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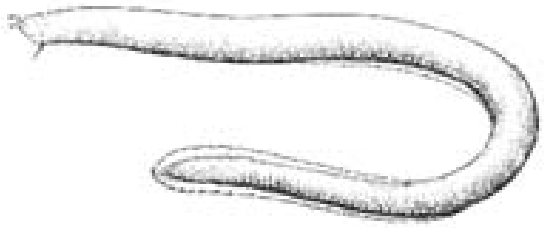
Canadian Science Advisory Secretariat
Gulf Region **Science Advisory Report 2017/008**

REVIEW OF THE EXPLORATORY FISHERY FOR ATLANTIC HAGFISH (*MYXINE GLUTINOSA*) IN NAFO DIV. 4T



Atlantic hagfish (Myxine glutinosa)

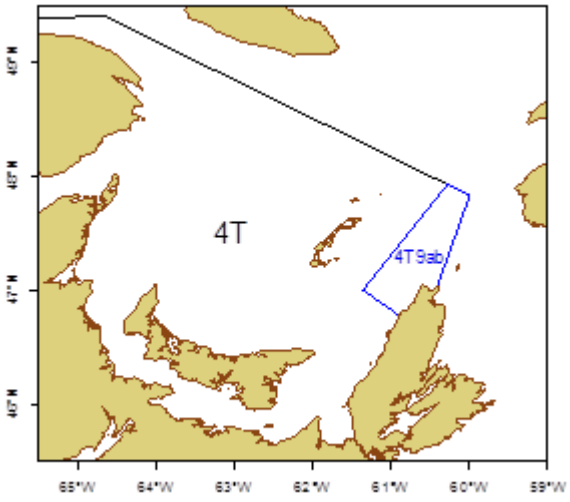


Figure 1. The 4T9ab management area for Atlantic hagfish, situated in the eastern part of NAFO 4T.

Context:

There was limited commercial interest and no fishery for Atlantic hagfish (Myxine glutinosa) in the southern Gulf of St. Lawrence (NAFO Division 4T) until recently. In 2011, four groundfish harvesters from Gulf Nova Scotia were licensed to conduct an exploratory fishery for hagfish in the 4T9ab management area located off northern Cape Breton (Figure 1). Conservation Harvest Plans since 2011 have allocated four licences for 4T9ab hagfish, although in most years only one licence has been active. Atlantic hagfish are harvested by baited barrels that are fitted with entrance funnels, and with escapement holes of a specified number and minimum diameter. The primary market for Atlantic hagfish is in Korea and Japan, where its skin is processed for fine leather goods and where it is also consumed. This report was undertaken to briefly review the biology of Atlantic hagfish, what is known of its ecology and population trends in the southern Gulf, and how it is managed in the southern Gulf and elsewhere. DFO policy restricts the publication of landing statistics in management areas where fewer than 5 harvesters are active. To maintain confidentiality, landings are not provided by NAFO area in this report. This review emphasizes the science requirements for assessing this fishery.

This Science Advisory Report is from the December 18, 2015 science peer review meeting 'Status of emerging fisheries species in the southern Gulf of St. Lawrence: hagfish'. Participants at the meeting included DFO Science and DFO Fisheries Management (Gulf region), the fishing industry and an expert from academia.

SUMMARY

- The East Coast fishery for Atlantic hagfish originated in NAFO 4X in 1989, but since 2000 has expanded, with total landings from all areas peaking at 3,610 tonnes in 2013. In 2011, four exploratory licences for Atlantic hagfish were issued in the southern Gulf of St. Lawrence (NAFO 4T) in the 4T9ab management area (Figure 1).
- Of the four licences issued for 4T9ab, one licence has been active each year since 2011; an additional two licences landed hagfish in 2012 exclusively.
- Annual total discards as a percentage of total catch ranged between 4% and 15%. The frequency and amount of hagfish discarding appears to be related to trap soak time, likely reflecting a relationship between catch spoilage and discarding.
- The primary source of data on hagfish population trends is groundfish trawl surveys conducted yearly in the southern Gulf every September since 1971 and in the northern Gulf in August since 1990. Distribution maps of catches in the two surveys show that hagfish occupy the deep channel waters of the central Gulf and the lower estuary. In the September survey, hagfish occupy depths >260m and prefer temperatures 5-6°C and salinities of 34-35 ppt.
- Hagfish abundance fluctuates widely from year-to-year in both surveys with wide annual confidence limits about the mean catch. In the September survey, the 4T hagfish abundance index increased sharply in the mid-1990s and has continued to fluctuate at a relatively high level since the late 1990s. The abundance index for the northern Gulf survey has varied widely over time without any trend since 1990, as has an abundance index for the 4T9ab management area that combines data for both surveys.
- Length-frequencies for hagfish from the September survey have generally remained the same since the 1990s. The surveys catch very few hagfish of market-size (≥43 cm), though to some extent this likely reflects low catchability to the survey trawl.
- It is currently not possible to determine the age or productivity of Atlantic hagfish. Many aspects of their biology are consistent with slow growing, long-lived fishes with low reproductive potential. In other fish species, such characteristics are associated with an elevated risk of overexploitation and long recovery times once depleted.
- The ability of Atlantic hagfish to sustain exploitation in the long term is uncertain. Given the uncertainties concerning the abundance and productivity of Atlantic hagfish in NAFO 4T, there is currently no scientific basis for determining a sustainable harvest level. Furthermore, given the lack of responsive abundance indices, adaptive management is not presently feasible for this fishery.

