## E. ATLANTIC HAGFISH

### 1.0 EXECUTIVE SUMMARY

In New England, a growing fishery for Atlantic hagfish (*Myxine glutinosa*) has initiated science and policy discussions about the development of the fishery, its potential for future expansion, and its effect on the resource. The hagfish fishery in New England was developed in the early 1990s, with the first reported landings of around 1 million pounds in 1993. Korean buyers quickly recognized that a fishery in the New England area could provide the high quality hagfish skins used in making leather as well as hagfish meat for human consumption.

Reported hagfish landings in New England quadrupled during the first four years of the fishery (1993-1996), exceeding the highest reported landings in other North American hagfish fisheries (including British Columbia, Oregon, Washington, California and Nova Scotia) by 1994. Landings increased six-fold from 1993 to 2000, with a reported 6.8 million pounds of hagfish landed in 2000 yielding over 1.8 million dollars in revenues. Landings in 2001 and 2002 are estimated to be 3-6 million pounds in each year. There is no management program for this fishery, and consequently no permitting or reporting requirements. Thus, there is considerable uncertainty regarding the actual level of hagfish landings, as the data provided by fishers and processors may be incomplete. Moreover, the level of discards and discard mortality of hagfish culled at sea or rejected by the dealer in port is unknown. Landings are highest during the summer and fall months.

The number of active vessels in the fishery has fluctuated between 1993 and the present, ranging from 5 to more than 30 vessels reporting landings per year. These vessels use specialized hagfish traps and land their catch primarily in Gloucester, Massachusetts. Hagfish are no longer landed in Maine. The average size of active vessels in the fishery has increased since 1993, with new entrants as large as 165 feet. The fishing capabilities and efficiency of these larger vessels has increased even over the past year, as fishermen have developed more effective means of sorting and storage of hagfish at sea, an enhanced awareness of localized aggregations of hagfish, and improved product quality control.

The fishery is prosecuted throughout the Gulf of Maine, from Nantucket to Downeast Maine and east to the Hague line, with the majority of landings from trips in the inshore Gulf of Maine between Gloucester and Portland. The vast majority of hagfish trips occur in the deeper waters (greater than 40 fathoms) of the Gulf of Maine, within a 60 nautical mile range of Gloucester, MA. The geographic range of the fishery and spatial distribution of hagfish trips have expanded since 1994, with vessels moving further offshore and trips more broadly distributed across the range of the fishery. Average trip duration, as reported via vessel trip reports, has generally increased since 1994. Nominal and standardized estimates of landings per unit of effort (LPUE) fluctuated from 1994 to 2002, with distinctions among LPUE trends for different seasons and statistical areas across the time period.

Hagfish have been captured in low numbers in the Northeast Fisheries Science Center groundfish bottom trawl surveys since 1963 from the Gulf of Maine to Cape Hatteras. Based on these trawl survey data and Gulf of Maine shrimp survey data, it appears that hagfish abundance in the Gulf of Maine decreased from the mid-1970s through the mid-1980s and remained at a fairly consistent low level until the early to mid-1990s, with an increase during the late 1990s. The factors which contributed to the apparent decline in the 1970s are unknown. Hagfish captured in the Gulf of Maine groundfish trawl survey are generally larger than those captured in the deeper offshore survey strata south of Cape Cod. Mean lengths of hagfish from the spring and fall groundfish surveys were 40.5 cm and 42.6 cm, respectively. In the offshore survey area, hagfish averaged 34.7 cm in the spring and 34.6 cm in the fall. Hagfish are most commonly captured in the survey at depths of 150-250 meters and at temperatures of 5-10°C, but are found across a broader range of depths and temperatures.

Little is known about the life history of hagfish. The age at maturity and lifespan of *Myxine* (in the Gulf of Maine and elsewhere), as well as timing, conditions and location of reproduction are not known. Hagfish have a limited reproductive potential, as evidenced by the small number of large, yolky eggs carried by the females. Hagfish serve an important ecological role, contributing to nutrient cycling, substratum turnover and removal of dead or dying organisms on the sea floor.

Developing a comprehensive understanding of the hagfish fishery and resource will require new scientific and fishery-dependent research and data collection efforts. A one-day working group that met to discuss hagfish science and management identified important information gaps and discussed a number of potential approaches to acquiring the data and information needed to fill them. Among these are the initiation of an at-sea observer program and port sampling for estimating discard levels and collecting length/weight data, tagging studies to estimate growth rates and examine movement of localized populations of hagfish, age and growth studies conducted in the laboratory, specialized broad-scale surveys of hagfish, investigation of spatial movement of the fishery through interviews with fishermen. Several potential approaches for stock assessment modeling were also described. However, it is unlikely that conventional stock assessment approaches will provide significant information in the near future due to lack of data. There are many opportunities for development of industry-based research projects and further collaborative efforts among scientists, fishermen, administrators and policy analysts. Implementation of some of these recommendations may require adoption of a formal fishery management plan.

## 2.0 INTRODUCTION

### 2.1 Background

On March 28, 2003, a working group of scientists, fishery analysts, fishermen and administrators met at the New England Fishery Management Council office to review biological and fishery information for Atlantic hagfish. This report is a result of the group's efforts to address informational needs of the Stock Assessment Review Committee (SARC) in its peer review meeting in June, 2003, and represents the best available fishery and stock information on the Atlantic hagfish.

**Participants**

The following individuals participated in the working group meeting and the production of this report.

Anne Beaudreau – New England Fishery Management Council
Mark Boulay – F/V Camano
Andrew Cooper – University of New Hampshire
Chad Demarest – New England Fishery Management Council
Larry Jacobson – Northeast Fisheries Science Center
Chad Keith – Northeast Fisheries Science Center
Christopher Kellogg – New England Fishery Management Council
Frederic Martini – University of Hawaii
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Mickie Powell – Birmingham-Southern College
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## 2.2 Working Group Objectives (Terms of Reference)

1. Characterize and describe the Atlantic hagfish fishery currently and historically, including fleet characteristics (number and size of harvesting vessels), harvesting techniques and gear, major ports of landing, landings and revenue trends, changes in landings per unit of effort (LPUE), and distribution of fishing effort.

2. Describe discarding in the hagfish fishery and identify other sources of uncertainty in fishery-dependent data. Discarding includes discarding at sea (culling), and discarding at the processing plant due to quality concerns.

3. Provide a description of what is known about hagfish life history. Include current information pertaining to growth rates, size at age, fecundity and reproduction.

4. Discuss strategies for determining stock abundance and trends in abundance using survey data available from the Northeast Fisheries Science Center (NEFSC) trawl surveys, and other fishery-independent measures of abundance and density.

5. Determine the utility of existing biological and fishery data for assessing the Atlantic hagfish stock and discuss general strategies for assessing hagfish.

6. Identify high priority data needs for hagfish assessment and management and discuss methods for collecting essential data about the stock and fishery.

# 3.0 HAGFISH LIFE HISTORY AND ECOLOGY

## 3.1 Morphological/Physiological Characteristics and Taxonomy

Hagfishes are recognized as the most primitive extant craniates and have been studied primarily in the context of vertebrate evolutionary history. Hagfish possess an entirely cartilaginous skeleton and are eel-like in form. While their olfactory capabilities are quite keen, they have limited sensitivity to light and possess reduced or degenerative eyes. Unlike most bony fish, hagfish lack scales. The pink-gray skin of the Atlantic hagfish is smooth and lined with slime glands along the ventral midline. Known commonly as the slime eel, the hagfish is capable of producing massive quantities of mucous when provoked or threatened. The slime likely 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. Knotting may also aid hagfish in predator evasion and provide leverage for the animals while feeding on carcasses of larger fish or marine mammals.

Hagfish are jawless, possessing an evertible toothplate lined with tiny denticles which allows them to attach to other fish and bore into body cavities, eating the flesh and viscera and leaving behind the tougher skin and bony structures. Hagfish are an irritant to hook and gillnet fisheries which target species such as haddock, hake, and cod, because of their proclivity for feeding on hooked or gilled fish. Though considered scavengers of dead or dying organisms, hagfish feed primarily on invertebrates. (For more information on their feeding habits, see Section 3.4.) Hagfishes are ubiquitous, with about 60 species of hagfish in two subfamilies found across the world's oceans. 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

Atlantic Ocean. Wisner and McMillan (1995) suggested that two species of hagfish may exist, differing in size at maturity and color of preserved specimens – *Myxine glutinosa* in the western Atlantic and *Myxine limosa* in the eastern Atlantic. However, in the absence of substantial supporting morphological data, this idea was dismissed and *M. limosa* has not been classified as a distinct species (Martini et al. 1998).

<u>Reference</u>: *Martini & Flescher in Collette & Klein-MacPhee 2002*

### 3.2 Geographic Range and Habitat

*M. glutinosa* are very common in the Gulf of Maine and occur as far south as Cape Fear, North Carolina. Up until the early 1990s, they were reported in large numbers in deeper parts of Massachusetts Bay and in the waters surrounding the Isles of Shoals and Jeffreys Ledge in the Gulf of Maine (Martini & Flescher in Collette & Klein-MacPhee 2002). It is suggested that the stock has substantially diminished in these inshore areas since the early 1990s (Boulay, Hill, Nippert, Palumbo, pers. comm. 2003). Habitat suitable for hagfish covers 60-70% of the bottom in the Gulf of Maine, but in several density studies which used trap survey data collected over a five year period in a part of the Gulf of Maine, hagfish were found in only 5% of the suitable habitat area in densities of 1:16.75 $m^2$ to 1:2 $m^2$ (based on the biomass estimate of 8119 $kg/km^2$ derived from the survey) (Martini et al. 1997b).

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 & Flescher in Collette & Klein-MacPhee 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 under 2 knots over short distances (Martini & Flescher in Collette & Klein-MacPhee 2002). Migratory behavior has only been observed in one species of hagfish, the Japanese hagfish *Eptatretus burgeri* (Fernholm 1974, cited in Martini et al. 1998).

### 3.3 Preferred Depth, Temperature, and Salinity

Hagfish distribution is determined by three factors, listed in order of importance: salinity, temperature and substrate type (Martini & Flescher in Collette & Klein-MacPhee 2002). Hagfish have been found at depths of 15 to 524 fathoms (27.4 to 958.3 m) in the Gulf of Maine (Bigelow & Schroeder 1953). They prefer low temperatures probably cooler than 50ºF, confining them to depths of at least 15-20 fathoms (27.4-36.6 m) or greater in the Gulf of Maine during the summer (Bigelow & Schroeder 1953). 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 & Flescher in Collette & Klein-MacPhee 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).

### 3.4 Feeding, Adaptability and Ecological Role

In hagfish, cutaneous respiration and a large blood volume, at 18% of its body weight, have allowed these organisms to adapt to hypoxic benthic environments. Other characteristics, such as a low energetic requirement and opportunistic feeding habits, allow hagfishes to thrive across a wide range of habitat (Lesser et al. 1996). The bulk of their diet is made up of invertebrates such as shrimp and polychaetes and supplemented with dead or dying organisms, including discarded bycatch, hooked or gilled groundfish, and dead marine mammals. It is suggested that hagfish may have a particular predatory influence on northern (Pandalid) shrimp in the Gulf of Maine. They contribute to the diet of marine mammals and many species of fish (Martini, Lesser et al. 1997). Hagfish play a significant ecological role in their natural environment, contributing to nutrient cycling, substratum turnover and removal of bycatch (Martini et al. 1997b).

### 3.5 Reproduction and Development

Little is known about the life history of hagfish. The age at maturity and lifespan of *Myxine* (in the Gulf of Maine or elsewhere) are not known. The timing, conditions and location of reproduction and egg deposition are not known (Martini et al. 1997a). However, it is evident that the reproductive potential of hagfish is extremely limited. The potentially small spawning stock increases the susceptibility of hagfish to overfishing.

Female hagfish produce small clutches of relatively large, yolky eggs encased in a leathery shell. Research on Pacific hagfish has shown that, on average, only 23.4 fully developed or developing eggs are found in the body of an adult female hagfish at any given time (Nakamura 1991, cited in Hultin et al. 1996). The average number of mature eggs typically found inside the female Atlantic hagfish is between 20-30 eggs, each about 22-28 mm in length and 10 mm in diameter (Martini et al. 1997a, Sower & Powell pers. comm. 2002). While the timing and location of fertilization and egg deposition is unknown, eggs have been trawled at depths of 50 to 150 fathoms (91.4 to 274.3 m) on mud, clay and sand bottoms (Martini & Flescher in Collette & Klein-MacPhee 2002). The time required to produce a crop of eggs has not been determined but is thought to be 1-2 years. Circumstantial evidence suggests that the eggs are deposited within burrows, and that breeding animals do not feed (Martini & Flescher in Collette & Klein-MacPhee 2002). The development time is not known, but the volume of yolk present suggests a period of several months. Hagfish do not have a larval stage (Worthington 1905). Only 4 embryos of *M. glutinosa* have been collected, none within the last 60 years, and only one of these was from the western North Atlantic (Dean 1899, Holmgren 1946, Fernholm 1969, Martini et al. 1997a); all were collected by trawling and were damaged as a result. 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). Hagfish are up to 1.5-2 feet long at maturity (Martini & Flescher in Collette & Klein-MacPhee). For more information on size distribution in the Gulf of Maine, see Section 4.2.

There are no external characteristics that can be used to distinguish males and females. Varying stages of oocytes and developing eggs have been found in males, and rudimentary testicular tissue is commonly found in animals with large developing eggs. Whether eggs found in males develop into mature eggs is unknown. Although stages of maturing eggs and the occurrence of spermatogenesis have been found simultaneously in a single hagfish (Walvig 1963, Patzner 1982, Sower & Powell pers. comm. 2002), there is no definitive evidence of functional hermaphroditism in hagfish (Martini & Flescher in Collette & Klein-MacPhee 2002). Mature eggs and mature sperm have not been found in the same individual. 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 (as in frogs, the eggs mature in clutches) (Sower & Powell pers. comm. 2002). The number of eggs produced has no relationship to the size of the female.

