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Assessment of potential impacts of bycatch mortality on the Arctic Cod (*Boreogadus saida*) populations from the Northern (*Pandalus borealis*) and Striped (*Pandalus montagui*) Shrimp fisheries in Shrimp Fishing Areas 1, 2, and 3

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Arctic Cod (*Boreogadus saida*) is considered a key forage species in Arctic marine ecosystems due to its pivotal role in the food web, serving as prey for numerous marine animals (seals, whales, birds, and fishes) and being an important consumer of secondary production (zooplankton). In recent years (i.e., since 2017), shrimp fishing vessels operating in Shrimp Fishing Areas 1 (Baffin Bay) and 3 (Hudson Strait), have occasionally reported large amounts (400–2300 kg per tow) of Arctic Cod bycatch. Fisheries and Oceans Canada (DFO) Resource Management approached DFO Science seeking advice on ecologically and biologically-responsible Arctic Cod removal levels in individual Shrimp Fishing Areas (SFAs) in the north. This research document reviews the Arctic Cod biology and ecology, considers distributional patterns, and analyzes historical bycatches in the Canadian Eastern Arctic shrimp fisheries. Also, an attempt was made to quantify Arctic Cod population size in the area of interest. Due to the limited data available for this analysis, the ecosystem requirements (i.e., consumption demands of Arctic Cod predators) were used as an indirect estimate of the population size. By contrasting the size of the estimated Arctic Cod population with the bycatch levels, the assumption was made that the impact of bycatch removal in each Shrimp Fishing Area on the Arctic Cod population is minimal. With a limited scope of the Arctic Cod biomass data and a high degree of uncertainty surrounding the biomass indices, ecologically and biologically-responsible Arctic Cod removal levels in individual Shrimp Fishing Areas (SFAs) cannot be established at present. Therefore, when amending the conditions of licence in response to the elevated Arctic Cod bycatch which would result in increased removals, caution is advised.

INTRODUCTION

Arctic Cod (*Boreogadus saida*; Figure 1) is considered a key (pivotal) forage species in Arctic marine ecosystems (Bradstreet et al. 1986). As a pelago-benthic dweller it occurs in both the pelagic realm and near the ocean floor (Geoffroy et al. 2016).

Figure 1. Arctic Cod (Boreogadus saida). Photo credit: Claude Nozères, DFO.

Larval and juvenile Arctic Cod concentrate mainly in the upper water column, taking advantage of the zooplankton (Copepoda) food base (Geoffroy et al. 2016). Upon reaching a certain age and length (age 1+, approx. 60 mm; Walkusz et al. 2013.) individuals descend to deeper depths and remain demersal for the rest of their life (Majewski et al. 2016). In benthic habitats, larger Arctic Cod feed on Amphipods and small fishes (Walkusz et al. 2013). Since younger and older individuals occur in both pelagic and benthic realms (Figure 2), it is difficult to study an entire Arctic Cod population as doing so would require the simultaneous use of pelagic and demersal fishing gear. Recently, hydroacoustic methods have proven useful for studying Arctic Cod populations; however, hydroacoustic signals still require ground-truthing to validate the remote observations.

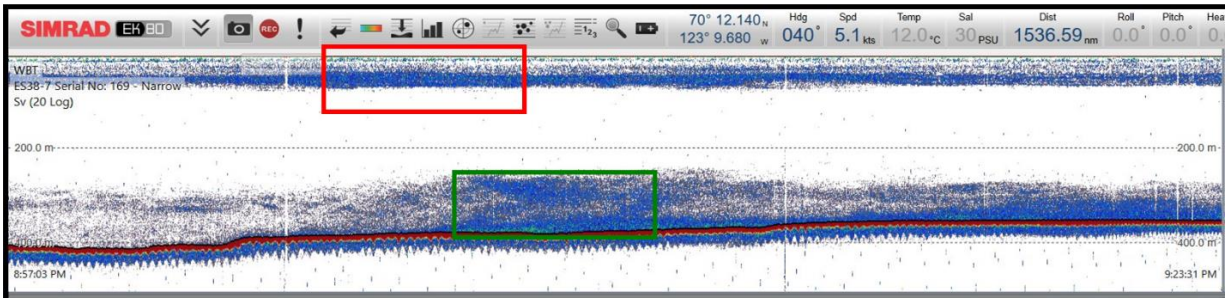

Figure 2. Echogram recorded with SIMRAD EK-80 acoustic system (38 kHz) at a 353 m station in the Amundsen Gulf. The red rectangle (top) indicates a subsurface aggregation of young-of-the year fish, while the green rectangle (bottom) indicates a benthic aggregation of larger individuals. Note the vertical extension (thickness, 80 – 100 m) of each of the aggregations in contrast to the sampling capacity of fishing gear (few meters vertical opening). Courtesy of Andy Majewski (DFO, data unpublished).