INTRODUCTION

Atlantic hagfish biology and ecology

Hagfish (*Myxine glutinosa*) are primitive jawless fishes. Due to their unique position in vertebrate evolution, research has focused on their morphology, physiology and genetics. Due to their cryptic nature, inaccessibility (often deep habitat) and difficulty maintaining them in captivity, many aspects of Atlantic hagfish life history and behavior, including their mode of reproduction, remain unknown.

Atlantic hagfish are mainly found in the North Atlantic at depths <1200 m, on the western side from Davis Strait to Florida; on the eastern side from the Barents Sea to the Mediterranean.

Hagfish occupy areas of high salinity and prefer substrates with soft clay or flocculent sediments where they can burrow. In the Gulf of St. Lawrence, hagfish occupy the deep channel waters of the central Gulf, in addition to the lower estuary (Figure 2). Densities are generally greatest in the western portion of the Laurentian channel and the lower estuary. Based on an annual survey of the southern Gulf, Atlantic hagfish occupy depths >260 m and prefer temperatures 5-6°C and salinities of 34-35 ppt.

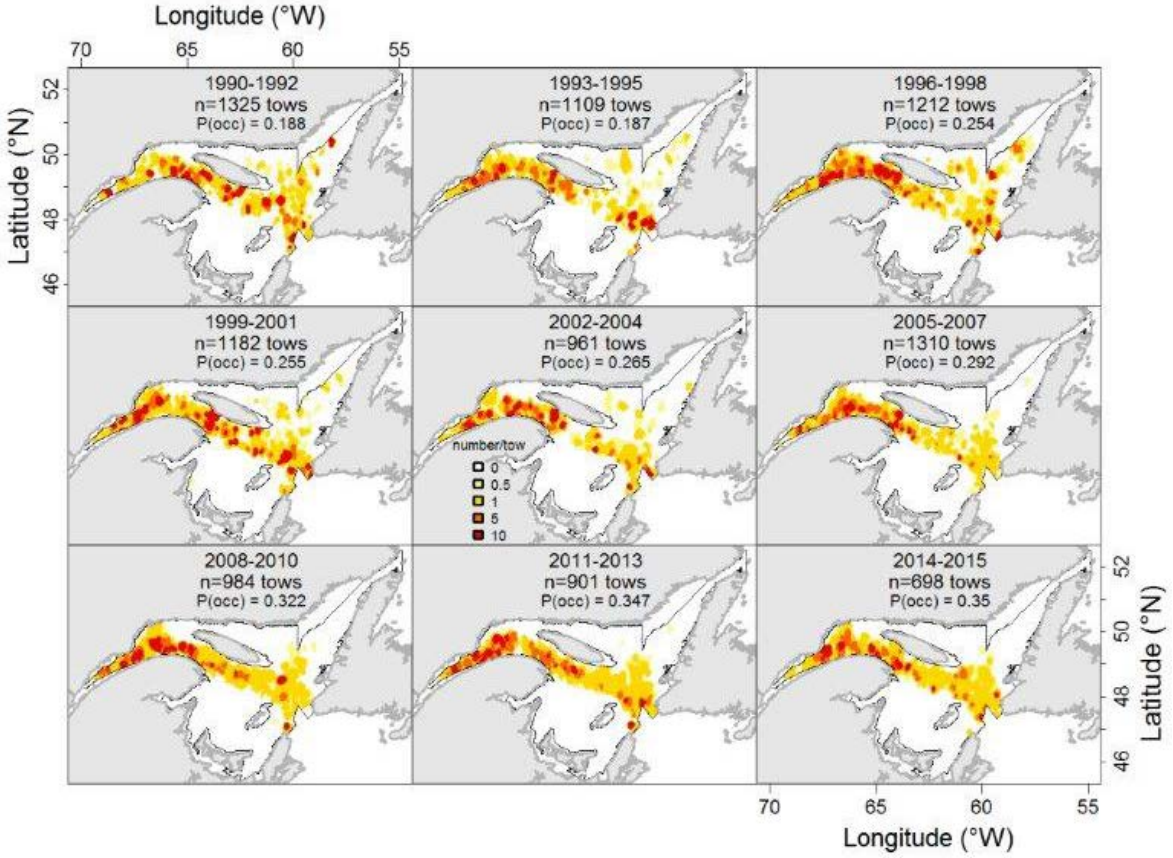


Figure 2. Density contours of Atlantic hagfish in surveys of the Gulf of St. Lawrence based on the number caught per standard tow in two or three-year blocks since 1990. All data have been standardized to equivalent catch efficiency with survey gear used in the southern Gulf. The total number of survey tows and the proportion that caught hagfish, P(occ), are indicated in each panel.

Hagfish spend a considerable portion of time burrowed into sediments. In a resting state, hagfish have an exceptionally low blood pressure and metabolic rate. They are reported to survive up to seven months without food in aquaria and are capable of surviving anoxic conditions, including being buried in sediments.