There is preliminary evidence of seasonal cycles of reproductive hormone production in Atlantic hagfish (Schutzinger et al. 1987, Powell & Sower unpub.), but no evidence of a synchronous breeding cycle in this species. Attempts to induce egg maturation and spawning through hormonal manipulation of captive hagfish have been unsuccessful (Tsuneki 1976). Inside the Gulf of Maine, gonadal development appears to begin when animals reach 400-450 mm in length. The sex ratio is strongly biased in favor of females; depending on the study and the collection site, the female:male ratio ranges from 5:1 to 10:1. The total lifespan has not been determined, nor has the duration of reproductive function, but large males and females (over 700 mm in length) contain functional gonads (Martini et al. 1997a). Surveys conducted on both sides of the Atlantic report that 15-25% of adult hagfish lack any macroscopically identifiable gonadal tissue (Martini et al. 1997a). The high proportion of non-reproductive adults further reduces the reproductive potential of the population.

## 4.0 FISHERY-INDEPENDENT INFORMATION

### 4.1 Hagfish Abundance

#### 4.1.1 Data Sources and Caveats

Atlantic hagfish have been collected in limited numbers throughout the 40 years of the NOAA Fisheries Northeast Fisheries Science Center (NEFSC) groundfish trawl survey. In general, hagfish are poorly represented in trawl surveys and trawl-based estimates of hagfish population density and abundance are likely to be substantially underestimated (Wakefield 1990, cited in Martini et al. 1998). However, trends in the population over an extended time period may be evident from these trawl survey data, and the NEFSC time series is a valuable indicator of presence and absence of hagfish in specific areas of the survey from the Gulf of Maine to Cape Hatteras over the past several decades.

Survey data in this report are presented for three areas in which the NEFSC groundfish and shrimp surveys are conducted:

- Two primary areas of the NEFSC groundfish trawl survey –
  - (1) Gulf of Maine (Figure E1)
  - (2) Offshore Area – deep water offshore area between Georges Bank and Cape Hatteras (Figure E2)
- One area of the NEFSC shrimp survey – Gulf of Maine (Figure E3)

Abundance data for hagfish in these analyses were from NEFSC spring (1968-2002) and fall (1963-2002) bottom trawl surveys for groundfish, and from NEFSC summer shrimp surveys from 1982 to 2002. Groundfish surveys covered the area between Cape Hatteras and the northern edge of Georges Bank (Offshore survey area) at depths of 110-183+ m and in the Gulf of Maine (GOM) at depths of 55-183+ m. The shrimp survey used shrimp bottom trawl gear in the GOM at depths of 55-100+ m. These NEFSC surveys provide the best available stock abundance information but none of the surveys covers the entire range of hagfish habitat, which extends over depths of 25-1000+ m. This report presents the first analysis of hagfish taken in the NEFSC shrimp survey. Relative abundance data for hagfish were either mean numbers per tow or the proportion positive tows (i.e. the proportion of tows with at least one hagfish).

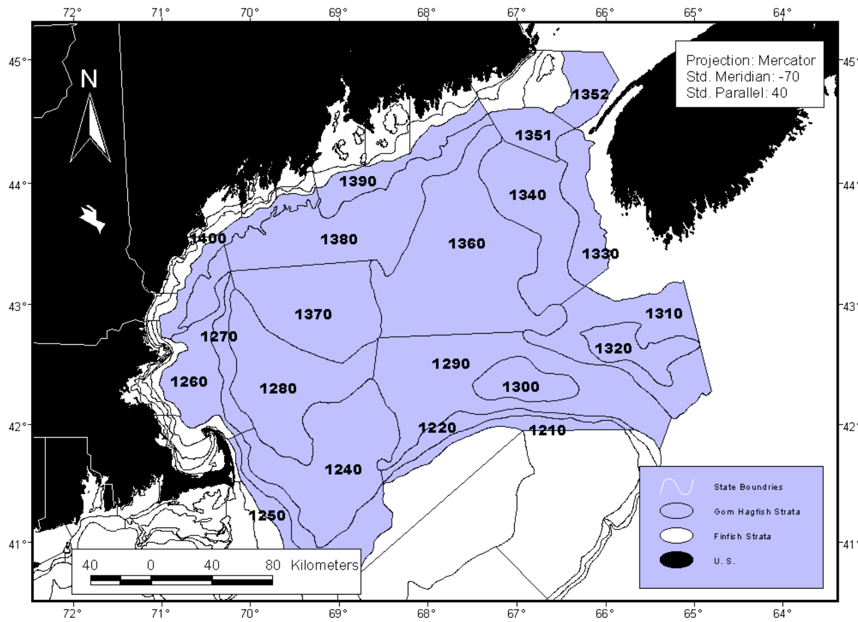



**Figure E1 - Gulf of Maine (GOM, NEFSC finfish survey strata 21-40)**

*Source: Northeast Fisheries Science Center*

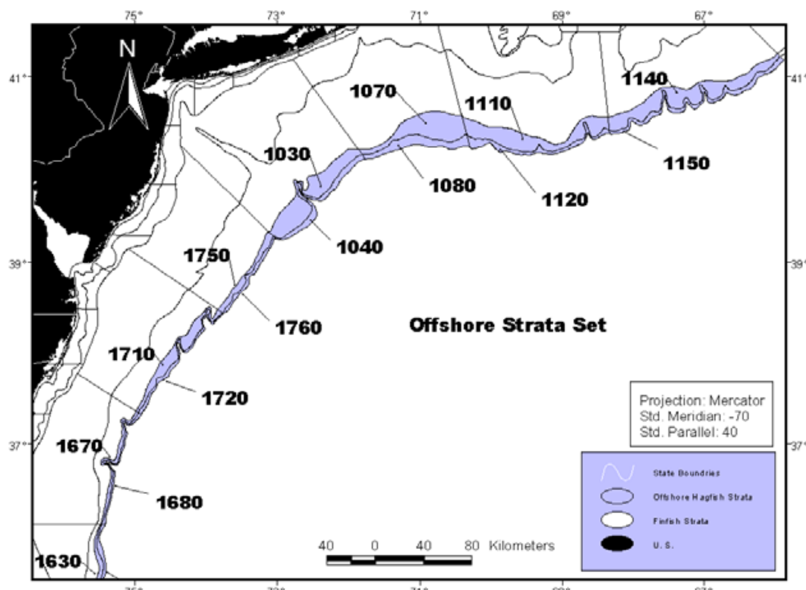



**Figure E2 - Offshore Southern New England (OFF, NEFSC finfish survey strata 3-4, 7-8, 11-12, 14-15, 63-64, 67-68, 71-72, and 75-76)**

*Source: Northeast Fisheries Science Center*

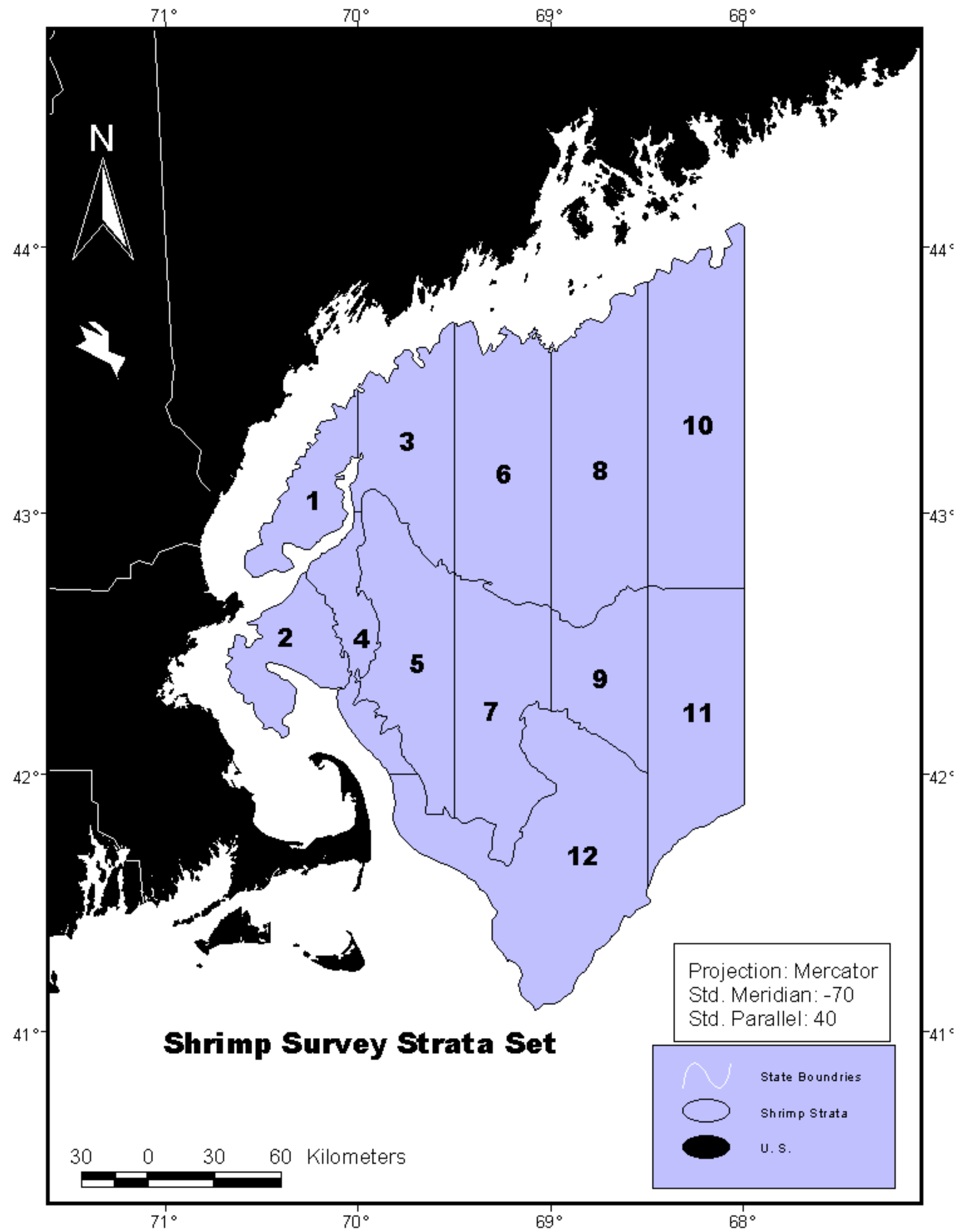



**Figure E3 - Gulf of Maine Shrimp (NEFSC shrimp strata 1-12)**

*Source: Northeast Fisheries Science Center*

### 4.1.2 Groundfish bottom trawl survey

Hagfish are captured in the fall and spring groundfish bottom trawl surveys and rarely taken during the winter survey. (Table E1 and Table E2) They are captured most frequently in the deeper strata of the Gulf of Maine survey area and along the shelf break of the Offshore survey area. Hagfish are rarely found on Georges Bank. Figure E4, Figure E5, Figure E6, and Figure E7 visually represent the number of hagfish captured in the fall survey from 1963-2002 and in the spring survey from 1968-2002. More hagfish were captured in fall surveys in both the Gulf of Maine and Offshore area than in spring surveys. Because so few individuals were captured in the bottom trawl surveys, these data were examined in terms of (a) the mean number of hagfish per tow, and (b) the proportion of total tows in which at least one hagfish was captured (proportion of positive tows). The latter method is useful for examining survey data in which a low number of individuals was captured and tows which capture no individuals (zero tows) occur relatively often. Mangel and Smith (1990) described the use of presence-absence sampling of eggs and larvae as a means of estimating adult biomass for pelagic species, focusing on the California sardine as a case study. While this sampling methodology is not directly applicable to hagfish, this study suggests that presence-absence data may be used to supplement other survey methods for species that are rare or difficult to sample. The percentage of tows in which at least one hagfish was captured was 11% for the Gulf of Maine fall survey. The proportion of positive tows was lowest for the Offshore fall survey, with only 5% of all tows capturing hagfish.

