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Maritimes Region | Science Response 2018/048

STATUS OF THE HAGFISH (*MYXINE GLUTINOSA*) FISHERY IN THE MARITIMES REGION

Context

A Special Science Response on the status of the Atlantic Hagfish resource was requested by Maritimes Region Resource Management. The advice will be used to support decisions about harvest levels in the Maritimes Region Hagfish fishery. The objectives of this document are to provide updated information on landings, catch per unit effort, and other possible fishery indicators for the Scotian Shelf and to advise on the health and impact of the fishery on the stock.

This Science Response Report results from the Science Response Process of May 11, 2018, on the Status of the Hagfish (*Myxine glutinosa*) Fishery in the Maritimes Region.

Background

The Maritimes Region Hagfish fishery takes place over the majority of the Scotian Shelf, in the Northwest Atlantic Fisheries Organization (NAFO) Divisions 4V, 4W, 4X and 5Z (Figure 1). There is little information on the life-history characteristics and stock structure of Hagfish in the Maritimes Region; there are no reference points in the fishery, and sustainable harvest levels are unknown. No assessment framework for the Maritimes Region Hagfish fishery has been developed, although a review of science and management strategies for the fishery took place in 2007 (DFO 2009a).

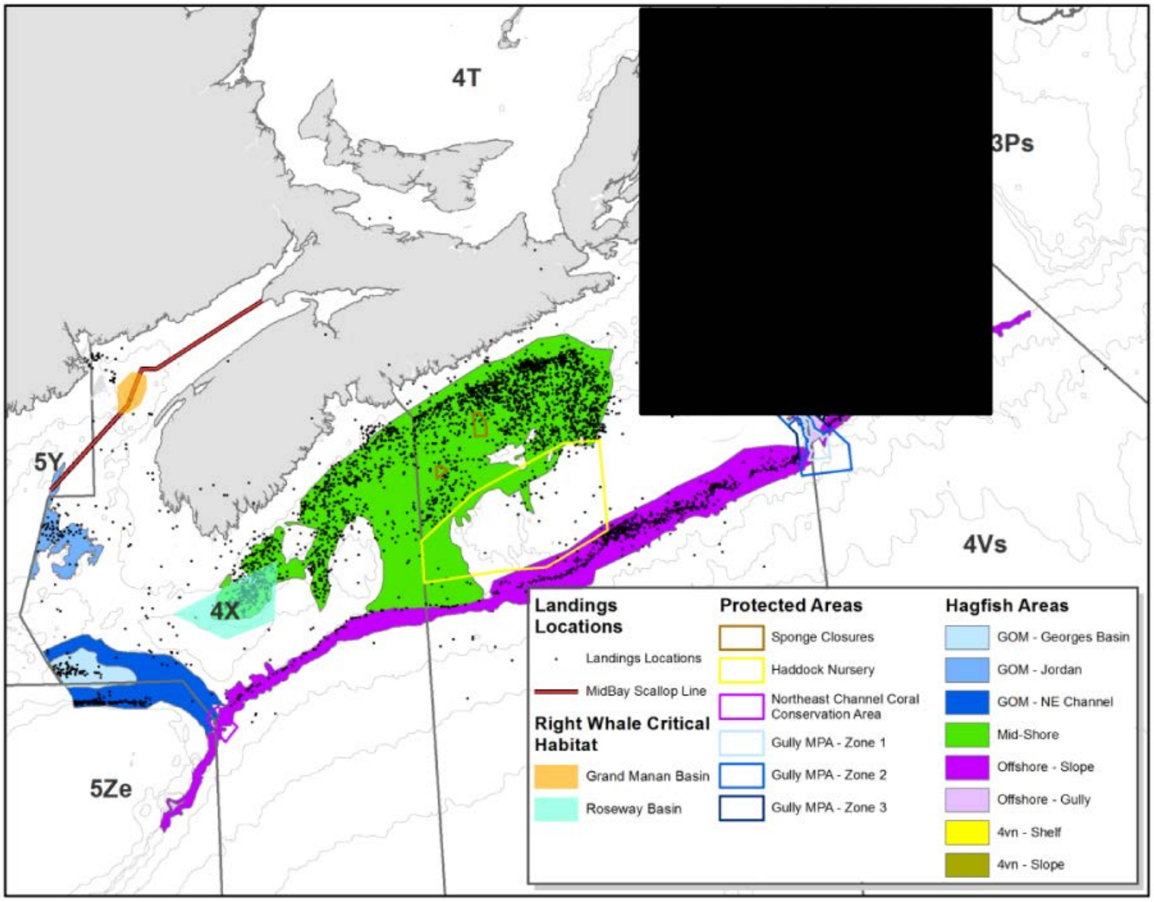

Figure 1. An overview of the Maritimes Region Hagfish fishery. Geographic areas on the map are expected to have consistent catch rate patterns over time. This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

Biology

The biology of Hagfishes has received considerable interest and attention in aspects related to their evolution, morphology, physiology and genetics, owing mainly to their unique position in fish evolution. In spite of this important research base, much of Hagfish life history and their population dynamics remain unknown.

Hagfishes are ubiquitous, with about 80 species of Hagfish in two subfamilies found across the world's oceans. Hagfishes and lampreys are frequently referred to as cyclostomes (Class Agnatha), or jawless fishes. These are the earliest forms of living vertebrates, distinct from the common jawed fishes. The Atlantic Hagfish is a member of the family Myxinidae, which is characterized by one pair of gill openings. The second family, Eptatretinae, is identified by multiple pairs of gill openings.

Myxine glutinosa is the only Hagfish species in the North Atlantic Ocean. Known commonly as the slime eel, the Hagfish is capable of producing massive quantities of mucus when provoked or threatened. The slime protects Hagfish from attacks by suffocating, trapping or diverting predators. A Hagfish will avoid suffocation in its own slime by forming its body into a knot and, through muscular contraction, passing this knot down the length of its body to draw off excess mucous.

Hagfish are reported to survive up to seven months without food in aquaria (Jensen 1966) and possess biochemical adaptations and cutaneous respiration, permitting them to survive anoxic conditions, including being buried in sediments (Sidell and Beland 1980; Lesser et al. 1996; Malte and Lomholt 1998). An exceptionally low metabolic rate permits them to live in nutrient-poor conditions by maintaining a quiescent state until food becomes available (Hessler and Jumars 1974).

A bottom-dwelling species, the Atlantic Hagfish spends most of its time embedded in soft clay or mud substrates with the tip of the snout protruding. The burrows of Atlantic Hagfish are transient, collapsing as the animal moves through the flocculant substrate (Martini and Flescher 2002). Hagfish have been reported on almost all substrate types, from muddy bottoms to sand, gravel and rock. Although they can swim in rapid bursts while feeding, Hagfish generally remain very sedentary in their natural environment. Swimming speeds have been estimated to be below 2 knots over short distances (Martini and Flescher 2002). Migratory behavior has only been observed in one species of Hagfish, the Japanese Hagfish *Eptatretus burgeri* (Fernholm 1974). Atlantic Hagfish prey on a variety of benthic marine invertebrates, including shrimp, polychaetes and nemerteans and also predate on fish.

A recent biological overview of the Atlantic Hagfish and its relationship to the exploratory fishery in the southern Gulf of St. Lawrence was provided by Morin et al. (2017) and provides greater detail on the Gulf of St. Lawrence population.

Reproduction

Many have suggested that Hagfish have limited reproductive potential with a variety of factors that lead to this assumption (Martini et al. 1997a and 1997b; Patzner 1998; Powell et al. 2004). Hagfish are presumed to exhibit a late age at maturity, as length at maturity occurs mid-way to the maximum length. Moreover, even though the majority of the population is expected to be female, they have low fecundity, with spawning females each releasing fewer than 30 eggs. The female gonad will contain eggs in all stages of development, from primary oocytes to very mature eggs. However, at any one time only 20-30 eggs will reach maturity while the remaining eggs appear to be “arrested” in their development during this time (NFSC 2003). The number of eggs produced has shown no relationship to the size of the female (NFSC 2003).

There is no evidence of a synchronous breeding cycle in this species (Schutzinger et al. 1987). The total lifespan has not been determined, nor has the duration of reproductive function, but large males and females (over 700 mm in length) have been observed to contain functional gonads (Martini et al. 1997a).

Hagfish trapping studies have shown a significant number of undifferentiated (non-reproductive) animals over a broad size range and a significant proportion of likely non-functional hermaphrodites. Louisbourg Seafoods Ltd. (2007)[1] found 20.4% undifferentiated individuals, 0.89% males, 70.4% females, and 8.4% hermaphrodites on the Scotian Shelf. The high proportion of non-reproductive adults further reduces the reproductive potential of the population.

Hermaphrodites are commonly found in Atlantic Hagfish populations with varying stages of oocytes and developing eggs found in males, and rudimentary testicular tissue commonly found in animals with large developing eggs (Walvig 1963; Patzner 1982). On Grand and St. Pierre Banks off Newfoundland, evidence of fully functional hermaphroditism has been found by Grant

[1] Louisbourg Seafoods Ltd. 2007. Comparative Biological Analysis of Hagfish (*Myxine glutinosa)* Captured on the Scotian slope versus Hagfish Captured off the South Coast of Newfoundland. Unpublished report.

(2016), but this is extremely rare and has not been noted in other locations thus far (Martini and Flescher 2002).

Atlantic Hagfish display an apparent lack of annual spawning, where the time required to produce a crop of eggs may approximate the teleost condition (i.e. 6-8 months) or be considerably longer (Patzner 1998; Powell et al. 2004). However, Grant (2016) has shown an increase in production coinciding with fishery removals of high numbers of individuals, and a reduction in the percentage of larger individuals in the population. The development time is not known, but the volume of yolk present suggests a period of several months to over a year. Circumstantial evidence suggests that the eggs are deposited within burrows, and that breeding animals do not feed (Martini and Flescher 2002).

These factors alone have led some authors to question whether Atlantic Hagfish can sustain exploitation in the long term (Martini et al. 1997a and 1997b). Much uncertainty persists as to the details of Hagfish reproduction, mainly due to their inaccessibility and the impossibility of observing their reproductive cycle in captivity.

Growth

Foss (1963) reported two tag recoveries of Atlantic Hagfish in Norwegian waters that suggest slow growth. Tagged at lengths of 27.0 and 36.1 cm, the fish gained 0.5 and 2.1 cm after 29 and 11 months, respectively. Based on their low metabolic rate, sedentary behaviour and their occurrence in areas of deep cold waters, it appears likely that they are slow growing, long-lived fishes (NFSC 2003).

Biomass

Wakefield (1990) estimated the biomass of *Eptatretus deani* at 600 m visually at 11,800 kg/km^2 in an area off central California where trawling estimated Hagfish biomass at 700 kg/km^2. Assuming a homogeneous distribution and a similar response to the bait stimulus, Martini et al. (1997b) estimated Atlantic Hagfish biomass at 8,119 kg/km^2 at 120 to 150 m depth in the Gulf of Maine (GoM).

The main source of information on the distribution and abundance of groundfish species in the Maritimes Region, the DFO Summer Research Vessel (RV) Survey, provides limited information on Atlantic Hagfish. Hagfish are poorly captured in the survey gear, which is attributed to the burrowing and generally immobile behavior of Atlantic Hagfish (Martini 1998). Therefore, although the biomass trend from the survey shows possible population increases around 1995 and declines beginning in early 2000 (Figure 2), the relationship to actual population biomass is not clear. Other surveys have noted increased catch of Hagfish upon a second trawl over an area, after a preliminary bottom disturbance (F. Martini, Pers. Comm.).

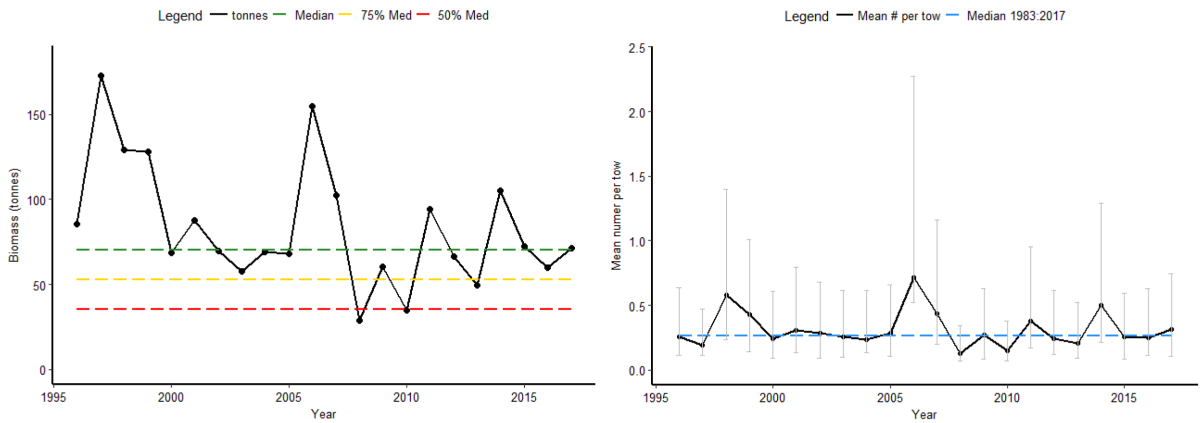

Figure 2. Hagfish biomass (right) and abundance (left) trends from the DFO Summer RV Survey.

Habitat

Atlantic Hagfish distribution has been described to be determined by three factors: salinity, temperature and substrate type (Martini and Flescher 2002). On the Scotian Shelf, landings were restricted to full seawater from 33 – 35 ppt, while they varied across a range of temperatures from 3.5 – 9 °C (Figure 3). The vast majority of landings on the Scotian Shelf occurred in deeper waters, from 50-300 m depth (Figure 3). Hagfish are not caught in the deeper areas on the Western Scotian Shelf, which are expected to get too cold. Atlantic Hagfish are expected to prefer warmer waters around Emerald Basin, on the Slope, and in the deeper basins in the Gulf of Maine.

