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A brief history of lumpfishing, assessment, and management across the North Atlantic

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This report documents the fishery, assessment, and management of lumpfish (*Cyclopterus lumpus*) across its distribution range. Targeting lumpfish for their roe on a large scale began in the 1950s in Iceland and Norway and then in Canada in the 1970s and Greenland in the 1990s. When the fishery began, there were few regulations, but limits on vessel size, mesh size, number of nets, and length of the fishing season were gradually implemented over time. Worldwide landings have varied from ca. 2000 to 8000 tonnes of roe between 1977 and 2016. Iceland and Canada accounted for >80% of the landings until 2000. After 2013, Greenland and Iceland accounted for >94%. All countries except Iceland show a decreasing trend in the number of boats participating in the fishery, which is related to several factors: the monetary value of the roe, changes in the abundance of lumpfish, and increasing age of artisanal fishers. Each country has a different combination of data available for assessment from basic landings and fishing effort data to more detailed fishery independent survey indices of abundance. The management of total catch also differs, with an effort-controlled fishery in Iceland and Canada, a total allowable catch (TAC) per boat in Norway, and TAC per area in Greenland. Population abundance is above management targets in Iceland and Norway, but the status is less clear in Greenland and around Denmark/Sweden and appears to be depleted around Canada. Certification by the Marine Stewardship Council was instrumental in the adoption of a management plan in Greenland; however, benefits to the fishers remain unclear. Aspects surrounding the biology of lumpfish, which is poorly understood and requires investigation, include growth rate, natural mortality, and population differentiation. In addition, there is concern about the potential impacts that the recent escalation in production of lumpfish for use as cleaner fish in the aquaculture industry could have on the wild population.

Keywords: gillnets, lumpsucker, Marine Stewardship Council, roe fishery

Introduction

During 2015 and 2016, experts on lumpfish from six countries (Canada, Greenland, Iceland, Norway, Sweden, and Denmark) came together to form the lumpfish working group (LWG) to share knowledge on the biology, research, fishery assessment, and management of lumpfish (*Cyclopterus lumpus*) in their respective countries. The group aimed at identifying (i) knowledge gaps which hinder the stock assessment of this species, (ii) where future research should be focussed, and (iii) possible implications from the recent development of catching lumpfish as broodstock for the cleaner fish industry. Given the challenges of understanding this species, the LWG aimed to collate the information and data presented into a form which could easily be shared with interested parties. This resulted in the current paper which outlines how the fisheries are conducted and managed and describes the different methods used for assessment of the population in each country. Landings data from each country are brought together and standardized into a common format in order to obtain an overview of total landings.

The lumpfish (Figure 1) is a non-shoaling, coldwater marine fish in the family Cyclopteridae (lumpsuckers) and is the only member of the genus *Cyclopterus*. It is distributed across the North Atlantic and is most abundant around the waters of Iceland, Norway, Greenland, and Canada. It is also found in the North Sea and Baltic Sea, and specimens have been caught off Galicia, Spain (Bañón *et al.*, 2008), along the coast of Portugal (Vasconcelos *et al.*, 2004), and in the Mediterranean Sea (Dulčić and Golani, 2006). Lumpfish is a semi-pelagic/semi-demersal species. Juveniles are thought to be mainly pelagic as they are frequently caught in pelagic nets, but rarely in demersal trawls (Holst, 1993; Eriksen *et al.*, 2014; ICES, 2016). However, upon reaching maturity and as spawning approaches, they begin their migration to coastal areas and display a mix of pelagic/demersal behaviour (Kennedy *et al.*, 2016). The males generally arrive at the coast between January and March, and the females several weeks later (Davenport, 1985). When the females arrive in coastal areas, they are the subject of commercial fishing, primarily for their roe (Johannesson, 2006). The age at maturation and longevity for most regions is uncertain because age estimation based on otoliths has not been validated (Thorsteinsson, 1981; Albert *et al.*, 2002). Initial estimates for Greenland put age at maturity at 3–4 years old, with the oldest fish examined being 5 years old, which indicates that this species may exhibit a semelparous life strategy (Hedeholm *et al.*, 2014).

Populations in the eastern and western Atlantic are genetically differentiated, which may be due to polar water, which flows southward along the east Greenland coast, acting as a barrier to gene flow (Pampoulie *et al.*, 2014; Garcia-Mayoral *et al.*, 2016; Jonsdottir *et al.*, 2018). There is genetic structuring of the lumpfish population in western Greenland, with two major subpopulations, the northern and southern. The northern subpopulation exhibits a greater similarity to the Canadian population than the geographically closer southern Greenland subpopulation (Garcia-Mayoral *et al.*, 2016). The population of lumpfish in the Northeast Atlantic exhibits a continuous distribution from the Irminger Sea off southeast Greenland, up into the Denmark Strait, and across the Norwegian Sea to Norway (ICES, 2016). There is no genetic differentiation within this population (Pampoulie *et al.*, 2014; Garcia-Mayoral *et al.*, 2016) and due to the continuous distribution between Iceland and Norway, it seems likely that there is some exchange of individuals between the Icelandic and Norwegian populations. However, the degree of exchange (if any) is unknown, and thus it is unclear if it has any significant implications for assessment or management. The lumpfish population within the Skagerrak, Kattegat, and Baltic is subject to a commercial fishery by both Denmark and Sweden,

Figure 1. Male (foreground) and female (background) lumpfish.

but the population structure within these areas is poorly understood.

An unusual characteristic of the lumpfish fishery is that it primarily targets females and almost universally, only the roe is landed. This makes it problematic for the accurate estimation of landings as the weight of the roe needs to be converted into ungutted weight of the whole fish. Different countries employ different methods for the collection of landings data and for the conversion to ungutted weight. The methods for doing this may also have varied over time within a country. For this reason, comparison of landings between countries is difficult.