| | Gulf of Maine area | | | | | Offshore area | | | | | Combined Areas | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Mean Number per Tow | CV (%) | Number Positive Tows | Total Number Tows | Propor- tion Positive Tows | Mean Number per Tow | CV (%) | Number Positive Tows | Total Number Tows | Propor- tion Positive Tows | Mean Number per Tow | CV (%) | Number Positive Tows | Total Number Tows | Propor- tion Positive Tows |
| 1968 | 0.199 | 46 | 7 | 95 | 0.07 | 0.038 | 100 | 1 | 50 | 0.02 | 0.179 | 45 | 8 | 145 | 0.06 |
| 1969 | 0.114 | 32 | 10 | 95 | 0.11 | 0.118 | 66 | 3 | 41 | 0.07 | 0.115 | 29 | 13 | 136 | 0.10 |
| 1970 | 0.123 | 38 | 9 | 106 | 0.08 | 0.220 | 36 | 8 | 49 | 0.16 | 0.135 | 31 | 17 | 155 | 0.11 |
| 1971 | 0.296 | 26 | 17 | 123 | 0.14 | 0.185 | 48 | 3 | 40 | 0.08 | 0.284 | 25 | 20 | 163 | 0.12 |
| 1972 | 0.280 | 32 | 9 | 106 | 0.08 | 0.064 | 55 | 4 | 47 | 0.09 | 0.256 | 31 | 13 | 153 | 0.08 |
| 1973 | 0.072 | 32 | 7 | 96 | 0.07 | 0.088 | 54 | 4 | 43 | 0.09 | 0.074 | 29 | 11 | 139 | 0.08 |
| 1974 | 0.672 | 32 | 18 | 91 | 0.20 | 0.794 | 26 | 11 | 36 | 0.31 | 0.687 | 28 | 29 | 127 | 0.23 |
| 1975 | 0.563 | 32 | 18 | 93 | 0.19 | 0.394 | 32 | 8 | 36 | 0.22 | 0.541 | 29 | 26 | 129 | 0.20 |
| 1976 | 1.017 | 24 | 18 | 109 | 0.17 | 0.754 | 41 | 11 | 41 | 0.27 | 0.985 | 22 | 29 | 150 | 0.19 |
| 1977 | 0.028 | 62 | 11 | 117 | 0.09 | 0.000 | 0 | 7 | 40 | 0.18 | 0.025 | 62 | 18 | 157 | 0.11 |
| 1978 | 0.203 | 33 | 12 | 125 | 0.10 | 0.272 | 57 | 6 | 40 | 0.15 | 0.211 | 30 | 18 | 165 | 0.11 |
| 1979 | 0.097 | 48 | 8 | 142 | 0.06 | 0.000 | 0 | 0 | 39 | 0.00 | 0.086 | 48 | 8 | 181 | 0.04 |
| 1980 | 0.103 | 36 | 8 | 95 | 0.08 | 0.374 | 76 | 4 | 39 | 0.10 | 0.137 | 35 | 12 | 134 | 0.09 |
| 1981 | 0.140 | 36 | 11 | 93 | 0.12 | 0.214 | 19 | 7 | 36 | 0.19 | 0.149 | 30 | 18 | 129 | 0.14 |
| 1982 | 0.007 | 100 | 1 | 99 | 0.01 | 0.026 | 77 | 2 | 41 | 0.05 | 0.009 | 70 | 3 | 140 | 0.02 |
| 1983 | 0.051 | 51 | 4 | 97 | 0.04 | 0.213 | 83 | 2 | 40 | 0.05 | 0.071 | 44 | 6 | 137 | 0.04 |
| 1984 | 0.019 | 100 | 1 | 93 | 0.01 | 0.057 | 100 | 1 | 40 | 0.03 | 0.023 | 76 | 2 | 133 | 0.02 |
| 1985 | 0.000 | 0 | 0 | 87 | 0.00 | 0.026 | 100 | 1 | 39 | 0.03 | 0.003 | 100 | 1 | 126 | 0.01 |
| 1986 | 0.000 | 0 | 0 | 96 | 0.00 | 0.015 | 100 | 1 | 40 | 0.03 | 0.002 | 100 | 1 | 136 | 0.01 |
| 1987 | 0.012 | 100 | 1 | 90 | 0.01 | 0.007 | 100 | 1 | 40 | 0.03 | 0.011 | 92 | 2 | 130 | 0.02 |
| 1988 | 0.182 | 57 | 7 | 85 | 0.08 | 0.220 | 0 | 3 | 25 | 0.12 | 0.187 | 48 | 10 | 110 | 0.09 |
| 1989 | 0.017 | 100 | 1 | 77 | 0.01 | 0.026 | 0 | 1 | 25 | 0.04 | 0.018 | 79 | 2 | 102 | 0.02 |
| 1990 | 0.094 | 34 | 7 | 85 | 0.08 | 0.000 | 0 | 0 | 25 | 0.00 | 0.081 | 34 | 7 | 110 | 0.06 |
| 1991 | 0.008 | 100 | 1 | 81 | 0.01 | 0.000 | 0 | 0 | 26 | 0.00 | 0.007 | 100 | 1 | 107 | 0.01 |
| 1992 | 0.042 | 55 | 4 | 77 | 0.05 | 0.000 | 0 | 0 | 23 | 0.00 | 0.036 | 55 | 4 | 100 | 0.04 |
| 1993 | 0.000 | 0 | 0 | 82 | 0.00 | 0.031 | 0 | 1 | 23 | 0.04 | 0.004 | 0 | 1 | 105 | 0.01 |
| 1994 | 0.000 | 0 | 0 | 83 | 0.00 | 0.000 | 0 | 0 | 25 | 0.00 | 0.000 | 0 | 0 | 108 | 0.00 |
| 1995 | 0.237 | 52 | 5 | 84 | 0.06 | 0.093 | 0 | 1 | 24 | 0.04 | 0.217 | 49 | 6 | 108 | 0.06 |
| 1996 | 0.036 | 50 | 3 | 76 | 0.04 | 0.000 | 0 | 0 | 30 | 0.00 | 0.031 | 50 | 3 | 106 | 0.03 |
| 1997 | 0.096 | 77 | 3 | 85 | 0.04 | 0.016 | 0 | 1 | 23 | 0.04 | 0.086 | 76 | 4 | 108 | 0.04 |
| 1998 | 0.063 | 38 | 8 | 111 | 0.07 | 0.000 | 0 | 0 | 25 | 0.00 | 0.054 | 38 | 8 | 136 | 0.06 |
| 1999 | 0.083 | 47 | 5 | 81 | 0.06 | 0.000 | 0 | 0 | 25 | 0.00 | 0.071 | 47 | 5 | 106 | 0.05 |
| 2000 | 0.044 | 57 | 4 | 84 | 0.05 | 0.000 | 0 | 0 | 25 | 0.00 | 0.038 | 57 | 4 | 109 | 0.04 |
| 2001 | 0.216 | 27 | 14 | 85 | 0.16 | 0.000 | 0 | 0 | 25 | 0.00 | 0.186 | 27 | 14 | 110 | 0.13 |
| 2002 | 0.448 | 44 | 9 | 86 | 0.10 | 0.030 | 0 | 1 | 25 | 0.04 | 0.391 | 44 | 10 | 111 | 0.09 |

**Table E1 - NEFSC spring bottom trawl survey data for hagfish in the Gulf of Maine area, offshore area, and the combined Gulf of Maine and offshore areas**

The Gulf of Maine area consists of NEFSC offshore survey strata 01210-01400 excluding stratum 01351. The offshore area consists of NEFSC offshore survey strata 01030-01040, 01070-01080, 01110-01120, 01140-01150, 01630-01640, 01670-01680, 01710-01720, and 01750-01760. All data are for "sucessful" tows only (database SHG code <= 136).

| | Gulf of Maine area | | | | | Offshore area | | | | | Combined Areas | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Mean Number per Tow | CV (%) | Number Positive Tows | Total Number Tows | Propor-tion Positive Tows | Mean Number per Tow | CV (%) | Number Positive Tows | Total Number Tows | Propor-tion Positive Tows | Mean Number per Tow | CV (%) | Number Positive Tows | Total Number Tows | Propor-tion Positive Tows |
| 1963 | 0.156 | 55 | 8 | 105 | 0.08 | 0.000 | 0 | 1 | 23 | 0.04 | 0.141 | 55 | 9 | 128 | 0.07 |
| 1964 | 0.078 | 38 | 6 | 95 | 0.06 | 0.000 | 0 | 0 | 29 | 0.00 | 0.070 | 38 | 6 | 124 | 0.05 |
| 1965 | 0.024 | 65 | 3 | 97 | 0.03 | 0.048 | 73 | 2 | 32 | 0.06 | 0.026 | 55 | 5 | 129 | 0.04 |
| 1966 | 0.214 | 29 | 13 | 96 | 0.14 | 0.289 | 22 | 9 | 32 | 0.28 | 0.222 | 25 | 22 | 128 | 0.17 |
| 1967 | 0.153 | 40 | 8 | 92 | 0.09 | 0.082 | 76 | 2 | 50 | 0.04 | 0.144 | 38 | 10 | 142 | 0.07 |
| 1968 | 0.079 | 52 | 4 | 95 | 0.04 | 0.047 | 60 | 3 | 42 | 0.07 | 0.075 | 49 | 7 | 137 | 0.05 |
| 1969 | 0.303 | 26 | 18 | 97 | 0.19 | 0.860 | 62 | 7 | 42 | 0.17 | 0.371 | 25 | 25 | 139 | 0.18 |
| 1970 | 0.355 | 25 | 17 | 103 | 0.17 | 0.015 | 0 | 2 | 42 | 0.05 | 0.313 | 25 | 19 | 145 | 0.13 |
| 1971 | 0.140 | 38 | 8 | 103 | 0.08 | 0.023 | 73 | 2 | 43 | 0.05 | 0.126 | 37 | 10 | 146 | 0.07 |
| 1972 | 0.939 | 55 | 18 | 104 | 0.17 | 0.292 | 80 | 5 | 41 | 0.12 | 0.860 | 53 | 23 | 145 | 0.16 |
| 1973 | 0.441 | 25 | 19 | 102 | 0.19 | 0.015 | 100 | 1 | 41 | 0.02 | 0.389 | 25 | 20 | 143 | 0.14 |
| 1974 | 0.258 | 58 | 7 | 107 | 0.07 | 1.523 | 97 | 4 | 41 | 0.10 | 0.413 | 54 | 11 | 148 | 0.07 |
| 1975 | 0.200 | 46 | 11 | 115 | 0.10 | 0.115 | 71 | 2 | 39 | 0.05 | 0.190 | 43 | 13 | 154 | 0.08 |
| 1976 | 0.380 | 38 | 12 | 97 | 0.12 | 0.095 | 100 | 1 | 41 | 0.02 | 0.345 | 37 | 13 | 138 | 0.09 |
| 1977 | 0.112 | 33 | 11 | 133 | 0.08 | 0.085 | 100 | 1 | 39 | 0.03 | 0.109 | 32 | 12 | 172 | 0.07 |
| 1978 | 0.230 | 27 | 25 | 201 | 0.12 | 0.071 | 78 | 2 | 38 | 0.05 | 0.211 | 26 | 27 | 239 | 0.11 |
| 1979 | 0.195 | 25 | 20 | 212 | 0.09 | 0.021 | 0 | 1 | 37 | 0.03 | 0.173 | 25 | 21 | 249 | 0.08 |
| 1980 | 0.373 | 31 | 15 | 105 | 0.14 | 0.000 | 0 | 0 | 36 | 0.00 | 0.328 | 31 | 15 | 141 | 0.11 |
| 1981 | 0.309 | 24 | 18 | 100 | 0.18 | 0.128 | 89 | 2 | 37 | 0.05 | 0.287 | 23 | 20 | 137 | 0.15 |
| 1982 | 0.022 | 71 | 2 | 104 | 0.02 | 0.000 | 0 | 0 | 38 | 0.00 | 0.019 | 71 | 2 | 142 | 0.01 |
| 1983 | 0.290 | 33 | 11 | 90 | 0.12 | 0.046 | 0 | 2 | 39 | 0.05 | 0.259 | 32 | 13 | 129 | 0.10 |
| 1984 | 0.155 | 85 | 4 | 98 | 0.04 | 0.000 | 0 | 0 | 39 | 0.00 | 0.137 | 85 | 4 | 137 | 0.03 |
| 1985 | 0.150 | 39 | 12 | 95 | 0.13 | 0.023 | 100 | 1 | 38 | 0.03 | 0.134 | 38 | 13 | 133 | 0.10 |
| 1986 | 0.106 | 48 | 7 | 101 | 0.07 | 0.032 | 72 | 2 | 39 | 0.05 | 0.097 | 46 | 9 | 140 | 0.06 |
| 1987 | 0.229 | 43 | 7 | 83 | 0.08 | 0.000 | 0 | 0 | 24 | 0.00 | 0.198 | 43 | 7 | 107 | 0.07 |
| 1988 | 0.017 | 100 | 1 | 84 | 0.01 | 0.026 | 0 | 1 | 25 | 0.04 | 0.018 | 80 | 2 | 109 | 0.02 |
| 1989 | 0.312 | 31 | 14 | 83 | 0.17 | 0.000 | 0 | 0 | 25 | 0.00 | 0.269 | 31 | 14 | 108 | 0.13 |
| 1990 | 0.226 | 31 | 14 | 85 | 0.16 | 0.000 | 0 | 0 | 24 | 0.00 | 0.196 | 31 | 14 | 109 | 0.13 |
| 1991 | 0.027 | 71 | 2 | 85 | 0.02 | 0.015 | 0 | 1 | 25 | 0.04 | 0.025 | 65 | 3 | 110 | 0.03 |
| 1992 | 0.112 | 54 | 5 | 82 | 0.06 | 0.121 | 100 | 1 | 22 | 0.05 | 0.113 | 49 | 6 | 104 | 0.06 |
| 1993 | 0.185 | 36 | 9 | 82 | 0.11 | 0.000 | 0 | 0 | 24 | 0.00 | 0.159 | 36 | 9 | 106 | 0.08 |
| 1994 | 0.656 | 26 | 23 | 84 | 0.27 | 0.026 | 0 | 1 | 24 | 0.04 | 0.569 | 26 | 24 | 108 | 0.22 |
| 1995 | 0.267 | 27 | 15 | 89 | 0.17 | 0.026 | 0 | 1 | 25 | 0.04 | 0.234 | 27 | 16 | 114 | 0.14 |
| 1996 | 0.118 | 41 | 8 | 81 | 0.10 | 0.000 | 0 | 0 | 25 | 0.00 | 0.102 | 41 | 8 | 106 | 0.08 |
| 1997 | 0.102 | 40 | 7 | 86 | 0.08 | 0.000 | 0 | 0 | 25 | 0.00 | 0.088 | 40 | 7 | 111 | 0.06 |
| 1998 | 0.406 | 32 | 12 | 99 | 0.12 | 0.000 | 0 | 0 | 25 | 0.00 | 0.350 | 32 | 12 | 124 | 0.10 |
| 1999 | 0.368 | 27 | 23 | 102 | 0.23 | 0.000 | 0 | 0 | 24 | 0.00 | 0.318 | 27 | 23 | 126 | 0.18 |
| 2000 | 0.602 | 42 | 14 | 83 | 0.17 | 0.013 | 0 | 1 | 26 | 0.04 | 0.521 | 42 | 15 | 109 | 0.14 |
| 2001 | 0.650 | 36 | 13 | 86 | 0.15 | 0.026 | 0 | 1 | 23 | 0.04 | 0.565 | 36 | 14 | 109 | 0.13 |
| 2002 | 0.186 | 28 | 8 | 81 | 0.10 | 0.179 | 0 | 5 | 25 | 0.20 | 0.185 | 24 | 13 | 106 | 0.12 |

**Table E2 - NEFSC fall bottom trawl survey data for hagfish in the Gulf of Maine area, offshore area, and the combined Gulf of Maine and offshore areas**

The Gulf of Maine area consists of NEFSC offshore survey strata 01210-01400 excluding stratum 01351. The offshore area consists of NEFSC offshore survey strata 01030-01040, 01070-01080, 01110-01120, 01140-01150, 01630-01640, 01670-01680, 01710-01720, and 01750-01760. All data are for "sucessful" tows only (database SHG code <= 136).