Hagfish have been found at depths of 27.4 to 958.3 m in the Gulf of Maine (Bigelow and Schroeder 1953). They prefer low temperatures, likely cooler than 10 ºC, confining them to depths of at least 27.4-36.6 m or greater in the Gulf of Maine during the summer (Bigelow and Schroeder 1953). In a trawl survey that covers the area between the Gulf of Maine and Cape Hatteras, Atlantic Hagfish are found across a broad range of depths and temperatures, but are most commonly captured between 150 and 250 m and at 5-10 °C (NEFMC 2003). Hagfish can be maintained in captivity at 0-4 °C and tolerate temperatures up to 15 °C short-term (Martini 1998).

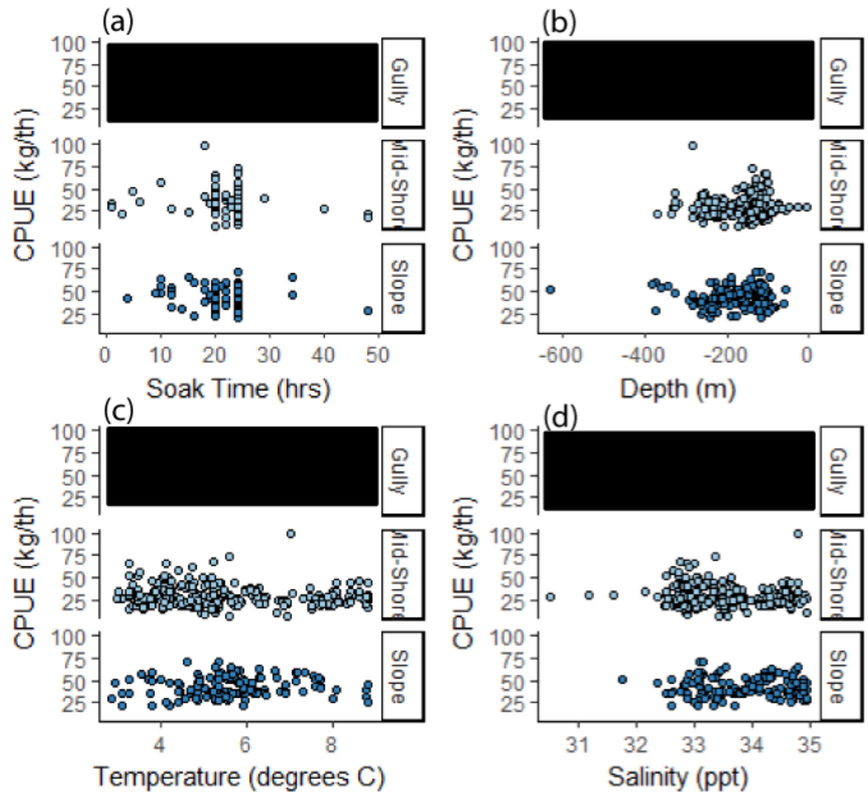

Figure 3. Catch rates from fisheries logbook data by (a) soak time, (b) depth, (c) temperature (extracted from modeled data), and (d) salinity (extracted from modeled data). This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

Distribution

Atlantic Hagfish are present on both sides of the temperate North Atlantic. On the western side, they are found from Davis Strait and Greenland, off Labrador and Newfoundland, in the Gulf of St. Lawrence and the Gulf of Maine, and along the continental slope to the coast of Florida (Martini and Flesher 2002). They are also reported from the South Atlantic off the southern coasts of Argentina and Chile, the Straits of Magellan and off South Africa (Martini and Flesher 2002). Throughout their distribution, Atlantic Hagfish occur at depths of more than 15 m (Scott and Scott 1988; F. Martini, Pers. Comm.).

Even though the DFO Summer RV Survey does not provide good abundance trends for Hagfish, the survey does provide evidence of Hagfish presence, and patterns over time are considered representative of the general species distribution (Figure 4).

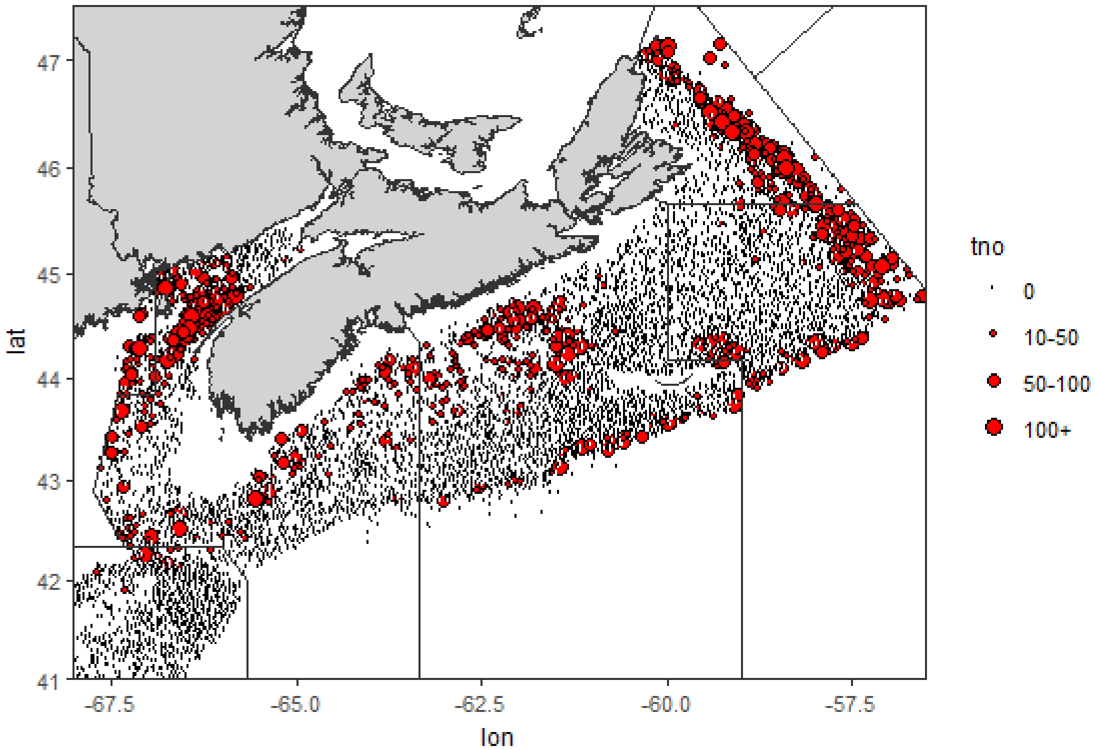

Figure 4. The spatial distribution of Hagfish found in the DFO Summer RV Survey from 1983 - 2017 (number/tow). A black dot on the map indicates a station where no Hagfish were found. Hagfish are not well captured with the DFO Summer RV Survey gear; however, patterns over time are considered representative of the general species distribution.

Movement

Evidence of short migrations (Walvig 1963) suggests that Atlantic Hagfish populations are localized and recruitment-dependent. Hagfish are typically described as patchy, and Martini (1998) speculated that low swimming speeds of hagfishes (0.25 m/s) may limit home range and prevent their ability to withstand areas of high current velocity (Grant 2016). Movements of about 2.5 km over a 4.5 year period by Atlantic Hagfish tagged within a fjord of the eastern North Atlantic (Walvig 1967) have been reported.

There is evidence of capture of large numbers of small juvenile (below the expected size at 50% maturity, described below) Atlantic Hagfish within specific areas on the Scotian Shelf, and Grand and St. Pierre Banks (Grant 2016). Grant (2016) has hypothesized a spawning migration to deeper waters for Atlantic Hagfish, where cooler and seasonally stable bottom water temperatures at greater depths may maximize larval development and survival. Further, male Atlantic Hagfish may be concentrated at these depths. On Grand and St. Pierre banks in Newfoundland, Hagfish with fully ripe gonads were restricted to the same depth zone, which also showed higher numbers of very small juveniles.

Adaptability and Ecological Role

Martini (1998b) concluded that, by their population size and combined energy requirements, Atlantic Hagfish are an important component of the substrate ecosystem of the Gulf of Maine.

Hagfish may play an important role in processing dead fish and marine mammals, including the discards of some commercial fisheries (Martini 1998a). Shelton (1978) examined the diet of

Atlantic Hagfish in the North Sea and concluded that they were active benthic predators filling an ecological niche comparable to large, burrowing errant polychaetes. Where Hagfish are abundant, they may also play an important role in marine ecosystems through substrate turnover and nutrient recycling (Martini et al. 1997b; Martini 1998).

At such densities, their impacts as predators and scavengers, as bioturbators of sediment, and as recyclers of nutrients could make them a critical ecosystem component in soft bottom benthic regions. Hagfish serve an important ecological role, contributing to nutrient cycling, substratum turnover and removal of dead or dying organisms on the sea floor (NFSC 2003).

Description of the Fishery

There has been a directed fishery for Hagfish in the Maritimes Region since 1989, centered in NAFO Div. 4X through the 1990s, then expanding eastward into 4W since 2000. The Hagfish fishery in the Maritimes Region currently occurs in NAFO Divisions 4V, 4W, 4X and 5Z (Figure 1).

Fisheries for Hagfish have their origins in Korea and Japan, first as minor food fisheries, then as a source of soft leather in post-Second World War Japan (Honma 1998). By the early 1980s, "eelskins" manufactured in Korea from Hagfish skins gained popularity, but stocks were quickly depleted. By 1987, Pacific Hagfish were being fished off California (Martini and Flescher 2002) and a fishery began in late 1988 off British Columbia (Neville and Beamish 1992). In 1989, Korean buyers expressed an interest in Atlantic Hagfish off New England (Martini and Flescher 2002) and, in the same year, 125 tonnes (mt) were landed by Canadian boats in NAFO Div. 4X.

Pacific United States (U.S.) and Canadian fisheries had effectively ended in the early 1990s due to Korean market limitations (including a ban on Hagfish imports), overproduction, and product quality issues and many other Hagfish fisheries worldwide have been characterized by overfishing (NFSC 2003). Following the decline of the Japanese fishery, Korea, British Columbia, Massachusetts and New Hampshire have either collapsed or been closed to fishing since 2010. General trends in overfished Hagfish fisheries include Catch Per Unit Effort (CPUE) declines, vessels gradually moving farther offshore, and a decrease in average length (DFO 2009b).

Reported Hagfish landings in New England expanded rapidly in the early years of fishing (early 1990s), exceeding the highest reported landings in other North American Hagfish fisheries (including British Columbia, Oregon, Washington, California and Nova Scotia) by 1994. Landings increased 6-fold from 1993 to 2000, with a reported 6.8 million pounds (approximately 3000 mt) of Hagfish landed in 2000. Landings in 2001 and 2002 were estimated to be approximately 1000-3000 mt in each year. In the late 1990s the Hagfish fishing fleet in the GoM were seeing classic signs of resource stress. In just two years, fisherman noted a diminishing marketable catch level per trap. After 1995, the Hagfish vessels in the GoM experienced fairly rapid local depletion with a corresponding need to continually shift fishing grounds to maintain catch rates (NFSC 2003).

The Canadian fishery remained centered in NAFO Div. 4X through the 1990s, expanding eastward into 4W since 2000 (Table 1; also described in DFO 2009b). The Hagfish fishery in the Maritimes Region occurs in the areas that correspond to NAFO Divisions 4V, 4W, 4X and 5Z. Even with evidence of quick declines in other Hagfish fisheries, it has been difficult to set guidelines for a fishery when the population size, total biomass, and distribution are unknown, and when individual growth rates, recruitment rates, and longevity remain to be determined.

The conservation objectives for the Maritimes Region Hagfish fishery are to keep total Hagfish removals to within 3,000 mt and to minimize the capture and retention of immature Hagfish using the following input controls and escapement measures:

- limit of 7 licences,
- limit of 450 barrels per licence,
- at least 36 escape holes per barrel,
- minimum escape hole diameter of 14.3 mm (9/16”),
- avoidance of areas with small Hagfish, and
- 6 month fishing season.

There have been many gear and dock-side monitoring practice changes over the course of the fishery, which influence the interpretation of catch rates and landings (Figure 5). Regulated escape-hole numbers and sizes have changed frequently, beginning with the first recorded escape-hole size of 5/16 (0.31)” in 2000. Escape-hole size changes were recorded in licence conditions in 2007 (9/16 (0.56)”), 2010 (8/16 (0.5)”) and 2014 (9/16 (0.56)”). The number of escape-holes changed in 2013, and 2014, increasing from 24 to 30, and 30 to 36, respectively. It is expected that there may have been variability around adoption of new escape-hole sizes; however, the extent of the variability is unknown.

Dockside monitoring practices have also modified their estimates of weight per barrel and wharf box, resulting in a variety of conversion factors described below to standardize landings and catch rates values.