In addition to the fishery for roe, a small fishery has recently developed in Norway, Iceland, and also the United Kingdom (where no significant lumpfish fishery existed previously) targeting mature individuals to be used as broodstock to produce juvenile lumpfish. These juvenile lumpfish are used as cleaner fish to control sea lice infestation in salmon aquaculture.

The information below describes the fishery, how the population is assessed, and how the fishery is managed in each country. Landings data from each country are collated in a common form (Figure 2), thus allowing a fair comparison of total landings from the six countries considered (Figure 3).

Fishery

Four countries largely dominate the worldwide landings of lumpfish: Iceland, Norway, Greenland, and Canada; there is also a small fishery in Denmark and Sweden (Figure 3). The fishery in Iceland and Norway began in the 1940s–1950s, during the 1970s in Canada, and in the 1990s in Greenland. In all these countries, the fleet consists exclusively of small coastal vessels generally <15 m in length, which target the fish with large-mesh bottom set gillnets. As lumpfish are targeted for their roe, and the carcass has little commercial value, the carcasses are discarded at sea and only the roe is landed. This practice is almost universal across all the countries, with the exception of a small amount of carcasses being landed in Greenland in recent years, while in Iceland, it became mandatory in 2012. In all countries except Iceland, the number of boats taking part in the fishery has been declining, with a concurrent decline in landings (Figure 2).

The fishery is concentrated in specific areas in each country. In Iceland, this is primarily on the western and northern coast, exclusively along the western coast of Greenland (from 60°N to

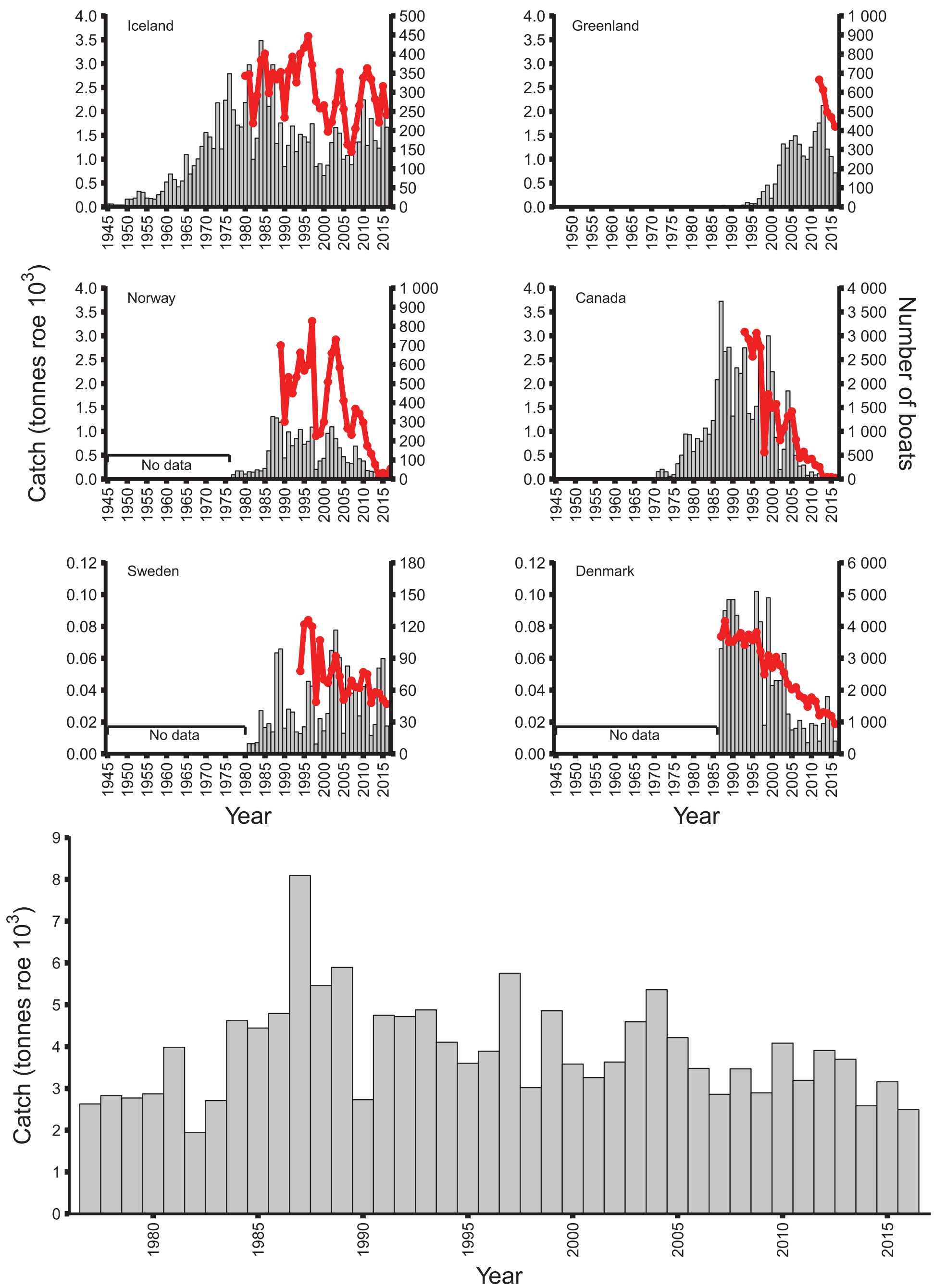

Figure 2. Landings of lumpfish roe (bars) and number of boats which participated in the fishery (lines) in each country and total landings from all countries combined (bottom graph). Areas labelled "no data" indicate that lumpfish were landed, but data was not collected. Note differing left *y*-axis scale for Sweden and Denmark and differing right *y*-axis between graphs.

70°N), and mainly along the northern coast of Norway between Lofoten and the Varanger peninsula (Figure 4). In Canada, the fishery was conducted on all coasts of Newfoundland and on the Quebec Lower North Shore. In recent years, fishing is concentrated at the northern tip of Newfoundland (Figure 4). Detailed information on lumpfish fishing areas for Sweden and Denmark is lacking.