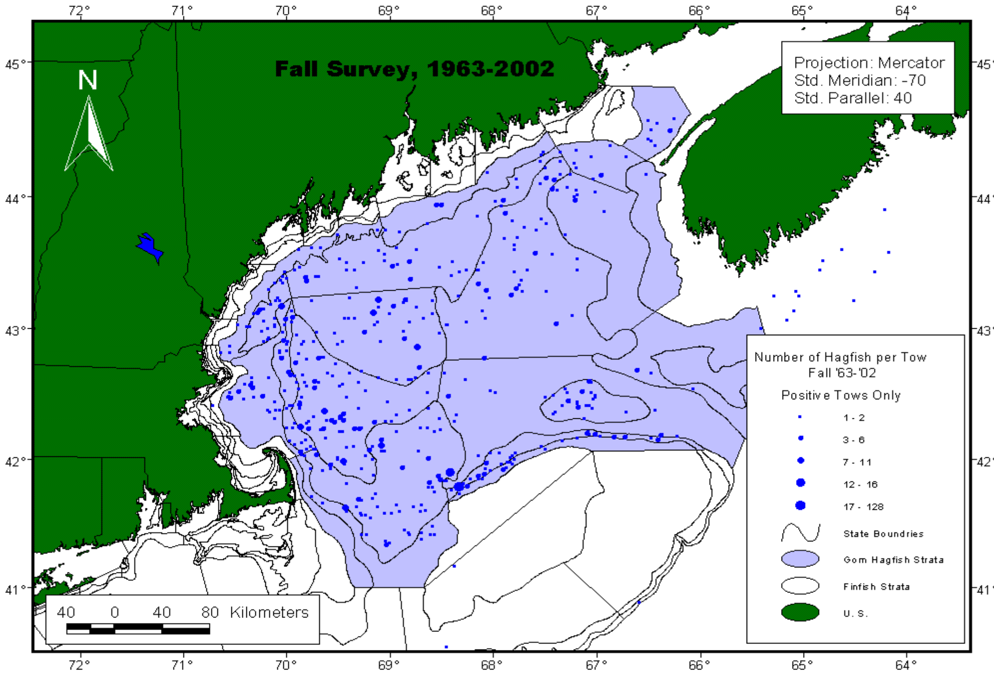



**Figure E4 - Number of hagfish per tow in NEFSC fall groundfish survey (Gulf of Maine strata), 1963-2002**

*Source: Northeast Fisheries Science Center*

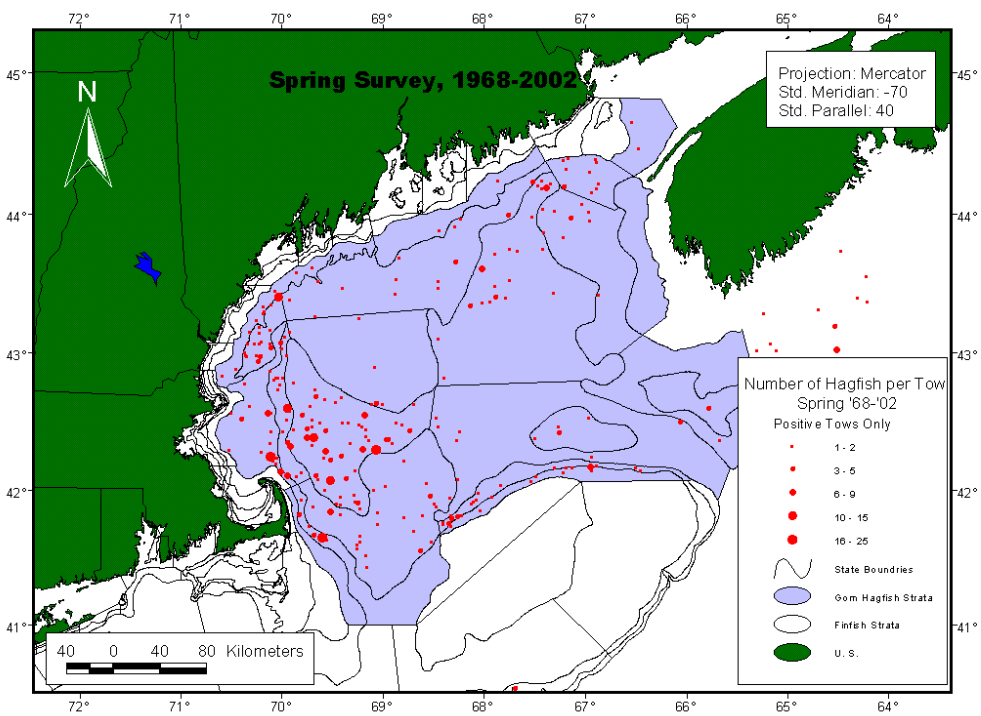



**Figure E5 - Number of hagfish per tow in NEFSC spring groundfish survey (Gulf of Maine strata), 1968-2002**

*Source: Northeast Fisheries Science Center*

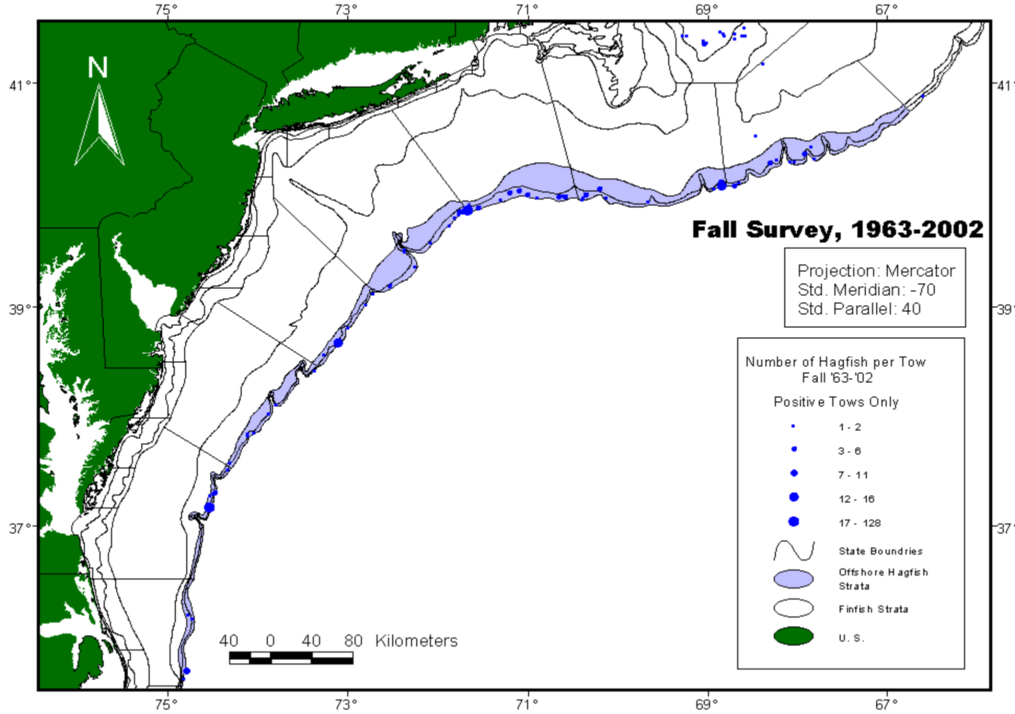



**Figure E6 - Number of hagfish per tow in NEFSC fall groundfish survey (Offshore strata), 1963-2002**

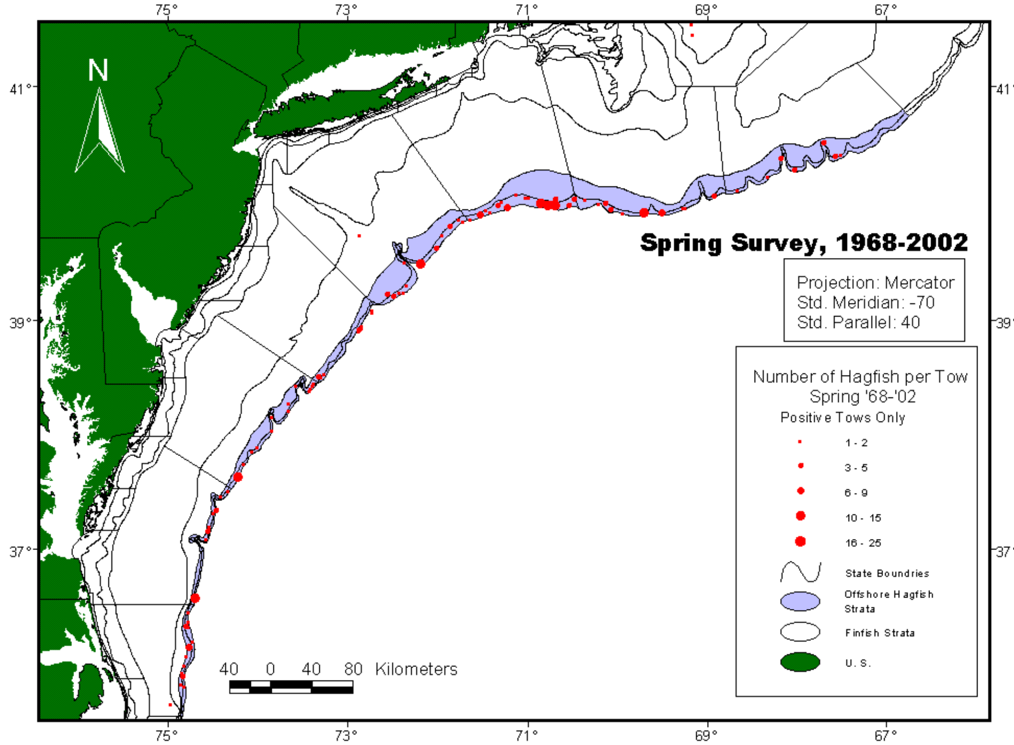



**Figure E7 - Number per tow in NEFSC spring groundfish survey (Offshore strata), 1968-2002**

*Source: Northeast Fisheries Science Center*

For all survey areas and seasons, mean number per tow and proportion of positive tow data were "smoothed" using a 3-year moving average to show longer-term trends. The Gulf of Maine survey data indicate a decline in hagfish abundance from the mid-1970s through the early 1990s, with increases afterwards. Abundance increased slightly through the late-1990s (Figure E8). Offshore survey data demonstrate a consistent decline in hagfish abundance in both the fall and spring (Figure E9). It should be noted that this survey covers only the edge of hagfish habitat in the region south of southern New England. Combining the offshore and Gulf of Maine survey data yields trends similar to those seen in survey data from the Gulf of Maine alone (Figure E10).

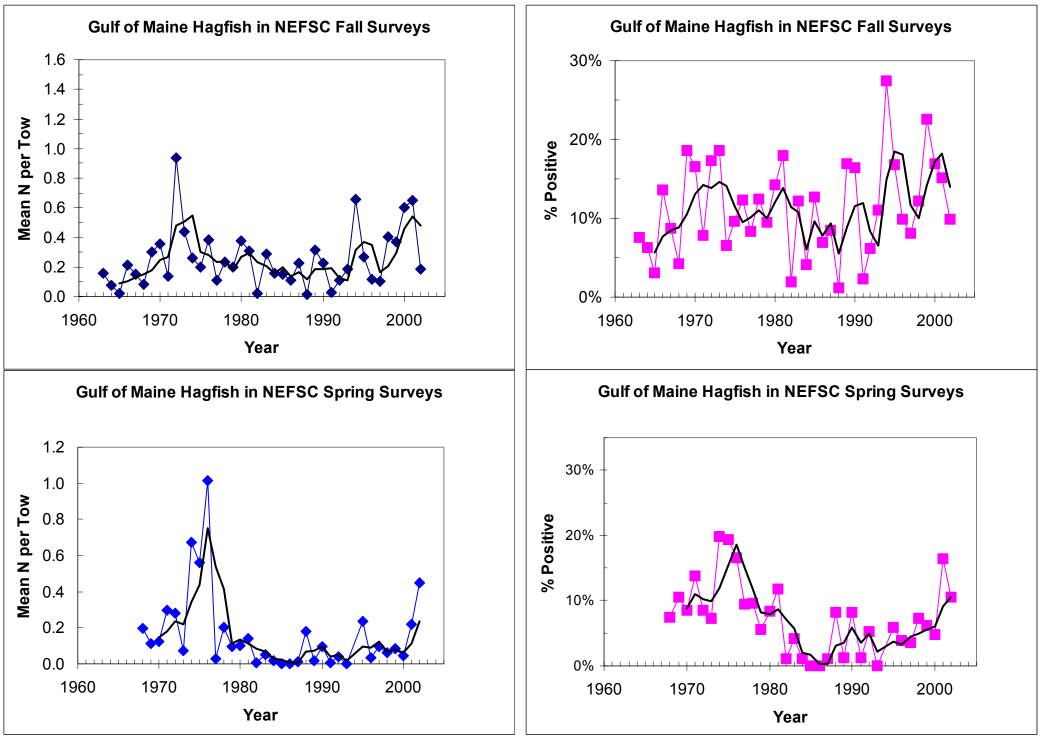



**Figure E8 - Hagfish abundance in Gulf of Maine survey area, fall (1963-2002) and spring (1968-2002)**

*Source: Northeast Fisheries Science Center*
*(smoothed trend line represents three-year moving average)*

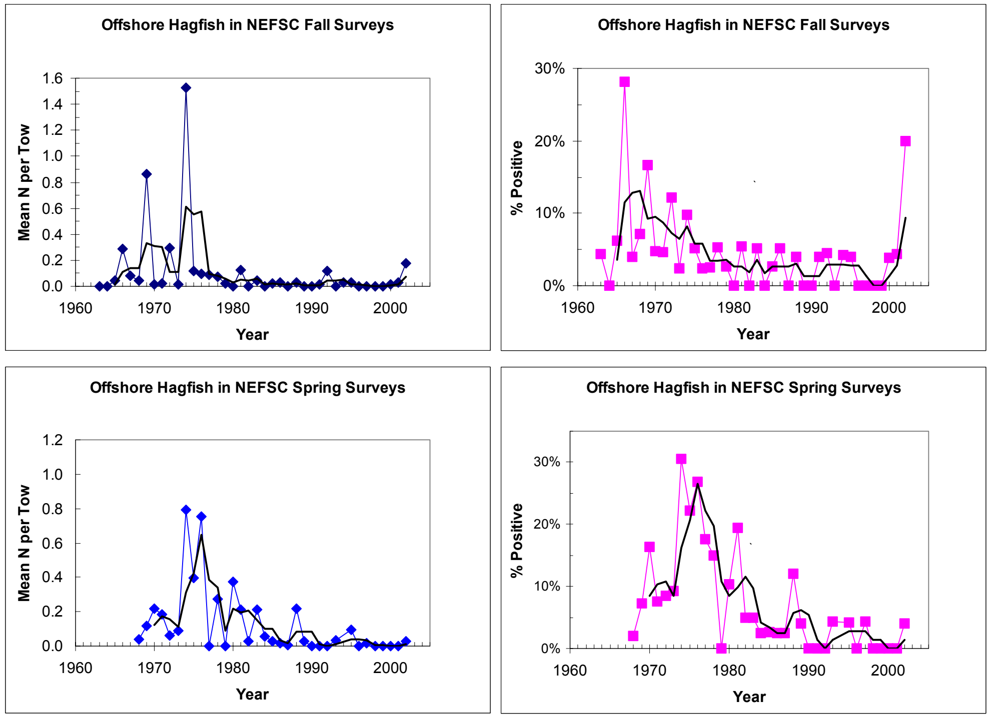



**Figure E9 - Hagfish abundance in offshore survey area, fall (1963-2002) and spring (1968-2002)**

*Source: Northeast Fisheries Science Center*
*(smoothed trend line represents three-year moving average)*