Hagfish reproduction is poorly known, mainly due to their inaccessibility and the impossibility of observing their reproductive cycle in captivity. The sex ratio of adults tends to be dominated by females. There appears to be no specific breeding season for Atlantic hagfish, with recruitment occurring year-round. Fecundity is low for mature hagfish of all sizes and the maturation of the clutch probably requires more than one year and may be punctuated by resting periods, depending on the nutritional intake.

Throughout their distribution, Atlantic hagfish may play an important role in the ecological processing of dead fish and marine mammals. Through their burrowing behavior and their

predation, hagfish may also play an important role in marine ecosystems through substrate turnover and nutrient recycling. This may be critical in areas where anoxic conditions prevail. In addition to their scavenging, Atlantic hagfish consume a range of fish and invertebrates.

Many aspects of their biology and ecology, including their low metabolic rate, sedentary behaviour and occurrence in areas of deep cold waters, are consistent with slow growing, long-lived fishes. Other aspects of their biology indicate that they have low reproductive potential, notably due to their low fecundity, their size at maturity and their apparent lack of annual spawning. These factors alone have led some authors to question whether Atlantic hagfish can sustain exploitation in the long term (Martini et al. 1997a, 1997b).

Fisheries

The East Coast fishery began in 1989 and remained centered in NAFO 4X through the 1990s. The fishery expanded into NAFO 4W and eastward after 2000, and overall landings peaked at 3,610 tonnes in 2013 (Figure 3). Significant catches were made in off the SW Grand Bank (NAFO 3O) and St. Pierre Bank (3Ps) in 2005, but since 2008 the Newfoundland fishery has been concentrated in 3Ps. Despite the apparent growth of the hagfish fishery in eastern Canada, it remains a specialized activity. In some NAFO divisions, as in 3Ps (Grant and Sullivan 2013), the exploratory fishery has been restricted to one vessel. The 4T9ab (southern Gulf; Figure 1) exploratory fishery which began in 2011 has had four licensed vessels annually, but with only one (common) vessel active in all years except 2012 (Table 1). Landings in that fishery peaked in 2012 and 2013.

Baited barrels are used to fish hagfish. Each barrel is fitted with several funnels through which hagfish enter and an array of holes of specified diameter through which small hagfish can escape. Various minimum commercial sizes have been reported for Atlantic hagfish fisheries. In the Gulf of St. Lawrence in 1992, Atlantic hagfish were accepted by processors when greater than 30 cm. In the Newfoundland fishery, 80 g (corresponding to around 40 cm in that area) is considered to be the minimum marketable weight for consumption and the minimum size for leather production is 50 cm. For the 4T Atlantic hagfish fishery in 2014, a buyer reported 80 g (around 43 cm in 4T) as the preferred minimum weight.

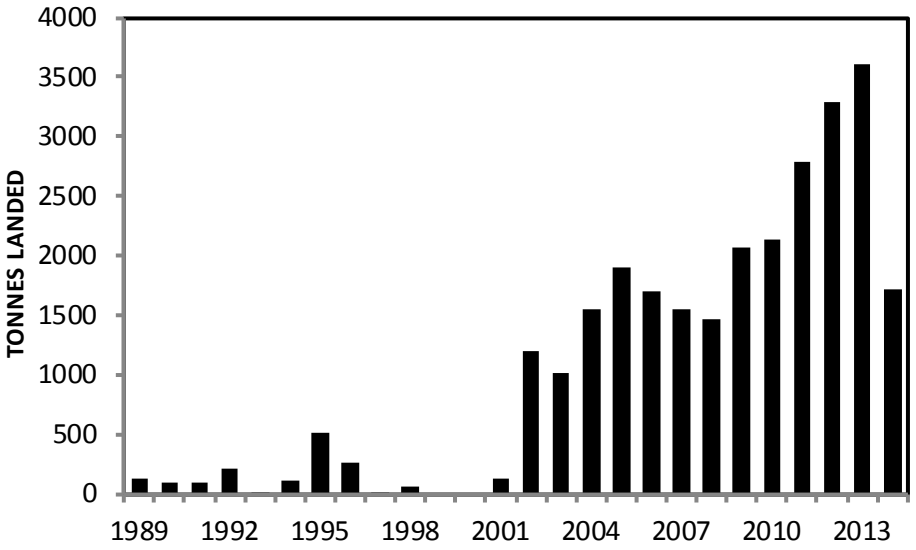


Figure 3. Landings of Atlantic hagfish in East Coast Canadian fisheries.

Table 1. Fishing activity and sampling in the 4T9ab hagfish fishery, including the number of active participants, the number of fishing trips and an index of landings relative to the highest level in 2013. Four participants were licensed each year in this fishery. The landings index is presented as an alternative to absolute estimates to comply with privacy requirements associated with the small number of participants. Discarding percentage is based on estimated catches from logbooks. Also indicated are the number of fishing trips accompanied by observers and length samples recorded by observers and dockside monitors (DM).