Arctic Cod is extremely important in Arctic marine ecosystems as food for numerous marine animals (seals, whales, birds, and fishes) and as an important consumer of secondary production (zooplankton). Due to its key linking role in food webs, Arctic Cod is also of interest

to Indigenous Peoples who directly profit from healthy populations of marine resources, through subsistence harvests and/or commercial fishing. The intermediary position of Arctic Cod in Arctic marine food webs is reflected in the relatively large number of scientific projects devoted to understanding its distribution, feeding, and life cycle. Through these observations, Arctic Cod has been found in dense aggregations offshore (Majewski et al. 2016) and in dense nearshore schools (Welch et al. 1996). This patchy distribution pattern might increase the risk to Arctic Cod populations from commercial fishing activities when fishing locations overlap with areas of high Arctic Cod density.

Since 2017, shrimp fishing vessels operating in Shrimp Fishing Areas (SFA) 1 (Baffin Bay) and 3 (Hudson Strait), have occasionally reported large amounts (400–2300 kg per tow) of Arctic Cod bycatch. In Eastern Canada, Arctic Cod is listed as a groundfish species (Atlantic Fishery Regulations 1985), which means that elevated amounts of Arctic Cod bycatch can trigger a standard "move away" licence provision, as per the Conditions of Licence (DFO 2018), which states: "*In the event that the total incidental catch of all groundfish species in any set exceeds the greater of 2.5% or 100 kg total weight, the licence holder/operator must immediately change the vessel's fishing area by a minimum of 10 nautical miles from any coordinate during the last tow*". High occurrences of Arctic Cod in bycatch, while not common, pose a significant burden on the fishing industry and presently unknown ecological consequences. With limited time to harvest the allotted shrimp catch each year (because of a relatively short open-water period and long transit times from southern ports of origin), the fishing industry in the Eastern Arctic has asked Resource Management for increased flexibility for Arctic Cod bycatch, with move away provisions triggered based on amounts caught averaged over a number of consecutive tows.

As a result, DFO Resource Management approached DFO Science seeking advice on ecologically and biologically-responsible Arctic Cod removal levels in individual SFAs.

Given the absence of a comprehensive Arctic Cod stock assessment, the purpose of this report is to discuss ecologically and biologically tolerable levels for Arctic Cod removals in SFAs 1-3 and if it is possible to create a "cap'' system for the total annual bycatch level.

REVIEW OF ARCTIC COD BIOLOGY AND ECOLOGY

Arctic Cod is a relatively small fish (maximum size: 400 mm, mean: 140 mm; Matley et al. 2013) with a maximum life span of seven years. It sometimes co-occurs with Polar Cod (*Arctogadus glacialis*), which is similar in appearance, and the two species can be mistakenly identified for each other. Arctic Cod spawns in winter (Hop et al. 1995) and the larvae hatch between April and June depending on geographical location (Bouchard and Fortier 2011). Larval Arctic Cod feed initially on smaller prey items (e.g., Copepoda nauplii, Rotifers), advancing to larger prey items as they grow (e.g., *Calanus* copepods; Walkusz et al. 2011). Juvenile fish (approx. 35 mm in length) continue feeding on Copepods. After reaching the size of descent (approx. 50 mm; Falk-Petersen et al. 1986, Majewski et al. 2016) Arctic Cod adopt a demersal life and in addition to *Calanus* copepods start feeding on Amphipods and fishes, including cannibalism. Arctic Cod is considered a schooling fish (Hop et al. 1997), however, "aggregating fish" seems a more appropriate term considering the dense aggregations of different size/age individuals and non-unidirectional movement observed by Geoffroy et al. (2011, 2016).

