO have not only varied by season, but also by area of coverage. Additionally, there have been gear changes over time (Table 1, Appendix 2, Simpson *et al.* (2016)). As well, seasonal differences in catchability of Lumpfish during demersal surveys, beyond gear changes, are expected due to their pelagic/demersal and inshore/offshore behaviours. Prior to 1995-1996 (pre-Campelen), there was considerable variability in both area and seasonal survey coverage whereas coverage became more consistent coincidental with the introduction of the Campelen trawl. Because of this, pre-Campelen abundance estimates are presented for general information, and detailed analyses were considered for the Campelen time series only. As well, the Campelen series covers a period (20 years) that is approximately equivalent to three generations (21 years).

During the fall surveys, coverage of Div. 2GH was intermittent, and Div. 3NO was not surveyed before 1990. Nonetheless, all areas were included in the analysis. Div. 2GH contributed only 2% of the total abundance in Div. 2GHJ3KLNO when examining years when those two divisions were sampled. The divisions where most of the abundance occurred, 2J3KL, were consistently sampled (except for Div. 3L that began in 1981). The reason for the generally higher values after 1985 compared to 1978–1985 is unclear (Figure 14).

The winter and spring survey coverage and timing varied considerably during the Yankee/Engel gear period, 1971–1995 (Figure 15). Because of this it is not possible to discern trends in abundance. Based on the winter surveys in Div. 3P, it is clear that catchability (q) is higher in winter likely due to Lumpfish being closer to the bottom during this time of year.

Post-1995 survey results overlap on the Grand Bank (Div. 3LNO) but the fall survey (Figure 16) covers the Labrador Shelf as well as the Grand Bank while the spring survey (Figure 17) also includes St Pierre Bank (Div. 3P) where Lumpfish are most densely concentrated. Both areas show the same steep downward trend during 2006-2008, fluctuating without trend prior to that.

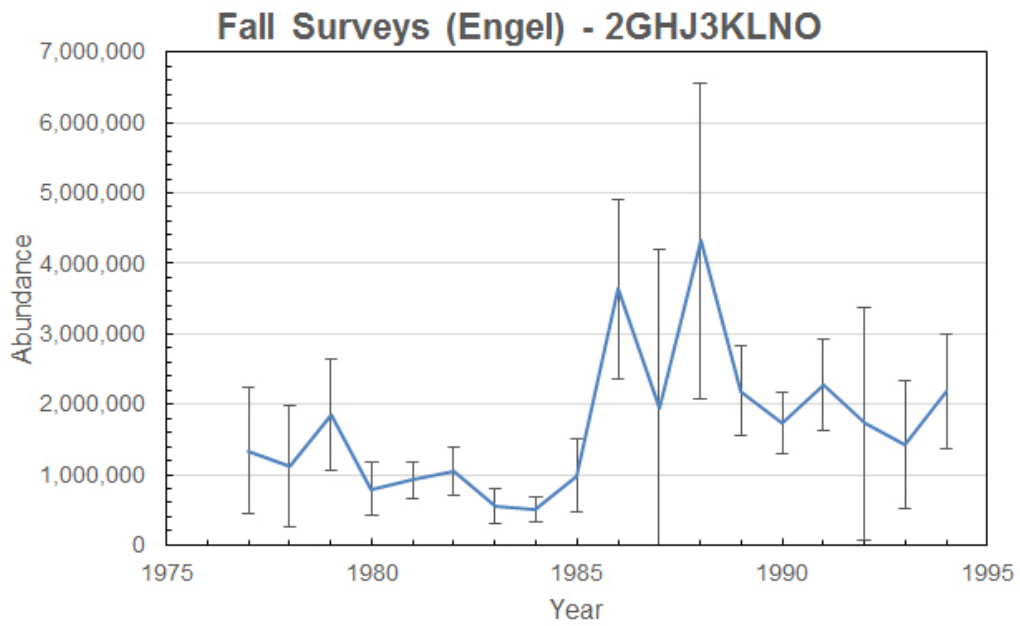

Figure 14. Minimum trawlable abundance estimates from fall surveys conducted by NL Region of DFO in Div. 2GHJ3KLNO using Yankee (up to 1983) and Engel (post-1983) gear. Error bars are 95% confidence intervals derived from the sampling variance.

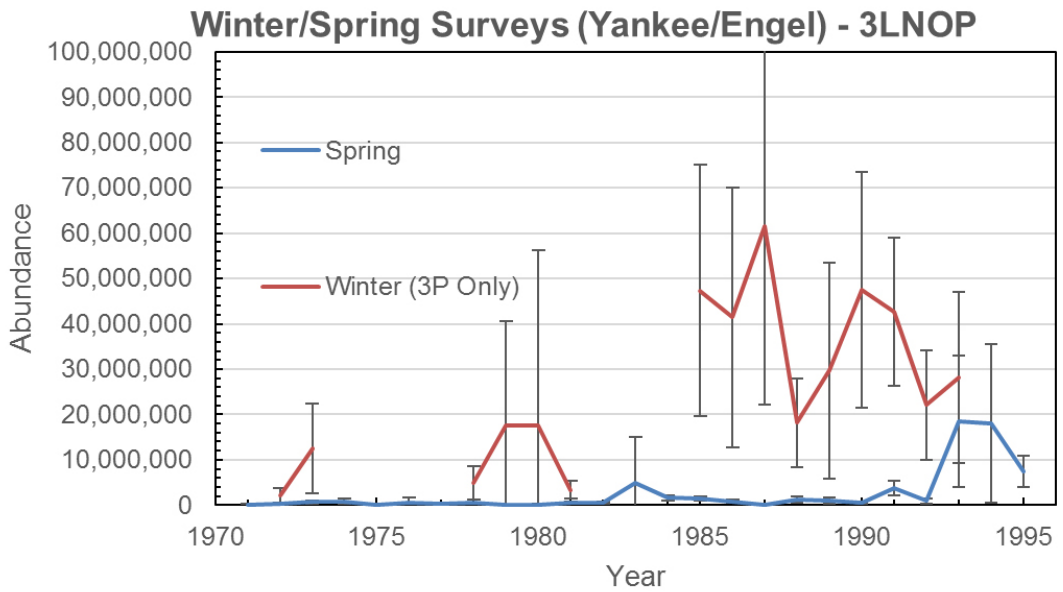

Figure 15. Minimum trawlable abundance estimates (total, with 95% confidence intervals) from surveys conducted by NL Region of DFO in Div. 3P (winter) Div. 3LNOP (spring) using Yankee/Engel gear (Yankee until 1983 then Engel). Note that the spring surveys only included 3P when there was no winter survey except for 1993 when two surveys were conducted.

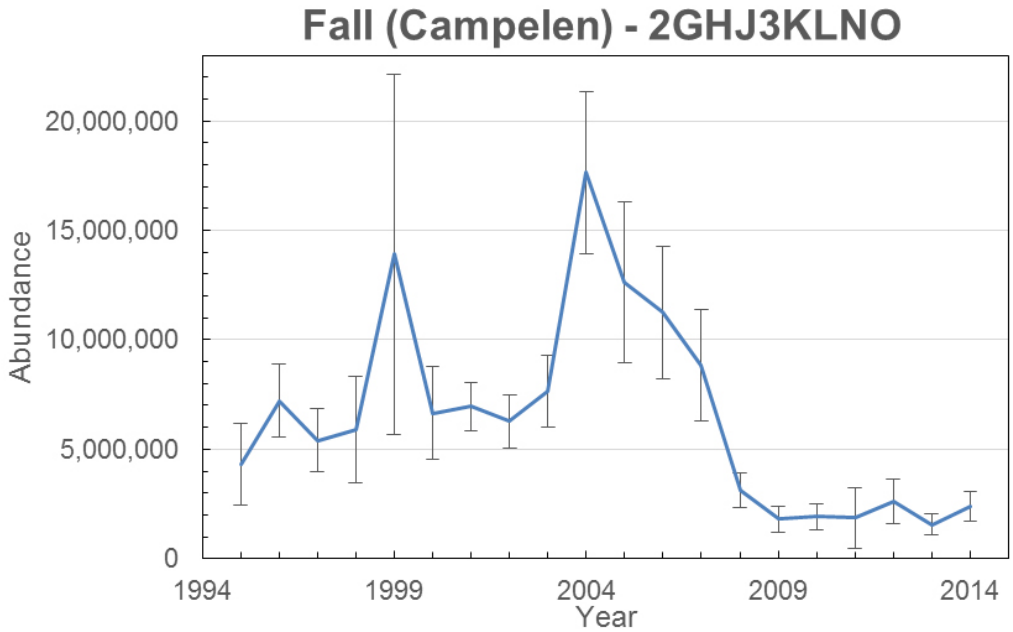

Figure 16. Minimum trawlable abundance estimates (total, with 95% confidence intervals) from fall surveys conducted by NL Region of DFO in Div. 2GHJ3KLNO using Campelen gear (Note that the fall survey was incomplete in 2014, due to partial coverage of Div. 3L and no sampling of Div. 3NO).

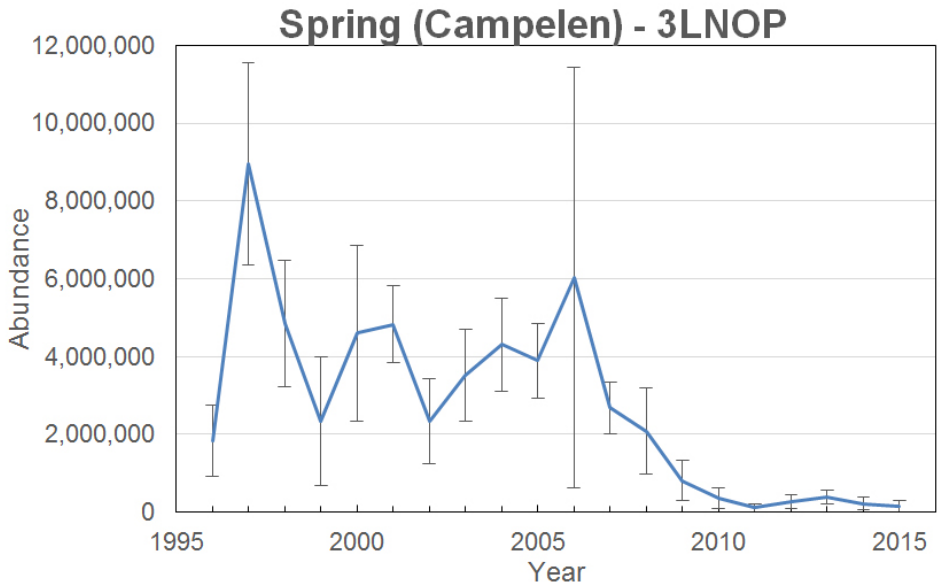

Figure 17. Minimum trawlable abundance estimates (total, with 95% confidence intervals) from spring surveys conducted by NL Region of DFO in Div. 3LNOP using Campelen gear (Note that most of Subdiv. 3Ps and deeper portions of Div. 3NO were not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties).

The percentage decline ($D_{\%}$) was determined based on mature abundance (assumed to be ≥ 34 cm) of sexes combined. The percentage decline 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 decline ($D_{\%}$) over y years can be calculated as

$$D_{\%} = (1 - e^{(\beta \times y)}) \times 100$$

Note that 3 generations corresponds to 21 years, so the 20 year period was chosen over which to calculate percent decline. The fall surveys had a percent decline of 81.2% (95% CI: 44.2% – 93.7%) (Figure 18), while that based on the spring surveys is 98.8% (95% CI: 94.6% – 99.7%) (Figure 19).