	Active	Vessel	Landings	%	Observer		DM
Year	participants	trips	ratio	discards	trips	samples	samples
2011	1	9	0.13	4.0	0	0	0
2012	3	12	0.98	9.7	1	5	0
2013	1	6	1.00	13.2	1	1	0
2014	1	5	0.41	15.4	0	0	1
2015	1	6	0.92	4.3	0	0	2

Management measures that are in effect in each DFO region are summarized in Table 2. The Newfoundland-Labrador (N-L) Region is the only region with an annual quota within a specified management area and with limits by subarea that prevent concentrated fishing effort and removals. Hagfish were exploited in the N-L Region from 2004-2008 in NAFO 3O and from 2005-2013 in NAFO 3Ps. The Total Allowable Catch (TAC) in these sectors was established through industry consultations and was considered to be reasonable amounts to store at sea and to market. The most recent update on the 3Ps fishery (Grant and Sullivan 2013) reported declining catch rates and reductions in the proportion of mature females. These results were viewed as indicating high fishing pressure on the 3Ps hagfish stock.

Table 2. Comparison of management measures in Atlantic hagfish fisheries, by DFO region. For the Newfoundland and Labrador (N-L) Region, the measures were effective in 2013 (no fishery in 2014 and 2015). For the Maritimes and Gulf regions, the measures were effective in 2015.

Management measures	N-L Region	Maritimes Region	Gulf Region
Type of licence	Exploratory	Commercial	Exploratory
Hail in / Hail out	100%	100%	100%
Dockside monitoring	100%	100%	100%
Observer coverage	100% biologist on some trips	Target 1 trip per licence per season	20%
VMS	Yes	Yes	No
Season	Sept – Nov (variable)	Apr 15 – Oct 15	Aug – Oct
Quota	NAFO 3Ps: 181 t.[1]	None	None
Authorized trap (barrel)	220 litres	Maximum 102.5 cm (H) x 61 cm (diam.)	114.3 cm (H) x 61 cm (diam.)
Maximum traps	200 per 24 hours	450	500
Entrance funnels[2]	Minimum 4	Maximum 4	Maximum 6
Escape holes (number; diameter)	115 (40% 9/16”, 60% 19/32”)	Minimum 36 9/16”	Minimum 24; at least ½”
Minimum fish size	60 g, limited to 5% of total catch	None	None

[1] authorized fishing is in seven blocks (six blocks 10’x10’ latitude & longitude; 1 block 10’x4’). The maximum authorized catch is no more than ¼ of the TAC (45 t per block).
[2] at least one funnel attached with biodegradable material.

The Maritimes Region manages the commercial fishery for hagfish by input controls, with limits on the number of licences, vessel size, the number of traps per licence, and trap configuration (Table 2). Management measures that were updated in 2014 included a 10% reduction in the

trap limit, a 20% increase in the minimum number of escape holes, an increase in the minimum diameter of escape holes and a reduction in the fishing season to six months. In 2015, the barrels increased in height from 93.5 to 102.5 cm and more flexibility was allowed in the number of entrance funnels, to a maximum of four. Updated measures were made in consultation with regional Hagfish Advisory Committee, composed of DFO Resource Management, Conservation and Protection Branch, representatives of the fishing industry and First Nations.

The Gulf Region approached the management of the exploratory hagfish fishery in 4T with some measures consistent with those established in the Maritimes Region, but differing particularly in the size and configuration of the gear. Managers in the Gulf Region imposed 20% at-sea fishery observer coverage of hagfish trips, unlike the Maritimes Region that had no requirement for observers on trips up to the 2014 fishery. Despite the requirement, only two of a total of 38 fishing trips in the 4T fishery have been covered by fishery observers due to a lack of observers available to cover this fishery.

Kept and discarded weights of hagfish were recorded in most logbooks in the 4Tab fishery. Annual total discards as a percentage of total catch ranged between 4% and 15% (Table 1). The frequency and amount of hagfish discarding appears to be related to trap soak time, which has ranged from 4 hours to 11 days. This likely reflects a relationship between catch spoilage and discarding. Discarding exceeded 10% of the catch for 7 of 45 catches associated with soak times < 24 hours and for 15 of 25 catches associated with soak times > 24 hours. At soak times > 60 hours, an average of 50% of the catch was discarded. The survival rate of hagfish discarded from spoiled catches is likely to be very low; in contrast, the survival of discarded hagfish in good condition is likely to be high.

Length frequency samples from the fishery were obtained by fisheries observers from five fishing sets in 2012 (1,280 fish) and one fishing set in 2013 (283 fish), and by dockside monitors from one landing in 2014 (data presently unavailable) and two landings in 2015 (500 fish). The distribution of lengths from the 2012 sample was shifted to larger sizes relative to the distributions in 2013 and 2015 (Figure 4). The percentage of the catch below 43 cm was 28% in 2012, compared to 72% in 2013 and 59% in 2015. Given the small number of samples used to derive these length frequencies, it is not possible to conclude whether the differences in size composition reflect sampling error or a real change in catch characteristics.

ASSESSMENT

Population indices

Data on Atlantic hagfish in the southern Gulf originate from two main sources; multispecies research vessel (RV) trawl surveys that have been conducted yearly in the southern Gulf since 1971 and northern Gulf since 1990, and a baited trap survey targeting hagfish that was performed in the western part of the Gulf in 1992. The trawl surveys provide time series of hagfish abundance trends spanning several decades. However, hagfish tend to be poorly represented in trawls due to low catchability and as a result trawl-based estimates of relative abundance can be quite variable. Annual Sentinel and snow crab surveys do not catch hagfish. Surveys using baited traps that target hagfish are effective but potentially costly to perform. In the Gulf, only one such survey was conducted in 1992.