Table 1. Uncorrected Landings (mt) by NAFO Division extending back to 1989, including the DFO Gulf and Maritimes Regions. "NA" represents zero landings. This table contains third party information that is not available for publication under Privacy Act *guidelines.*

	Gulf	Maritimes					
Year	**4T**	**4Vn**	**4VS**	**4W**	**4X**	**5Y**	**5ZE**
1989	NA	NA	NA	NA	125.0	NA	NA
1990	NA	NA	NA	NA	88.0	NA	NA
1991	NA	NA	NA	NA	87.0	NA	NA
1992	NA	NA	NA	NA	205.0	NA	NA
1993	NA	NA	NA	NA	7.0	NA	NA
1994	NA	NA	NA	NA	108.0	NA	NA
1995	NA	3.0	NA	NA	501.0	NA	NA
1996	NA	NA	NA	NA	269.0	NA	NA
1997	NA	NA	NA	NA	15.0	NA	NA
1998	NA	NA	NA	NA	55.0	NA	NA
2001	NA	NA	NA	NA	NA	NA	NA
2002	NA	NA	1.9	890.2	239.4	2.0	NA
2003	NA	6.1	NA	183.5	832.3	NA	NA
2004	NA	NA	NA	806.3	740.3	NA	NA
2005	NA	NA	0.6	1257.5	259.7	NA	NA
2006	NA	1.0	NA	804.4	532.8	NA	NA
2007	NA	0.6	NA	864.3	362.8	NA	NA
2008	NA	[redacted]	[redacted]	863.1	335.6	NA	53.8
2009	NA	[redacted]	[redacted]	1788.8	217.0	NA	60.2
2010	NA	[redacted]	[redacted]	621.0	646.8	5.1	684.7
2011	12.3	[redacted]	[redacted]	1741.5	487.9	NA	345.5
2012	95.1	[redacted]	[redacted]	2286.3	363.0	NA	152.6
2013	97.3	[redacted]	[redacted]	1878.0	452.3	NA	178.8
2014	40.1	[redacted]	[redacted]	915.0	217.3	NA	232.7
2015	89.7	[redacted]	[redacted]	878.0	238.2	NA	NA
2016	NA	[redacted]	[redacted]	174.3	336.2	NA	60.9

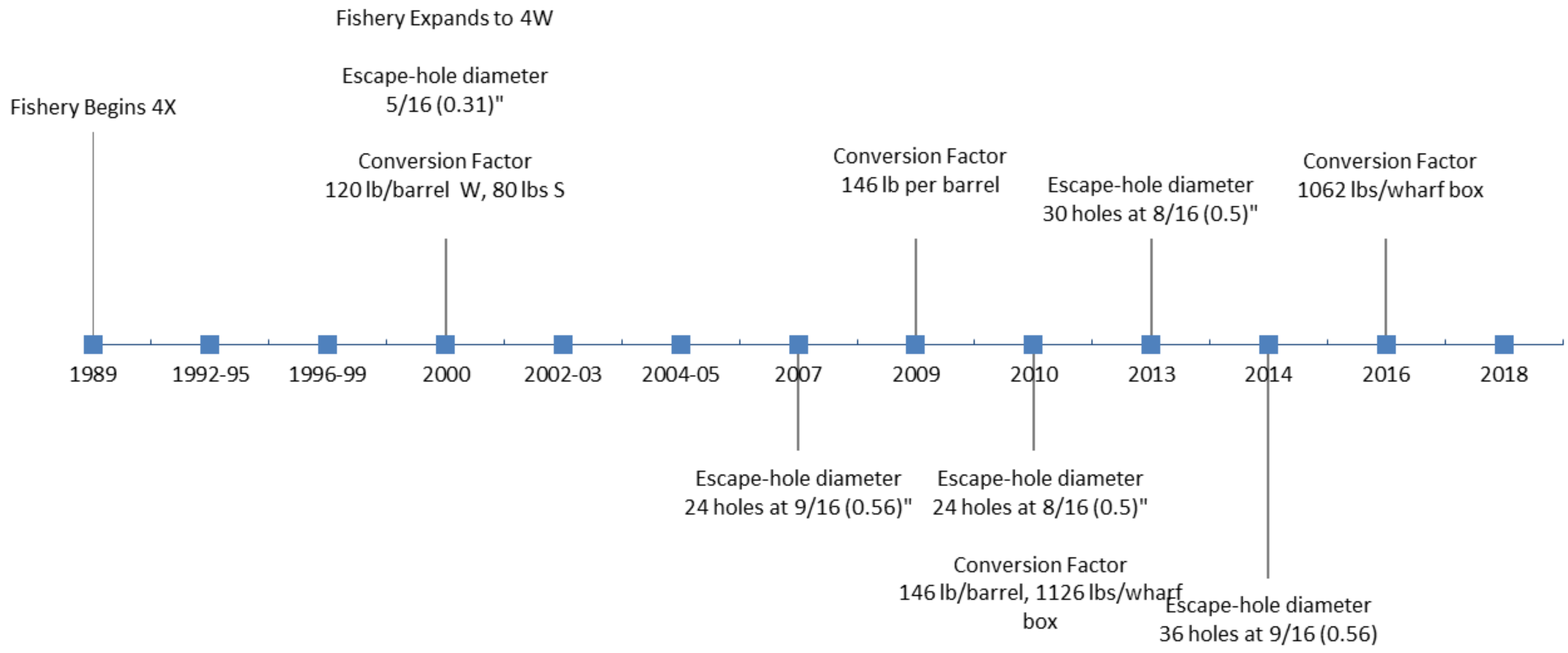

Figure 5. Timeline of changes to the Maritimes Region Hagfish (Myxine glutinosa) fishery.

Licences

There are seven limited entry commercial Hagfish licences in the Maritimes Region (Table 2). Licences are a combination of inshore, enterprise allocation and commercial communal licence. In 2001, the licence for Millbrook Frist Nations was added and, in 2006, the new Enterprise Allocation was created and given to Louisbourg Seafoods Ltd.. In 2007, four licences remained exploratory and two were made permanent. These exploratory licences became permanent in 2011.

Table 2. Hagfish licences in the Maritimes Region.

Licence	Holder*	Type	Fishing Area**
336696	Millbrook First Nation	Commercial communal	4V, 4W
336702	Louisbourg Seafoods Ltd.	Enterprise Allocation	4V, 4W
336698	Gary Burchell	Inshore(<45)	4V, 4W
336699	Anthony Kristensen	Inshore(<45)	4W, 4X
336700	Four Links Fisheries Ltd.	Inshore(<45)	4W, 4X, 5Z
336701	Danny Attwood	Inshore(<45)	4W, 4X, 5Z
336697	Christopher Leblanc	Inshore(<45)	4X

*As of March 20, 2017.
**Access in 4X is limited in the Bay of Fundy to the area south of the midbay scallop line (Figure 1).

Analysis and Response

Landings

Before 2000, Hagfish landings were almost exclusively from NAFO Division 4X (Table 1). Since then, the fishery has expanded eastward into NAFO Division 4W, which has become the dominant source of Hagfish landings. Landings were reported from NAFO Division 5Z for the first time in 2008. The fishery initially had low landings, increasing as the fishery expanded into 4W.

Average yearly landings over all NAFO Divisions have been 1915 mt since the expansion of the fishery beyond 4X in 2002. Hagfish landings peaked in 2013, at 3198 mt (Table 3). Landings have been steadily decreasing on the Scotian Shelf with a 5-year decline of 84%, and a 1-year decline of 25%, to 556 mt in 2017 (Table 3 and Figure 6). The geographic area fished for the longest time-span, the Mid-Shore has had average yearly landings of 1067 mt (Table 5). The majority of landings in 2017 were in 4W (Table 4: 260 mt). Declining effort and landings are expected to be due to poor market conditions in countries that purchase Hagfish (primarily South Korea).

In 2017, landings were only present around the Gully Marine Protected Area and in a few areas Mid-shore around Emerald Basin (Figure 7). The spatial distribution of landings has shifted over time (Figure 7). From 2003-2010, landings were primarily in the Mid-shore. In 2011, the fishery primarily moved Offshore to deeper waters on the slope, around the Gully Marine Protected Area, and in Georges Basin (Figure 1). Since 2011, effort has been spread across all geographic areas.

Table 3. Corrected landings, effort (in trap hauls (th)), and catch rates of Atlantic Hagfish in the Maritimes Region from fisheries logbooks. For a description of how landings data are corrected to reflect changes in catch reporting, see the Landings Conversion Factors section. Cells marked "NA" indicate that data is unavailable.

Year	Landings (kg)	Effort (th)	CPUE (kg/th)
2002	1,792,538	NA	NA
2003	1,500,826	NA	NA
2004	2,793,394	NA	NA
2005	2,354,437	NA	NA
2006	2,135,317	46,300	24.2
2007	1,819,456	66,960	28
2008	2,021,025	64,596	30.9
2009	1,887,612	73,470	23.7
2010	1,792,985	34,148	47.9
2011	2,312,949	36,400	58
2012	2,813,346	53,852	53.4
2013	3,197,616	63,752	46
2014	1,562,959	49,605	38.2
2015	1,564,849	40,780	48.2
2016	933,848	27,772	42.4
2017	556,935	21,592	30.7

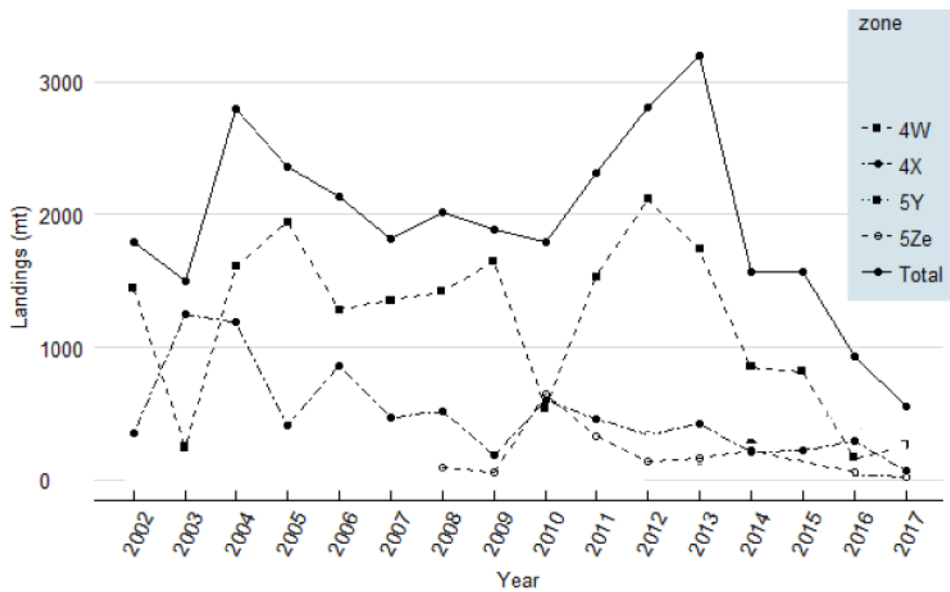

Figure 6. The corrected 2002 - 2017 landings (mt) of Atlantic Hagfish from fisheries logbook data, by NAFO Division. Information related to Divisions 4Vn and 4Vs has been removed under Privacy Act *guidelines.*

Table 4. Corrected landings, effort (trap hauls) and catch rates of Atlantic Hagfish from fisheries logbooks, by NAFO Division. For a description of how landings data are corrected to reflect changes in catch reporting, see the Landings Conversion Factors section. Cells marked "NA" indicate that data is unavailable. This table contains third party information that is not available for publication under Privacy Act *guidelines.*

Zone	Year	Landings (kg)	Effort (th)	CPUE (kg/th)
4Vn	2003	[redacted]	[redacted]	[redacted]
	2006	[redacted]	[redacted]	[redacted]
	2007	[redacted]	[redacted]	[redacted]
	2008	[redacted]	[redacted]	[redacted]
	2010	[redacted]	[redacted]	[redacted]
	2013	[redacted]	[redacted]	[redacted]
4Vs	2002	[redacted]	[redacted]	[redacted]
	2005	[redacted]	[redacted]	[redacted]
	2010	[redacted]	[redacted]	[redacted]
	2012	[redacted]	[redacted]	[redacted]
	2013	[redacted]	[redacted]	[redacted]
	2014	[redacted]	[redacted]	[redacted]
	2015	[redacted]	[redacted]	[redacted]
	2016	[redacted]	[redacted]	[redacted]
	2017	[redacted]	[redacted]	[redacted]
4W	2002	1,443,207	NA	NA
	2003	246,800	NA	NA
	2004	1,609,059	NA	NA
	2005	1,942,812	NA	NA
	2006	1,279,701	28,400	28.7
	2007	1,352,847	43,920	32.2
	2008	1,418,871	43,850	32.2
	2009	1,647,000	62,430	23.7
	2010	540,710	8,475	22.1
	2011	1,526,986	22,780	53.7
	2012	2,115,297	40,435	52.6
	2013	1,738,629	43,355	36.5
	2014	851,213	31,130	34.8
	2015	814,447	27,185	38
	2016	164,390	9,655	23.1
	2017	260,042	13,451	25
4X	2002	346,329	NA	NA
	2003	1,249,671	NA	NA
	2004	1,184,335	NA	NA
	2005	410,624	NA	NA
	2006	853,972	17,780	19.2
	2007	465,509	23,030	20.7
	2008	512,696	19,904	23.7
	2009	183,866	10,340	17.5
	2010	594,980	17,075	30.7
	2011	460,130	10,130	46.6

Zone	Year	Landings (kg)	Effort (th)	CPUE (kg/th)
	2012	342,349	8,702	39.7
	2013	426,494	7,200	56.2
	2014	204,941	9,015	31.9
	2015	224,605	3,510	88.4
	2016	297,037	7,052	44.3
	2017	72,464	3,081	28.6
5Ze	2008	87,285	842	106.1
	2009	56,746	700	83.3
	2010	645,684	8,550	90.4
	2011	325,833	3,490	92.6
	2012	143,889	2,055	73.4
	2013	168,573	1,880	90.2
	2014	219,431	4,160	59.8
	2016	57,400	1,070	64.2

Table 5. Corrected landings, effort and catch rates of Atlantic Hagfish from fisheries logbooks, by year and Geographic Area. For a description of how landings data are corrected to reflect changes in catch reporting, see the Landings Conversion Factors section. Zone 'Other' is any zone outside of the coloured areas in Figure 1. Cells marked "NA" indicate that data is unavailable. This table contains third party information that is not available for publication under Privacy Act *guidelines.*