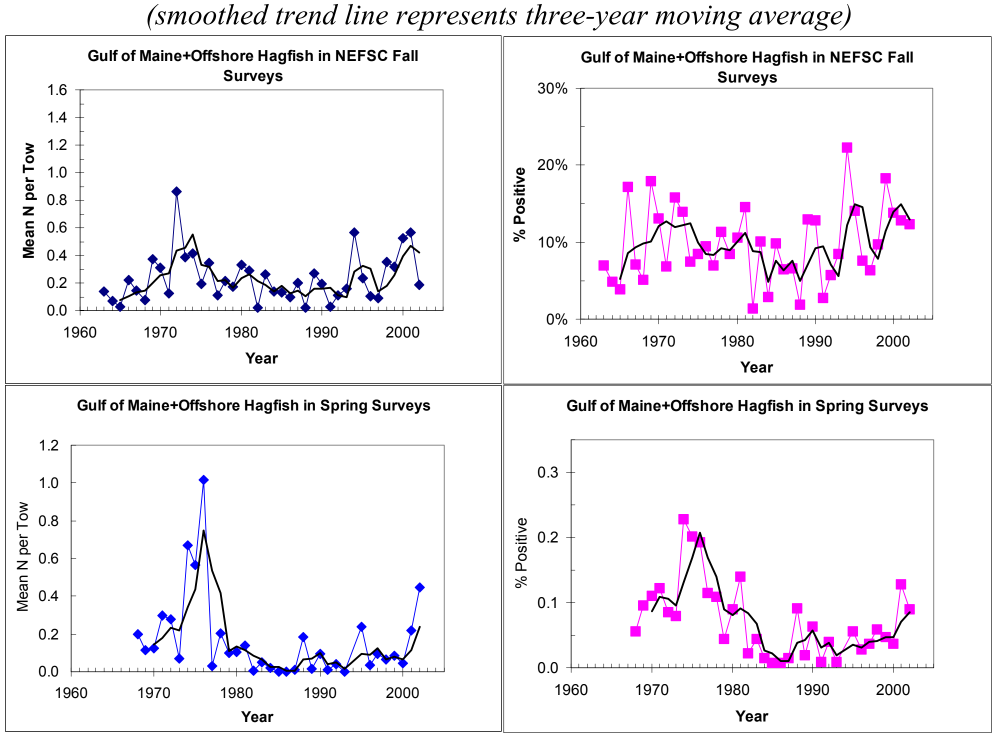



**Figure E10 - Hagfish abundance in Gulf of Maine and offshore survey areas, fall (1963-2002) and spring (1968-2002)**

*Source: Northeast Fisheries Science Center*
*(smoothed trend line represents three-year moving average)*

Hagfish are captured in the survey at depths of 50 to 450 meters (Figure E11), with the highest numbers of individuals per tow occurring at depths of 150-250 meters.

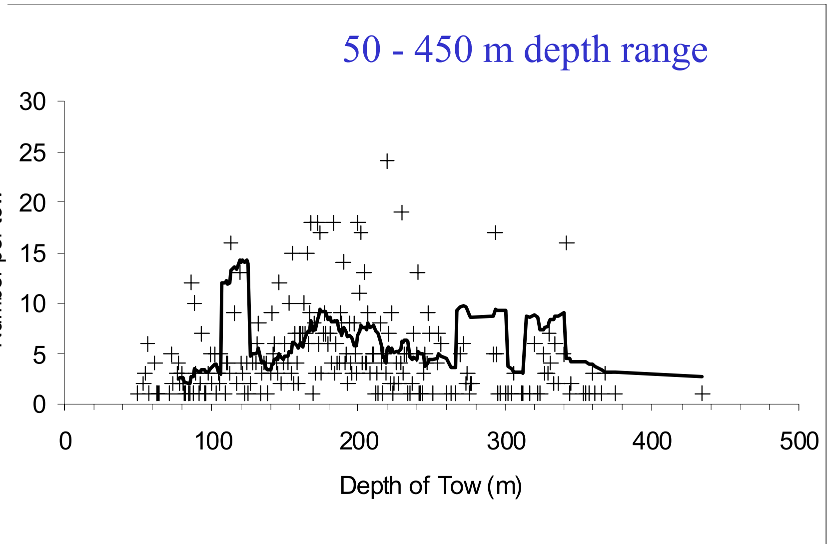



**Figure E11 - Depth for bottom trawl (groundfish) survey tows with hagfish**

*Source: Northeast Fisheries Science Center*

Hagfish were caught in areas with bottom temperatures ranging from 2 to 15°C but were most commonly encountered at temperatures of 5-10°C (Figure E12).

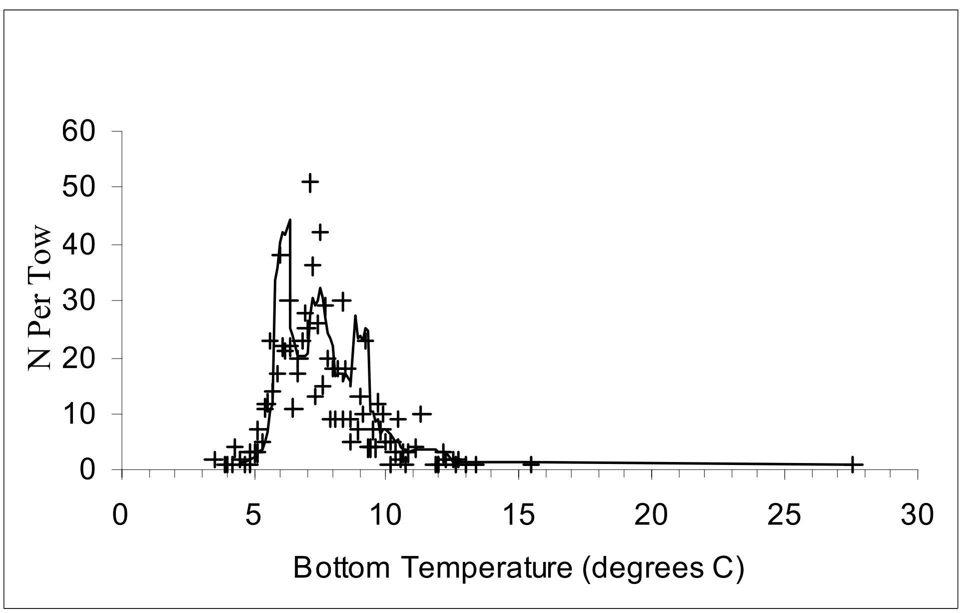



**Figure E12 - Catch and bottom temperature for bottom trawl (groundfish) survey tows with hagfish**

*Source: Northeast Fisheries Science Center*

### 4.1.3 Shrimp survey

The Gulf of Maine Northern Shrimp Survey has been conducted by the Northeast Fisheries Science Center (NEFSC) in cooperation with the Northern Shrimp Technical Committee of the Atlantic States Marine Fisheries Commission since 1983. The survey is designed to provide data required for annual stock assessments and related tasks. Hagfish are captured incidentally in this survey in low numbers. The overall trend in mean number of hagfish per tow and proportion of positive tows in the shrimp survey was highly variable with a peak during 1993-1994 (Table E3; Figure E13 and Figure E14).

| Year | Total Tows | # of Hagfish | Positive Tows | Mean # / Tow | Proportion Positive |
|---|---|---|---|---|---|
| 1983 | 22 | * | * | NA | NA |
| 1984 | 39 | 5 | 2 | 0.13 | 5.13 |
| 1985 | 55 | 2 | 2 | 0.04 | 3.64 |
| 1986 | 54 | * | * | NA | NA |
| 1987 | 57 | 4 | 3 | 0.07 | 5.26 |
| 1988 | 44 | 0 | 0 | 0.00 | 0.00 |
| 1989 | 49 | 2 | 2 | 0.04 | 4.08 |
| 1990 | 48 | 4 | 4 | 0.08 | 8.33 |
| 1991 | 56 | 4 | 4 | 0.07 | 7.14 |
| 1992 | 57 | 1 | 1 | 0.02 | 1.75 |
| 1993 | 53 | 10 | 8 | 0.19 | 15.09 |
| 1994 | 49 | 8 | 8 | 0.16 | 16.33 |
| 1995 | 53 | 0 | 0 | 0.00 | 0.00 |
| 1996 | 58 | 12 | 6 | 0.21 | 10.34 |
| 1997 | 55 | 3 | 3 | 0.05 | 5.45 |
| 1998 | 61 | 0 | 0 | 0.00 | 0.00 |
| 1999 | 61 | 7 | 6 | 0.11 | 9.84 |
| 2000 | 55 | 3 | 2 | 0.05 | 3.64 |
| 2001 | 57 | 4 | 4 | 0.07 | 7.02 |
| 2002 | 54 | 3 | 3 | 0.06 | 5.56 |

**Table E3 – Hagfish abundance in the NEFSC summer shrimp survey, 1983-2002**

*Source: Northeast Fisheries Science Center*

** only weight recorded in database*

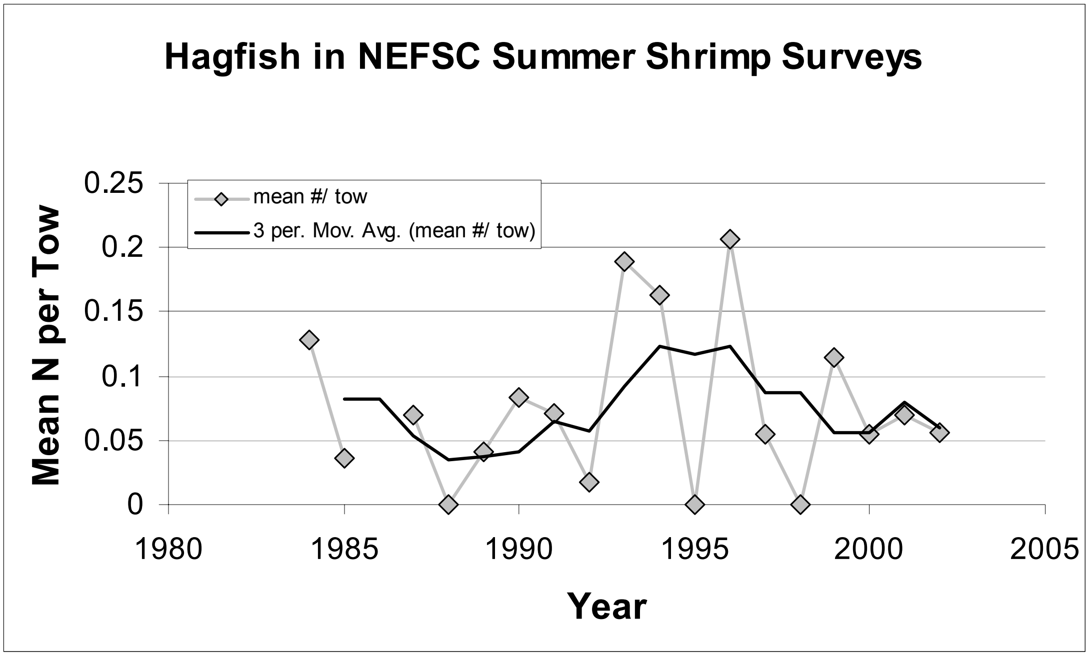



**Figure E13 – Mean number of hagfish per tow in Gulf of Maine shrimp survey areas, summer (1983-2002)**

*Source: Northeast Fisheries Science Center*

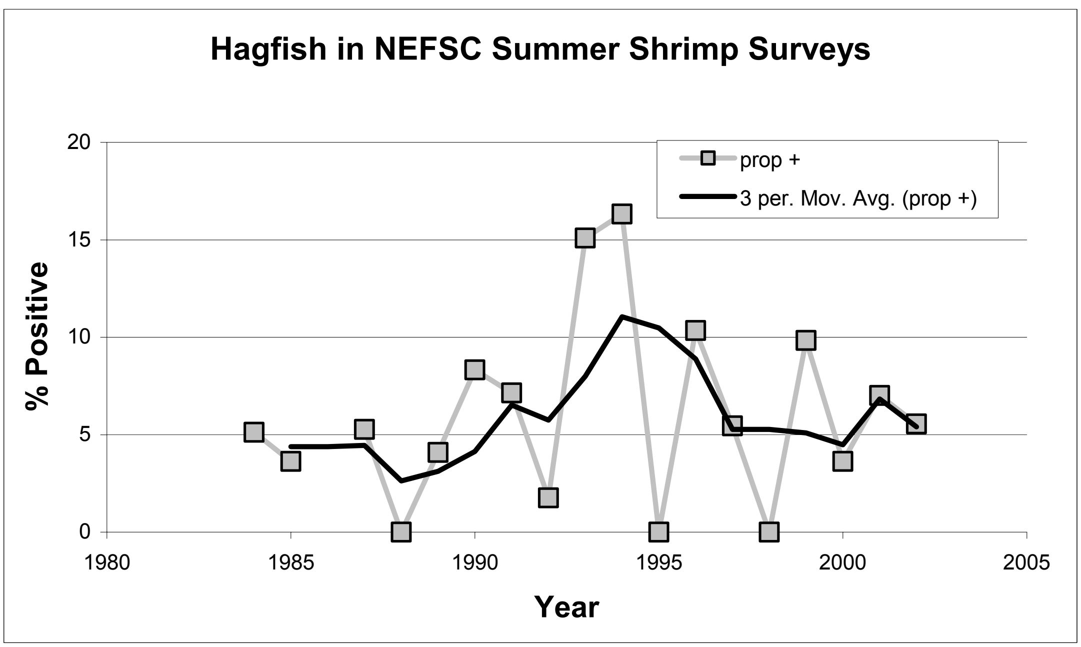



**Figure E14 – Proportion of positive hagfish tows in Gulf of Maine shrimp survey areas, summer (1983-2002)**

*Source: Northeast Fisheries Science Center*

**Summary**
In general, hagfish are rare in both groundfish bottom trawl and shrimp surveys and it is not known to what degree trends in abundance are confounded by noise resulting from small sample sizes. Data from groundfish bottom trawl surveys cover a larger area, are based on more tows, and may be more reliable.