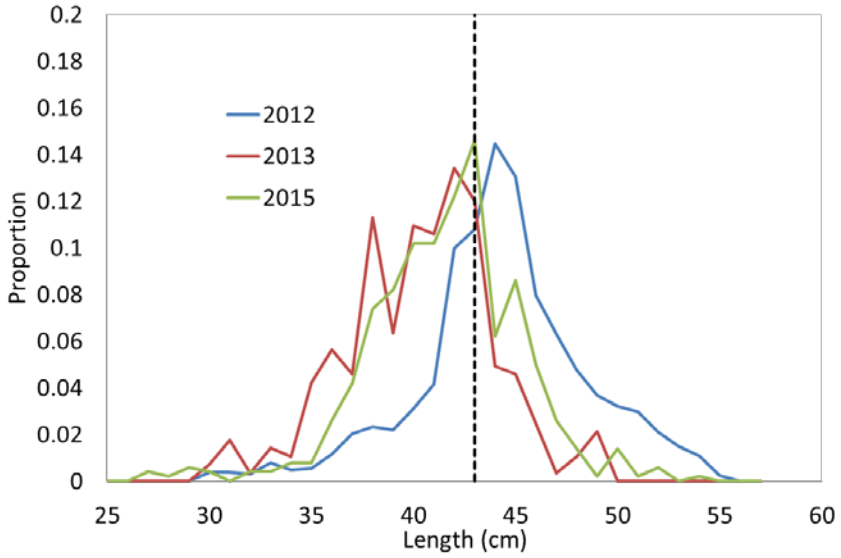


Figure 4. Length frequencies of Atlantic hagfish in sampled catches from the exploratory fisheries in the southern Gulf of St. Lawrence. The dotted line indicates the length corresponding to the preferred minimum size (80 g or 43 cm) of Atlantic hagfish for buyers for the leather industry.

The RV survey of the southern Gulf covers the Magdalen shallows, as well as the southern slope of the Laurentian channel, where Atlantic hagfish occur. The northern Gulf RV survey covers the lower St. Lawrence estuary and the deep channels of the Gulf (Laurentian, Anticosti and Esquiman), areas preferred by Atlantic hagfish in the Gulf of St. Lawrence. The surveys overlap in the Laurentian channel, including in the 4T9ab area.

The relative abundance of Atlantic hagfish in the southern Gulf RV survey fluctuated at a low level from 1971 to the mid-1990s, rising rapidly in the late 1990s to a more elevated level about which abundance has fluctuated since (Figure 5). In contrast, the abundance index for the northern Gulf RV survey fluctuated without trend from 1990 to 2015 (Figure 6). Uncertainty in both the southern and northern Gulf RV survey indices is elevated. The northern Gulf survey catches approximately 10 times more hagfish than the southern Gulf survey, likely due to a difference in the survey trawl used and the fact that the northern Gulf survey covers a higher proportion of hagfish habitat.

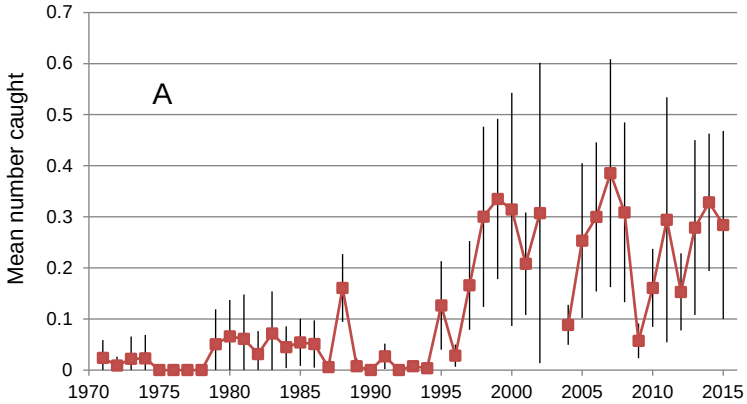


Figure 5. Stratified mean number per tow (with 95% confidence limits) of Atlantic hagfish in the southern Gulf of St. Lawrence derived from the annual RV bottom trawl survey, 1971-2015.

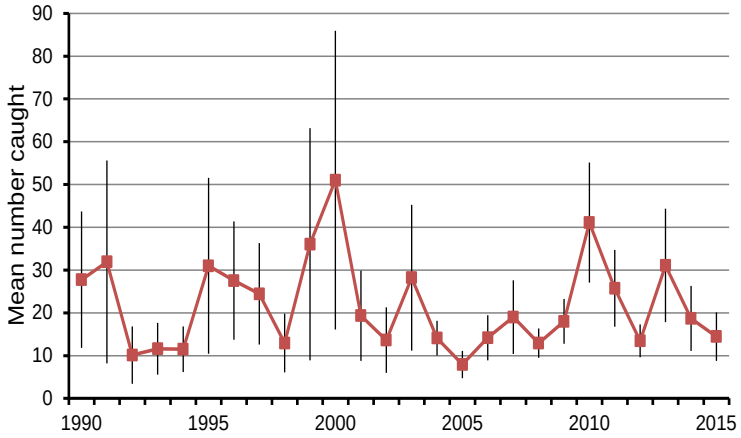


Figure 6. Mean stratified number per tow of Atlantic hagfish (with 95% confidence limits) caught in the northern Gulf RV survey.