Zone	Year	Landings (kg)	Effort (th)	CPUE (kg/th)
GoM	2008	221,995	6,842	45.5
	2009	56,746	700	83.3
	2010	778,427	11,025	79.2
	2011	630,390	8,555	75.6
	2012	251,159	4,447	61.4
	2013	301,144	3,480	88
	2014	254,064	5,180	49.6
	2015	182,594	2,100	110.4
	2016	81,474	1,680	50.5
	Avg	**306,444**	**4,890**	**71.5**
Mid-shore	2002	1,711,965	NA	NA
	2003	1,247,567	NA	NA
	2004	2,513,058	NA	NA
	2005	2,185,982	NA	NA
	2006	1,736,634	36,700	26.4
	2007	1,655,658	60,650	28.4
	2008	1,598,575	49,857	31.6
	2009	1,633,607	65,240	22.7
	2010	817,270	21,205	25.4
	2011	139,531	5,515	27
	2012	205,567	6,135	33.6
	2013	763,684	22,070	31.8
	2014	420,985	18,805	21.2
	2015	521,253	19,420	27.9
	2016	376,749	14,395	27.4
	2017	308,378	15,797	19.9
	Avg	**1,067,230**	**27,982**	**26.9**
Offshore	2002	3,002	NA	NA
	2005	849	NA	NA
	2007	18,302	400	45.8
	2011	1,327,876	19,090	56.2
	2012	2,078,697	37,898	56.5
	2013	1,803,624	33,664	44.8
	2014	816,206	23,245	31.4
	2015	776,212	16,815	40
	2016	434,801	10,515	39.9
	2017	198,854	4,710	37.8
	Avg	**745,842**	**18,292**	**44.0**
4Vn	2003	[redacted]	[redacted]	[redacted]
	2006	[redacted]	[redacted]	[redacted]
	2007	[redacted]	[redacted]	[redacted]
	2008	[redacted]	[redacted]	[redacted]
	2010	[redacted]	[redacted]	[redacted]
	2013	[redacted]	[redacted]	[redacted]
	Avg	[redacted]	[redacted]	[redacted]
Other	2002	85,524	NA	NA
	2003	259,645	NA	NA
	2004	303,382	NA	NA

Zone	Year	Landings (kg)	Effort (th)	CPUE (kg/th)
	2005	203,160	NA	NA
	2006	407,339	9,780	20.2
	2007	168,859	6,610	24.5
	2008	198,283	7,897	20.2
	2009	199,248	7,530	22.8
	2010	212,447	1,870	35.1
	2011	215,152	3,240	39.9
	2012	277,923	5,372	48.8
	2013	236,209	3,700	46.7
	2014	71,704	2,375	28
	2015	84,790	2,445	33.1
	2016	40,824	1,182	39.4
	2017	58,221	1,350	27.5
	Avg	**208,833**	**4,445**	**32.2**

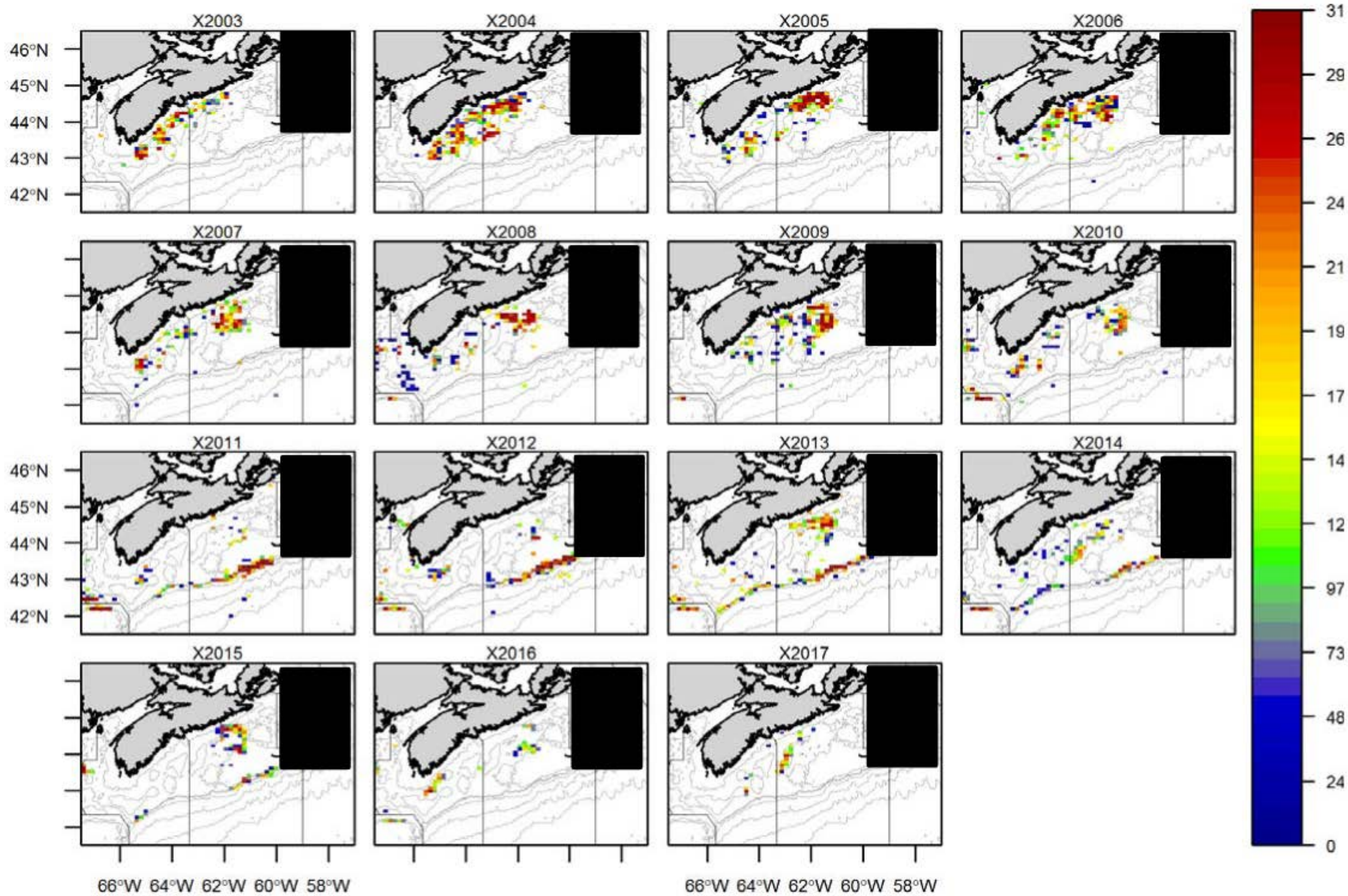

Figure 7. The 2003 – 2017 spatial distribution of corrected Hagfish landings (kg/5 minute grid) from fisheries logbook data. This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

Landings Conversion Factors

Conversion Factors

Through time, dockside monitors have estimated landings per barrel or wharf box using different values. Landings and catch rates were standardized to the latest value (beginning in 2016) of 1062 lbs/wharf box. Previous values and their corresponding conversion factor are provided (Table 6). The standardization had the largest impact on landings and catch rates in 2009. Previously, a large increase in landings and catch rates was noted in 2009. Landings and catch rates were also artificially increased from 2009-2015, before the conversion, due to a larger value (1126 lb/wharf box) used.

The instructions for recording largely empty boxes were also changed in 2016. Historically, boxes with few Hagfish were counted as full. In 2016, the last partially filled container was disregarded as it was shown to contain very few Hagfish (Rodman 2015)[2]. It is unclear how long largely empty Hagfish boxes have been recorded. Instructions have also been given for wharf boxes that were ¾, ½, and ¼ full. There is evidence of these being used for two trips in 2017, but it seems to have rarely happened before this date.

Table 6. Conversion values used by dockside monitors, and corresponding conversion factors used to standardize landings and catch rates.

Year	Barrel/Wharf Box Value	Conversion Factor
Before 2009	120 lb per barrel winter (1 Nov-30 April) 80 lbs summer (1 May – 31 October)	1.15 1.72
2009	146 lb per barrel (wharf box conversion unknown, 1126 lbs per wharf box used)	0.943
2010	146 lb/barrel, 1,126 lbs/wharf box	0.943
2016	1062 lbs/wharf box (¾ full 797, ½ full 531, ¼ full 266)	Not applicable

Effort

Information on fishing effort, the number of trap hauls, is only present after 2006 and has not been recorded consistently (Table 7). All years after 2007 have recorded effort in at least 74% of records, with most years above 80%.

Fishing effort has been above 40,000 trap hauls in the majority of years where effort data is available (Figure 8). Exceptions are 2010 and 2011 when effort decreased while landings did not, corresponding to a spatial shift in fishing patterns towards Div. 4X in 2010 and to the Scotian Slope in 2011. Higher catch rates are described below for these regions. Effort has continually decreased since 2013, dropping below 40,000 trap hauls in 2016 and 2017. This decrease in effort corresponds to a decrease described by fishers in the South Korean market for Hagfish, and it does not correspond to any notable change in catch rates.

The Hagfish fishery is characterized by continually shifting fishing grounds. It is rare that harvesters concentrate their effort in the same location twice (Figure 9). An analysis of frequency of years fished within 2.5 km grid squares (6.25 km^2) showed that most areas have only been fished once in the 14 years of the fishery, leaving 14 years of recovery. Of those areas fished more than once, most have been fished 2/14 years, leaving 7 years of recovery,

[2] Rodman, K. 2015. Study to Determine the Net Weight of Hagfish in Standard Insulated Containers. Unpublished Report

with very few areas fished more than 3/14 years (Table 8). In trap surveys in the Gulf of Maine, after one year of surveying in 1993, it took 10 years of recovery time before Hagfish returned, with areas yet to reach prior densities after 24 years (F. Martini, Pers. Comm.).

In 2017, the majority of effort was in Emerald Basin (Figure 10). The spatial distribution of effort over time shows a similar pattern to the spatial distribution in landings (Figure 10). Effort was primarily Mid-shore, in Div. 4W and Div. 4X, from 2006 – 2010 and most of the effort was distributed east of Emerald Basin. In 2011 and 2012, fishing was primarily on the Scotian Slope, with fishers slowly moving back Mid-shore. Around the Gully was the only area of the Scotian Slope fished in 2016 and 2017.

Table 7. Frequency of effort information (number of logbooks recording trap hauls) by year.

Year	Effort	No Effort	Percent
2002	0	376	0
2003	0	240	0
2004	0	412	0
2005	0	292	0
2006	150	206	42%
2007	234	7	97%
2008	267	17	94%
2009	357	45	89%
2010	224	80	74%
2011	215	64	77%
2012	271	37	88%
2013	315	70	82%
2014	220	16	93%
2015	194	18	92%
2016	120	5	96%
2017	81	6	93%

Table 8. For grid cells fished for Hagfish at least once between 2002 to 2017, the number of years each cell was fished, over a 2.5 km (6.25 km^2) grid.

Total Number of Years Each Cell was Fished	Percent of Cells (Number)
1	68.7% (1490)
2	20.8% (453)
3	7.4% (160)
4	2.5% (55)
5	0.4% (10)
6	0.1% (4)

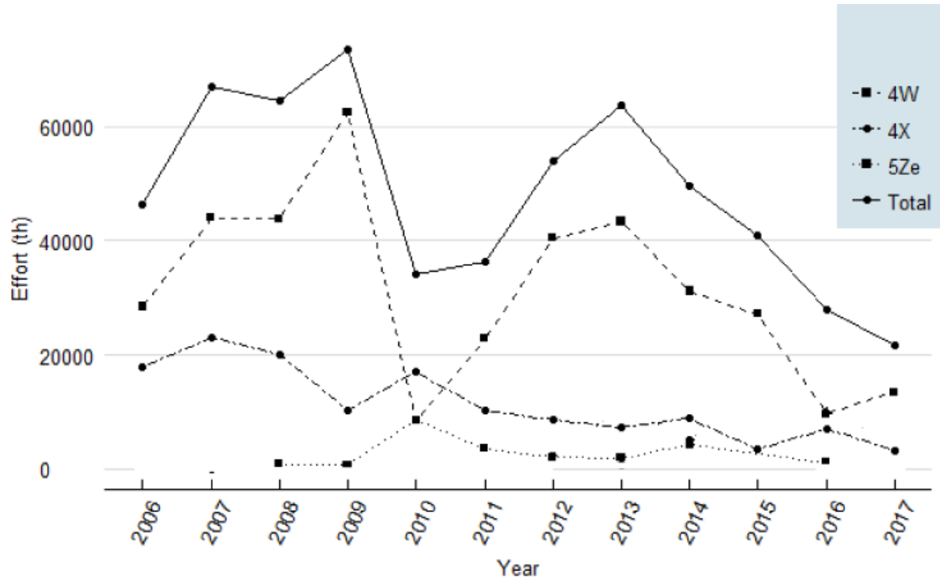

Figure 8. The 2006-2017 effort (trap hauls) of Atlantic Hagfish from fisheries logbook data, by NAFO Division. Information related to Divisions 4Vn and 4Vs has been removed under Privacy Act *guidelines.*