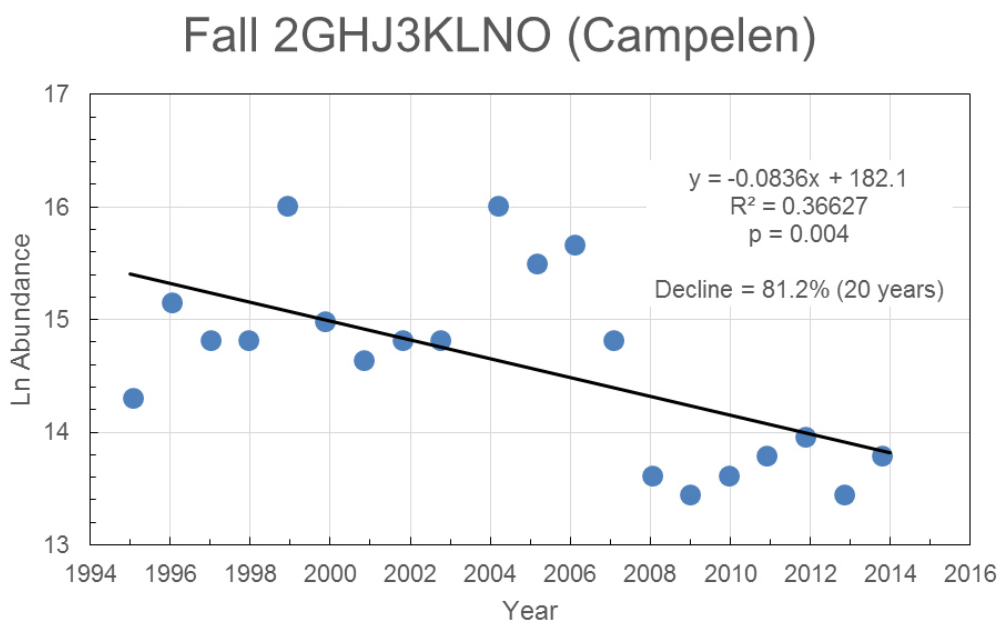

Figure 18. Percent decline in mature abundance (≥34 cm) based on fall surveys in 2GHJ3KLNO using Campelen gear (Note that the fall survey was incomplete in 2014, due to partial coverage of Div. 3L and no sampling of Div. 3NO).

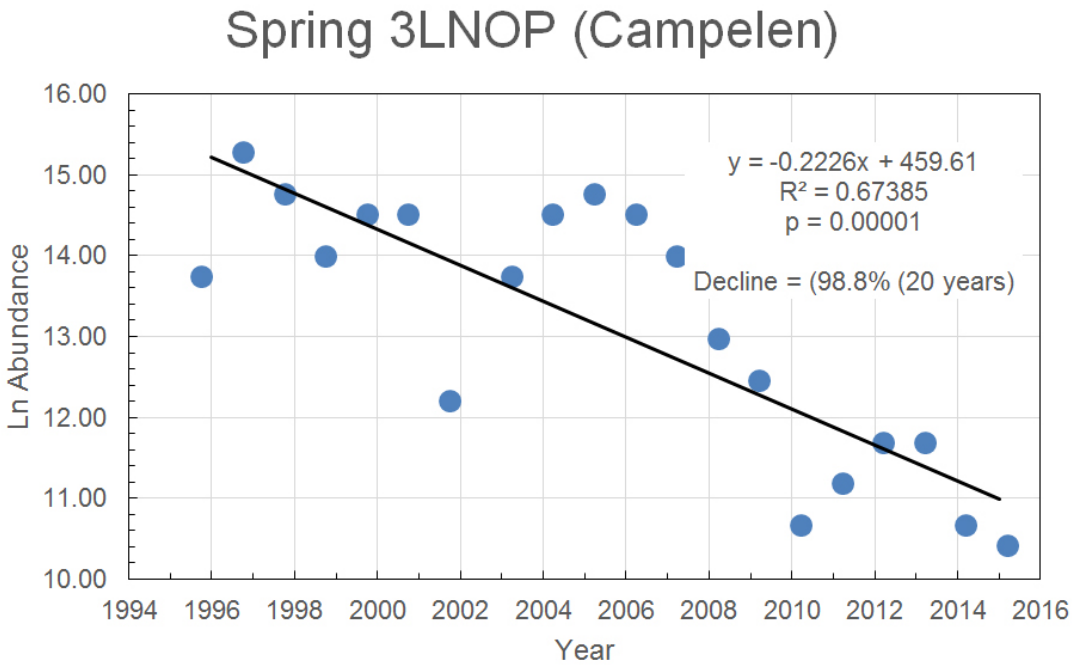

Figure 19. Percent decline in mature abundance (≥34 cm) based on spring surveys in 3LNOP using Campelen gear (Note that most of Subdiv. 3Ps and deeper portions of Div. 3NO were not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties).

A decline in commercial activity targeting Lumpfish corresponds with a decline in relative survey abundance off Newfoundland. Despite record high prices and a strong market for roe product, roe landings during 2009-2012 were only 4% of the 1997-2000 levels. Historically (prior to 2007), about 50% of landings were attributable to NAFO Div. 3P. After 2011, it was < 1%. This suggests that the biggest reductions occurred off the south coast of Newfoundland where Lumpfish were previously most abundant. Lumpfish bycatch in other directed fisheries also showed a similar degree of reduction (refer to **Threats** section below).

Sexed length frequency information is available from the NL surveys. For both SA2+ Div. 3KLNO (fall) (Figure 20) and Div. 3LNOP (spring) (Figure 21) there appear to be three reasonably distinct periods: 1995 - ~2000 when there were mostly large adults caught, 2001 - ~ 2008 when there appeared to be improved recruitment but also fewer larger fish, and ~2008 to the present when there were fewer fish of all sizes.

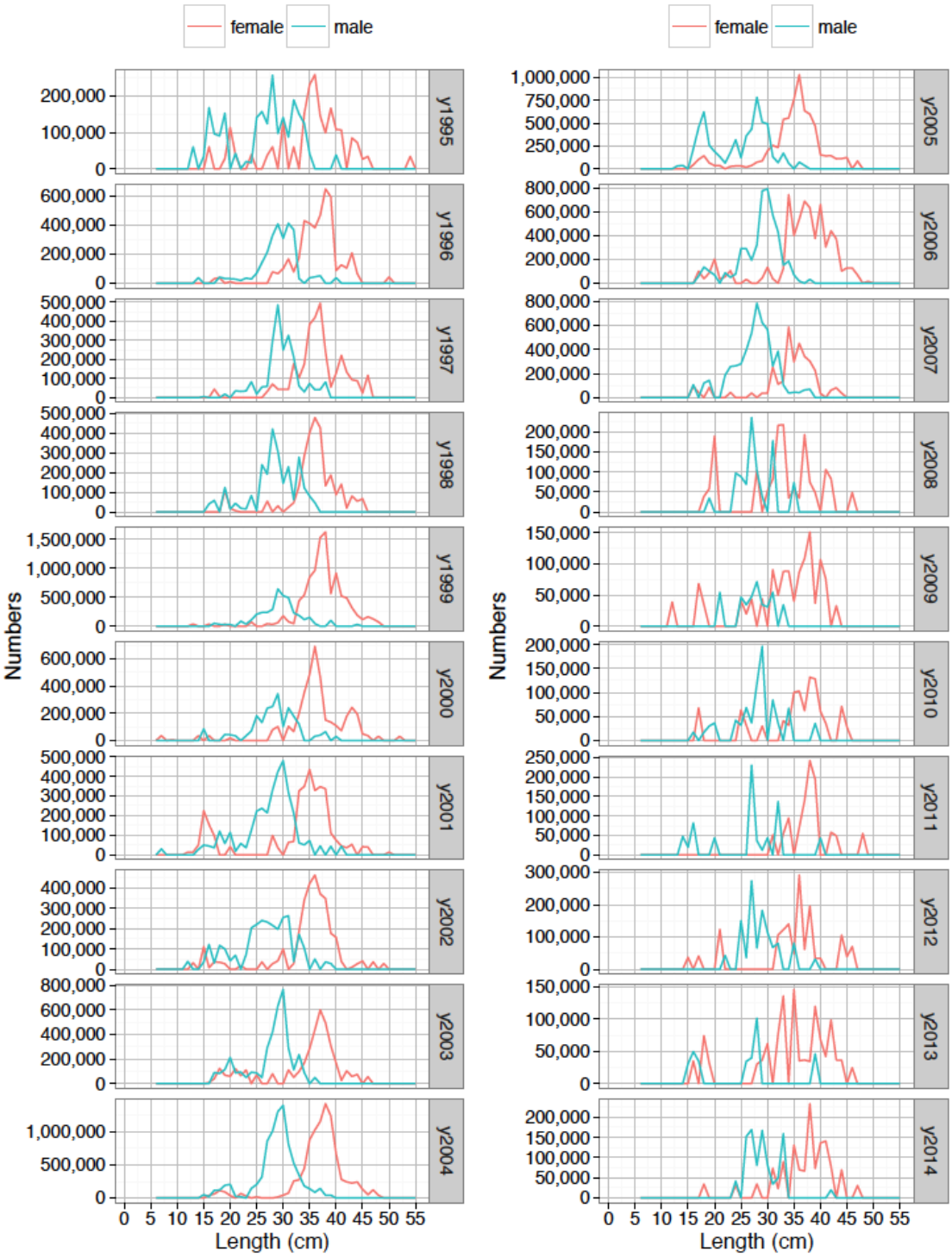

Figure 20. Sexed length frequencies of Lumpfish caught during fall NL research surveys in SA2+3KLNO (Note that the fall survey was incomplete in 2014, due to partial coverage of Div. 3L and no sampling of Div. 3NO).

Figure 21. Sexed length frequencies of Lumpfish caught during spring NL research surveys in 3LNOP (Note that most of Subdiv. 3Ps and deeper portions of Div. 3NO were not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties).

Northern Gulf of St. Lawrence

Coverage in the northern Gulf of St. Lawrence (Div. 3Pn4RS) winter surveys conducted from 1978 through 1994 was highly variable. Results for the Div. 3Pn4R portion of the survey were most consistent; therefore the time series is examined for this area only (Figure 22). Overall, the index varied without trend. Length frequency data were not available from this survey.