Timing of the fishery varies among countries, with the longest season in Iceland which typically lasts from March until August. Fishing usually takes place in April–May and April–June in Greenland and Norway, respectively. In Canada, the fishing season is dependent on the melting of sea ice, but typically takes place in May–July. There is currently limited information on the timing of the fishing season in Sweden and Denmark.

In addition to the female roe fishery, there is also a small-scale commercial fishery in Iceland for male lumpfish. Since 2002, between 2 and 17 boats have participated in this fishery each year. These are fished with gillnets with a mesh size which must be between 178 and 203 mm. Landings have varied from 30 to 70 tonnes per year between 2002 and 2016 and is primarily for the

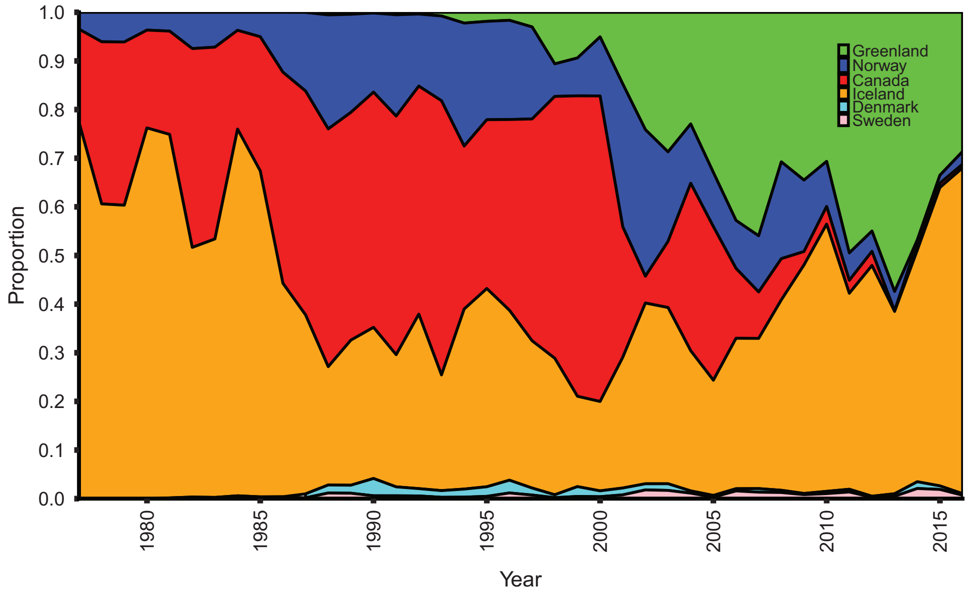

Figure 3. Proportion of landings of lumpfish roe landed by country between 1976 and 2016.

local food market. There are no restrictions on the total allowable catch (TAC), but it is illegal to fish using male lumpfish nets between 15 June and 31 December. The majority of landings are from January to March, after which catches and prices decline.

A recent development in the salmon aquaculture industry has been the use of juvenile lumpfish as cleaner fish. The lifecycle has not been closed, and production relies upon broodstock taken from the wild. The removals of wild fish is low in comparison with the roe fishery, ~200 fish in Iceland and ~6.4 tonnes of fish in Norway in 2017. However, a fishery for adult broodstock is also developing in countries where no lumpfish fishery previously existed, i.e. United Kingdom and Ireland.

Assessment

The availability of data for assessment varies among countries (Table 1). To monitor changes in abundance, Iceland (Figure 5), Canada (Figure 6), and Sweden (Figure 7) utilize data from bottom-trawl surveys, while Norway utilizes data from a pelagic survey (Figure 5). As lumpfish is not routinely aged in any country, precluding the use of age-structured population models, and because the catchability of lumpfish in trawl surveys is unknown, survey indices are only a relative index of changes in population biomass between years. While the survey indices from Iceland and Norway are considered to give a reliable indication of changes in stock size (Eriksen *et al*., 2014; Kennedy and Jónsson, 2017), this has never been explicitly examined in Canada or Sweden. The Swedish survey catches an average of <1 kg of lumpfish per hour of trawling, which raises doubt about whether this is a true reflection of abundance. In both Iceland and Norway, landings data and the stock index are used to calculate an index of relative fishing mortality (F_{proxy}) over time.

In Greenland, there are no surveys which can be used to provide an estimate of population size. Thus, assessment is entirely based upon landings data, which is used to give an index of landings per unit effort (lpue) (Figure 8). In Canada, only the Gulf of St. Lawrence lumpfish population is assessed which is done using a variety of indicators, including data from bottom-trawl surveys, trends in landings and effort in the fishery, and a fishery performance index which is essentially an aggregated cpue index (total landings from fleet/number of fishing trips). In Sweden, the situation is similar, with data from two ICES bottom-trawl surveys in the North Sea and Baltic Sea, and cpue data from the fishery are used to provide an indication of population trends. In Denmark, there is no formal assessment.

Based upon the stock assessment, the research institutions responsible for the assessment in Iceland, Greenland, and Norway issue TAC advice for their respective populations. In Greenland, the TAC, along with the number of fishing days, is set according to a harvest control rule (Figure 9). In Iceland, the goal of the advice is to maintain F_{proxy} below the average value from the reference period (1985–2011). This was initially estimated to 0.75, but after revision of historical landings, this is now 0.66, but the initial value continues to be used. Thus, the TAC corresponds to a value that would lead to an F_{proxy} of 0.75. The Norwegian advice is based upon trend analysis of survey data, but there are no defined reference points. The aim of the advice is to keep the harvest rate around 1% of the biomass index. No TAC advice is given for the fisheries in Canada, Denmark, or Sweden.