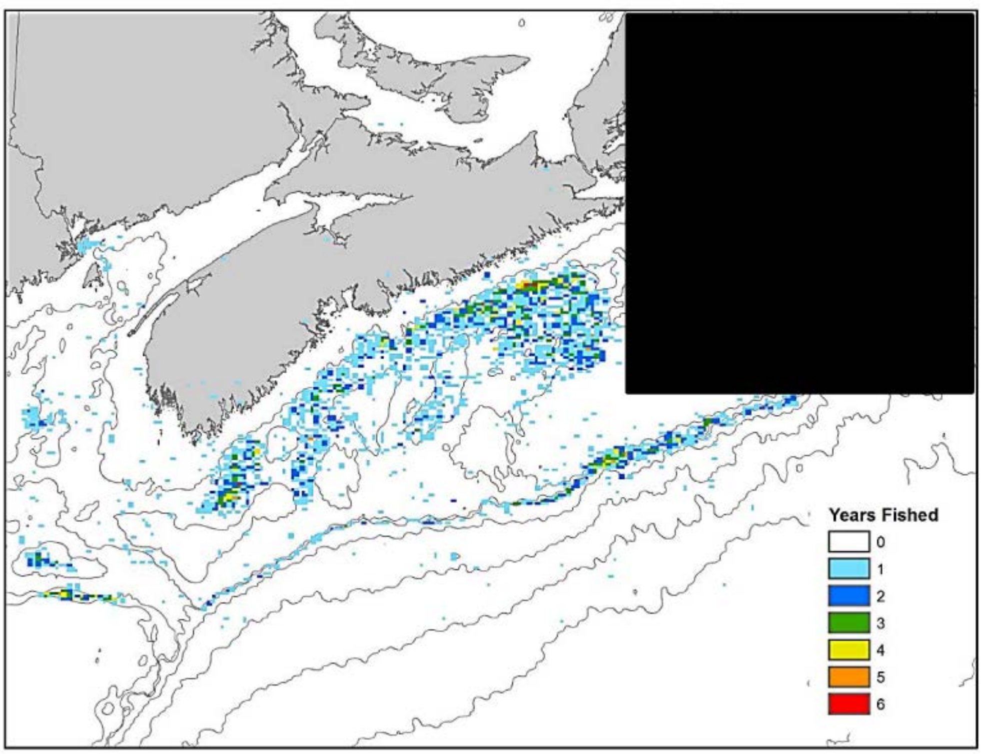

Figure 9. The spatial distribution of fishing effort over time (years cell was fished/2.5 km grid). This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

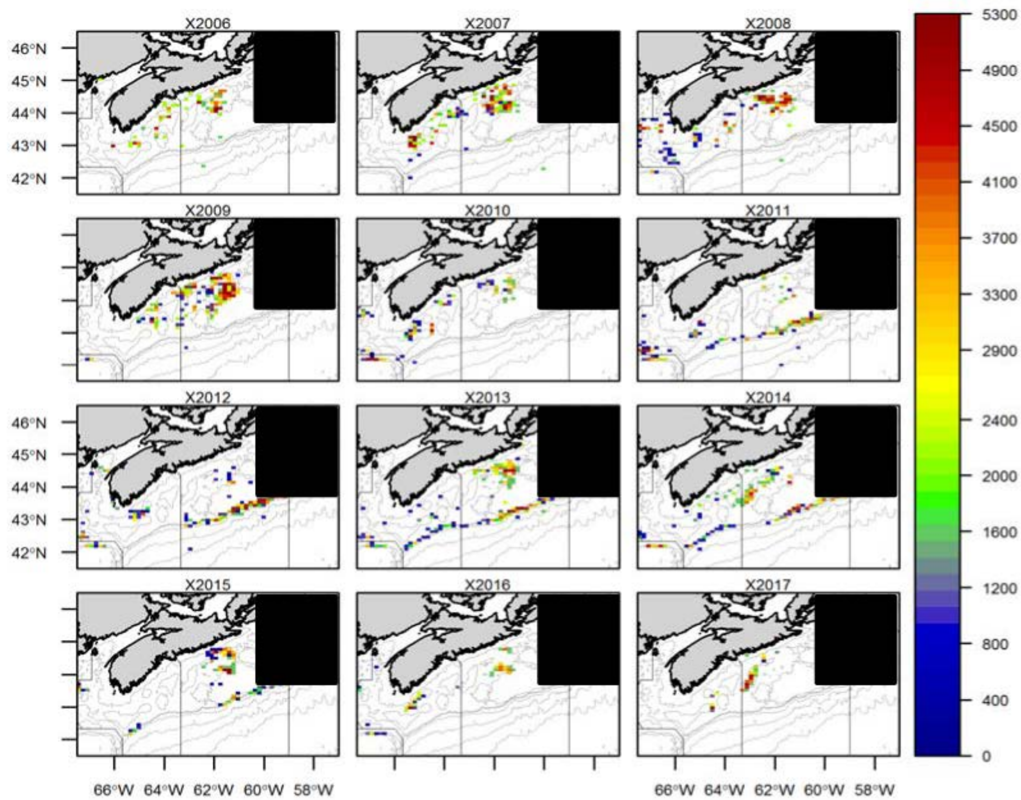

Figure 10. The 2006 - 2017 spatial distribution of Hagfish effort (trap hauls/5 minute grid) from fisheries logbook data. This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

Catch Rates

Catch rates are available after 2006, as they depend on effort data (Table 7). Years after 2007 are considered representative of general catch rate patterns, as all years after 2007 have recorded effort (number of trap hauls) in at least 74% of records, with most years above 80%.

A correction factor was applied to catch rates after 2014, to account for an increase in escape-hole size from 8/16 (0.5)" to 9/16 (0.56)". The correction factor was added to each trap haul (12.5 kg Slope and 5 kg Mid-shore), based on work completed by Louisbourg Seafoods Ltd. (2006)[3] comparing the average catch rates by escape-hole size and location on the Scotian Shelf. Correction factors were not available for the Gulf of Maine side of Div. 4X. These values are not expected to be precise, therefore vertical lines were marked on plots associated with timing of gear changes and modified dockside monitoring procedures.

Catch rates have previously been presented by NAFO Division (Figure 11), which showed steeply declining catch rates after 2012 in NAFO Divisions 4W and 5Ze. Further examination has shown strong evidence that single NAFO Divisions contain areas with significantly different long-term catch rates (Figure 12). The largest differences were found between the Mid-shore and the Scotian Slope (Figure 12), with a long term average of 28 kg/th on the Mid-shore,

[3] Louisbourg Seafoods Ltd. 2006. Prosecution of an Offshore Experimental Fishing Licence for Atlantic Hagfish (*Myxine glutinosa*) in NAFO Zones 4Vs and 4W: Report on Year 1 Activities. Unpublished Report.

versus 48 kg/th Offshore). Corrected catch rates have been consistent over the 16-year time series in the Mid-shore (Figures 12, 13 and 14). This supports previous findings from smaller scale trap studies, which found higher catch rates on the Scotian Slope in the early years of the fishery (Louisbourg Seafoods Ltd. 2006)[3]. Higher catch rates have also been reported for Hagfish in deeper waters around Newfoundland (DFO 2009a).

Frequent shifts in fishing grounds increase the difficulty in presenting catch rates by NAFO Division. As shown above, it is rare that harvesters concentrate their effort in the same location twice in the 14-year time period, causing artificial increases and decreases in catch rates presented by NAFO Division, depending on the locations fishing during the year.

Most areas show a slight reduction in catch rates from 2016 to 2017; however, 2017 was a year of decreased fishing effort. On the Scotian Slope, catch rates have shown slight decreases from the initial average of 55 kg/th in the first 2 years of fishing (2011 and 2012). This trend is what might be expected from the expansion of a fishery to a virgin area in 2011. These declining catch rates also correspond to gear changes, increasing the number of escape-holes per barrel by 6 in 2013, and then increasing the escape-hole size from 8/16 (0.5)” to 9/16 (0.56)” in 2014 (Figure 5). The correction factor mentioned above was applied to account for the increase in escape-holes size in 2014; however, the factor may not be precise, therefore it is expected that the decrease in catch rates after 2014 is explained by a variety of factors including stabilizing catch rates and imprecise correction factors.

NAFO Div. 4X has been consistently fished since 1989 and seems to experience higher catch rates on the Gulf of Maine side of Div. 4X, although areas have not been fished regularly enough to identify long-term patterns.

It is unknown whether average catch rates in the Div. 4W Mid-shore Region (Figure 14) ever approached the average catch rates found on the Scotian Slope, as the effort data series begins six years after the expansion of the fishery into Div. 4W.

Going forward, catch rates should be consistently presented by the geographic areas shown in Figure 1 (Gulf of Maine, Mid-Shore and Offshore), which reflect boundaries that are expected to have consistent catch rate patterns in absence of fishing induced changes. Subunits within these larger groupings did not have enough data to determine if there were consistent differences between them, but they were fished differently (by different fishers and in different years) from each other. They represent convenient groupings and expected to be units of homogeneous habitat at a meso-scale (Greenlaw et al. unpublished). There was not enough fishing in 4Vn to assess whether this was one unit or should be separated into 4Vn Shelf and 4Vn Slope components.

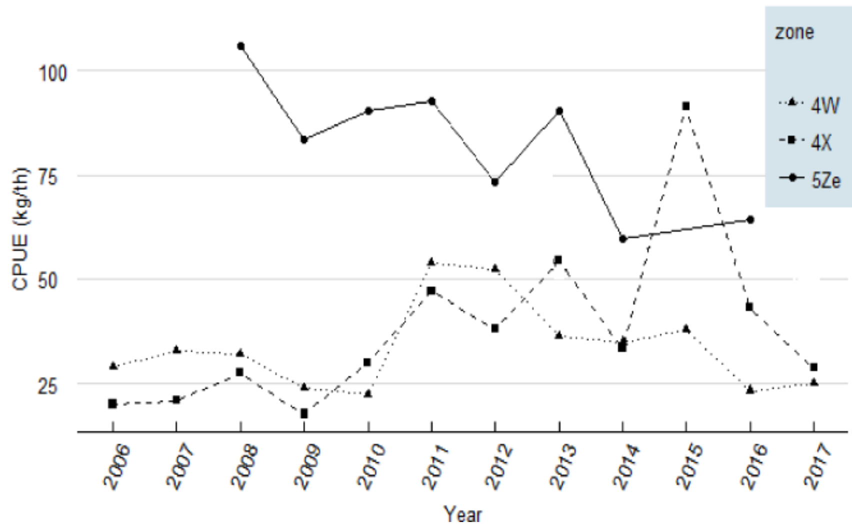

Figure 11. The 2006 - 2017 corrected catch rates (kg/trap haul) of Atlantic Hagfish on the Scotian Shelf by NAFO Division, from fisheries logbook data. Information pertaining to Division 4Vs has been removed under Privacy Act *guidelines.*

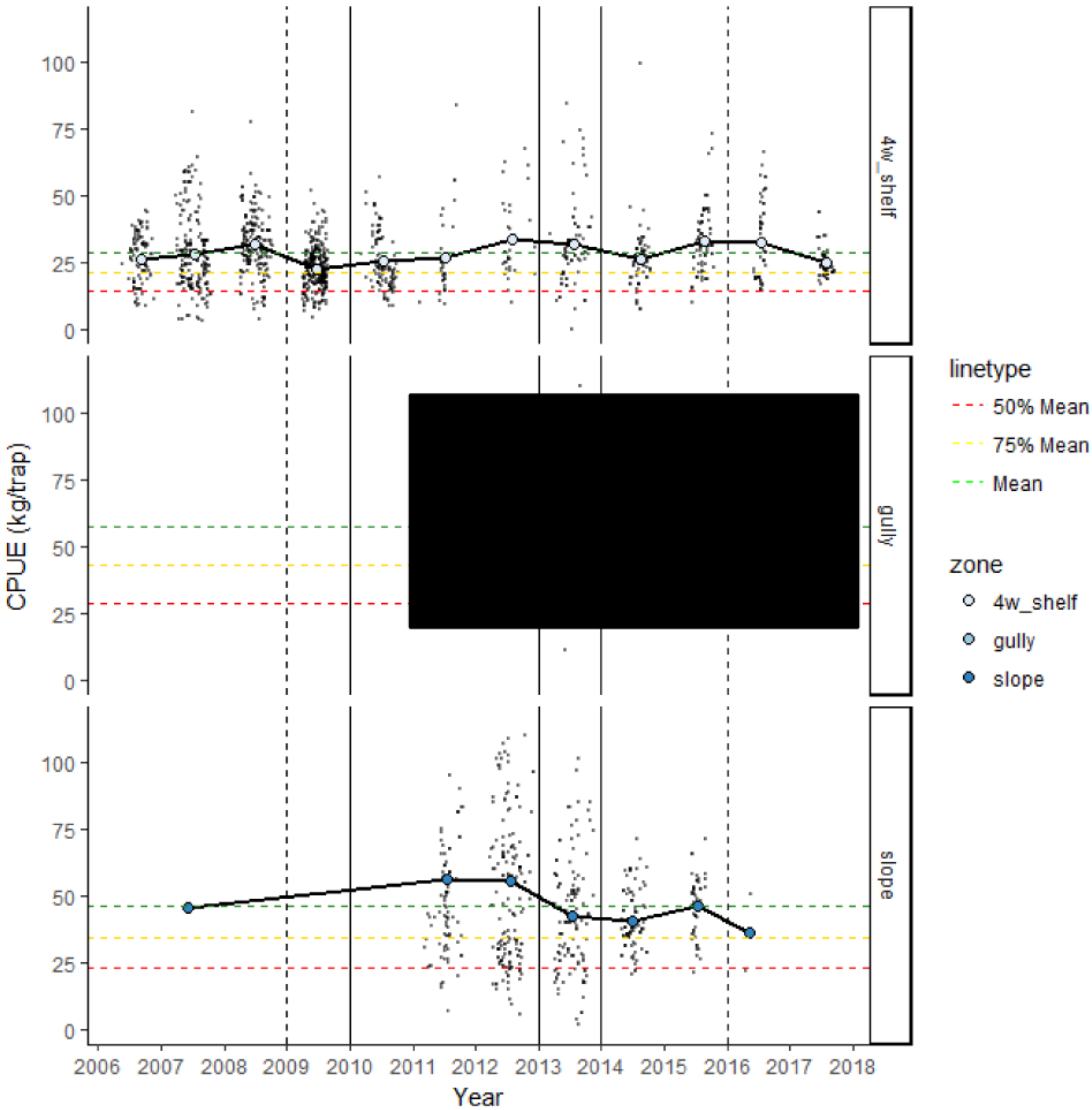

Figure 12. The 2006 - 2017 corrected catch rates (kg/trap haul) of Atlantic Hagfish on the Scotian Shelf and Scotian Slope from fisheries logbook data. Small black dots are daily catch rates, and the larger dots represent yearly mean catch rates. Correction factors for changing dockside monitoring practices and gear changes have been applied to the data. Solid vertical lines correspond to gear changes, and dashed lines correspond to modified dockside monitoring practices. "4w_shelf" refers to the Mid-Shore geographic area, "gully" refers to the Offshore-Gully geographic area, and "slope" refers to the Offshore-Slope geographic area. This figure contains third party information that is not available for publication under Privacy Act guidelines.