### 4.2 Hagfish Length Frequencies

#### 4.2.1 Data Sources and Caveats

- Length frequency data for hagfish in these analyses were taken from NEFSC spring (1968-2002) and fall (1963-2002) bottom trawl surveys for groundfish, and from NEFSC summer shrimp surveys from 1982 to 2002.
  - Length data for hagfish were total length from snout to tip of tail in centimeters.
  - Length composition data were numbers per 1 cm size group for all hagfish measured in successful random survey tows (database SHG codes ≤ 136). Since tows are allocated to strata randomly and all fish are identified and measured, simple counts are adequate for characterizing length frequency of survey catches.

- Length data from spring and fall bottom trawl surveys were aggregated by two geographic areas [Gulf of Maine (GOM) and Offshore (OFF), see Figure E1 and Figure E2] for analysis. Length and survey catch data from the Gulf of Maine shrimp survey were for a third area, which largely overlapped the Gulf of Maine trawl survey area (Figure E3).

- Survey coverage –
  The number of tows in OFF declined over time but all strata were sampled in most years (Figure E15, Figure E16, Figure E17, and Figure E18).

- For some length frequency analyses, fall survey data were aggregated by decade to examine trends over time. Spring groundfish trawl and shrimp survey data were too sparse for this type of analysis.

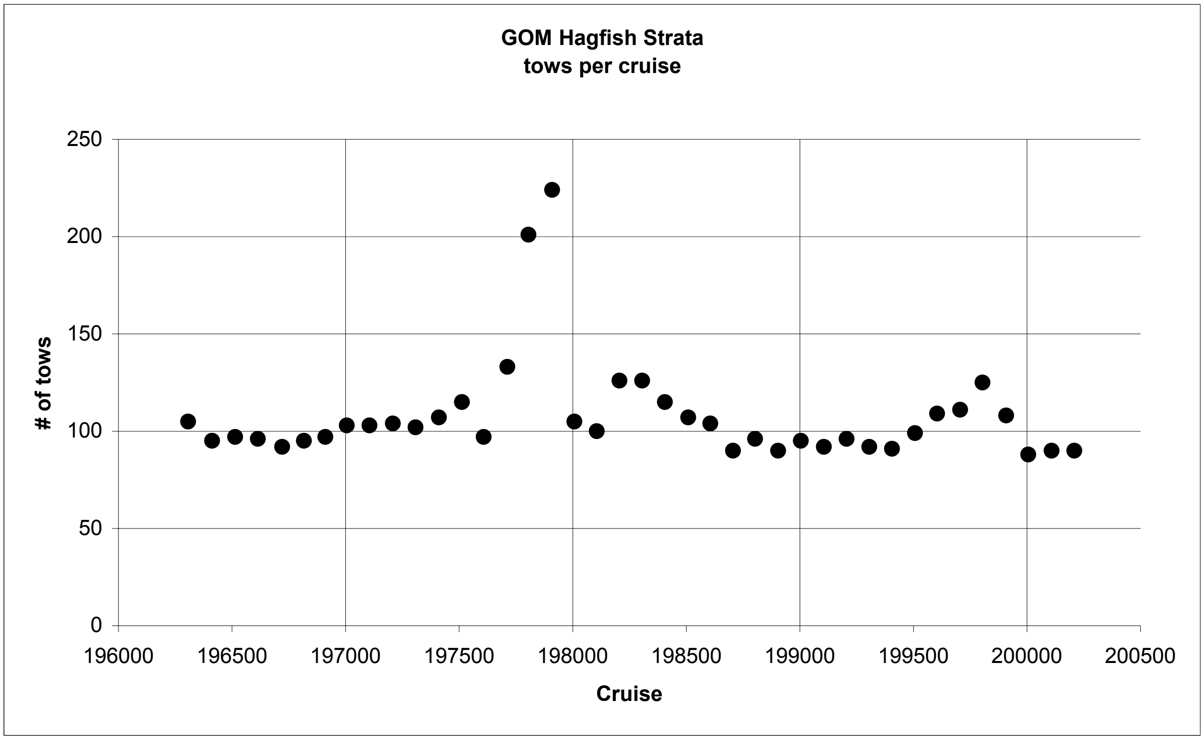



**Figure E15 - Tows per cruise in the GOM fall survey area**

*Source: Northeast Fisheries Science Center*

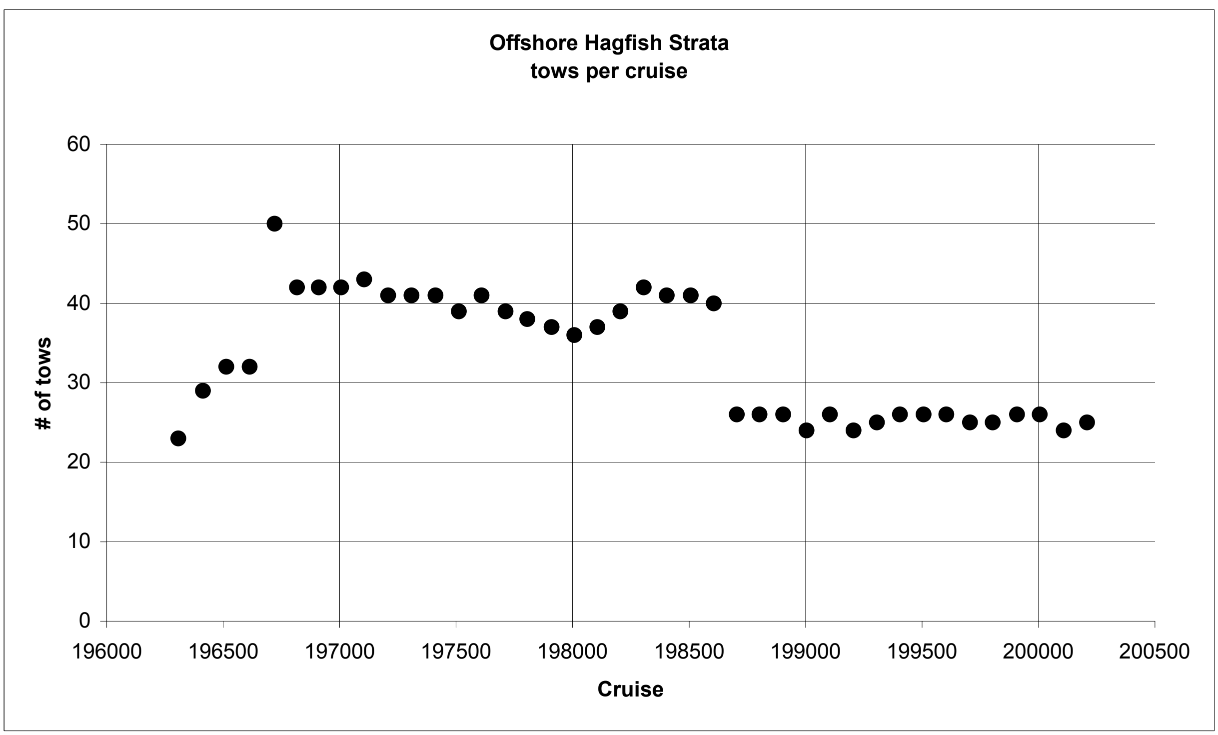



**Figure E16 - Tows per cruise in the Offshore fall survey area**

*Source: Northeast Fisheries Science Center*

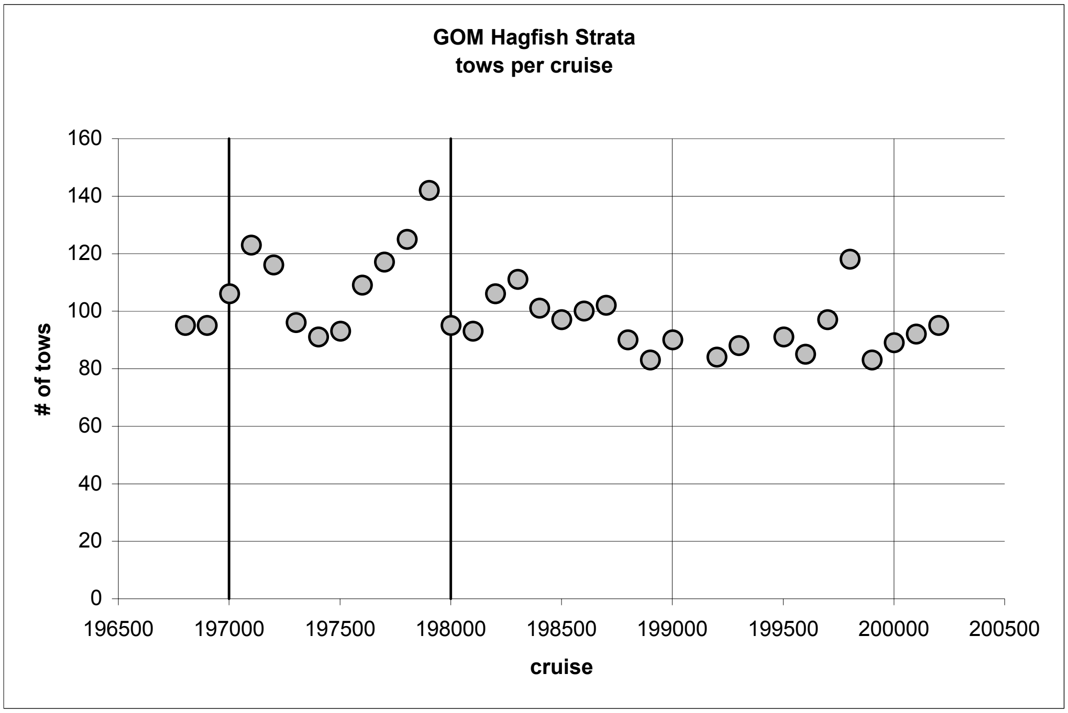



**Figure E17 – Tows per cruise in the GOM spring survey area**

*Source: Northeast Fisheries Science Center*

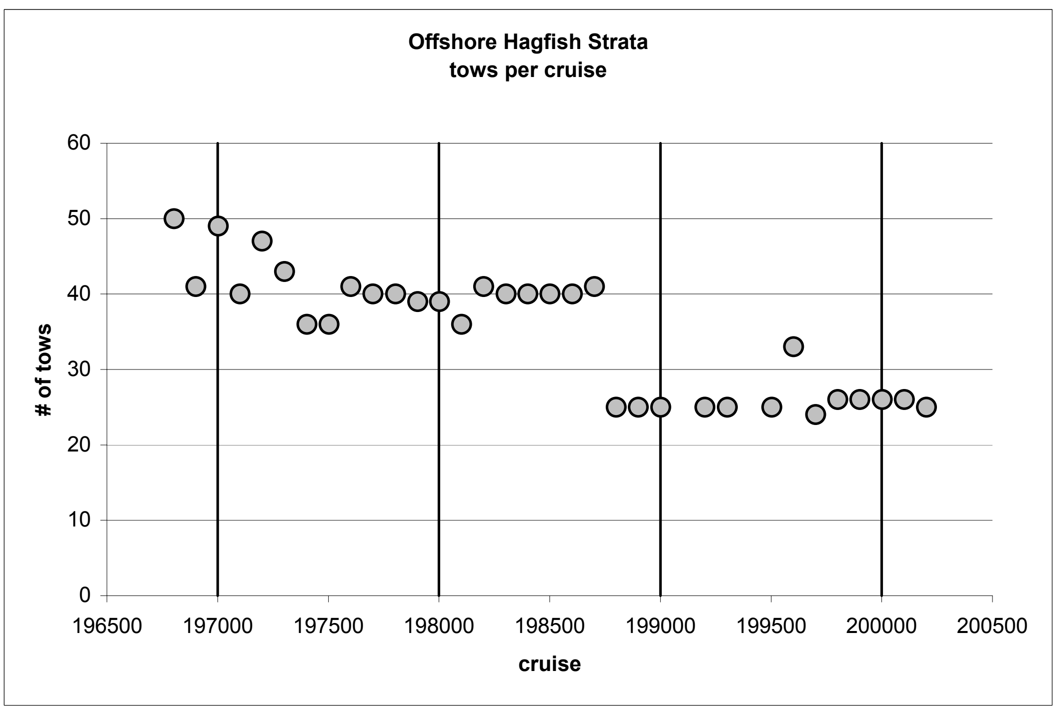



**Figure E18 – Tows per cruise in the Offshore spring survey area**

*Source: Northeast Fisheries Science Center*

### 4.2.2 Groundfish Bottom Trawl and Shrimp Surveys

Hagfish caught during spring and fall surveys in the GOM were larger than animals captured in the Offshore area. Hagfish caught in the shrimp surveys had the highest mean length (Table E4).

| Area | Grand Mean Catch Per Tow (N/Tow) | Proportion Positive Tows (%) | Modal Length (cm) | Mean Length (cm) | Minimum Length (cm) | Maximum Length (cm) | N Measured |
|---|---|---|---|---|---|---|---|
| GOM spring | 0.164 | 7 | 43 | 40.5 | 10 | 70 | 589 |
| GOM fall | 0.253 | 11 | 42 | 42.6 | 5 | 91 | 1035 |
| OFF spring | 0.126 | 7 | 36 | 34.7 | 19 | 48 | 269 |
| OFF fall | 0.106 | 5 | 37 | 34.6 | 15 | 50 | 294 |
| Shrimp summer survey | 0.08 | 6 | 60 | 55.5 | 18 | 66 | 65 |

**Table E4 – Catch and length data for hagfish in the groundfish and shrimp surveys**

*Source: Northeast Fisheries Science Center*

Length frequency curves were similar for hagfish caught during the spring and fall in both the Gulf of Maine and Offshore areas. In the Gulf of Maine, hagfish length averaged 40.5 cm in the spring and 42.6 cm in the fall. In the Offshore survey area, mean length in the spring was 34.7 cm and 34.6 in the fall. (Figure E19, Figure E20, Figure E21, and Figure E22).