An abundance index combining data from both surveys, adjusting for differences in catchability, was developed specifically for the 4T9ab area. Since 1990, an annual minimum of eight (in 2010) and a maximum of 24 (in 1998) survey tows have been undertaken in this area. The abundance index for this area is associated with high estimation error and large inter-annual fluctuations that have varied without trend. This is at least partly due to the low sampling density in the area.

Based on these results, it appears that the RV surveys can only detect coarse long-term changes in hagfish abundance. These surveys are unlikely to provide reliable indices that can track short term fluctuations in abundance in response to the fishery or other factors.

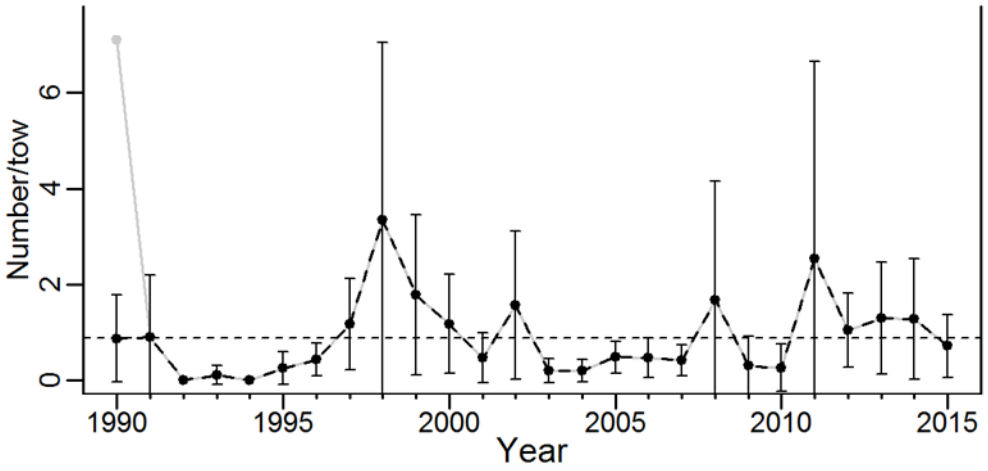


Figure 7. Index of hagfish abundance (with 95% confidence limits) in the 4T9ab management area from intercalibrated data of the northern and southern Gulf of St. Lawrence trawl surveys. The black symbols are for the index that excludes a single high abundance tow conducted in 1990 and the gray symbol and line includes it. he horizontal dashed line shows the long-term mean catch rate (years 1990-2015) in 4T9ab.

Length frequencies for Atlantic hagfish from the southern Gulf RV survey prior to the mid-1980s were based on very few captured fish and are very sparse (Figure 8). The relative distribution of lengths captured in the survey has varied little since 1986, with most fish measuring between 30

and 40 cm. The proportion of fish ≥43 cm tends to be very small. Relative to the commercial fishery (Figure 4), it is clear that the RV survey captures relatively fewer large hagfish.