Management

The degree of management of lumpfish is substantially different in each country, with each country employing a unique range of management measures (Table 2) that have evolved over time (Table 3). The fishery in Denmark is essentially unmanaged, with no regulations specific to the targeting of lumpfish, while in Sweden, only the mesh size when targeting lumpfish is regulated. In Canada, the fishery has been managed through effort controls since 1992. These measures include a limit of 50 gillnets of 91 m (50 fathoms), a minimum mesh size of 267 mm, time limit on the duration of the season and the completion of logbooks (Simpson *et al*., 2016).

The lumpfish fishery in Greenland was unregulated prior to 2015 when a management plan was adopted in connection with

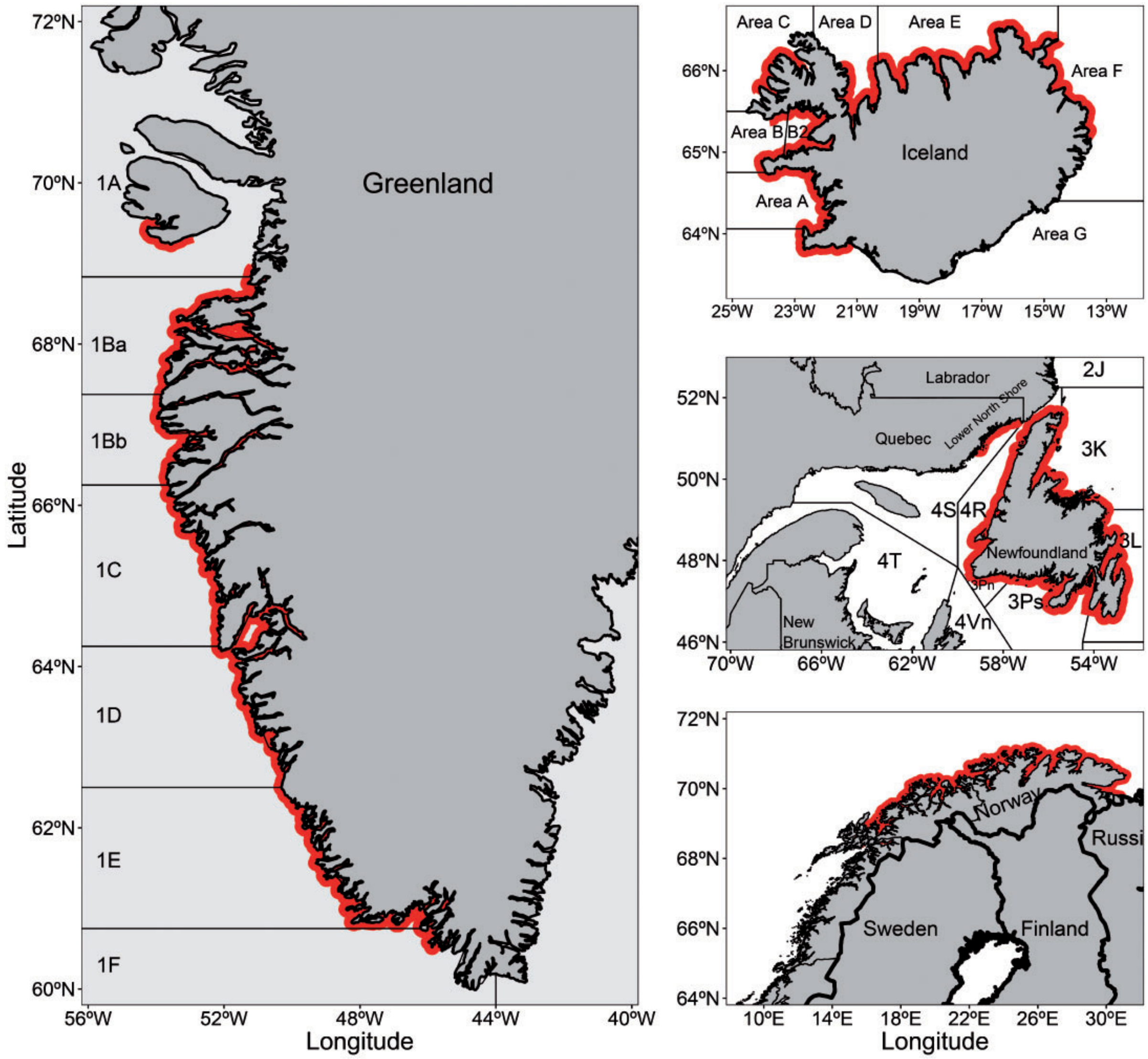

Figure 4. Map of Greenland, Iceland, Norway, and Canada depicting the main fishing areas (highlighted area) for lumpfish. Lumpfish management areas are shown on Iceland map, and NAFO statistical areas are shown on map of Greenland and Canada.

Table 1. Summary of information regarding assessment and management in each country.

Country	Frequency of assessment	Fishery independent population index	Are cpue data available?	Routine collection of additional data	Management plan	MSC certification
Iceland	Annual	Relative biomass index from demersal survey.	Yes	Length–weight data collected from landings.	No formally adopted plan but aim of advice is to maintain F_{proxy} below average of reference period and maintain biomass above historical minimum.	2015 Suspended 2018
Greenland	Annual	None	Yes	No	Harvest control rule	2016
Norway	Annual	Relative biomass index from pelagic survey.	Yes	No	None	2018
Canada	Irregular	Relative biomass index from demersal survey.	Yes	No	None	No
Sweden	Annual	Relative biomass index from demersal survey.	Yes	No	None	No
Denmark	None	Relative biomass index from demersal survey.	No	No	None	No