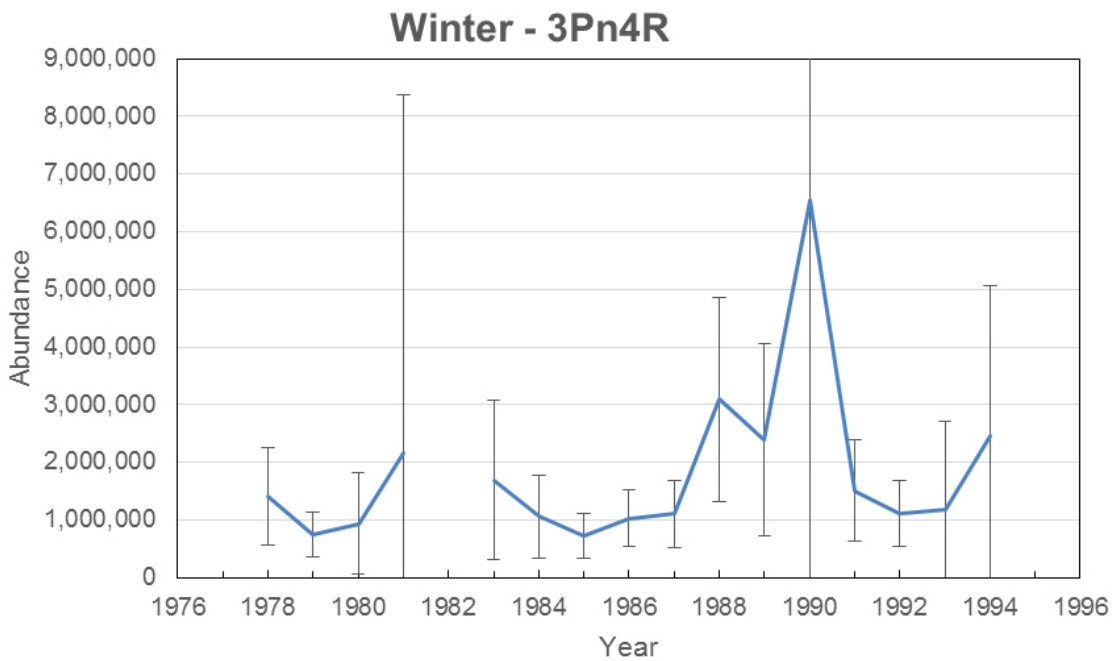

Figure 22. Minimum trawlable abundance estimates (total, with 95% confidence intervals) from winter surveys conducted by Quebec Region of DFO in Div. 3Pn4R during winter. Upper CI in 1990 was 17 million.

During the summer surveys of Div. 4RST (Gulf of St. Lawrence), Lumpfish are only caught infrequently and the confidence intervals around the estimates are quite large. The increase in the estimates after 2004 coincides with a change in gear for this survey and overall it is considered that there is no detectable trend (Figure 23) (Simpson *et al.* 2016).

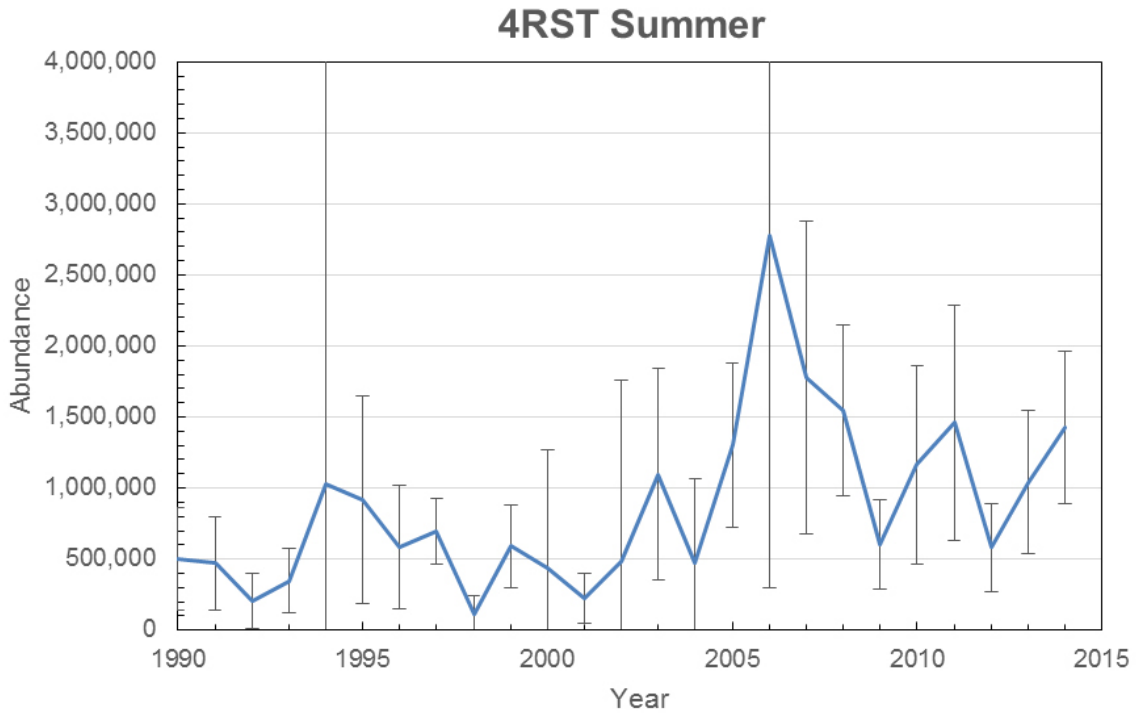

Figure 23. Minimum trawlable abundance estimates (total, with 95% confidence intervals) from summer surveys conducted by Quebec Region of DFO in Div. 4RST. Upper CIs in 1994 and 2006 were 6.5 and 5.3 million respectively. There was a gear change between 2004 and 2005 but comparative fishing experiments indicated that vessel/trawl combinations have no effect on Lumpfish catchability so no correction was required to combine data from the two summer survey series (Simpson *et al.* 2016).

Unsexed length frequency information is available from these summer surveys. Based on an assumed knife-edge maturity of ≥34 cm (Simpson *et al.* 2016 and above) the proportion of mature individuals was generally low (≤ 10% of the total) in all but 4 years. These low values may be due to the mature portion of the population being nearshore during the time of the surveys for spawning. Overall, there is considerable inter-annual variability in the mature abundance with no clear trend over time (Figure 24). While the overall abundance increased somewhat with the change in gear, the mature biomass did not, suggesting the more recent gear has a higher catchability (q) for smaller fish. The high value in 2006 corresponds to the high overall estimate of mature Lumpfish in that year (Figure 23), but still represents only 11% of the total abundance.

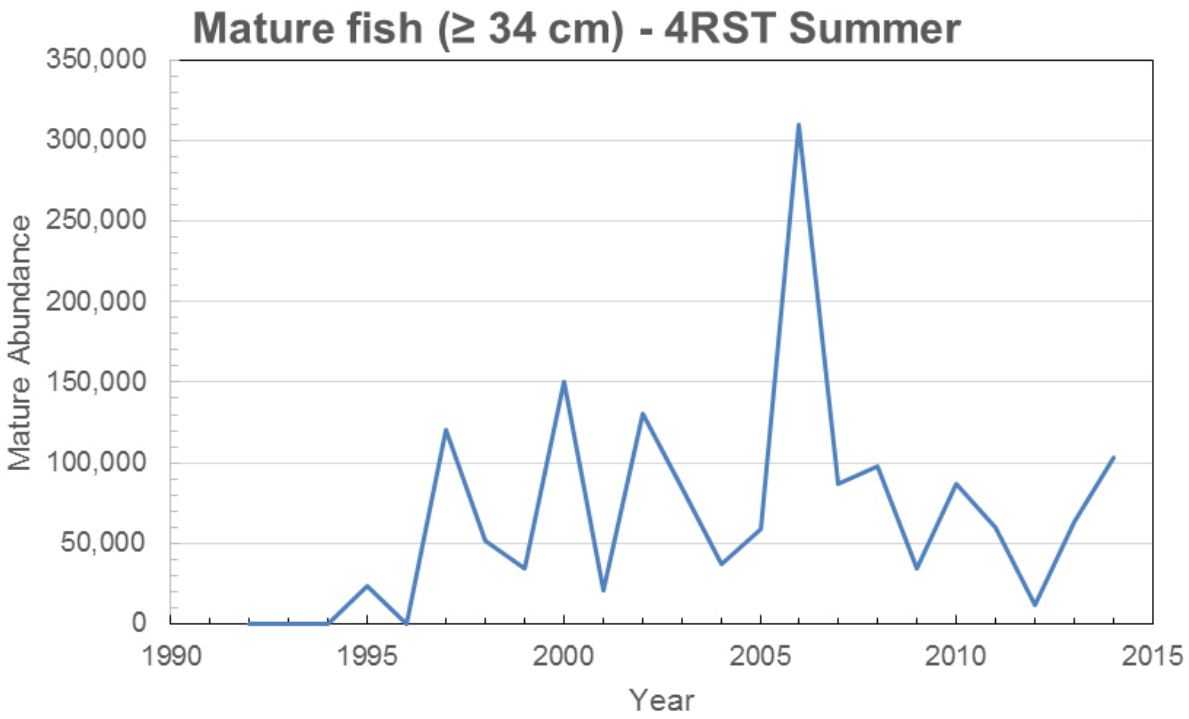

Figure 24. Minimum trawlable abundance estimates (mature (≥34 cm)) from summer surveys conducted by Quebec Region of DFO in Div. 4RST. There was a gear change between 2004 and 2005 but comparative fishing experiments indicated that vessel/trawl combinations have no effect on Lumpfish catchability so no correction was required to combine data from the two summer survey series (Simpson *et al.* 2016).

Southern Gulf of St. Lawrence

There are relatively few Lumpfish in the southern Gulf of St. Lawrence (Div. 4T) and there is a great deal of interannual variability in both site and magnitude of catches (Figure 25). There are no discernable trends over time regardless of the type of trawl gear used.

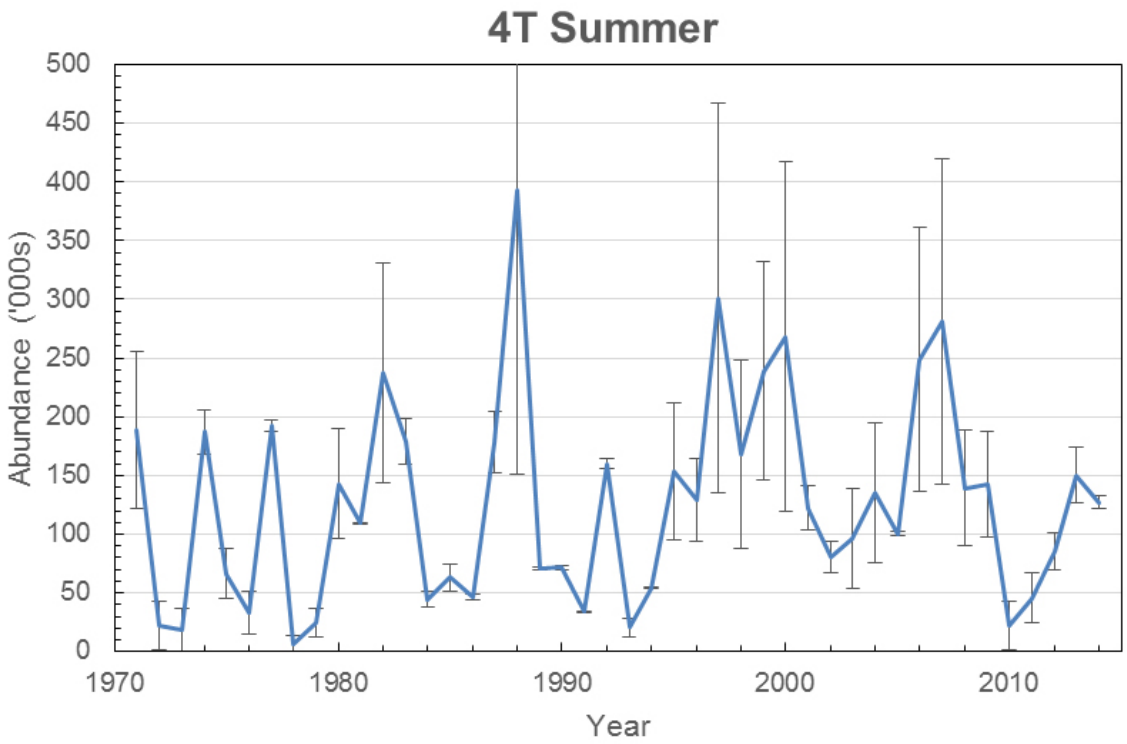

Figure 25. Minimum trawlable abundance estimates (total, with 95% confidence intervals) from summer surveys conducted in the southern Gulf of St. Lawrence, Div. 4T. There was a gear change between 2003 and 2004.During comparative fishing experiments, Lumpfish were seldom caught so a conversion factor could not be derived. Consequently, each vessel/gear combination is assumed to capture this species with the same efficiency (Simpson *et al.* 2016).