DISTRIBUTIONAL PATTERNS AND BIOMASS INDICES

Arctic Cod is widely distributed in the Arctic. It is often dispersed in the water column (Figure 2) and is therefore hard to properly quantify using any one type of direct sampling gear (either demersal or pelagic). Walkusz et al. (2019) calculated Arctic Cod biomass indices for SFAs 1, 2,

and 3 based on biomass estimates from demersal scientific surveys only (2005–2017). These biomass estimates (maximum 138 t, 47,000 t, and 30,000 t in SFA 1, 2, and 3, respectively) were certainly underestimated as Arctic Cod can essentially occupy the entire water column and its distribution is extremely patchy. Arctic Cod has been observed in large nearshore schools in Barrow Strait (Welch et al. 1996), with aggregations being estimated to have a biomass of 20,000 t. Also, Welch et al. (1992) claimed that nearshore Arctic Cod aggregations along the Canadian Arctic Archipelago are common and were estimated to be approximately 75,000 t. Using acoustic methods that integrate biomass in the water column and near the bottom, Benoit et al. (2008) recorded large aggregations of Arctic Cod in Franklin Bay, with average biomass being 11.2 kg m^{-2} (equal to 11,200 t km^{-2} assuming continuous distribution) from February to April, with the maximum reaching 55 kg m^{-2} (equal to 55,000 t km^{-2} assuming continuous distribution). These high densities were assumed to be localized. Using similar methods, Geoffroy et al. (2011) detected a large winter aggregation in the Amundsen Gulf. They calculated that in February the biomass peaked at 0.732 kg m^{-2} (equal to 732 t km^{-2} assuming continuous distribution); however, the aggregation was most likely confined to the northern portion of the Amundsen Gulf.

ECOSYSTEM REQUIREMENTS

Using predator populations to estimate food base requirements has been used in marine research. For example Stenson (2013) estimated the energy requirements of individual prey populations required to sustain Harp Seal population. Walkusz et al. (2013) showed that for the Canadian Beaufort Shelf (area of 63,000 km^2), biomass calculated from demersal trawl surveys only accounts for a small fraction of all Arctic Cod biomass needed to meet the bio-energetic requirements of the ecosystem (i.e., feeding by seals, whales, birds, and fishes). Similar conclusions were presented by Welch et al. (1992) who claimed that biomass estimates from ‘dispersed’ fish produce significantly underestimated values. Walkusz et al. (2013) estimated that using the conservative assumption of approximately 20,000 beluga whales that consume a total of 440 t of fish per day and 500,000 ringed/bearded seals that consume a total of 2,500 t of fish per day require a total of 3,000 t of Arctic cod daily to sustain their predators' needs in the Beaufort Sea. It means that 500,000–1,000,000 t of fish are consumed over the course of the year (whales and birds are absent from the area after freeze-up). This amount, while high, would not be exceptional, considering Welch et al. (1992) estimated that 148,000 t of Arctic Cod is consumed annually in Lancaster Sound (area of 98,000 km^2).

Based on recent estimates for fish, bird, seal, and whale populations in Baffin Bay/Davis Strait (Table 1), Arctic Cod biomass requirement for ecosystem maintenance is similar (or higher) than the Beaufort Sea (i.e., > 500,000 t Arctic Cod annually, assuming 10% of all Northwest Atlantic marine mammal populations utilizing the area of interest). While this approach most likely puts the estimate of Arctic Cod biomass required to sustain their predators on the conservative side, it provides a general estimate as to the order of magnitude of the Arctic Cod biomass held in the ecosystem.

Table 1. Species and abundances of known Arctic Cod predators present in the Baffin Bay/Davis Strait area (source: Treble 2017, NIRB 2018).

Species	Abundance
Fishes (t)	
Greenland Halibut	200,000
Birds (individuals)	
Thick-billed Murre	860,000
Little Auk (dovekie)	30,000,000
Northern Fulmar	Not quantified but sizeable
Seals (individuals)	
Ringed seal	1,200,000
Bearded seal	Not quantified, but considered very abundant
Harp seal	7,400,000 in the Northeast Atlantic
Whales (individuals)	
Beluga whale	20,000
Narwhal	45,000

ANALYSIS OF HISTORICAL BYCATCHES

Arctic Cod, which is similar in size to shrimp, is a common bycatch species in the Eastern Canadian Arctic shrimp fishery. While the amount of Arctic Cod bycatch in a single tow is usually low, large catches are occasionally reported. Arctic Cod catches have no economic value and are discarded at sea.