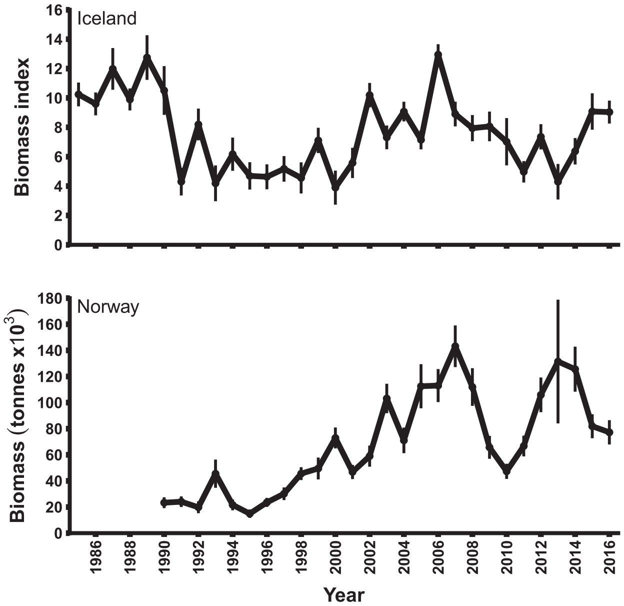

Figure 5. Biomass for index female lumpfish in Iceland from the Iceland spring groundfish survey and Norwegian 0-group pelagic survey. 95% confidence intervals shown.

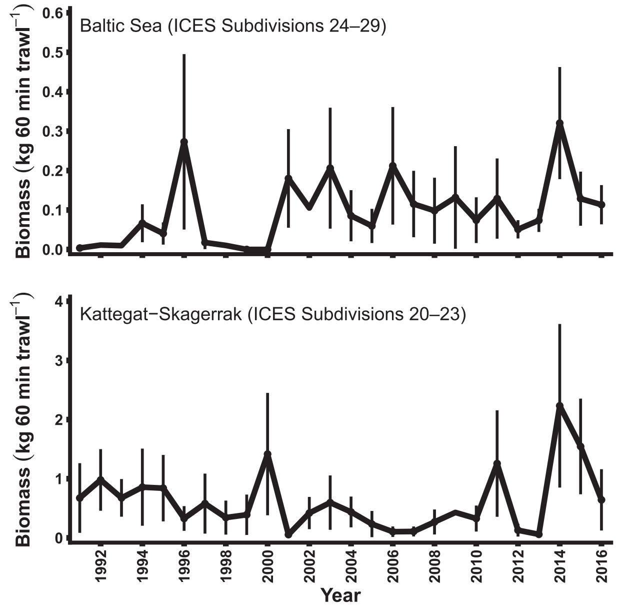

Figure 7. Average catch of lumpfish from the Baltic Sea bottom trawl survey (BITS) (top) and the North Sea International Bottom Trawl Survey (IBTS) (bottom) standardized to 60-min trawl.

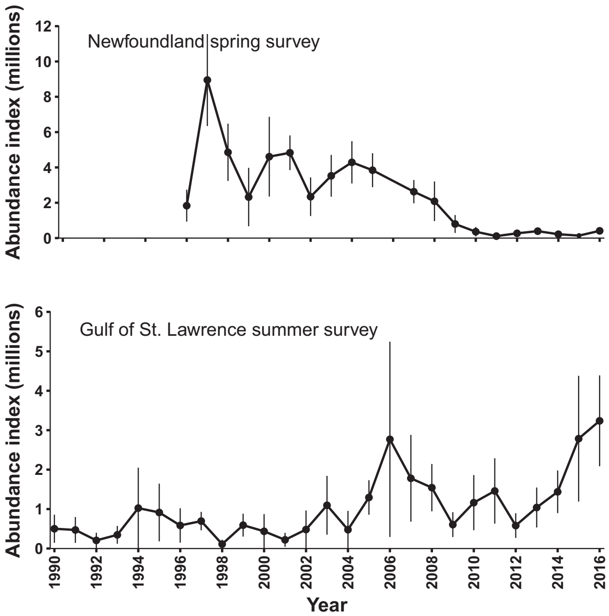

Figure 6. Abundance index from the summer bottom trawl survey in the northern Gulf of St. Lawrence, Northwest Atlantic Fisheries Organization (NAFO) Divisions 4RST, and the spring bottom trawl survey in Divisions 3LNOP. 95% confidence intervals shown.

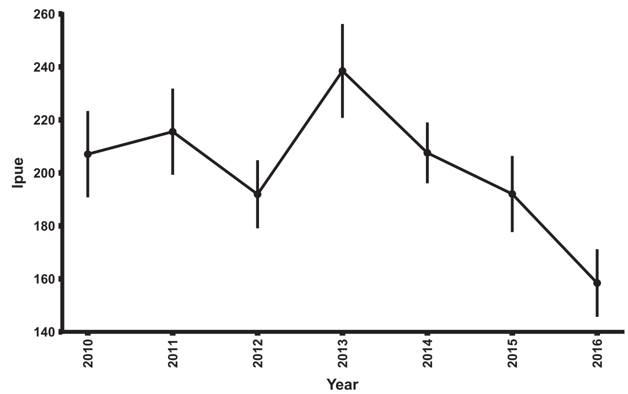

Figure 8. Landings per unit effort (lpue) from the Greenland lumpfish fishery.

Marine Stewardship Council (MSC) certification (MSC, 2014). This involved the introduction of a TAC (initially set at 1500 tonnes of roe, which is the average landings between 2010 and 2013) and a maximum number of fishing days. This quota is divided among seven management areas [six NAFO management areas with Division 1B split into two (Figure 4)], with the local buyers of roe deciding when to start the fishery. The fishery proceeds until either the quota for the management area is exhausted or when the designated number of fishing days has been reached. The majority of the commercial fleet is not obligated to fill out logbooks as most vessels are exempt due to their size (below 9 m).

The fishery has been regulated in Norway since 1988, but only in the three most northern counties: Nordland, Troms, and Finmark. Anyone can participate in the fishery if their boat is below 13 m in length. The fishery is regulated through a TAC per boat, which was initially set at 6.5 tonnes of roe. The initial minimum mesh size was set at 252 mm and was increased in 1999 to 267 mm. Since 2006, fishing is limited to the period before 20 June (5 July for East Finmark).