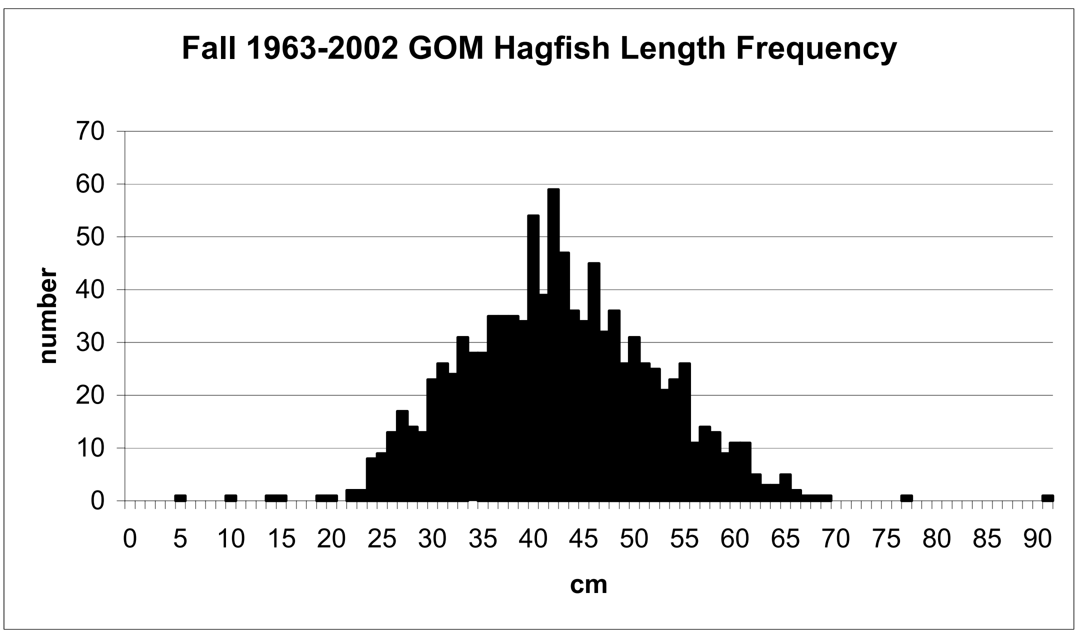



**Figure E19 – GOM hagfish length frequency in the fall groundfish survey**

*Source: Northeast Fisheries Science Center*

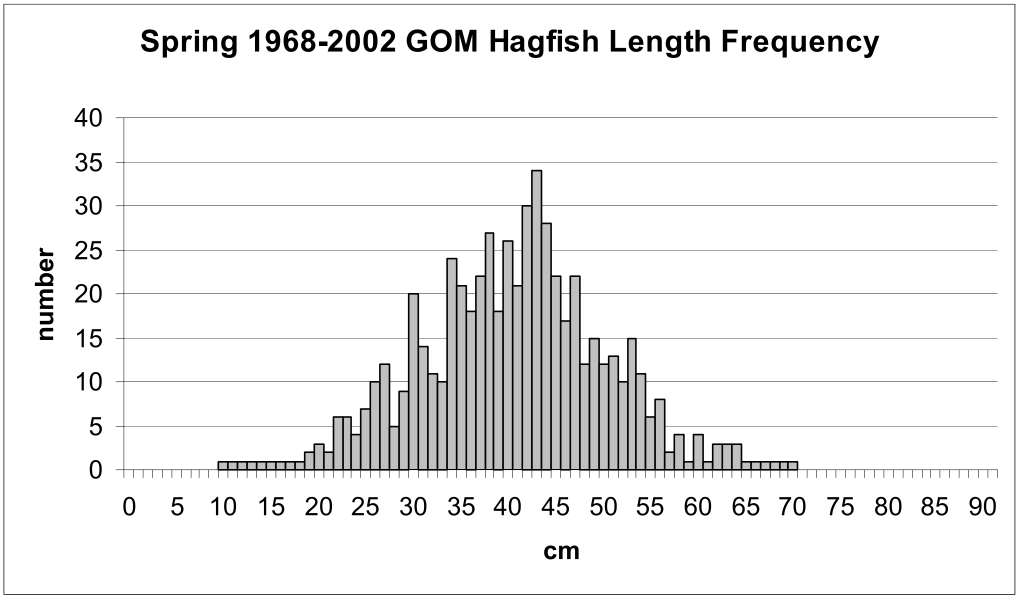



**Figure E20 - GOM hagfish length frequency in the spring groundfish survey**

*Source: Northeast Fisheries Science Center*

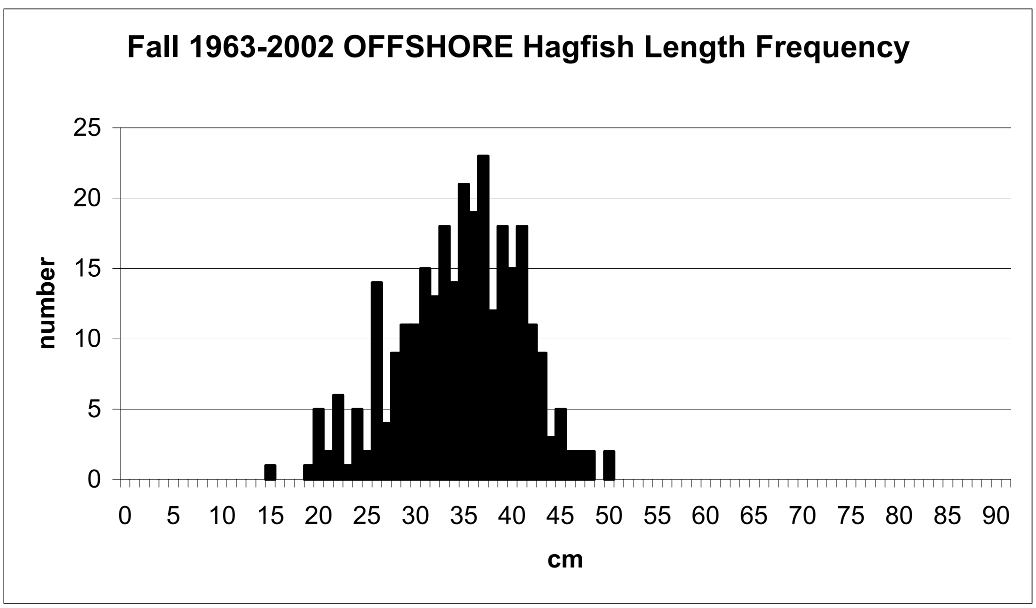



**Figure E21 - Offshore hagfish length frequency in the fall groundfish survey**

*Source: Northeast Fisheries Science Center*

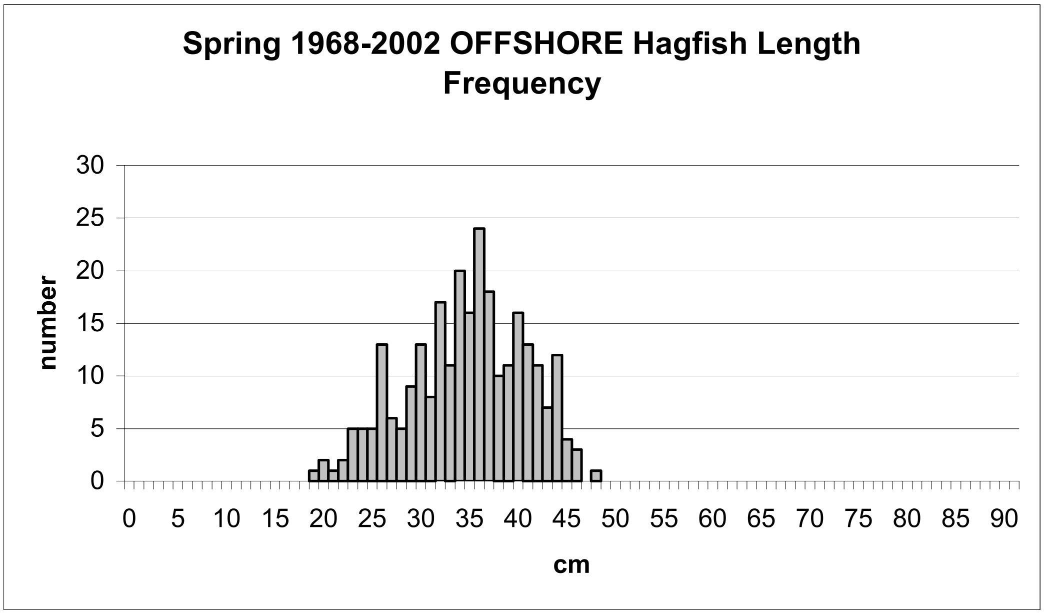



**Figure E22 - Offshore hagfish length frequency in the spring groundfish survey**

*Source: Northeast Fisheries Science Center*

Length frequencies for hagfish caught during the summer shrimp survey have a higher mean and mode than the other surveys but a much smaller sample size, with only 65 individuals measured and a mean of 0.08 individuals per tow (Table E4 and Figure E23).

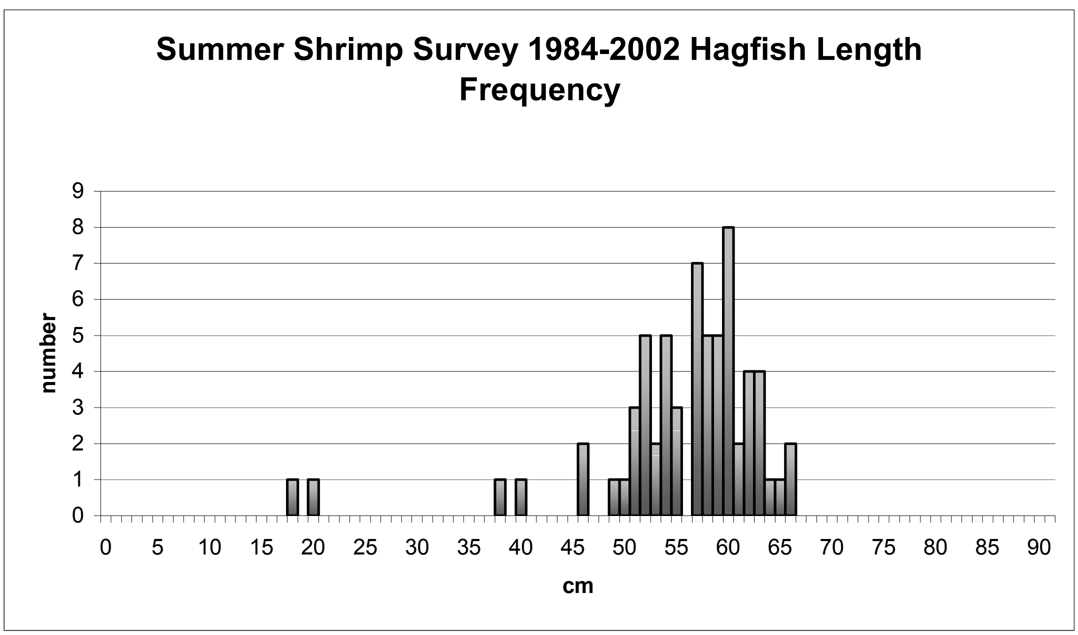



**Figure E23 - GOM hagfish length frequency in the summer shrimp survey**

*Source: Northeast Fisheries Science Center*

Based on visual analyses, it appears that modal length declined in the Gulf of Maine from the 1980s to 2002 (Figure E24, Figure E25, Figure E26, and Figure E27). Too much noise exists in data from spring surveys to detect changes in modal size. Mean length for hagfish in the GOM declined after the 1970s (Table E5). Mean values for the 1960s and 2000s are uncertain because of low sample size and fewer years of data.

| Survey/Region | 1963/8-69 | 1970-79 | 1980-89 | 1990-99 | 2000-02 |
|---|---|---|---|---|---|
| Spring GOM | 40.0 (29) | 41.3 (365) | 43.4 (55) | 38.5 (70) | 35.5 (56) |
| Fall GOM | 39.0 (97) | 44.8 (424) | 44.2 (187) | 40.3 (220) | 38.4 (107) |
| Spring OFF | 34.0 (9) | 34.8 (187) | 34.8 (65) | 32.5 (6) | 37.5 (2) |
| Fall OFF | 33.4 (143) | 35.4 (141) | 35.4 (14) | 32.9 (8) | 36.8 (9) |

**Table E5 - Mean length (cm) and sample size (number hagfish) in NEFSC surveys**

*Source: Northeast Fisheries Science Center*
*Note - First value in each column is mean length and second is sample size.*