Historical records for Arctic Cod bycatch in SFA 1 ranging between zero in years with no fishing to 143 t in 1993 (Figure 3; Walkusz et al. 2019). In SFA 2, the peak Arctic Cod bycatch was 31 t in 2004/05 (Figure 4).

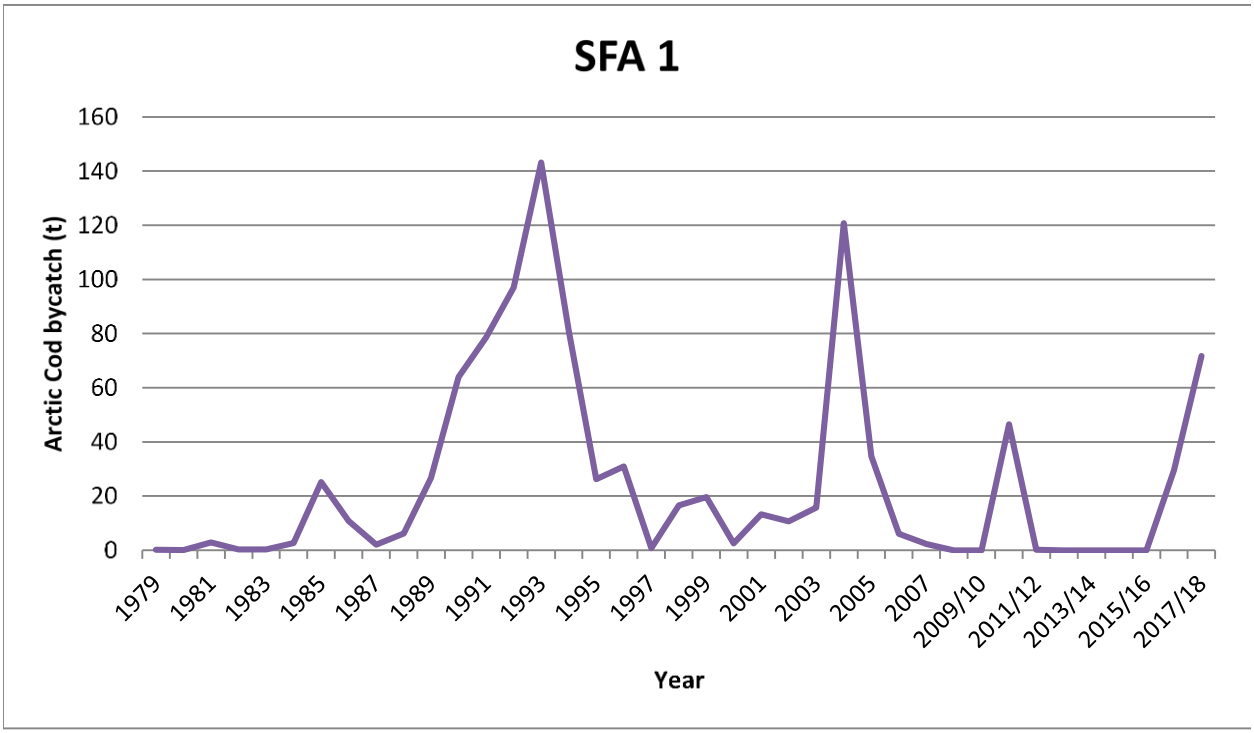

Figure 3. Arctic Cod bycatch in SFA 1 for 1979–2018 (Walkusz et al. 2019).