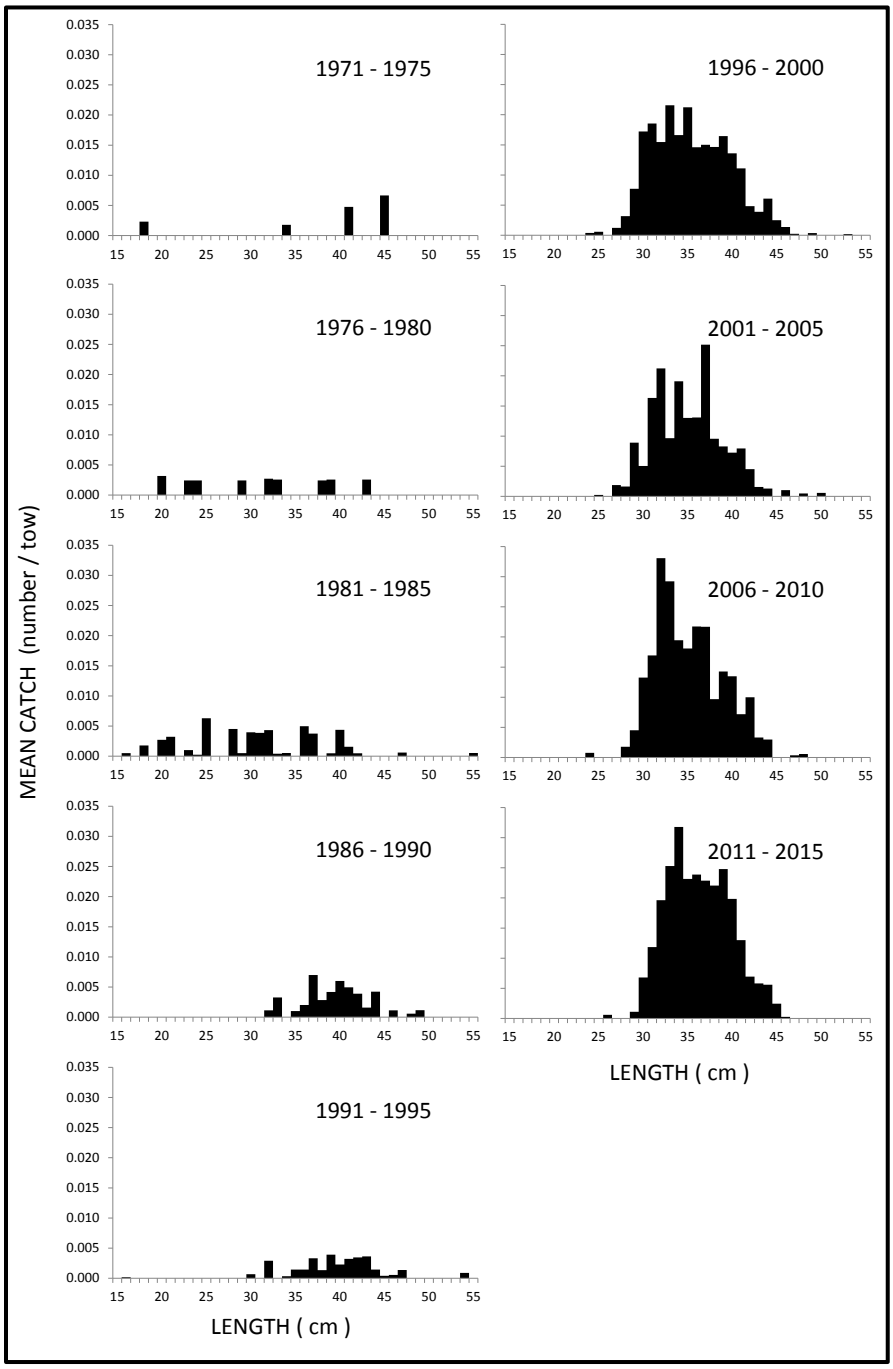


Figure 8. Five-year mean catch-at-length of Atlantic hagfish in annual trawl surveys of the southern Gulf of St. Lawrence.

A fine scale baited trap survey (SENPAQ survey) was conducted in August 1992 using two commercial fishing vessels. The survey area was divided into 255 blocks (or sites) determined by 5' latitude by 10' longitude, of which 249 were fished successfully by one vessel or the other. The traps fished for 2 to 3 hours during daytime. The traps used for this survey were scaled

down to 5 gallon plastic pails (22.7 L). An entry funnel was set at one end of each trap and 154 holes were drilled in the sides and covers (¼ inch or 6.4 mm in diameter).

The highest densities of hagfish in the SENPAQ survey were found in the western portion of the Laurentian channel, and the lowest densities in the Anticosti channel (Figure 9), consistent with the results of the RV surveys (Figure 2). While the survey demonstrated the potential for baited trap surveys for Atlantic hagfish, the available information limits any inferences to a description of the spatial distribution of catch rates in 1992 because the survey was limited to that year and length composition data from the survey has regrettably been lost.