The Icelandic fishery is managed using input controls with limited entry, limited fishing period, maximum number of consecutive fishing days for each boat, maximum length of nets, and maximum size of boat. In 1991, the number of boats which could participate in the fishery was effectively capped, as only boats which had fished for 1 year in the previous 4 years could participate in the fishery. A similar rule was implemented in 1996, and

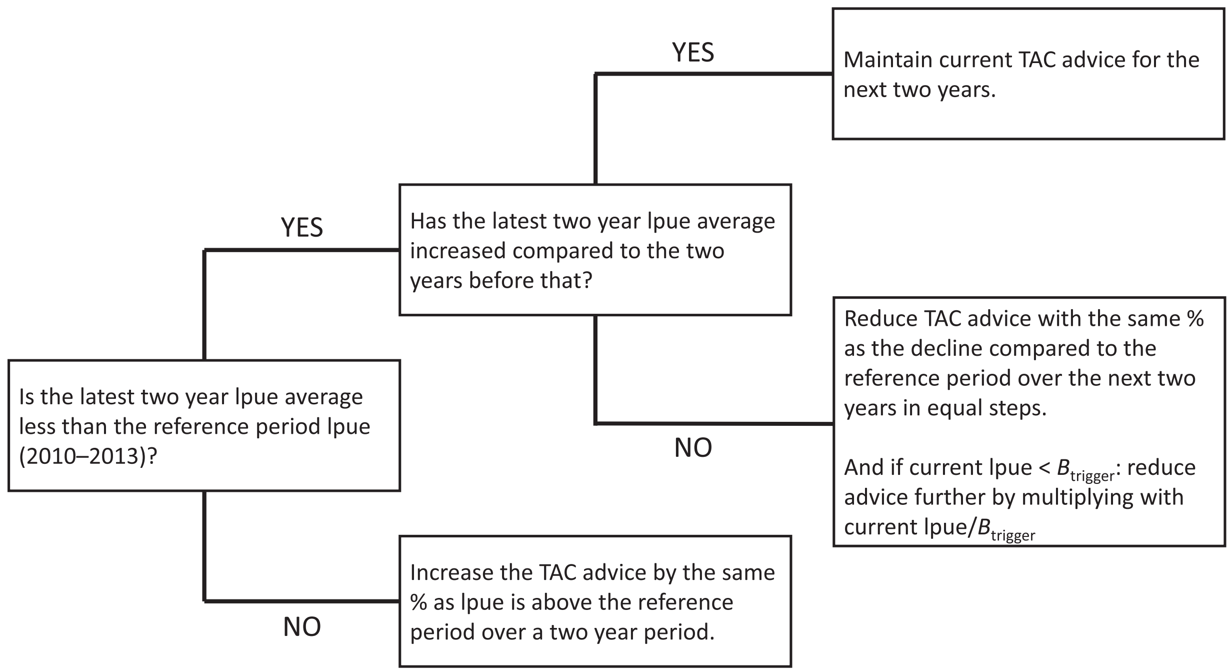

Figure 9. Harvest control rule for setting the TAC and number of fishing days for the Greenland lumpfish fishery.

Table 2. Summary of management regulations in each country.

Country	Regulations for participation	Input controls	TAC	Min-max mesh size (mm)	Logbooks
Iceland	Boats require a lumpfish licence of which there are a limited number Boat must be under 15 GT	Limited entry Length of fishing period Area management Total length of nets	No	267–292	Yes
Greenland	Commercial fishing licence required for commercial operations No licence for non-commercial fishing	Length of fishing period Area management	Yes	Not regulated	Only boats >9 m
Norway	Boat must be under 13 m	Length of fishing period Area management	TAC per boat	267–no max	Yes
Canada	Commercial fishing licence required for commercial operations	Total number and length of nets Length of fishing period	No	267–no max	Yes
Sweden	Commercial fishing licence required for commercial operations No licence required for non-commercial fishing	None	No	120–no max (200 within Kattegatt and The Sound between 1 January and 31 March	Yes
Denmark	Commercial fishing licence required for commercial operations No licence required for non-commercial fishing	None	No	None	No

all boats which were eligible to participate in the fishery were assigned a lumpfish permit, which is required to participate in the fishery. The permits are transferrable between boats, no new permits are issued, and a permit can be lost if a boat is scrapped and the licence is not transferred to a new boat within a specified period. To utilize a permit in any particular year, the boat owner must notify the Directorate of Fisheries before commencing fishing and must select one of seven management areas (Figure 4) for his/her fishing operations for that year. At the time of writing (May 2018), 449 boats had a permit to fish lumpfish (www.fiskistofa.is).

In 2005, following a request from the National Association of Small Boat Owners (NASBO) in response to falling prices for lumpfish roe, the government introduced a limit on the maximum number of consecutive days each boat could fish. The allocated days could be used at any time within the fishing season of their chosen area. In 2012, MFRI began offering advice on the TAC for lumpfish. This is now taken into consideration alongside input from NASBO when the maximum number of fishing days for fishing is decided. Since 2005, the number of consecutive days fishing has varied from 32 to 62 days.

Table 3. Timeline of introduction of significant management measures.