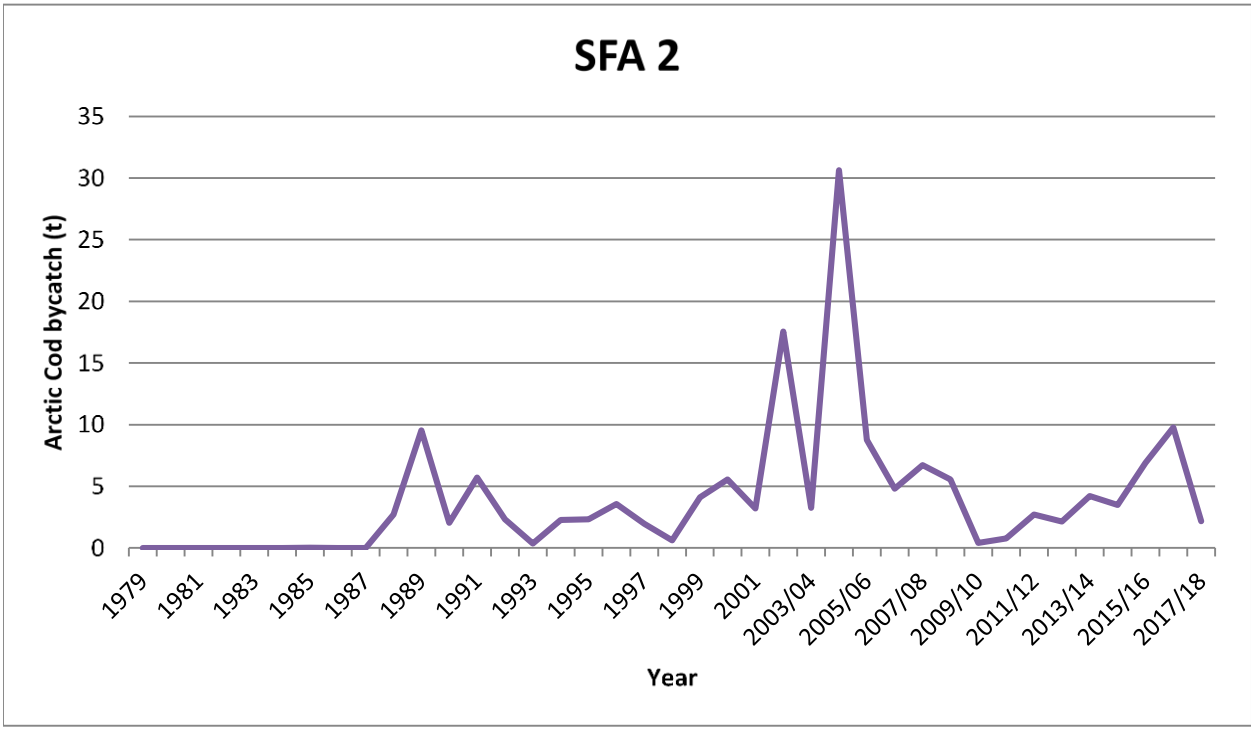

Figure 4. Arctic Cod bycatch in SFA 2 for 1979-2018. Shrimp fishery management cycle changed from calendar year to fiscal year starting in 2003.

In SFA 3, incidental catches of Arctic Cod were low until recent years, when 47 t was caught in 2018 (Figure 5). The size of Arctic Cod catches is heavily related to aggregating processes, therefore incidental catches will reflect fluctuations in these processes.