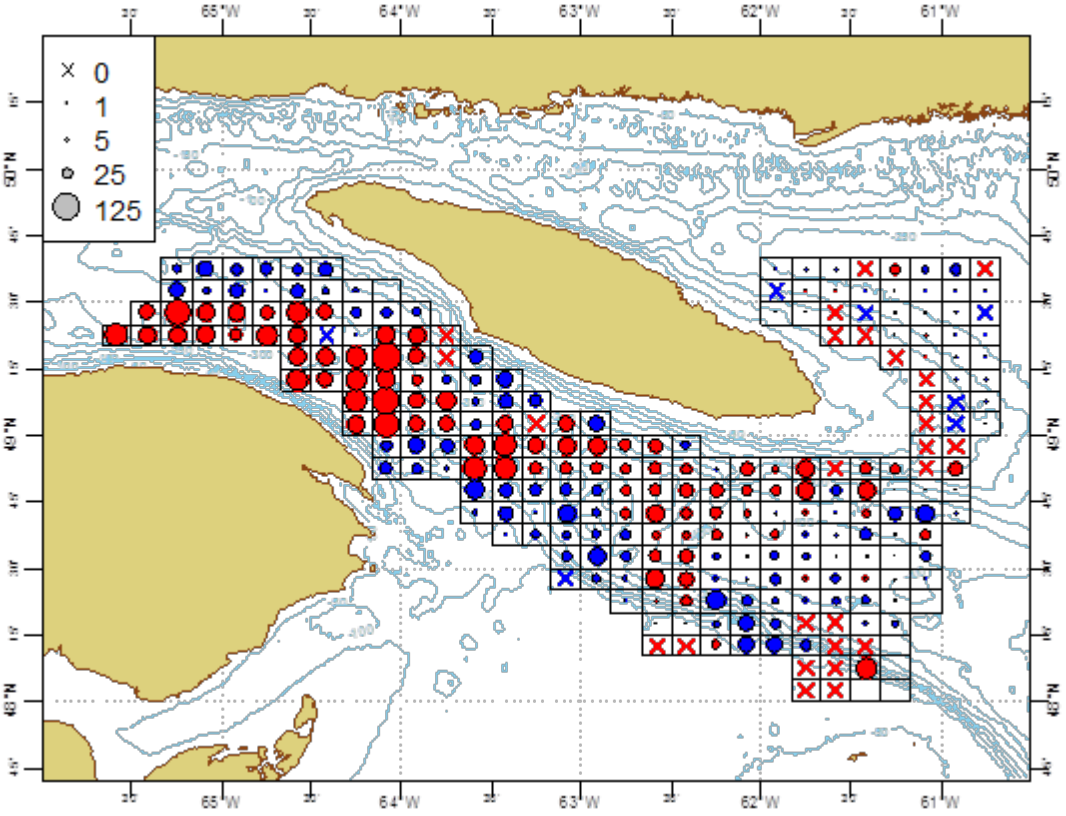


Figure 9. Survey grid and catch densities for the August 1992 trap survey in the western Gulf of St. Lawrence. Catch per unit effort (number per trap per 1-hour fishing time) are shown by symbol size (see legend) and for each of the two participating vessels (symbol colour).

Sources of uncertainty

Although the biology of Atlantic hagfish has several characteristics of slow growing, long lived fishes, there is no known method for determining the age of hagfish. As a result, it is impossible to know with any certainty the stock age structure, growth rate, total mortality, or age at reproduction. There is therefore little information to determine the productivity of hagfish populations and therefore their potential for sustainable exploitation. Furthermore, there is presently no information available on the size at maturity of hagfish of the Gulf of St. Lawrence. A common fisheries management approach is to restrict the capture of fish less than the body length at which 50% are mature (L50), to increase the likelihood that fish will survive fishing to spawn at least once. In neighboring areas, L50 was identified as 38 cm for the SW Grand Bank population and 42.4 cm for the Scotian Shelf hagfish population.

There is no information on the stock structure of Atlantic hagfish in Atlantic Canada. Annual trawl surveys provide long-term coarse trends in abundance, but the catchability of hagfish to trawling gear is low. The surveys appear to have a limited ability to track short-term changes in abundance and size structure of hagfish in areas where they are exploited.

Discarding, reported in harvester logbooks, may exceed 10% of the weight of hagfish catches. Though there appears to be a relationship between soak time and the extent of discarding, some uncertainty remains concerning the causes of discarding and their potential effect. The survival of discarded hagfish is probably very low when the catch is spoiled; however, survival may be high if hagfish are released live from traps.

CONCLUSIONS AND ADVICE

It is currently not possible to determine the age or productivity of Atlantic hagfish in the southern Gulf of St. Lawrence. Nonetheless, many aspects of their biology, including their low metabolic rate, sedentary behaviour and occurrence in deep cool waters, are consistent with slow growing, long-lived fishes. They also appear to have low reproductive potential, in part due to their low fecundity. In other fish species, such characteristics are associated with an elevated risk of overexploitation and long recovery times once depleted. The ability of Atlantic hagfish to sustain exploitation in the long term is therefore uncertain. Given the uncertainties concerning the abundance and productivity of Atlantic hagfish in NAFO 4T, there is currently no scientific basis for determining a sustainable harvest level.

Available abundance indices from trawl surveys are very unlikely to be responsive to short-term changes in abundance or population size structure caused by the fishery or other factors. An adaptive management approach for this fishery is therefore not presently feasible.

Discarding of spoiled hagfish catches constitutes a waste of the resource and results in an unnecessary fishing mortality. Matching gear limits to the capacity to fully fish set gear during a fishing trip would reduce the chances of the catch spoiling and consequently reduce discarding. Furthermore, there are reports of spoiled catches associated with high densities of amphipods (sand fleas), though it is not clear if the amphipods caused the spoilage or if they were drawn by it. Similar problems were experienced in the Newfoundland fishery. Documenting and then avoiding areas with high amphipod densities might improve catch quality and reduce discarding.

Escape holes in hagfish barrels are an important measure to avoid the capture of undersized hagfish. Current management measures in NAFO 4T impose a ½ inch minimum diameter for the hole size, a smaller size than is used in fisheries managed by DFO in the Newfoundland-Labrador and Maritimes regions. Limited catch sampling in 2013 and 2015 indicates that around 60% or more of catch in the 4T9ab fishery is comprised of hagfish below the minimum preferred commercial size of 43 cm and the 42.4 cm L50 value for the neighboring Scotian Shelf population. Increases in the size of escape holes would reduce this percentage. Furthermore, additional catch sampling by at-sea observers and dockside monitors would provide greater certainty in the size composition of hagfish catches. Presently, the fishery is not meeting the nominal requirement for observer coverage of 20%, despite the harvesters complying with the hail-out provisions.

SOURCES OF INFORMATION

This Science Advisory Report is from the December 18, 2015 science peer review meeting on the status of emerging fisheries species in the southern Gulf of St. Lawrence: hagfish. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Grant, S.M., and Sullivan, R. 2013. Update of the Atlantic hagfish (*Myxine glutinosa*) fishery in NAFO Subdivision 3Ps: 2005-2012. MS Report to Policy and Planning Branch, Newfoundland and Labrador Department of Fisheries and Aquaculture. Centre for Sustainable Aquatic Resources, Fisheries and Marine Institute of Memorial University of Newfoundland, St. John's, NL. Rep. P409. 32 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. Part I: Morphometrics and reproductive state. Fish. Bull. 95: 311-320.

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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.

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