Year	Country	Management measure
1976	Iceland	Boat size limited to 8 GRT and fishers must submit logbooks
1977	Iceland	Maximum boat size increased to 12 GRT
		Coast is divided into four areas, with season limits for each area
		Limits are placed on number of nets, 40 per fisher, never more than 150 per boat
		Introduction of minimum mesh size of 267 mm
1978	Iceland	Licensing system introduced
1988	Norway	Introduction of limit on number of boats and TAC (6.5 tonnes) per boat
1991	Iceland	Only boats which participated in fishery for at least one year between 1987 and 1990 may participate
1992	Canada	Introduction of limit of 50 gillnets of 91 m (50 fathoms) with minimum mesh size of 267 mm and time limit on length of season
1994	Iceland	Number of nets increased to 100 per fisher with maximum of 300 per boat
		Breiðifjörður (area B) split into two areas to reduce bycatch of eider ducks
1996	Iceland	Only boats which participated in fishery for at least one year between 1991 and 1994 may participate
1998	Iceland	Only boats which could participate in fishery in 1997 can participate
	Norway	Size limit (13 m) placed on vessels which can participate in fishery
1999	Norway	Minimum mesh size increased from 252 to 267 mm
2005	Iceland	Limitations on days at sea introduced by National Association of Small Boat Owners for economic reasons
2006	Norway	Fishing restricted to period before 20 June (5 July for East Finmark)
2008	Iceland	Directorate of Fisheries begins collecting landings data
2012	Iceland	MRI offers first TAC advice
		Mandatory to land bodies
2013	Iceland	Number of nets reduced from 100 per crew member (max 300) to max 200 per boatMaximum soak time reduced from 6 to 4 days
2014	Iceland	Fishery received MSC certification
2015	Iceland	Maximum number of nets replaced by maximum length
	Greenland	Greenland management plan implemented
		Fishery received MSC certification
2016	Greenland	Introduction of specific lumpfish license
2017	Norway	Fishery received MSC certification
2017	Canada	Lumpfish assessed by the Committee on the Status of Endangered Wildlife in Canada and designated as threatened.
2018	Iceland	MSC certification suspended

Discussion

The current status of lumpfish populations spans the whole range from healthy and fairly certain to depleted and unknown. The populations in Iceland and Norway have increased following low population biomass in the 1990s and are above the long-term average. It appears that the lumpfish population in Canada is depleted. Due to the short time-series, there is less certainty about the population status in Greenland, and the population status in the Baltic Sea and Kattegat is unknown due to lack of reliable data.

Participation in lumpfish fisheries has been declining in all but one country (Iceland). Anecdotal information suggests the declining price of roe, both in real terms and in relative terms in regard to the price of other species such as Atlantic cod (*Gadus morhua*) and Greenland halibut (*Reinhardtius hippoglossoides*), is the primary reason. Other factors such as status of the lumpfish population can also play a role; with a low population biomass, catches are low so targeting lumpfish can be unprofitable, which might be the case in Canada.

As the lumpfish fishery is seasonal, the ability to easily move to other fisheries during other times of the year is an essential component for participation. For established fishers, the decision to take part in the fishery does not require a substantial long-term investment, but only a small investment in gillnets, which are typically replaced after 1–2 years. This flexibility means that participation can rebound quickly, as was seen in Iceland between 2007 and 2011 when the number of boats taking part increased 2.5-fold (Marine Research Institute Iceland, unpublished data). Social changes may also play a role, which is thought to be the case in Denmark and Sweden, with a decline in number and increase in the average age of subsidiary fishers, which went from 1069 fishers with an average of 59.1 years to 972 fishers with an average age of 64.1 years between 2007 and 2016 (http://webfd.fd.dk/stat/aldersstatistik/bierhvervsfiskere_eng2016.html, accessed June 2018).

Strong management and regular assessment of stock status is the key to a sustainably managed species (Hilborn and Ovando, 2014; Melnychuk *et al.*, 2017; Pons *et al.*, 2017). The case of the lumpfish population in Canada strongly emphasizes this point, with limited management restrictions, a lack of data on the fishery, and few assessments. This highlights the need for lumpfish populations to be regularly assessed, coupled with responsive management measures in place to prevent long-term overfishing. This is, however, not the case for Sweden or Denmark, where there is only limited assessment of the population and few meaningful restrictions on the fishery. As Denmark and Sweden are very likely targeting the same population, greater collaboration to pool assessment and fishery data and to produce a combined management plan for this species would be advisable.

A major hindrance in the stock assessment of lumpfish is the difficulty in interpreting otoliths for estimating age. In addition, the ageing technique currently in use has not been validated (Albert *et al.*, 2002; Hedeholm *et al.*, 2014). Ageing of lumpfish in Greenland suggests that the majority of the spawning population comprises 3- and 4-year-old fish. This suggests that post-spawning survival is low, and that lumpfish exhibit a semelparous life strategy (Hedeholm *et al.*, 2014, Kasper *et al.*, 2014). An alternative explanation is that growth is very low after spawning, making it difficult to distinguish growth rings on the outer edge of otoliths of older age classes. In Iceland, as the population declined between the 1980s and 1990s, there was a concurrent truncation in the length distribution (Kennedy and Jónsson, 2017). A change in length distribution is not an expected response for a semelparous species undergoing a population decline. These differences may reflect a difference in life history between populations. In order to resolve this issue, further studies are needed, and age validation should be a high priority in future lumpfish research.

There are also several issues which hinder the assessment of specific stocks. The location and distribution of juveniles and mature fish outside the breeding season (if assuming an iteroparous life history) from the Greenland and Canadian populations are unknown. Such knowledge could allow for an estimation of abundance of prerecruits, as management, in the case of Greenland, is currently based upon stock assessments from the previous year. This is even more relevant if lumpfish have a high degree of semelparity. It could also allow an evaluation of stock structure along the coast of Greenland.

Each country has its own unique combination of management measures, some of which have been in place for several decades. The majority of these management measures were not intended to limit catches to a specific level, as the populations were not formally assessed. However, population assessment and management measures have been slow to appear, with catch limits not being introduced in Norway until 1988, and it was not until 2012 that MFRI in Iceland began to offer TAC advice. In contrast, the formulation of a management plan in Greenland in 2015 was fairly quick in comparison as the fishery did not begin until the late 1990s.