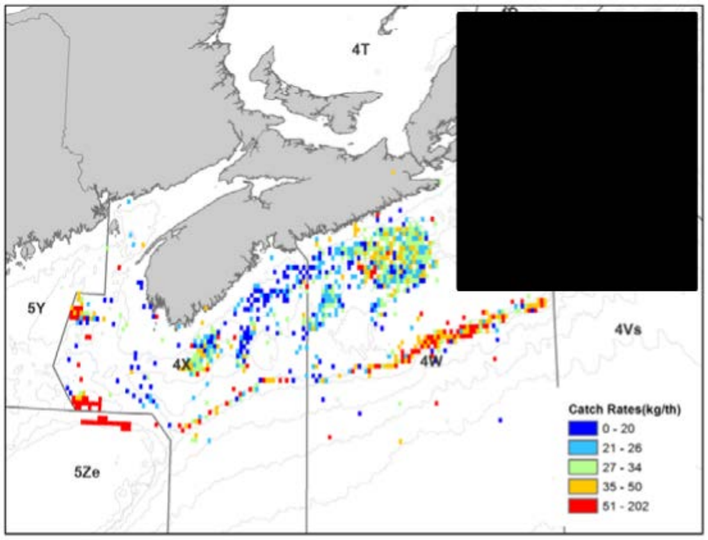

Figure 13. Average corrected catch rates from 2006 – 2017 (kg/trap haul). After 2007, over 80% of records had associated effort data to calculate catch rates. This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

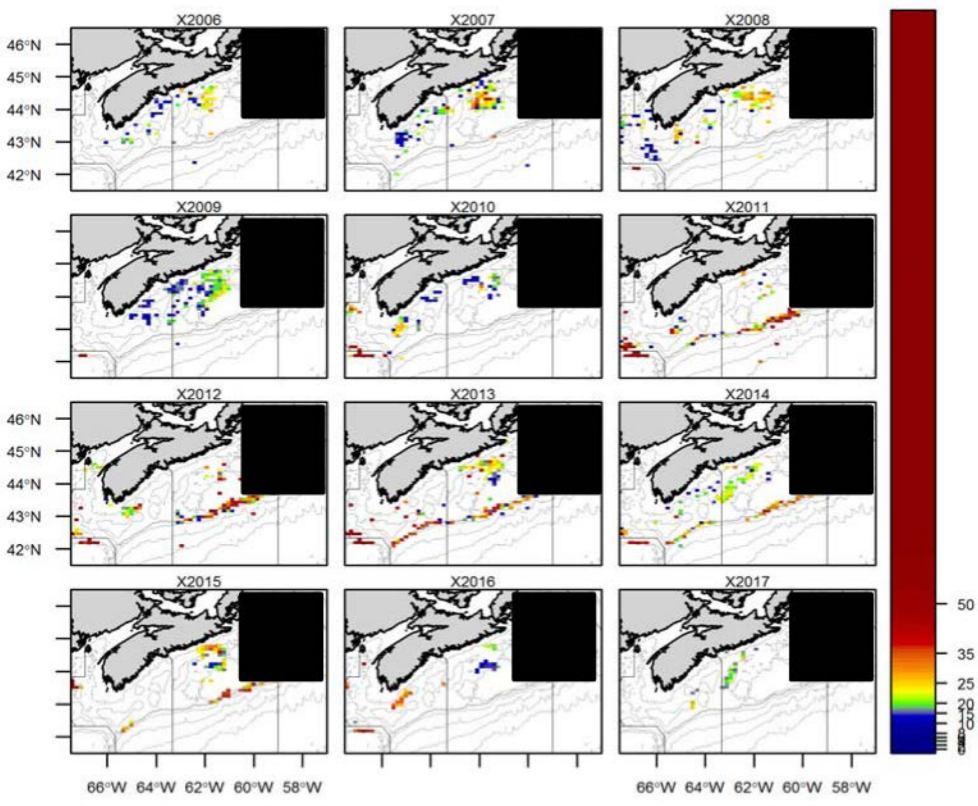

Figure 14. The corrected 2006 - 2017 spatial distribution of Hagfish catch rates (mean kg/trap haul, 5 minute grid) from fisheries logbook data. This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

Seasonal Effort

Historically, on the Scotian Shelf and Slope, Hagfish have been fished year round, with the majority of landings from April – September (Figure 15). In 2014, the fishing season was restricted to April – September to reflect this. In 2017, most effort was completed in July, with effort from June – September. In general, winter Hagfish fishing has been described as difficult, and it is avoided if other species revenue is available, which may explain changing fishing practices over time.

In the Gulf of Maine, fishermen have indicated that they land the greatest abundance and largest sized Hagfish from late spring through November, when waters are warmer (NFSC 2003). Hagfish tend to “herd” or aggregate when water is warmer. Dense aggregations of active, feeding Hagfish are captured in summer months, resulting in barrels packed full of Hagfish. When the waters cool in late fall and winter, Hagfish are expected to scatter and become dormant, becoming more difficult to capture (NFSC 2003).

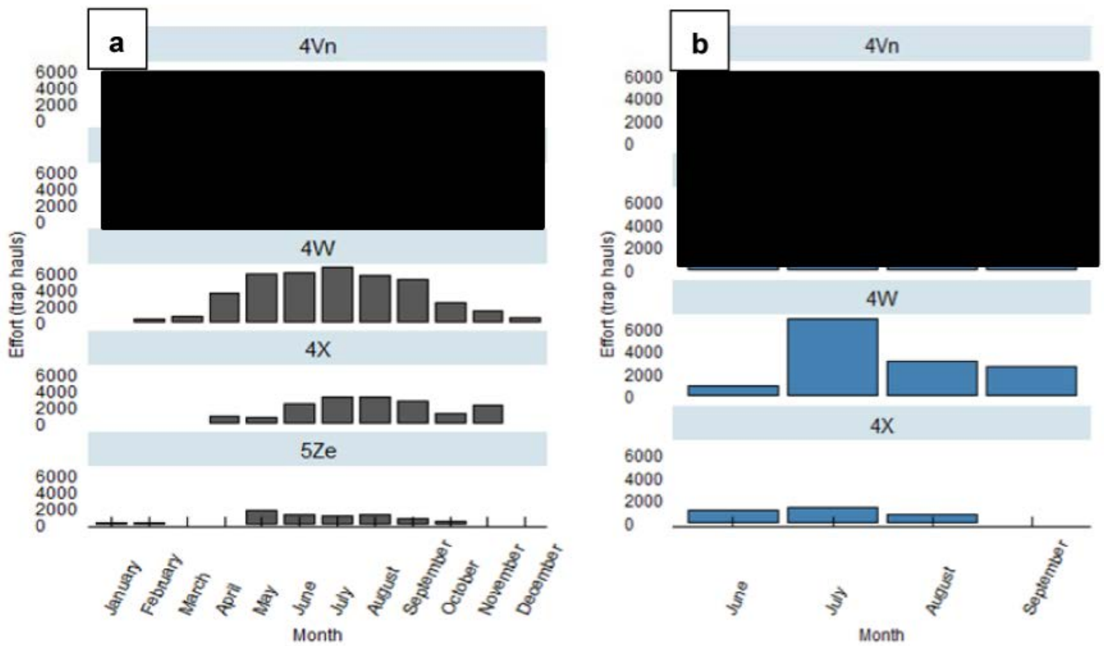

Figure 15. Frequency of trap hauls per month from 2006 to 2017 (a) and in 2017 (b). This figure contains third party information that is not available for publication under Privacy Act *guidelines.*

Soak Time

Recorded soak times from fisheries logbook data vary from 1 to 48 hours, with gear most frequently tended within 20 to 24 hours (Figure 3a). Historically, there does not appear to be any advantage to soaking traps beyond 20-24 hours, although fishers have described having to tend to their gear more frequently with the increase in escape-hole size in 2014. It is unknown when soak times start to affect the quality of the catch. Long soak times have been hypothesized to increase spoilage in catch in other areas (DFO 2017).

Shorter soak times elsewhere have meant smaller catches but fewer undersize animals while escape holes are still patent (F. Martini, Pers. Comm.). Decreased soak time is expected to influence juvenile catch rates most significantly when population density is high (F. Martini, Pers. Comm.). Grant (2016), however, describes a minimum soak time to let juveniles properly escape, at 12 hours.

Size Range

The size range reported for Atlantic Hagfish is expected to vary by geography and depth. On the Scotian Shelf, Louisbourg Seafoods Ltd. (2006[1] and 2007[2]) found the mean size of Hagfish to be 39.5 cm in length, and they find the size range to be from 20 to 60 cm in a baited trap study using control traps with 1/8" escape-holes. This range is slightly lower than the 17 to 95 cm size range (mean = 53 cm) reported in baited trap studies in the Gulf of Maine (Martini et al. 1997a).

Atlantic Hagfish may reach smaller maximum sizes in more northern waters, although their size may be confounded by depth effects. In the Gulf Region, a baited trap survey with 0.5" escape-holes (SEnPAQ Consultants Enr 1992) recorded Hagfish sizes between 15 and 56 cm, but with one large individual of 71 cm (mean = 34.4 cm, n = 10,244). With comparable gear and at similar depth, Grant (2006) recorded Hagfish of 20 to 55 cm on the southwest slope of the Grand Bank (mean = 38.1 cm, n = 250). Off the southwest Grand Bank, individual body size increased with greater depths over a depth range of 146 to 664 m (Grant 2006).

In the DFO Scotian Shelf groundfish trawl survey, Hagfish size ranged between 12 and 64 cm (Figure 16: 1983 to 2017). Gulf of Maine groundfish trawl surveys aggregated from 1962 to 2002 caught Hagfish between 20 and 70 cm, with occasional records of 91 cm Hagfish (NEFSC 2003).

Port sampled and at-sea observer sampled data are sporadic in the Hagfish fishery. These data should be interpreted with caution, given that they are based on a limited number of samples. It is unlikely that any changes in length frequency caused by the fishery would appear in these data, due to sporadic sampling combined with continually shifting fishing locations.

On the Scotian Shelf, Atlantic Hagfish sampled through port sampling and observer sampling were similarly sized to those from previous trap studies (Figure 17), and ranged in size from 17 to 72 cm Mid-shore (mean = 46.2 cm), 21 to 62 cm Offshore (mean = 43.9 cm), and 19 to 65 cm in the GoM (mean = 46.2 cm), although this is based on limited numbers of samples per year, especially in the Offshore (Table 9).

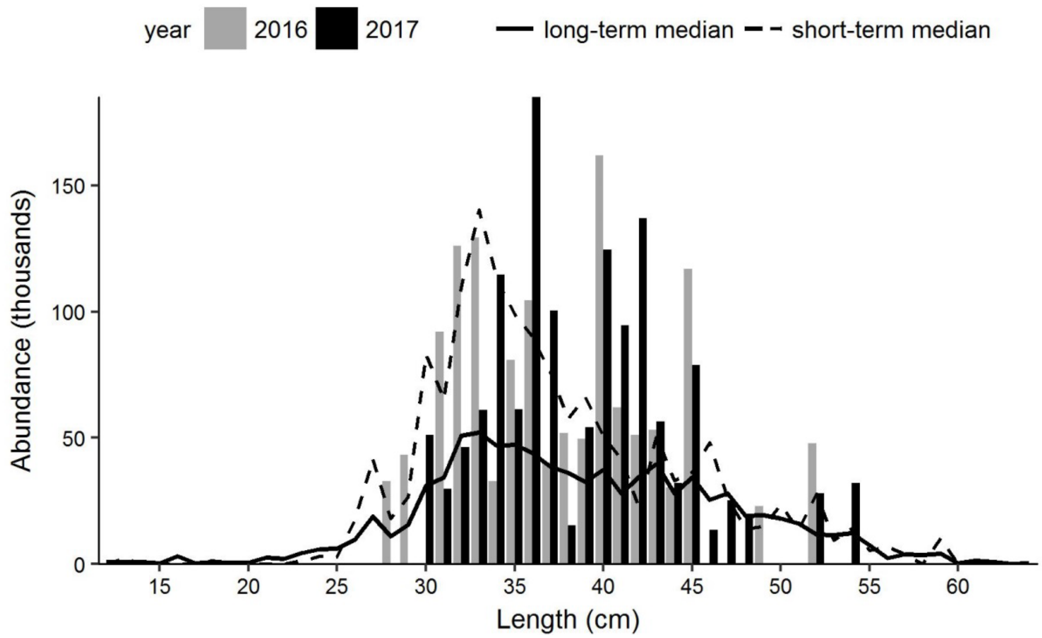

Figure 16. Length frequency histogram of Hagfish measured in the DFO Summer RV Survey (1983 – 2017).

Table 9. Number of port sampled Hagfish per year, in each geographic area.