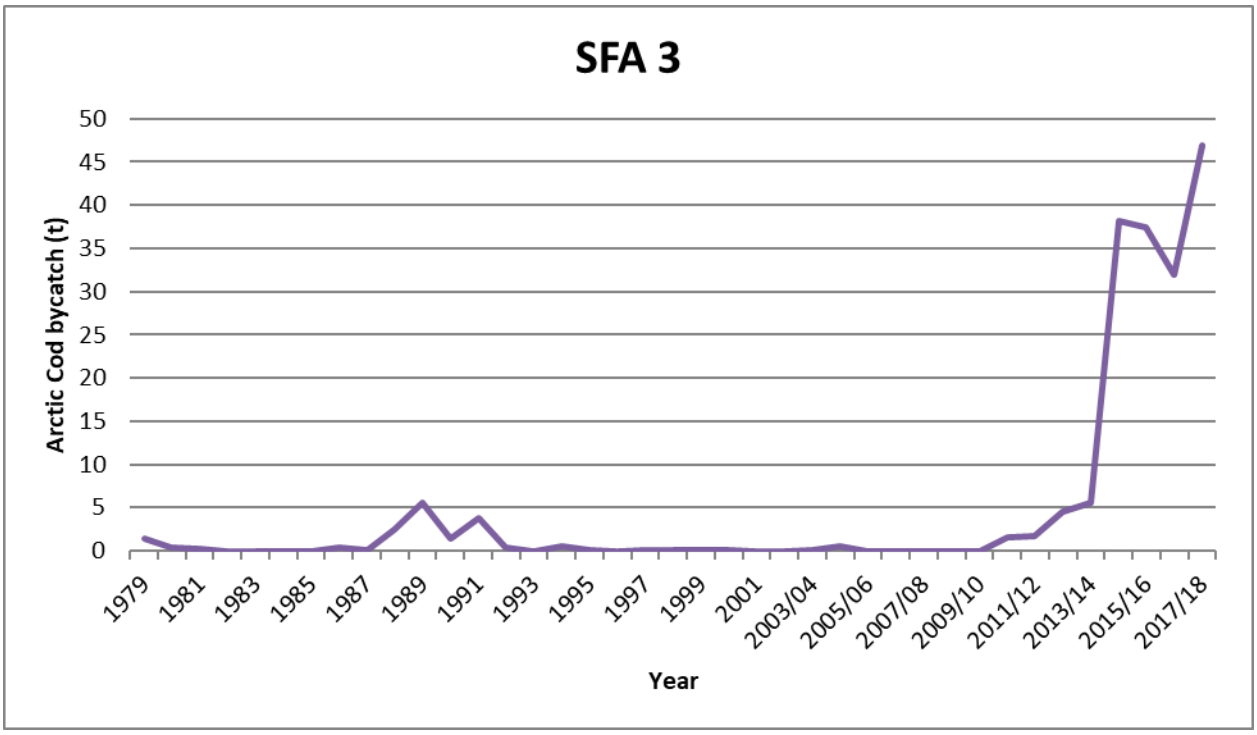

Figure 5. Arctic Cod bycatch in SFA3 for 1979–2018. Shrimp fishery management cycle changed from calendar year to fiscal year starting in 2003.

UNCERTAINTIES OF ANALYSIS

Overall lack of knowledge of Arctic Cod biology in the studied area.

While general biology of Arctic Cod has been studied extensively in various Arctic locations, its biology is poorly understood in the geographic area considered in this review. That limitation applies to the timing of descent of juvenile Arctic Cod from pelagic to benthic habitats (i.e., when they become susceptible to mortality due to the shrimp fishery). Multi-seasonal sampling along with length analyses of individuals caught would provide insight into the ontogenetic vertical migrations of Arctic Cod.

Insufficient data collection for the proper biomass index analysis.

In this analysis, the biomass index was based solely on the benthic catches; however, Arctic Cod is considered a pelago-benthic dweller. The lack of information on the pelagic portion of the population can lead to significant underestimates of the biomass. Application of acoustic methods along with pelagic trawl sampling would address this knowledge gap.

Insufficient data on distribution and abundance of Arctic Cod predators.

Analysis of predation pressure on Arctic Cod was done using published abundances of predators with the assumption that a portion of the predator population (i.e., 10%) would be present in the area of interest. Using this assumption, the biomass of Arctic Cod required to sustain its predators was estimated. While this generalization provides some insight into Arctic

Cod abundance, it is not a direct measure of fish biomass and the uncertainty associated with this approach can be significant.

Potential observer data bias

All offshore vessels operating in the area of interest are obliged by the Conditions of Licence, to have an At Sea Observer (ASO) onboard. The data collected by the ASO is meant to be fishery independent; however, it can be expected that there are times when particular tows are not monitored due to the limitations of having only one ASO onboard, which may create bias in the information reported.

DISCUSSION

Considering the relatively small total mortality (less than 0.1% of the stock annually as proposed above based on predators' requirements) of Arctic Cod stemming from the Eastern Canadian Arctic shrimp fishery, it can be assumed that the impact of shrimp trawling on the Arctic Cod population is minimal. It should also be noted that the Arctic Cod bycatch is not retained by fishing vessels and gets discarded, thus, the biomass is not removed from the ecosystem.

With a limited scope of the Arctic Cod biomass data and a high degree of uncertainty surrounding the biomass indices, ecologically and biologically-responsible Arctic Cod removal levels in individual Shrimp Fishing Areas (SFAs) cannot be established at present. Therefore, when amending the conditions of licence in response to elevated Arctic Cod bycatch which would result in increased removals, caution is advised.

In order to answer the question of the ecologically and biologically-responsible Arctic Cod removal levels in individual SFAs, the following would have to take place:

- Study of Arctic Cod biology/ecology including migratory patterns, aggregating events, and vertical distribution patterns (population split between pelagic and benthic habitats); this could be achieved by a dedicated survey that would combine acoustic survey with pelagic and benthic trawl sampling to ground truth the acoustic data; and,
- Study of Arctic Cod role in the ecosystem, including its role as a consumer (of zooplankton) and food for higher trophic levels (fish, seals ,whales, birds); this could be achieved by studies of Arctic Cod stomach contents and biomarkers (stable isotopes and fatty acids), and through a better assessment of the marine mammals and bird populations in the area.

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