As the different management measures have been in place during a short period and during a time of low participation in the fishery, it is difficult to compare their effectiveness. However, there are some obvious flaws in several of these approaches. Both Iceland and Canada employ effort restrictions as their main method of limiting catches. Both countries have limits on the number of nets and number of fishing days. In addition, Iceland also has a cap on the number of boats that can participate in the fishery. However, the number of fishing days for the season is decided before the number of boats that will participate in the fishery is known. This makes it very difficult to precisely control total effort in the fishery and thus limits the effectiveness of this approach. While Norway and Greenland employ a TAC system, the Norwegian system sets a TAC for each boat. However, there is no limit on the number of boats that can participate in the fishery. In Norway, if participation in the fishery were to rise, the current management approach could make it difficult to limit catches within a particular year. However, if the increase in boat numbers were gradual over several years and provided there are no major fluctuations in boat numbers from year to year, TAC per boat can be adjusted to compensate for this increase in boat numbers. The disadvantage of such a system is that there can be an underutilization of the TAC if fewer boats than expected participate in the fishery. Greenland is the only country to employ a fisheries-wide TAC; however, there is no allocation of quota to individual boats. The lack of individual quotas can result in a "race to fish" scenario, which has several disadvantages (Branch *et al.*, 2006). As the fishing season is constrained by the biology of the species, i.e. the spawning period, there is little possibility to extend the fishing season. Thus, the benefits of an individual transferable quota (ITQ) system (Grafton, 1996) may not be realized. Lastly, given that the population is monitored using lpue from fisheries data, there is the possibility that an overall population decline may be masked due to fish remaining equally abundant in "hot spots"; thus, a fishery independent indicator should ideally be considered.

The MSC certification has played an interesting role in the assessment and management of the lumpfish fishery. The advice issued by the MFRI (Iceland) was met with resistance from the fishers (Bogason, 2014); however, when the fishery was MSC certified, this situation improved. Following the MSC certification in Iceland, Greenland also sought certification, and the management plan in Greenland was a direct result of the MSC assessment. Without a management plan in place, it seems unlikely that MSC certification would have been achieved. There has been no specific investigation into the effect of the MSC certification on the price received by fishers. Anecdotal information suggests that the price did not increase, which reflects the situation which followed the MSC certification of Atlantic cod in Sweden (Blomquist *et al.*, 2015). Decreasing participation in the Greenland fishery suggests the achievement of MSC certification has not been sufficient to maintain interest in the lumpfish fishery; note that the alternative fishing opportunities (coastal fishing for Atlantic cod and Greenland halibut) are not MSC certified. While the MSC certification was instrumental in implementing management of lumpfish, the benefits for fishers themselves are currently unclear. The lumpfish fishery in Norway was recently MSC certified (MSC, 2017a); whether this will rekindle interest in this fishery remains to be seen.

Due to the removal of roe at sea, the total weight of ungutted lumpfish has to be estimated based upon the amount of roe present in the ovary. The current official conversion factor utilized by Norway and Greenland (6.7 for fresh roe) is unrealistic and greatly overestimates total catch. Estimates from fish sampled from the fishery in Greenland put the gonad weight at an average of 27% of the total weight of the fish, which equates to a conversion factor of 3.7 (Hedeholm *et al.*, 2014). A similar value (30.5%, a conversion factor of 3.28) was estimated for lumpfish in Iceland using logbook data (Kennedy and Jónsson, 2017). In Canada, two studies also concluded that during the fishing season, the female lumpfish gonad represented, on average, 28% of the fish total weight (Stevenson and Baird, 1988; Gauthier *et al.*, 2017). If landings data are consistently reported as weight of roe, then the actual conversion factor is not vastly important as the data can still be used to assess relative change in the amount of lumpfish caught over time. However, inaccurate conversion factors create problems when comparing catches among countries. For example, Powell *et al.* (2018a) attributes ca. 70% of the world catch of lumpfish to Greenland; a more accurate estimate would be 20–40%. Problems can also arise if the method for collecting landings data changes, as it did in Iceland, where landings are almost exclusively ungutted lumpfish. In this case, to ensure comparability between historical and present landings, an accurate estimation of the amount of roe is essential.

The large mesh size of lumpfish nets is highly selective for lumpfish and with very low levels of fish bycatch. Fish caught are of marketable size, and thus there is little concern in regards to the capture and discarding of juvenile fish. Lumpfish can survive for several days when caught in the net (Kennedy *et al.*, 2016); thus, lumpfish nets may be left in the water for several days. This extended soak time can lead to discarding of non-target species due to the deterioration in fish quality. There are currently no data available on discarding of non-target species in lumpfish fisheries, but this should be evaluated as this represents an unaccounted source of fishing mortality for the species in question.

Bycatch of non-fish species is of significant concern in many fisheries. The use of gillnets in shallow water in coastal areas presents significant risks for coastal seal species and diving birds (Žydelis *et al.*, 2013). This is of significant concern in Iceland, Norway, and Canada. Due to a lack of data on the exact levels of bycatch, it is difficult to estimate the risk that lumpfish fisheries pose to bird populations. With Iceland, Norway, and Greenland all receiving MSC certification [note that Iceland's certification was suspended in 2018 due to issues of bycatch (MSC, 2017b)], these fisheries must increase effort in collecting data on bycatch of marine mammals and birds. For this to happen and to find solutions to any bycatch issues that may become apparent, active engagement from managers, research institutions, and fishers themselves is required.

There is currently intense focus on the development and use of lumpfish in the fight against sea lice in the salmon aquaculture industry (Imsland *et al.*, 2014). The production and sale of lumpfish has risen rapidly in the last few years. In Norway, the number of cultured lumpfish sold to the aquaculture industry increased from 431 thousand to 13.4 million fish between 2012 and 2015 (http://www.fiskeridir.no). This rapid rise in production raises concerns about potential impact of escapees on their wild counterparts (Powell *et al.*, 2018b), which is a major concern in other species, e.g. Atlantic salmon (*Salmo salar*) (Jonsson and Jonsson, 2006).

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