Scotian Shelf

Due to differences in survey gears and seasons, the abundance estimates for the Scotian Shelf were separated by area and survey. Surveys conducted by Maritimes Region capture few Lumpfish (they were only caught in 3% of all tows between 1970 and 2015) and as such there are wide fluctuations in the abundance estimates between years, both with the spring/winter surveys (Figure 26) and the summer surveys (Figure 27). Overall, there are no apparent trends in either of the survey series.

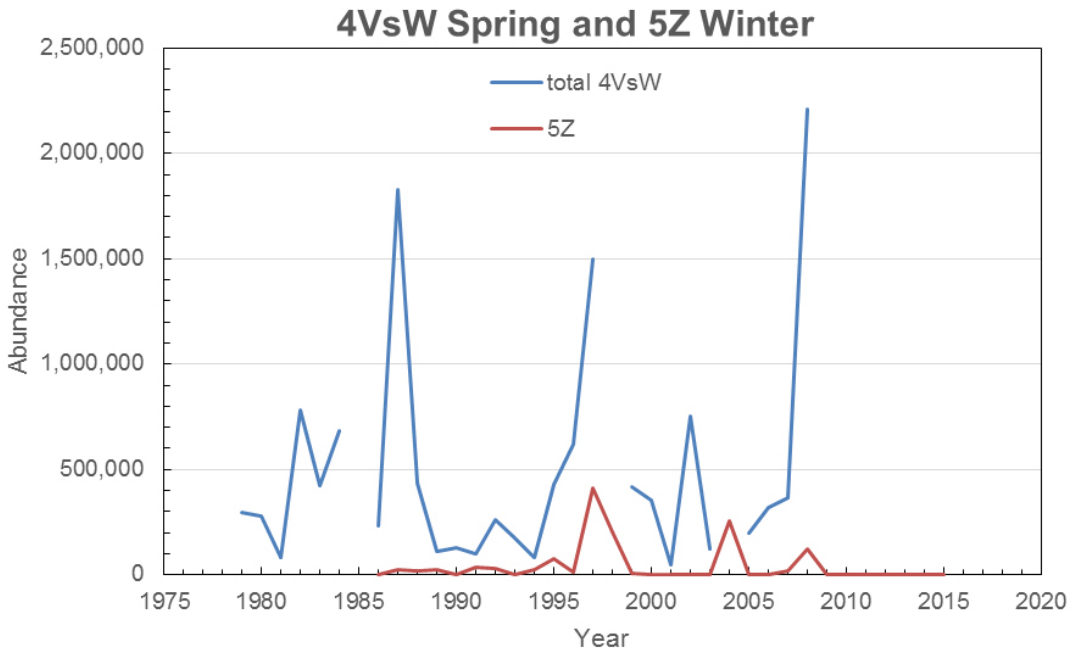

Figure 26. Minimum trawlable abundance estimates from surveys conducted in Div. 4VsW (Spring) and 5Z (Winter) (confidence intervals not provided).

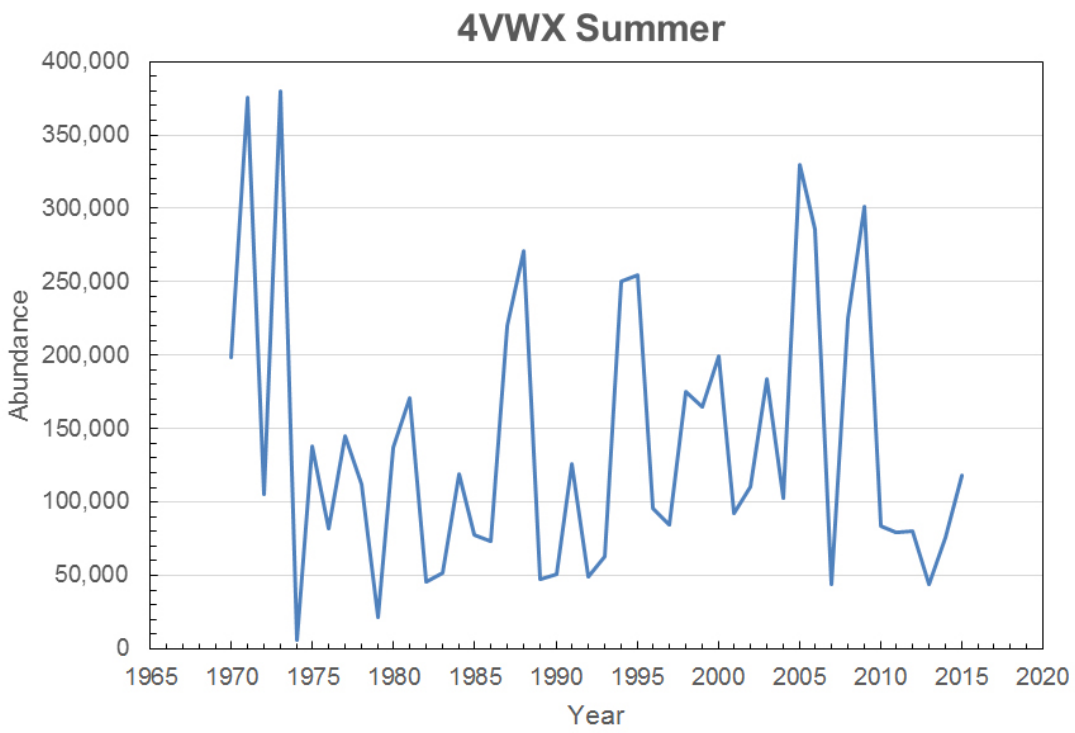

Figure 27. Minimum trawlable abundance estimates from summer surveys in Div. 4VWX (confidence intervals not provided).

Summary of Abundance Trend Information

Overall, there has been a decline in abundance of about 58% indicated in bottom trawl surveys over 19-20 years conducted in the core part of its Canadian range (off southern Newfoundland) However, abundance appears to have remained stable across other parts of the Canadian range such as the northern Gulf of St. Lawrence. In other areas, Lumpfish are only caught infrequently.

Rescue Effect

Lumpfish do occur in areas adjacent to Canadian waters, namely in the USA (survey records), Greenland (see e.g., Nygaard and Jørgensen 2014) and the Flemish Cap (Wells and Baird 1989). The information from Wells and Baird (1989) was based on winter surveys. More recent surveys of the Flemish Cap (Alpoim *et al.* 2002) conducted during summer did not catch any Lumpfish, suggesting that the winter occurrences may have been migrants from within Canadian waters that move shoreward from the Cap during spring. Except for Greenland, the other areas are marginal habitat for Lumpfish; the bulk of the biomass resides in Canadian waters. Thus, rescue from the USA or Flemish Cap is unlikely. The possibility of rescue from Greenland is unknown.

THREATS AND LIMITING FACTORS

Key factors evaluated as potential threats to Lumpfish off Canada include fishing, change in habitat and seismic exploration. Mortality due to fishing is the only threat for which direct, quantitative data are available. Seismic activity associated with oil exploration could potentially affect pelagic, near-surface larval and YOY stages near the acoustic arrays. Seismic activity has been extensive off Canada (see Figure 33), particularly in areas around Newfoundland. Warming that has occurred over the past 20 years potentially may affect population growth.

Number of Locations

Lumpfish do not occupy multiple discrete locations (in the COSEWIC usage of the term) but rather form a nearly continuous distribution over 26 degrees of latitude (~2900 km) along the shelf waters of West Greenland, Canada and the USA. Over this range, Lumpfish are exploited in various fisheries, both directed and bycatch. In the COSEWIC context, locations are equivalent to threats, and if each fishery constitutes a threat, the number of locations would be >5.

The Fishery

The Newfoundland and Labrador Provincial Department of Fisheries became involved in promoting and developing a Lumpfish roe fishery during the late 1960s and early 1970s (Allen 1978; Sturge 1980; Warren 1980; Blackwood and Mercer 1981; Blackwood 1983). As the fishery developed, Canadian round weight equivalent landings (almost entirely females) increased from 16 t in 1969, peaking in 1986 at 14,559 t, and averaging 8,700 t annually from 1985 to 2000 (Figure 28). After 1970, >99% of the reported round equivalent landings were attributable to the roe fishery and 98% of those landings were taken from near shore waters surrounding Newfoundland.

Johannesson (2006) indicated that Canada became a leading exporter of Lumpfish roe from the 1980s to the mid-2000s supplying more than one third of the global market share in most years and exceeding that of other major producers (Denmark, Iceland and Norway).

Despite continuing high market prices in recent years and no changes in the way that the resource was managed, Canadian landings declined rapidly in the mid-2000s returning to catch levels observed in the early 1970s. Average reported landings for 2009-2012 was 430 t, 4% of the peak catches recorded a decade earlier. In 2013-2015, landings were down to < 160 t. A synchronous decline in survey abundance (lines in Figure 28) with landings strengthens the argument that Lumpfish abundance declined rapidly off Newfoundland.

The Lumpfish roe fishery is dependent on market conditions. The Cod and Snow Crab (*Chionoectes opilio*) fisheries also affect it as it is regarded only as a secondary activity to much larger, more lucrative fisheries. For example, fishers licensed for both Lumpfish and Cod/Snow Crab may switch over to the latter at any time, hence the large differences in landed amounts from year to year. However, since 2005, landings have consistently declined sharply, despite a lucrative market and the highest export values on record (Figure 5 in Fréchet *et al.* 2012). This further suggests a significant decline in resource availability.

The fishery is relatively shallow (primarily at depths of 10 to 40 m (Figure 29), and coastal. It is conducted by small vessels < 35 ft. in length and to a lesser extent in the early years by vessels between 35 and 65 ft. (Stevenson and Baird 1988). The fishery occurs between April and July, with 90% of the landings occurring mainly in May and June (Figure 29). It is primarily a gillnet fishery, using nets constructed of monofilament nylon webbing with stretched mesh size of 10 1/2” (267 mm) or 11” (279 mm). Season and mesh size are regulated, but there is no quota regulation.

Processing generally comprises removal of the egg mass at sea and placement in barrels for further processing on shore (salting and separating of the egg masses). The female carcass and males are discarded at sea as they have almost no value.