Zone	Year	Total
GoM	2008	230
	2010	1266
	2011	1012
	2012	238
	2013	240
Mid-shore	2003	410
	2004	229
	2005	1789
	2006	645
	2007	529
	2008	518
	2009	679
	2010	1203
	2012	725
	2013	710
	2014	250
	2016	467
	2017	471
Offshore	2011	230
	2012	260
	2013	240
	2014	250

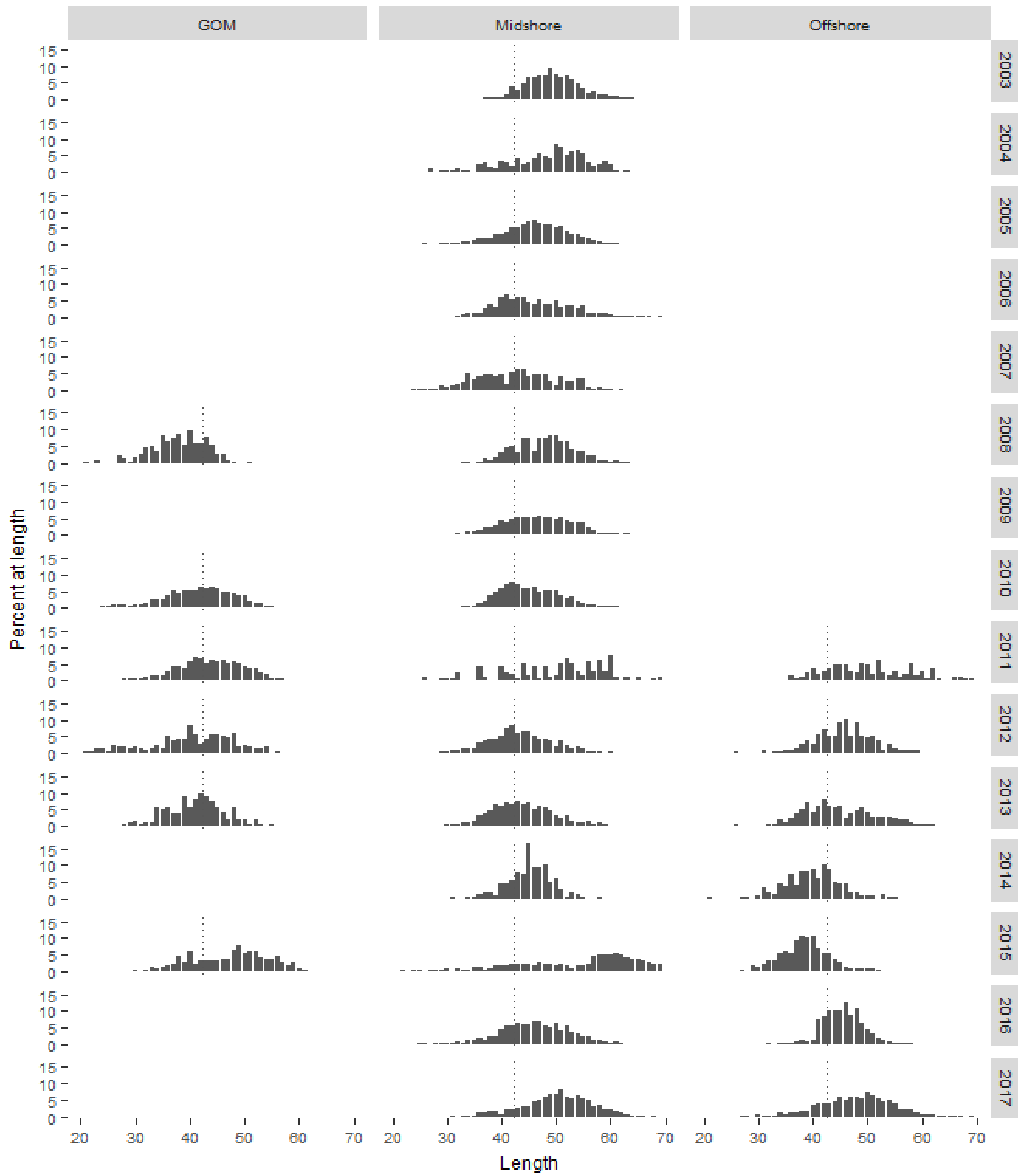

Figure 17. Length-frequency histograms of port sampled Atlantic Hagfish. The dashed vertical line represents the expected size at 50% maturity of 42.5 mm on the Scotian Shelf.

Size at Maturity

In samples from the Scotian Shelf (4W), Louisbourg Seafoods Ltd. (2007[1]) found no sharp transition from immature to mature Hagfish by length. Average size at first maturity was shown to be 38 cm and the size at 50% maturity was 42.4 cm. Size at 100% maturity did not occur, as a significant percentage of larger sized animals remained undifferentiated (20.4% show no signs of sexual maturity and are assumed sterile). This is common, and has been found to represent roughly 25% of Hagfish in similar studies in the Gulf of Maine (Martini et al. 1997a). In the Gulf of Maine, Martini et al. (1997a) reported that of 122 sampled Atlantic Hagfish, all fish up to 40 cm in length were sexually immature. There are no external characteristics that can be used to distinguish males and females. However, methods to determine maturity vary widely for Atlantic Hagfish, as described in Louisbourg Seafoods Ltd. (2007)[1]. A quarter of Atlantic Hagfish on the Scotian Shelf measuring >40 cm were sexually sterile, i.e. without macroscopically identifiable gonad tissue.

The sex ratio on the Scotian Shelf is also typical and heavily favours females, with 70.4% of samples being female, 0.89% male, and 9.4% hermaphrodites (Louisbourg Seafoods Ltd. 2007[1]). In the Gulf of Maine, the sampled sex ratio was about 10:1 in favour of females. Reasons for the unequal sex ratio and scarcity of ripe male and female Atlantic Hagfish in baited traps remain unclear, but it has been established that the capture of females and males in the final stages of gonadal maturation in preparation for spawning is rare (Patzner 1998). It has been suggested that the sexes may be geographically separate during certain times of the year. Holmgren (1946) and Walvig (1963) summarize cases where male Atlantic Hagfish were plentiful in the eastern North Atlantic; however, similar locations have not been identified on the Scotian Shelf or Grand and St. Pierre banks.

Hagfish are not currently able to be aged, due to the lack of calcified body structures. Despite some success at identifying growth bands in the statoliths of sea lampreys (Beamish and Northcote 1989), the same structures have not proved useful for aging the Hagfish *Paramyxine nelsoni* (Lee et al. 2007).

Hagfish do not have a larval stage (Worthington 1905). At hatching, individuals are reported to be approximately 65 mm in length. Trapping surveys and trawls on both sides of the Atlantic have failed to collect animals below 150 mm in length, and there is no information available regarding the habitat and ecology of juvenile Hagfish in the 65-150 mm size range (Martini et al. 1997a). Most Hagfish species are up to 1.5-2 feet (45 – 61 cm) long at maturity (Martini and Flescher 2002).

Louisbourg Seafoods Ltd. (2006)[3] demonstrated that escape-hole sizes above 8/16 (0.5)" worked best to avoid the capture of juvenile Hagfish. However, all escape-holes sizes tested caught a substantial number of fish that were below the expected size at 50% maturity. This, combined with the broad transition from immature to mature Hagfish, reduces the potential for escape-hole size to be an effective tool to ensure the sustainability of the fishery.

Over the course of the fishery, escape-hole size increases have not been successful at aiding juvenile Hagfish escape the gear. In the Mid-shore, port sampling data is available from 2003, which indicates that of the animals measured, 28% of trapped and retained animals have been below expected size at maturity (Figure 17). A gear change to increase escape-hole size to 9/16 (0.56)" took effect in 2014 and the percentage of animals below size at maturity decreased slightly, but still represents a significant portion of the catch (22%).

In the Offshore, the time series of port sampling data begins as the fishery moved to this area in 2011. Over the course of the Offshore fishery, 44% of the catch has been juveniles, which has increased to 69% of the catch since 2014 despite the increase in escape-hole size implemented in that year. Port sampling from the Gulf of Maine has been more sporadic, but it also indicates a large percentage of the catch is below the expected size at maturity (58%).

F. Martini (Pers. Comm.) has observed that escape-holes perform well for short sets or in areas with few Hagfish. Once multiple Hagfish enter the trap and begin to slime, escape efficiency decreases. When the trap is full, small animals do not have access to escape-holes.

Early studies on Atlantic Hagfish gear led Grant (2006) to recommend 14.3 mm escape-holes or larger in the Newfoundland fishery, which has a smaller expected size at 50% maturity. However, gear selectivity studies were continued in the Newfoundland Region with 15.1 mm escape-holes also. These larger escape-holes captured significantly fewer undersized Hagfish than traps with 9/16 (0.56)" escape holes. Atlantic Hagfish below the length at 50% maturity accounted for 10-12% of the catch in traps with 9/16 (0.56)" escape holes, compared to 5-6% in traps with 19/32 (0.59") escape-holes. Atlantic Hagfish below 80 g (which corresponds to the expected size/weight at maturity on the Scotian Shelf) accounted for 34-41% of the catch in traps with 9/16 (0.56)" escape-holes; compared with 20-24% in traps with 19/32 (0.59") escape-holes. It was suggested that the greatest escapement of juveniles may be achieved with 40% of fishing effort carried out using traps with 9/16 (0.56") escape-holes, and 60% of effort using 19/32 (0.59") escape-holes. With higher concentrations of juveniles on the Scotian Slope, compared to the Shelf, modified restrictions by geographic area should be considered. Testing a similar 40-60% split in the Maritimes may help reduce juvenile catch. In areas with higher catches of juvenile hagfish such as the Offshore, increasing all escape-holes to 19/32 (0.59") could be tested.

Discards

Despite the large quantities of juvenile Hagfish caught in the Maritimes Region fishery, discarding is not authorized. There is little evidence that Hagfish discarded at the surface survive. Hagfish are exclusively marine organisms, requiring full salinity sea water to function (33-35 ppt). Sudden changes in temperature and salinity will render the animals moribund (Martini and Flescher 2002). Because of their extreme sensitivity to shifts in temperature and salinity, it is suggested that mortality of Hagfish culled at sea may be high (Martini et al. 1997a). Instead, management measures have focused on trying to reduce the number of juveniles captured by allowing undersized fish to escape, with limited success in the Maritimes Region, as described above.

Surrounding regions describe frequent discarding recorded in logbook data. In the experimental Gulf of St. Lawrence fishery, discarding occurs and has exceeded 10% of the catch weight in 2 of the 5 years of the fishery (Morin et al. 2017). Discarding may be partly due to spoiled catches when traps were deployed and untended for more than 24 hours, or discarding of small, unmarketable sizes. Discarding of small Hagfish does not appear to be happening at-sea in the Maritimes Region, as Hagfish below marketable size represent a significant proportion of the catch (Figure 17). The marketable size for Hagfish varies, but the market generally does not accept pieces less than 80 g, which are sorted out at processing plants.

Observer Coverage

The at-sea observer coverage target for this fishery is 2 trips per active licence holder per season; however, the target has rarely been attained in recent years despite the harvesters complying with hail provisions. Measures should be put in place to ensure that the required numbers of trips are covered by observers, as observers provide data on a set-by-set basis, which provides the actual location of sampling, which is not provided by dockside monitoring. This would be helpful for determining the areas with the highest concentration of juveniles and observing length frequency changes in relation to location. Furthermore, observers can provide reliable information on spoiled catch in relation to soak times.

Research Recommendations

A study to look at depletion rates would improve information that could be used in an assessment for this species. In populations in which fishing removes enough individuals to significantly reduce the catch per unit effort, depletion methods (Leslie, DeLury, and regression techniques) may be employed for population estimation. All are based on the principle that a decrease in catch per unit effort as the population is reduced or depleted is directly related to the extent of population decrease. Through a similar approach, effects of different exploitation rates on the population could also be investigated.

Due to the high levels of juveniles caught in the Offshore, the size and number of escape holes appropriate for this region may differ from other Regions. The impact of soak time on juvenile catch is also unknown and may differ between geographic areas. Further research could inform development of appropriate management measures by geographic area.

There are potentially very different sizes at 50% maturity in the Offshore versus Gulf of Maine areas of the Maritimes Region. Investigation into the size at maturity in different geographic areas within the Maritimes Region would indicate whether different management strategies may be needed in different areas.

With high juvenile catch rates, discard survival studies would help to determine the probability of survival if discarding was authorized, which could potentially aid the population if survival is a possibility.

A detailed look into a possible spatial rotational fishing plan for this fishery could be investigated, using basic estimates of life history characteristics, and different zoning options.

A Management Strategy Evaluation case-study has been initiated for Hagfish, but the feasibility of this approach for developing appropriate management plans for Hagfish, or other data-limited species, has not been determined.

Evidence of functional hermaphroditism has been found in Newfoundland, whereas other areas that fish *Myxine glutinosa* have only found evidence of non-functional hermaphrodites. Work could be initiated to determine whether hermaphrodites in the geographic areas in the Maritimes Region also show evidence of functional hermaphroditism, which would aid future estimates of reproductive capacity.

Conclusions

1. What is the status of the Hagfish population(s) in Maritimes Region?

   The status of the Hagfish population in the Maritimes Region is unknown. There are currently no reference points for the stock, but catch rates have been stable over time in geographic areas where data was available. In no geographical area have CPUEs declined below 75% of the average CPUE from 2006-2017.

2. What impact has the Hagfish fishery had on the Hagfish population(s)?

   It is unclear if the Hagfish fishery has had an impact on the Hagfish population in the Maritimes Region. Catch rates have been stable over time in the Mid-shore, although this could be masking effects yet to be seen due to hyperstability, and/or fishers continually rotating fishing grounds. In the Offshore, there has been a slight decline in catch rates; however, this is what would be expected from moving to a virgin area.

3. How effective have current management strategies and tactics been in ensuring that fishing mortality is sustainable?

The Maritimes Region fishery is the longest known continuously operating Hagfish fishery. Limiting the amount of licences to 7, with 450 traps per licence, is expected to have been an effective measure to extend the longevity of this fishery thus far. However, existing input controls have not prevented significant increases in fishing pressure. In 2011 and 2012 landings increased dramatically, which put additional pressure on the population. These increases are inherently risky. Recently, market declines have decreased landings and effort, and have reduced pressure on the fishery, possibly mitigating effects of previous increases in landings.