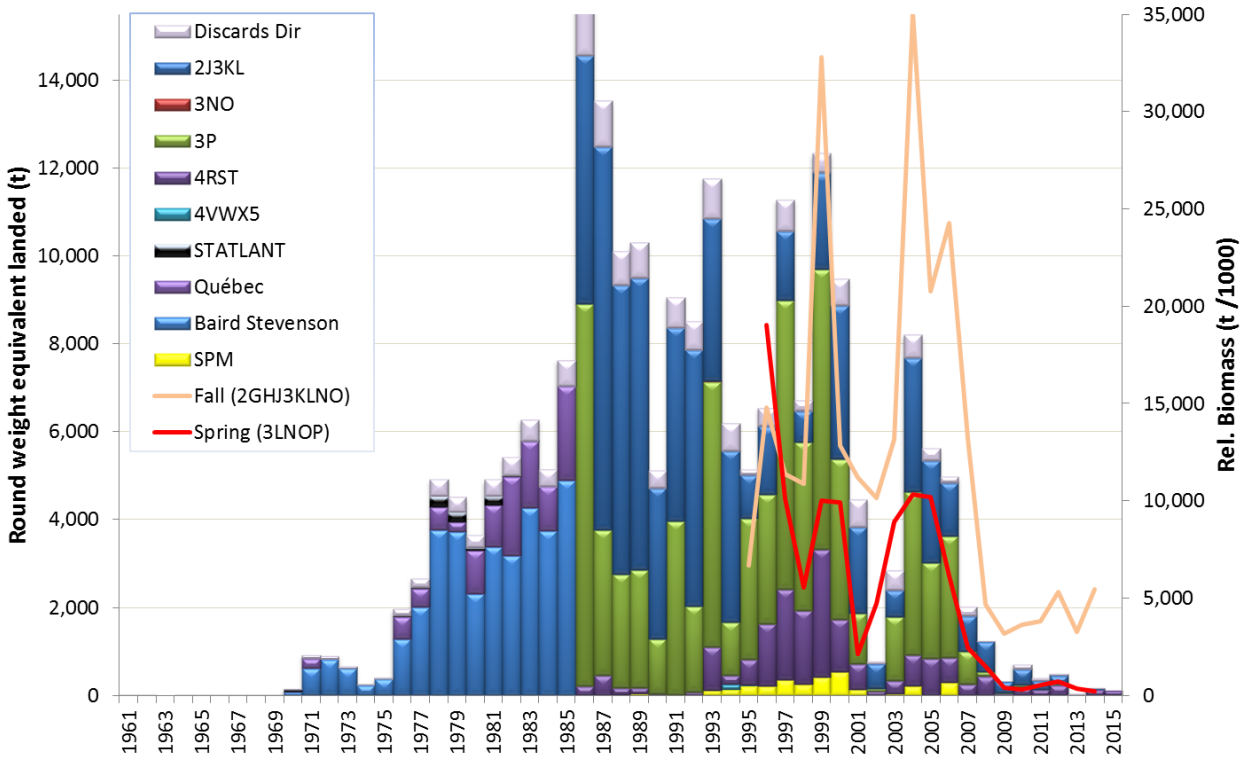

Figure 28. Round weight equivalent of Lumpfish landings[5] for Canadian and SPM (St. Pierre and Miquelon) waters. SPM: St. Pierre and Miquelon. Canada - Baird Stevenson: Roe weight reported by Stevenson and Baird (1988) for DFO NL Region were converted to round equivalent for 1970 to 1985. Quebec: 1970-1985 DFO Quebec Region reported round weight equivalent. STATLANT: Lumpfish landed round (for flesh) reported by DFO NL Region to NAFO (STATLANT) for 1961 to 1985. Post-1985, ZIFF[6] roe landing records of round equivalent plus whole fish landings, broken out by NAFO statistical areas are illustrated. Areas are 2J3KL - northern Newfoundland and southern Labrador; 3P – Newfoundland south coast; 4RST – Gulf of St. Lawrence; 4VWX5 – waters surrounding Nova Scotia namely the Scotian Shelf and Bay of Fundy. Discards Dir: fish, mainly males discarded in the directed fishery. NL Region spring and fall survey abundance indices are overlaid, scaled on the right axis.

[5] Canada (DFO) records and reports (to NAFO via STATLANT21a and 21b forms) weight of Lumpfish roe product for the fishery rather than the round weight equivalent as is done for all other fish species. For this analysis, roe weight has been converted to round weight equivalent using a conversion factor of 4 (Stevenson and Baird 1988) and combined with the round weight bycatch records and estimated discards from the Lumpfish directed fishery.

[6] ZIFF – Zonal Interchange File Format used in Atlantic Canada for compiling fisheries landings, as reported by Canadian fishers in their logbooks and on fish plants' purchase slips.

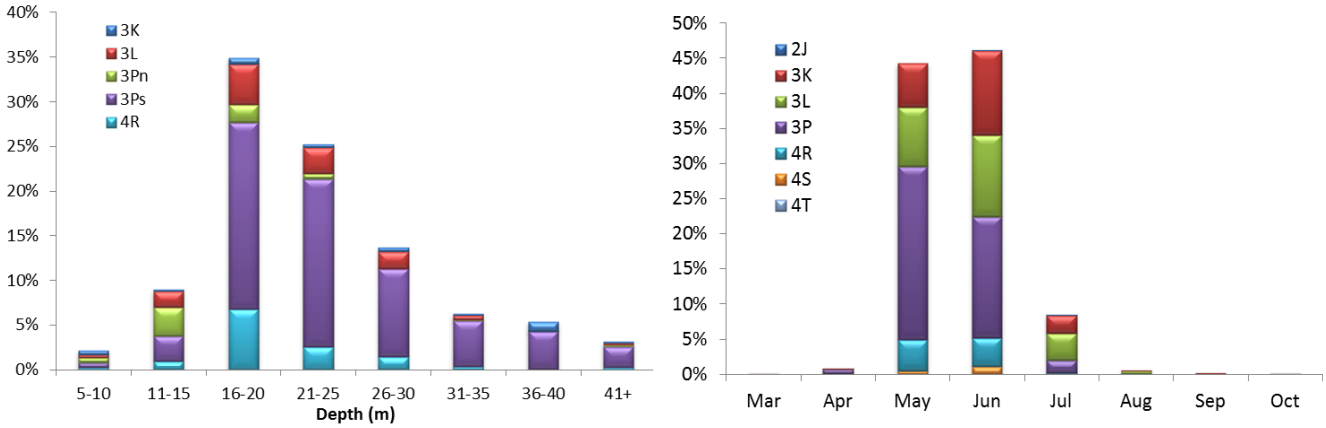

Figure 29. Fishery records illustrating depth and season of the fishery. Depth distribution is based on fishery observer records (1983-2012) and months fished is based on ZIFF records (1986-2012).

In addition to landed round weight equivalent of females, there are 2 other sources of fishery related mortality: a) males discarded in the directed fishery that do not survive; and b) discarded bycatch in other directed fisheries.

Length frequencies of catch in the roe directed fishery indicated that males, because of their smaller size, can escape through the large mesh, and therefore they make up only about 7% of the catch (Figure 30). Those discards go unreported and survival rates have not been determined. However, the fishery occurs in very shallow water and Lumpfish do not have a swim bladder, increasing their chance of post-release survival, if discarded alive.

Lumpfish bycatch (discarded at sea) has been reported in the Gulf Shrimp (*Pandalus borealis*) fishery (Savard 2013; Savard *et al.* 2013), the Nova Scotia Scallop (*Placopecten magellanicus*) fishery (Sameoto and Glass 2012), the Grand bank Yellowtail (*Limanda ferruginea*) fishery (Kulka 2001) and the NL Cod fisheries (Kulka 1986). However, there has never been a comprehensive analysis of the discarded bycatch of Lumpfish in Canadian waters or elsewhere. Such an analysis was undertaken for this report.

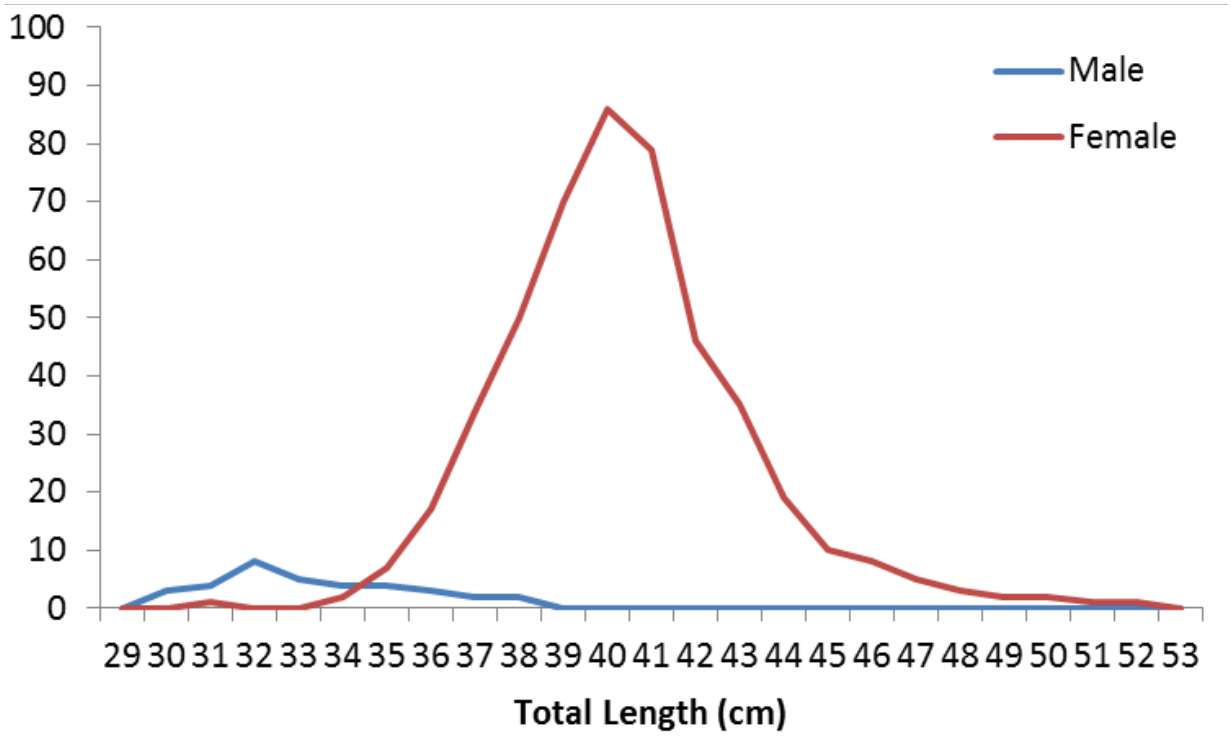

Figure 30. Length frequency of Lumpfish discards from the commercial fishery based on at-sea sexed measurements by fishery observers. Y-axis is number of fish measured.

Using fishery observer data (at sea observations of catches across a broad range of fisheries), the ratio of weight of Lumpfish bycatch (kg) derived from fishery observer records to kept weight of the directed species was calculated by fishery by year. This value was then multiplied by landed weight of each corresponding target species recorded in the ZIFF landing records (DFO Statistics). Each fishery comprised a gear/directed species/area component namely North (SA 0, Div. 2GH), Div. 2J3KL, Div. 3NO, Div. 3P, Div. 4RST, Div. 4VWX5Y). This breakdown should account for different capture rates in different gears and at different areas. In years where there were no fishery observer records, a ratio of Lumpfish bycatch weight to kept directed species weight averaged over all years observed was used.

Certain fisheries without observer coverage were not included in the analysis, such as some Lobster (*Homarus americanus*) fisheries, but these were not thought to be major contributors to bycatch.

Bycatch of Lumpfish was observed to occur in a wide range of fisheries off Canada (Figure 31). From 1988-2012, bycatch represented an average of 10% of the total removals of Lumpfish (the other 90% from the directed fishery), averaging 721 t annually. Since 2006, bycatch was lower averaging 134 t/year, but the rate of Lumpfish bycatch in other fisheries was higher at 14% given the greatly reduced directed Lumpfish fishery in recent years.

Fisheries for 20 directed species fished with 9 gears unintentionally captured Lumpfish, all discarded. Captures occurred in all areas off Canada to varying degrees. Although small in terms of geographical area, the largest proportion of bycatch, 52%, came from Div. 3P off southern Newfoundland, slightly lower at 48% in post-2005 years. Next highest areas of capture were Div. 2J3KL and Div. 4RST at 15% each. In years prior to 1992, the Lumpfish bycatch was highest in the American Plaice (*Hippoglossoides platessoides*) directed fisheries (52% of total across all fisheries), before many of those American Plaice fisheries were closed. Other fisheries of importance in terms of Lumpfish bycatch during that early period were Atlantic Cod and Witch Flounder (*Glyptocephalus cynoglossus*). Since 2006, the key directed fisheries capturing Lumpfish as bycatch have been for Skate, Greenland Halibut (*Reinhardtius hippoglossoides*), Atlantic Cod and Winter Flounder (*Pseudopleuronectes americanus*). The dominant gears capturing Lumpfish as bycatch were otter trawl (68% of captures) and gillnet (26%) across all years examined.

Because of the lack of a swim bladder, some level of survival of the discarded bycatch is expected, but has not been quantified. Survival is expected to be higher for Lumpfish discarded in the directed Lumpfish fishery compared to those discarded in other directed fisheries because of the shallow depths fished.

Although annual estimates of fishing mortality (F) cannot be derived because there is no absolute estimate of population biomass, relative F (round weight equivalent landings of Lumpfish /biomass index) can be calculated to examine the relative effect of the fishery on the population (Sinclair 1998). For this calculation, all sources of fishing mortality were used:

Catch =landings + bycatch + discards

in all fisheries and this comprised the numerator. Survey abundance indices from areas where the fisheries occurred (Div. 2J3KLNOP4RS) were added together to comprise the denominator. Relative F values have fluctuated over time but were higher during 1995-2001 compared to 2002-2012 (Figure 32).

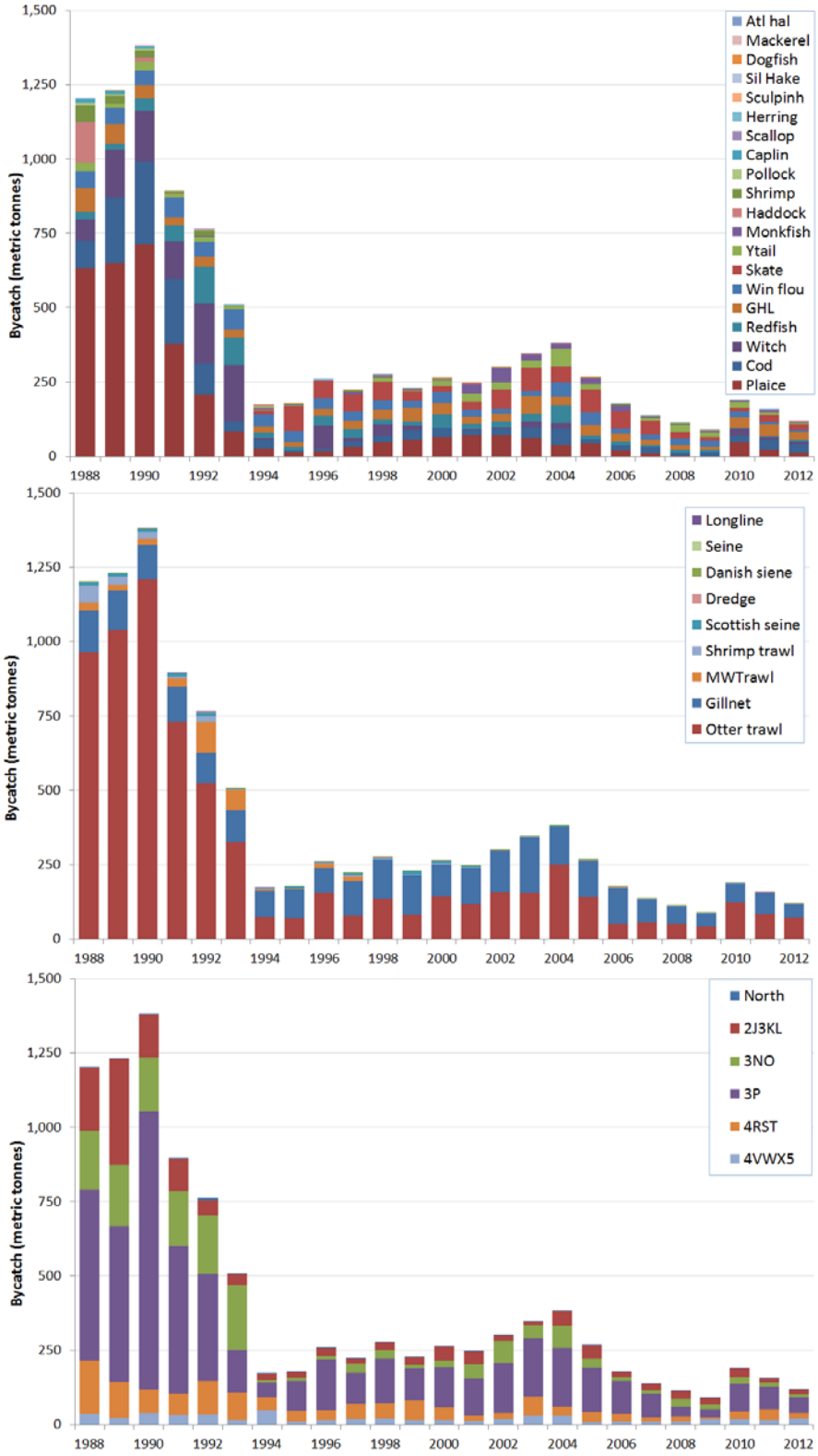

Figure 31. Estimated bycatch of Lumpfish in Canadian Atlantic fisheries by species, gear and area. GHL is Greenland Halibut. North includes SA 0 and Div. 2GH.

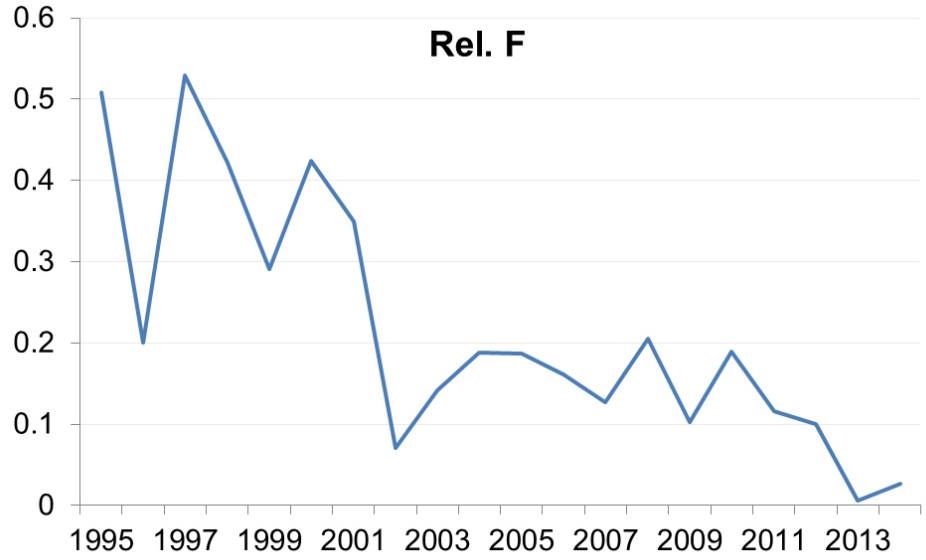

Figure 32. Relative F index (round weight equivalent landings of Lumpfish/Canadian survey biomass) for Div. 2J3KLNOP4RS, 1995-2014.

It remains unclear how mortality due to fishing affected abundance: while there is no evidence that the fishery was the proximal cause of the decline, relative F was higher leading up to the decline. Further, the decline in the fishery is the result of a declining resource. This is not uncommon in largely unregulated fisheries. However, the selective removal of large gravid females may have had an impact on the population off southern Newfoundland.

Seismic Activity

Seismic oil exploration surveys used to map the ocean floor have been common throughout many parts of Atlantic Canada since the 1970s and the distribution of Lumpfish and oil exploration seismic activity widely overlap (compare Figure 33 and Figure 4). There is greater potential for interaction of seismic activity offshore with the early stages of Lumpfish that inhabit near surface waters over much of the shelf. Lumpfish larvae and post-larval stages spend about a year near the surface (Daborn and Gregory 1983, OBIS 2015, IYGPT records) where they would be most vulnerable to any seismic effects in the immediate area.

High intensity compression and decompression sound waves produced by air guns during seismic activity can damage or kill planktonic forms at close range (Dalen and Knutsen 1987, Boudreau *et al.* 1999). Known effects of airguns on fish mortality, gross pathology, histopathology, physiology, biochemistry are summarized in Appendix C of Anon. 2011). Observed effects were mixed. For example, lab studies undertaken by Payne *et al.* (2009) identified no effects on Monkfish (*Lophius americanus*) larval mortality or on developing capelin eggs. Damage was noted in certain cases, such as loss of structural

integrity and the reduced functional responses leading to temporary impairment in Atlantic salmon *Salmo salar* (Sverdrup *et al.* 1994). However, the study of Sverdrup *et al*. 1994 demonstrated responses to detonations of explosives at ~ 2 MPa, which is greater than the peak pressure produced by seismic air guns.

There is no documentation of interaction with Lumpfish and there has not been a sharp increase in seismic activity during the mid-2000s when Lumpfish abundance declined. The possibility that seismic effects could lead to a long-term decline in the population over a wide area is unknown.