The current management measures also do not prevent the possibility of bulk removals of catch from one location, as happened on the Scotian Slope in 2011 and 2012. With evidence of possible spawning migrations into deeper waters, this could be detrimental to the population as a whole. Over the course of the fishery, the fishing grounds have spread considerably into Div. 4X and onto the Scotian Slope.

There is required at-sea observer coverage in this fishery of 2 trips per active licence per season; however, that target has rarely been attained in recent years despite the harvesters complying with hail provisions. Measures should be put in place to ensure that the required numbers of trips are covered by observers, as observers provide data on a set-by-set basis, which is not possible from dockside monitoring. Furthermore, observers can provide reliable information on spoiled catch in relation to soak times.

Collection of length-frequency information is important for this fishery. This could be collected through at-sea observers, although measurements from port samples may be more reliable as a result of the challenges related to measuring live Hagfish at sea. Port sampling is considered to be an important data source for the fishery. Other methods such as harvesters setting aside samples for length-frequency analysis could be investigated.

Over the course of the fishery, escape-hole size increases have not been adequate at reducing juvenile catch. In the Mid-shore, port sampling indicates that, of the animals measured, 28% of trapped and retained animals have been below expected size at maturity. A gear change to increase escape-hole size took effect in 2014 and the percentage of animals below size at maturity decreased slightly, but still represents a significant portion of the catch (22%). In particular, higher levels of Hagfish below expected size at maturity have been observed in the Offshore fishery. Shorter soak times and increasing the number or size of escape-holes could also be investigated to alleviate this. If areas with high numbers of juvenile Hagfish are identified, spatial closures could be implemented.

Spatial rotational management is a common approach applied in invertebrate fisheries, which could lead to greater commercial viability of the fishery in the Maritimes Region, coupled with on-going monitoring to estimate depletion and recovery rates of high density Hagfish areas. Rotational management is implemented in situations under which restricting access to portions of a stock for a period of time provides a better result than if it were managed under continuous access, and has been associated with increased yields in many fisheries (O'Boyle et al. 2017). This is a technique commonly used for fisheries of sedentary species. Hagfish is not completely sedentary, but it has been described as a sedentary fish.

A rotational fishery with multiple open and closed zones would allow time to monitor the impact of the fishery and stock recovery. In some cases, reserve areas are used as an additional precautionary measure. This is particularly the case if there are zones that serve as a source of recruits for so-called sink zones, which is hard to ascertain for Hagfish. The fishery may also benefit from experimental fisheries zones, which examine the effects of a range of exploitation rates on the population (e.g. Canadian West Coast Sea Cucumber Fishery).

Due to the large proportion of juveniles harvested, explicit spatial rotation would benefit the fishery by also giving individuals a chance to grow. Benefits of spatial rotation are further enhanced when there is a market incentive to avoid smaller sizes, which is the case for Hagfish (O'Boyle et al. 2017).

Design of an effective spatial rotation system would require additional analysis.

4. What are the risks to the Hagfish population(s) if fishing were to continue under existing management strategies?

   Risks to the Hagfish population if fishing were to continue under existing management strategies are not well understood. Despite stable catch rates in the Mid-shore (which has the longest time span of catch rate data), this population shows a variety of high risk factors, including low fecundity, long lifespan, late age of maturity, and poor knowledge of many aspects of their biology. Given the life-history characteristics of this species, a very conservative approach to harvesting is recommended.

   It is unknown whether catch rates are reflective of general population trends, as they may exhibit characteristics such as hyperstability, or population changes may be masked by rotational fishing practices. Although catch rate declines have not been seen in the last 20 years of the fishery, the life span of the species is expected to be long, with slow growth rates, which could create difficulties for sustainability in the future. Based on life-history characteristics of Hagfish, the rate of biomass increase in an exploited population is expected to be very low. In this case, if there is no effective control, the stock aggregations are "mined" with the fishery moving to unexploited zones as those fished are depleted, with the unfished recovery period for a depleted zone being very long. There may be situations where all zones have been depleted, forcing closure of the fishery until recovery takes place.

   Currently, most areas have only been fished once in the 14 years of the fishery, leaving 14 years of recovery. Of those areas fished more than once, most have been fished 2/14 years, leaving 7 years of recovery, with very few areas fished more than 3/14 years. It is possible that signs of depletion could become evident if fishers are forced to repeatedly fish areas they have fished multiple times in the past. Management procedures could be put in place to ensure that catch, or effort, does not increase substantially, as high uncertainty remains.

   Catch rates should also be carefully monitored going forward, as declines could happen quickly if they begin. It would be possible to set up a monitoring framework and science plan to assess these issues going forward.

5. If stock status has declined, what level of fishing in the near term would not cause further decline in stock status and that would allow for recovery within a reasonable timeframe?

   At this time, stock status is unknown, as are sustainable levels of effort or removals. Despite stable catch rates, effort and removal levels should be very conservative due to the risk factors associated with the life-history of this species, and the risk that catch rates are not reflective of population trends. Also, as mentioned above, it is recommended that bulk removal from single geographic areas be prevented. Rotational fishing and reserves should be explored and observer coverage targets achieved.

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Sources of Information

Beamish, R.J., and Northcote, T.G. 1989. Extinction of a Population of Anadromous Parasitic Lamprey, *Lampetra tridentate*, Upstream of an Impassable Dam. Can. J. Fish. Aquat. Sci. 46: 420-425.

Bigelow, H.B. and Schroeder, W.C. 1953. Fishes of the Gulf of Maine. U.S. Department of the Interior. Fishery Bulletin of the Fish and Wildlife Service, Vol. 53. U.S. Government Printing Office: Washington DC, 1953.

DFO. 2009a. Assessment of NAFO Division 3O and Subdivision 3Ps Atlantic Hagfish (*Myxine glutinosa*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/042.

DFO, 2009b. Proceedings of a Workshop on Canadian Science and Management Strategies for Atlantic Hagfish. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2009/009.

DFO. 2017. Review of the Exploratory Fishery for Atlantic Hagfish (*Myxine glutinosa*) in NAFO Div. 4T. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/008.

Fernholm, B. 1974. Diurnal Variations in Behavior of the Hagfish, *Eptatretus burgeri*. Mar. Biol. 27: 351-356.

Foss, G. 1963. Myxine in its Natural Surroundings; pp. 42-45. In: A. Brodal and R. Fange (eds.) The Biology of Myxine. Universitetsforlaget, Oslo.

Grant, S.M. 2006. An Exploratory Fishing Survey and Biological Resource Assessment of Atlantic Hagfish (*Myxine glutinosa*) Occurring on the Southwest Slope of the Newfoundland Grand Bank. J. Northw. Atl. Fish. Sci. 36: 91-110.

Grant, S.M. 2016. Hagfish Fisheries Research; pp. 41-71. In: S.L. Edwards and G.G. Goss (eds.) Hagfish Biology. CRS Press, Taylor & Francis Group.

Hessler, R.R., and Jumars, P.A. 1974. Abyssal Community Analysis from Replicate Box Cores in the Central North Pacific. Deep-Sea Res. 21: 185-209.

Holmgren, N. 1946. On two Embryos of *Myxine glutinosa*. Acta Zoologica XXVII: 1-90.

Honma, Y. 1998. Asian Hagfishes and their Fisheries Biology; pp. 45-56. In: J.M. Jorgensen, J.P. Lomholt, R.E. Weber, and H. Malte (eds.). The Biology of Hagfishes. Chapman & Hall, London.

Jensen, D. 1966. The Hagfish. Sci. Am. 214(2): 82-90.

Lee, Y.-H., Huang, H.-T., and Mok, H.-K. 2007. Microscopic Structure and Digital Morphometric Analysis of the Statoconia of Hagfish, *Paramyxine nelsoni* (Myxiniformes). Zool. Stud. 46: 1-5.

Lesser, M.P., Martini, F.H., and Heiser, J.B. 1996. Ecology of the Hagfish, *Myxine glutinosa* L. in the Gulf of Maine. I. Metabolic Rates and Energetics. J. Exp. Mar. Biol. Ecol. 208: 215-225.

Malte, H., and Lomholt, J.P. 1998. Ventilation and Gas Exchange; pp. 223-234. In: J.M. Jørgensen, J.P. Lomholt, R.E. Weber, and H. Malte (eds.). The Biology of Hagfishes. Chapman & Hall, London.

Martini, F.H. 1998. The Ecology of Hagfishes; pp. 57-77. In: J.M. Jørgensen, J.P. Lomholt, R.E. Weber, and H. Malte (eds.) The Biology of Hagfishes. Chapman & Hall, London.

Martini, F.H., and Flescher, D. 2002. Hagfishes. Family Myxinidae;pp. 9-12. In: B.B. Collette and G. Klein-MacPhee (eds.). Bigelow and Schroeder's Fishes of the Gulf of Maine. Smithsonian Institution Press, Washington. 748 p.

Martini, F., Heiser, J.B., and Lesser, M.P. 1997a. A Population Profile for Atlantic Hagfish, *Myxine glutinosa* (L.), in the Gulf of Maine: Morphometrics and Reproductive State. Fish. Bull. 95(2): 311-320.

Martini, F., Lesser, M., and Heiser, J.B. 1997b. Ecology of the Hagfish, *Myxine glutinosa* L., in the Gulf of Maine: II. Potential Impact on Benthic Communities and Commercial Fisheries. J. Exp. Mar. Biol. Ecol. 214(1997): 97-106.

Martini, F.H., Lesser, M.P., and Heiser, J.B. 1998. A Population Profile for Hagfish, *Myxine glutinosa*, in the Gulf of Maine. Part 2: Morphological Variation in Populations of Myxine in the North Atlantic Ocean. Fish. Bull. 96: 516-524.

Morin, R., Ricard, D., Benoît, H., and Surette, T. 2017. A Review of the Biology of Atlantic Hagfish (*Myxine glutinosa*), its Ecology, and its Exploratory Fishery in the Southern Gulf of St. Lawrence (NAFO Div. 4T). DFO Can. Sci. Advis. Sec. Res. Doc. 2017/017. v + 39 p.

NEFMC (New England Fisheries Management Council). 2003. Final Report of the Atlantic Hagfish Working Group: A Review of Atlantic Hagfish Biological and Fishery Information with Assessment and Research Considerations. 88p.

NFSC (Northeast Fisheries Science Center). 2003. A Report by the Atlantic Hagfish Working Group for the New England Fishery Management Council May 30, 2003; pp. 518-597. In: Report of the 37th Northeast Regional Stock Assessment Workshop (37th SAW) Stock Assessment Review Committee Consensus Summary of Assessments. Northeast Fish. Sci. Cent. Ref. Doc. 03-16: 597 p.

Neville, C.M. , and Beamish, R.J. 1992. Hagfish; pp. 267-280. In: B. Leaman [ed.]. Groundfish Stock Assessments for the West Coast of Canada in 1991 and Recommended Yield Options for 1992. Can. Tech. Rep. Fish. Aquat. Sci 1866.

O'Boyle, R., Roddick, D., and Sinclair, M. 2017. A Review of Rotational Management of Fisheries and its Application to Canadian East Coast Arctic Surfclam (Mactromeris polynyma). DFO Can. Sci. Advis. Sec. Res. Doc. 2017/066. vi + 33 p.

Patzner, R. A. 1982. Die Reproduktion der Myxinoiden. Ein Vergleich von *Myxine glutinosa* und *Eptatretus burgeri*. Zool. Anz. 208(3-4): 132-144.

Patzner, R.A. 1998. Gonads and Reproduction in Hagfishes; pp 378-395. In: J.M. Jørgensen, J.P. Lomholt, R.E. Weber, and H. Malte (eds.). The Biology of Hagfishes. Chapman & Hall, London.

Powell, M.L., Kavanaugh, S.I., and Sower, S.A. 2004. Seasonal Concentrations of Reproductive Steroids in the Gonads of the Atlantic Hagfish, *Myxine glutinosa*. J. Exp. Zool. 301A: 352-360.

Schuetzinger, S., Choi, H.S., Patzner, R.A., and Adam, H. 1987. Estrogens in Plasma of the Hagfish, *Myxine glutinosa* (Cyclostomata). Acta Zoologica (Oxford) 68(4): 263-266.

Scott, W.B., and Scott, M.G. 1988. Atlantic Fishes of Canada. Can. Bull. Fish. Aquat. Sci. 219: 731 p.

SEnPAQ Consultants Enr. 1992. Suivi scientifique de la pêche de la myxine du nord *Myxine glutinosa* dans les eaux profondes du Golfe du Saint-Laurent. Manuscript report presented to Department of Fisheries and Oceans. Moncton, NB: 60 p.

Sidell, B.D., and Beland, K.F. 1980. Lactate Dehydrogenases of Atlantic Hagfish: Physiological and Evolutionary Implications of a Primitive Heart Isozyme. Science 207: 769-770.

Shelton, R.G. 1978. On the Feeding of the Hagfish *Myxine glutinosa* in the North Sea. J. Mar. Biol. Ass. U.K. 58: 81-86.

Wakefield, W.W. 1990. Patterns in the Distribution of Demersal Fishes on the Upper-continental Slope off Central California, with Studies on the Role of Ontogenetic Vertical Migration on Particle Flux. PhD dissertation, Scripps Institution of Oceanography, Univ. California San Diego, La Jolla, CA, 178.

Walvig, F. 1963. The Gonads and the Iormation of the Sexual Cells; pp. 530-580. In: A. Brodal and R. Fange (eds.) The Biology of Myxine. Universitetsforlaget, Oslo, Norway.

Walvig, F. 1967. Experimental Marking of Hagfish (*Myxine glutinosa* L.) Norw. J. Zool. 15:35-39.

Worthington, J. 1905. Contribution to our knowledge of the Myxinoids. The American Naturalist 39(465): 625-663.

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