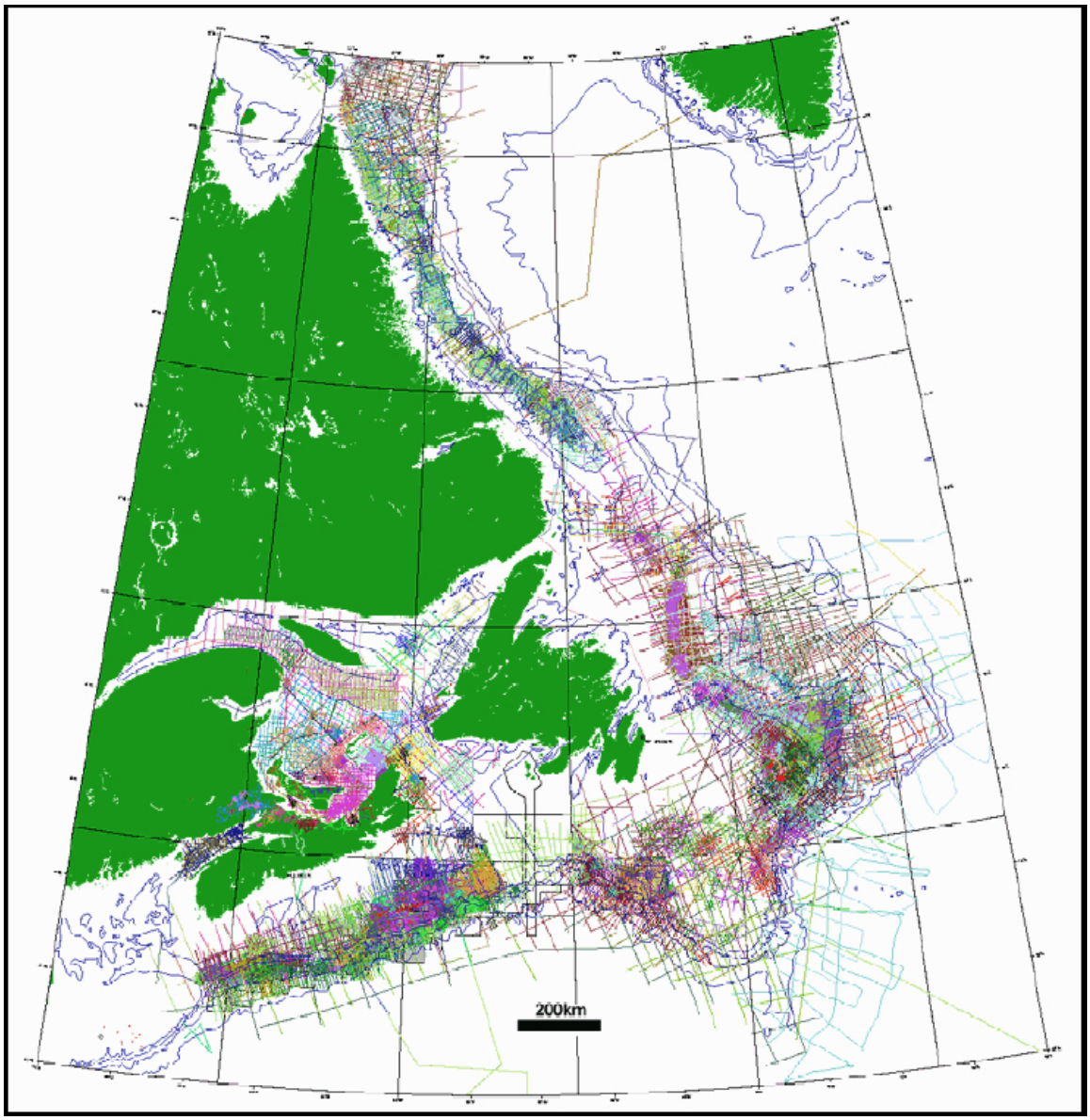

Figure 33. Cumulative seismic activity off Canada to 2002. Source: LGL Ltd. (2003). Note that a legend was not available from the source.

Warming/Climate Change

If other threats such as excessive fishery removals were at play, stress due to warming could accentuate the main affect. However, there is no direct evidence that increasing temperature that has occurred in recent years (see Figure 12) has affected survival of Lumpfish and observed increases in temperature do not extend beyond the preferred temperature range for demersal young and adult Lumpfish of 2º to 5ºC.

Davenport (1985) reported that there is some evidence that storms cause Lumpfish egg masses to be swept away from spawning sites and deposited in the intertidal zone. If a side-effect of climate change is an increase in storm activity, as well as increased storm intensity (Webster *et al.* 2005), it is possible that spawning could be increasingly impacted negatively.

Predation

As noted in the Interspecific Interactions section, young Lumpfish are a prey item for Thorny Skate and sharks. Sperm whales and seals prey upon adult Lumpfish. Grey Seal (*Halichoerus grypus*) populations in particular have increased in size since the mid-1980s (Hammill *et al.* 2014). Predation effects are unknown but Grey Seals distribute mainly off Nova Scotia and the southern Gulf of St. Lawrence, separated from the centre of mass of Lumpfish off Newfoundland where the decline in abundance was observed.

Inuit hunters in four Nunavik communities and Kuujjuraapik hunters and Elders both identified and verified Lumpfish as Beluga (*Delphinapterus leucas*) prey (Breton-Honeyman *et al*. 2016). However, hunters did not specify which species of Lumpfish was observed and it is quite plausible it is the Atlantic Spiny Lumpsucker (*Eumicrotremus spinosus*) or Leatherfin Lumpsucker (*Eumicrotremus derjugini*) (K. Breton-Honeyman, pers. comm. 2017).

PROTECTION, STATUS AND RANKS

Legal and Non-legal Protection and Status

The species has recently been listed by IUCN as NT (Near Threatened) (Appendix 1, Red List status of European marine fishes) for the Northeast Atlantic. http://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_marine_fishes.pdf.

In Canada and the USA, Lumpfish are ranked as follows:

NatureServe Status

(http://explorer.natureserve.org/servlet/NatureServe?searchName=Cyclopterus+lumpus)

1. Global: GNR, Not Yet Ranked
2. National: Canada N4, (Apparently Secure, 06 May 2013)
   c. Ontario (SNA, Not Assessed)
   d. Quebec (S4, Apparently Secure; Quebec (S4, Apparently Secure; in Quebec, this species is not listed as “Threatened” under the “Loi sur les espèces menacées ou vulnérables” (RLRQ, c E-12.01) (LEMV) (Act respecting threatened or vulnerable species) (CQLR, c E-12.01).

      Also, this species is not included on the Liste des espèces susceptibles d’être désignées menacées ou vulnérables (list of wildlife species likely to be designated threatened or vulnerable). This list is produced according to the the “Loi sur les espèces menacées ou vulnérables” (RLRQ, c E-12.01) (LEMV) (Act respecting threatened or vulnerable species) (CQLR, c E-12.01).
3. National: United States, Rhode Island: SNR, Not Yet Ranked (southern limit).

Regulatory measures in place in the Iceland fishery have been described by Gascoigne *et al.* (2014). Some regulatory measures are also in place in Norway (season, mesh size, vessel size and individual TAC), Greenland (management plan and MSC certification since 2015, TAC, fishing season) and Denmark and Sweden (logbook, mesh size)

In Canada, only occasional, rudimentary assessments of Lumpfish have been carried out (e.g., DFO 1996, 2002, 2006, 2011, Frechet 2012) and thus their population status is not well understood nor is the fishery managed based on changes in the population. The Lumpfish fisheries are managed by two DFO regions, Newfoundland and Labrador (for Div. 2J3KL and 3Ps) and Quebec (for Div. 3Pn4RS). There is no quota for the species, but Conservation Harvesting Plans (CHPs) are in place for each of the two regions. Management measures include vessel, gear and seasonal restrictions. In all areas, the fishery is restricted to vessels <65 ft. using demersal gillnets with a minimum mesh size of 268 mm (10.5 in). The opening and closing dates have varied but the fishery usually opens early mid-May and closes beginning of July.

Habitat Protection and Ownership

Although several protected areas can be found throughout the Canadian Atlantic, none are specifically designed to protect Lumpfish. The degree of protection attributable to any of these areas is likely minor as they are mainly offshore, The Gully is an offshore Marine Protected Area (MPA) but the NL MPAs are inshore e.g., Gilbert Bay, Eastport, and encompass about 0.1% of Canadian waters.

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BIOGRAPHICAL SUMMARY OF REPORT WRITERS

Bruce Atkinson

Mr. Atkinson is a retired fisheries biologist with more than 30 years' experience primarily related to the biology, life history and assessment of groundfish. His extended career with DFO in NL also included many years of participation in NAFO as well as management positions within Science, culminating in the position of Regional Director of Science and Oceans sectors. Since retirement in 2005, he has 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 as rapporteur, served as a reviewer of fisheries related proposals for European Union Framework Programme (FP7) 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 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. He is currently a member of the COSEWIC (Committee on the Status of Endangered Wildlife in Canada) Marine Fishes Specialist Subcommittee.

David Kulka

Mr. Kulka is retired from a 33-year career with DFO in NL with experience primarily related to species at risk, sampling programs and assessment of data deficient species. Species at risk work included the preparation of numerous marine fish risk assessments (pre-COSEWIC analyses), formulation of policies and procedures, preparation of Action Plans and jurisdictional review of marine fish COSEWIC reports. He participated for many years in NAFO Scientific Council and STACTIC, International Council for the Exploration of the Seas (ICES) working groups and the IUCN Elasmobranch Specialist Group, presently as regional co-vice Chair, Northwest Atlantic. He has authored and reviewed numerous Redlist reports. He also carried out work on sampling programs in the Caribbean. Since retirement in 2008, he has undertaken various aspects of Marine Stewardship Council (MSC) assessments and has conducted analytical work for the Canadian fishing industry,

oil industry regulators, World Wildlife Fund (WWF) and Food and Agriculture Organization of the UN (FAO). He is currently a member of the COSEWIC Marine Fishes Specialist Subcommittee and has previously written several other COSEWIC species status reports. As scientist emeritus, he continues to participate in DFO species at risk processes. He has written about 170 scientific publications and technical reports, reviewed numerous primary publication submissions and is presently an editor for the Journal of the Northwest Atlantic Fisheries Science.

COLLECTIONS EXAMINED

No specimens were examined although data records from various museums were utilized.

Appendix 1. Estimation of Generation Time and Natural Mortality.

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

$$G = A_{1st} + {}^{1}/_{M} \qquad (1)$$

where *G* is generation time, A_{1st} is age at first reproduction and *M* is natural mortality. Age at first reproduction is often approximated by the age at which 50% of the females are mature such that A_{1st} is represented by A_{50}. There are no maturity ogives reported in the literature for Lumpfish so neither A_{1st} nor A_{50} is known.

There have been several studies where length and age have been examined in relation to maturity (Table A1-1).

Table A1-1. Summary of data found in Cox (1920) - Study 1, Bagge (1964) - Study 2, Thorsteinsson (1983) - Study 3, Grant (2001) - Study 4, Albert *et al.* (2002) - Study 5, Hedeholm *et al.* (2014) - Study 6 and Kasper *et al.* (2014) - Study 7. A_{1st} is either as reported or an average of ages at first maturity in the study samples, A_{max} is the maximum age encountered during the study, L_{1st} is the length corresponding to A_{1st} and L_{50} is the length corresponding to A_{50}.

Study	Area	A_{1st}	A_{1st} Range	A_{max}	L_{1st} (cm)	L_{1st} Range (cm)
1	NW Atlantic (female)	5			25.4	
2	North Sea (female)	5		9	44.9	
3	Iceland (female)	6.5	5-8	14	37.8	36-40
4	NW Atlantic (female)	5.6	4-7	11	~32	~32-40
5	North Sea, Iceland, Norwegian Sea & coastal waters of both southern & northern Norway (sexes combined)	3.5	3-4	6	~34	32.1-34.8
6	Greenland (female)	2.5	2-3	4	27	
7	Iceland & Norway (female)	~4				

There are no specific estimates of natural mortality in the Lumpfish literature. Hewitt and Hoenig (2005) suggested that natural mortality can be estimated by

$$M = {}^{4.22}/_{t_{max}} \qquad (2)$$

where t_{max} is the age at which ~1.5% of the population remains.

There are no specific estimates of t_{max} for Lumpfish, but if maximum age may be considered a first approximation for use in estimating *M* (equation 2), then a first estimate of *G* can be derived (Equation 1) (Table A1-2).

Table A1-2. Estimation of generation time based on values of A_{max} reported in studies 2-6.

Study	A_{1st}	A_{max}	$M_{equation\ 2}$	$G_{equation\ 1}$
2	5	9	0.47	7.1
3	6.5	14	0.30	9.8
4	5.6	11	0.38	8.2
5	3.5	6	0.70	4.9
6	2.5	4	1.01	3.5
7	~4	Unknown	Unknown	Unknown

Estimates for Studies 5 (Albert *et al.* 2002) and 6 (Hedeholm *et al.* 2014) are very high (*M*'s of 0.7 and 1.01) compared to the others and may not be realistic. However, uncertainties exist in relation to all the estimates as they may in part reflect selectivity of the gear used for capture. Additionally, maximum ages may simply reflect the captures rather than the overall ages in the population.

FishBase (Froese and Pauly 2016) also provides a means to calculate generation time based on von Bertalanffy growth parameters (see http://www.fishbase.org/manual/key% 20facts.htm) (Froese *et al.* 2005). In most fishes, L_{opt} is the length class giving the maximum yield and hence having the maximum egg production (Beverton 1992). As such, the corresponding age (t_{opt}) is a good approximation of generation time in fishes (Froese *et al.* 2005).

$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.65431 \log_{10} K + 0.4634 \log_{10} T$ (Pauly 1980)[7] (3)

$L_{opt} = L_{inf} * (3 \div (3 + {}^{M}/_{K}))$ (Froese *et al.* 2005) (4)

$\log_{10}(-t_0) = -0.3922 - 0.2752 \log_{10} L_{inf} - 1.038 \log_{10} K$ (Froese *et al.* 2005) (5)

$G = t_{opt} = t_0 - \ln(1 - {}^{L_{opt}}/_{L_{inf}}) \div K$ (Froese *et al.* 2005) (6)

where L_{inf} is asymptotic length, *K* is the von Bertalanffy growth function (growth coefficient) and *T* is temperature (ºC).

Several of the studies above developed von Bertalanffy growth curves for Lumpfish. Additionally, the data used in Study 4 are available (Appendix IV of Grant (2001)) and were analysed in R (R Core Team 2015) using the growth function in the package 'fishmethods' (Nelson 2015) to estimate the von Bertalanffy growth parameters (Table A1-3).

[7] FishBase uses a re-estimated version based on analysis of a larger dataset so results are not identical to those calculated using this equation.

Table A1-3: Estimates of von Bertalanffy growth parameters from studies 3 – 7.

Study	Sex	*K*	L_∞ (cm)	t_0
3	Female	0.290	49.000	0.000
4	Female	0.1535	53.372	-2.042
5	Mixed	0.421	45.700	0.570
6	Female	0.683	43.510	0.546
7	Female	0.256	52.700	-0.174

Entering the estimated parameters for L_{inf} and *K* into the FishBase Life History Tool (as ø) (http://www.fishbase.de/PopDyn/KeyfactsSummary_1.php?ID=62&GenusName=Cyclopterus&SpeciesName=lumpus&vStockCode=72&fc=284) (assumed temperature (*T*) of 5ºC) provides estimates of first age of maturity (A_{1st}), natural mortality (*M*) and generation time (*G*) (Table A1-4).

Table A1-4. Estimates of natural mortality (*M*) and generation time (*G*) from FishBase.

Study	ø	t_0	*M*	L_{1st}	A_{1st}	L_{opt}	t_{max}	*G*
3	2.84	-0.50	0.37	27.50	2.70	34.4	9.8	3.7
4	2.64	-0.97	0.22	29.70	4.40	35.9	19.0	6.5
5	2.94	-0.35	0.49	25.90	1.60	32.9	6.8	2.7
6	3.11	-0.21	0.72	24.70	1.00	32.2	4.2	1.8
7	2.85	-0.57	0.32	29.40	2.70	36.9	11.4	4.2

All estimates of A_{1st} are lower than the observed values in Table A1-2 above. With the exception of Study 4 (Grant 2001), all estimates of *G* are lower (or the same as (Study 7)) than the observed A_{1st} in Table A1-2.

Equation 1 above can also be applied using the FishBase estimates of M and A1st (Table A1-5) to estimate G.

Table A1-5. Estimates of generation time (*G*) using Equation 1 with FishBase estimates of *M* and A_{1st}.

Source	A_{1st}	*M*	*G*
3	2.30	0.37	5.0
4	4.40	0.22	8.9
5	1.60	0.49	3.6
6	1.00	0.72	2.4
7	2.70	0.32	5.8

Only the *G*'s estimated for Studies 4 and 7 are greater than the observed A_{1st} in Table A1-2.

Alternate estimates of *G* can also be derived using Equation 6 inputting L_{opt} from FishBase and t_0 and *K* as estimated by the authors (Table A1-6).

Table A1-6. Estimates of generation time (*G*) using Equation 6 with the FishBase estimate of L_{opt} and t_0 and *K* as estimated by the authors.

Study	*G*
3	4.2
4	5.2
5	3.6
6	2.5
7	4.5

All estimates of *G* are less than or about the same as the observed A_{1st} in Table A1-2.

M can also be estimated by inputting the t_{max} values from FishBase into Equation 2 and *G*'s then estimated via Equation 1 (TableA1-7).

Table A1-7. Estimates of natural mortality (*M*) using the t_{max} values from FishBase in Equation 2 then applying the estimated *M*'s to estimate generation time (*G*) using Equation 1.

Study	*M*	*G*
3	0.43	4.6
4	0.22	8.9
5	0.62	3.2
6	1.00	2.0
7	0.37	5.4

Again, only the *G*'s estimated for Studies 4 and 7 are greater than the observed A_{1st} in Table A1-2.

Froese *et al.* (2005) provided an alternate equation for the estimation of *M*.

$$\log_{10} M = 0.566 - 0.718 * \log_{10} L_{inf} + 0.2 * T \quad (7)$$

Entering the information from the von Bertalanffy equations (Table A1-3) in Equation 7 and applying Equation 1 gives yet another set of estimates of *M* and *G* (Table A1-8).

Table A1-8. Estimates of natural mortality (*M*) using von Bertalanffy parameters (Table A1-3) in Equation 7 then applying the estimated *M*'s to estimate generation time (*G*) using Equation 1.

Study	*M*	*G*
3	0.283	5.8
4	0.267	8.2
5	0.298	5.0
6	0.309	4.2
7	0.269	6.4

The different estimates of *G* can be summarized (Table A1-9). The estimates shown in red are those that are considered to be too low when compared to the reported observations of A_{1st} (Table A1-2) so are rejected.

Table A1-9. Summary of estimates of generation time (*G*) based on the various estimation approaches as per tables A1-2, A1-4 – A1-8. The estimates in red were rejected because they are low compared to the reported estimates of (A_{1st}) in the various studies.

Study	Table A1-2	Table A1-4	Table A1-5	Table A1-6	Table A1-7	Table A1-8
3	9.8	3.7	5.0	4.2	4.6	5.8
4	8.2	6.5	8.9	5.2	8.9	8.2
5	4.9	2.7	3.6	3.6	3.2	5.0
6	3.5	1.8	2.4	2.5	2.0	4.2
7	Unknown	4.2	5.8	4.5	5.4	6.4

The overall arithmetic mean *G* considering only those estimates not rejected is 7.0 years while the geometric mean is 6.8 years.

The different estimates of *M* can also be summarized (Table A1-10). The estimates shown in red correspond to estimates of *G* that were rejected.

Table A1-10. Summary of estimates of natural mortality (*M*) based on the various estimation approaches as per tables A1-2, A1-3, A1-7 and A1-8. The estimates shown in red correspond to estimates of *G* that were rejected. Study 2 was not included as there were no corresponding estimates of *G*.

Study	Sex	Table A1-2	Table A1-3	Table A1-7	Table A1-8
3	Female	0.30	0.37	0.43	0.28
4	Female	0.38	0.22	0.22	0.27
5	Mixed	0.70	0.49	0.62	0.30
6	Female	1.01	0.72	1.00	0.31
7	Female	UK	0.32	0.37	0.27

The arithmetic mean and geometric mean of the accepted estimates is 0.29.

Based on all of the above it is considered that the best estimate of *M* is 0.3 and *G* is 7 years, although it must be cautioned that there is considerable uncertainty associated with both estimates.

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Appendix 2.[1]Summary of research surveys conducted by DFO's NL Region and used to derive abundance estimates.

YEAR	FALL								WINTER			SPRING				
	2G	2H	2J	3K	3L	3N	3O		3M	3Ps		3L	3N	3O	3Ps	3Pn
1971												X	X			
1972										X		X	X			
1973										X		X	X	X		
1974												X	X		X	
1975												X	X	X	X	
1976				X								X	X	X	X	
1977			X	X					X			X	X	X	X	
1978	X	X	X	X					X	X		X	X	X		
1979	X	X	X	X					X	X		X	X	X		
1980			X	X					X	X		X	X	X		
1981	X	X	X	X	X				X	X		X	X	X		
1982			X	X	X				X			X	X	X	X	
1983			X	X	X				X						X	
1984			X	X	X				X			X	X	X	X	
1985			X	X	X				X	X		X	X	X		
1986			X	X	X					X		X	X	X		
1987	X	X	X	X	X					X		X	X	X		
1988	X	X	X	X	X					X		X	X	X		
1989			X	X	X					X		X	X	X		
1990			X	X	X	X	X			X		X	X	X		
1991	X	X	X	X	X	X	X			X		X	X	X		
1992			X	X	X	X	X			X		X	X	X		
1993			X	X	X	X	X			X		X	X	X	X	
1994			X	X	X	X	X					X	X	X	X	
1995			X	X	X	X	X					X	X	X	X	
1996	X	X	X	X	X	X	X					X	X	X	X	
1997	X	X	X	X	X	X	X					X	X	X	X	
1998	X	X	X	X	X	X	X					X	X	X	X	
1999	X	X	X	X	X	X	X					X	X	X	X	
2000		X	X	X	X	X	X					X	X	X	X	
2001			X	X	X	X	X					X	X	X	X	
2002			X	X	X	X	X					X	X	X	X	
2003			X	X	X	X	X					X	X	X	X	
2004		X	X	X	X	X	X					X	X	X	X	X
2005			X	X	X	X	X					X	X	X	X	X
2006		X	X	X	X	X	X					X	X	X	X	X
2007			X	X	X	X	X					X	X	X	X	X
2008		X	X	X	X	X	X					X	X	X	X	
2009			X	X	X	X	X					X	X	X	X	X
2010		X	X	X	X	X	X					X	X	X	X	X
2011		X	X	X	X	X	X					X	X	X	X	X
2012		X	X	X	X	X	X					X	X	X	X	X
2013		X	X	X	X	X	X					X	X	X	X	X
2014		92,444	X	X	X							X	X	X	X	
2015												X	X	X	X	

[1]Colours depict different survey gears

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