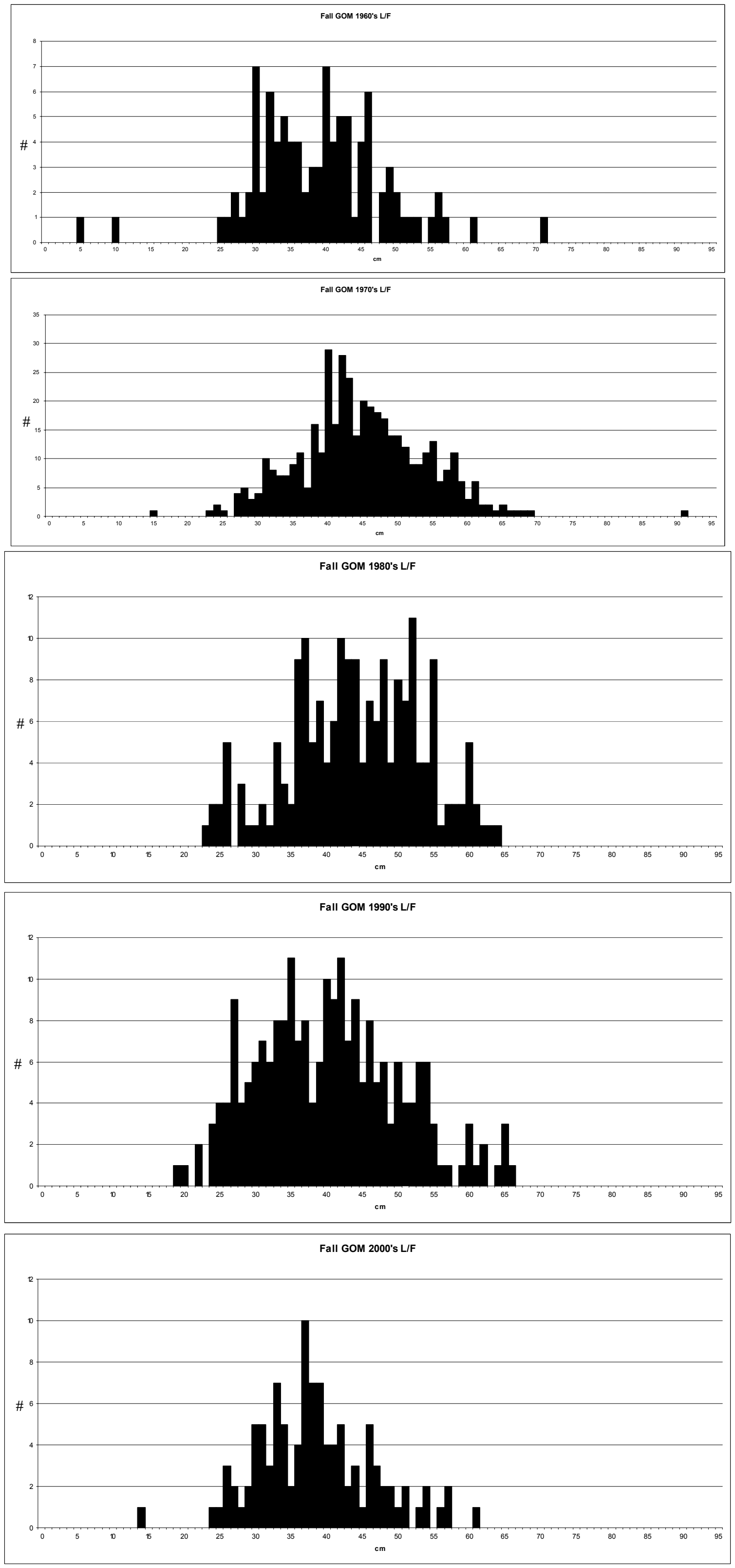



**Figure E24 - Hagfish length frequencies in the Fall GOM bottom trawl survey**

*Note: Y-axes are variable*

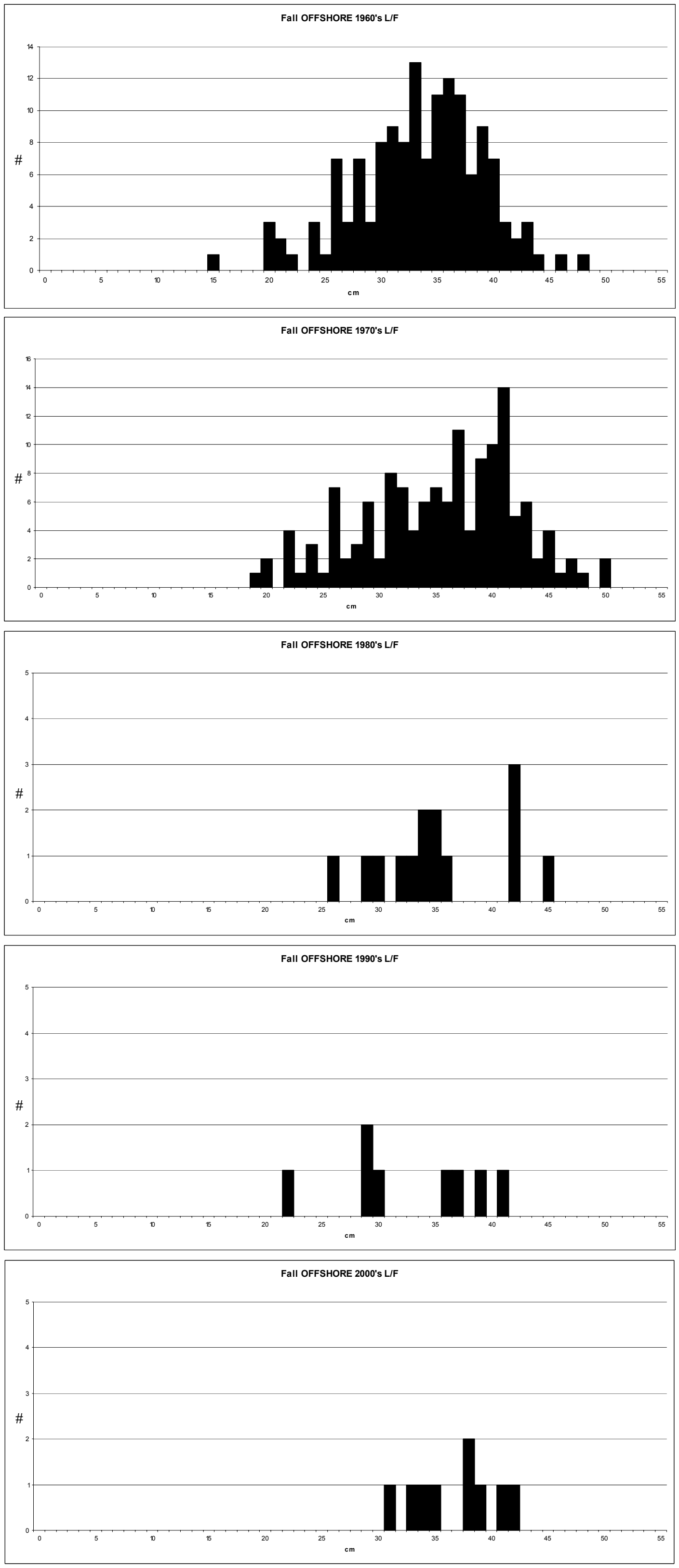



**Figure E25 - Hagfish length frequencies in the Fall Offshore bottom trawl survey**

*Note: Y-axes are variable*

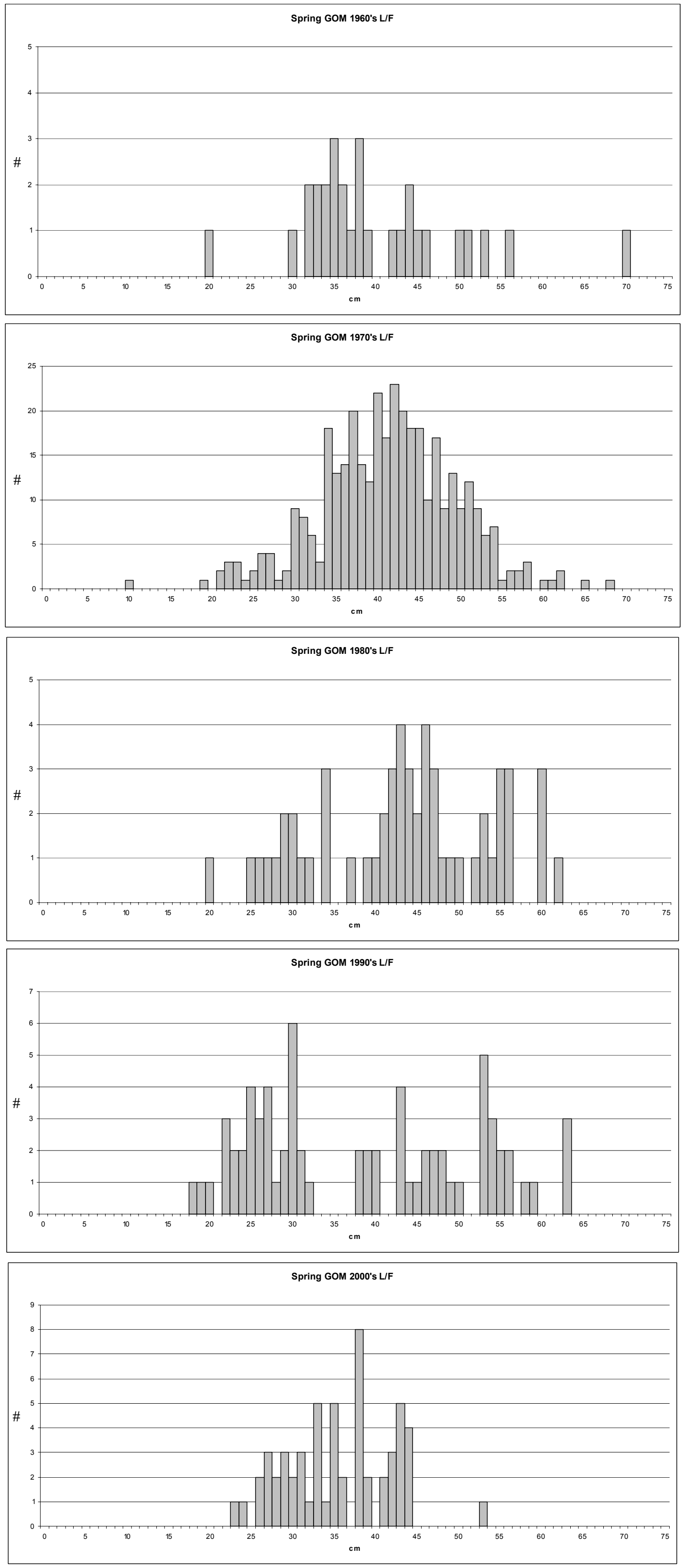



**Figure E26 - Hagfish length frequencies in the Spring GOM bottom trawl survey**

*Note: Y-axes are variable*

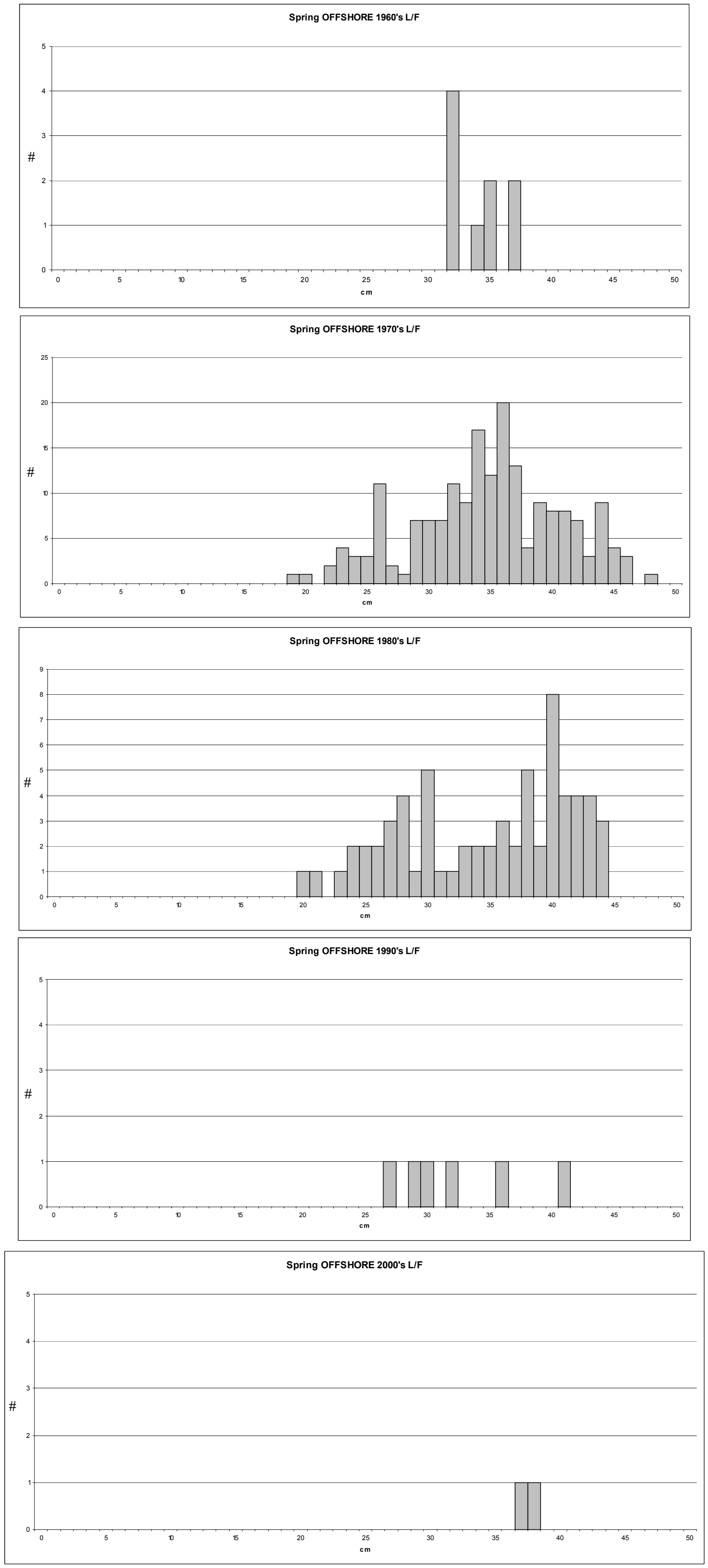



**Figure E27 - Hagfish length frequencies in the Spring Offshore bottom trawl survey**

*Note: Y-axes are variable*

### 4.2.3 Length-Weight Relationship

A preliminary length-weight relationship was estimated based on all available length and weight data for individual hagfish in NEFSC surveys (Figure E28). Sample size was low (n=49) with specimens taken from GOM in 2002.

Linear (W=0.0028L-0.0616) and power ($W=0.0004L^{2.5571}$) models were fit by linear regression to individual length and body weight data for hagfish. Both models fit the bulk of the data for hagfish 20-50 centimeters well, however, there is uncertainty about the nature of the relationship for larger hagfish due to a lack of data for specimens larger than 50 cm. Length-weight data for larger specimens would be useful for improving estimates of the length-weight relationships for hagfish.

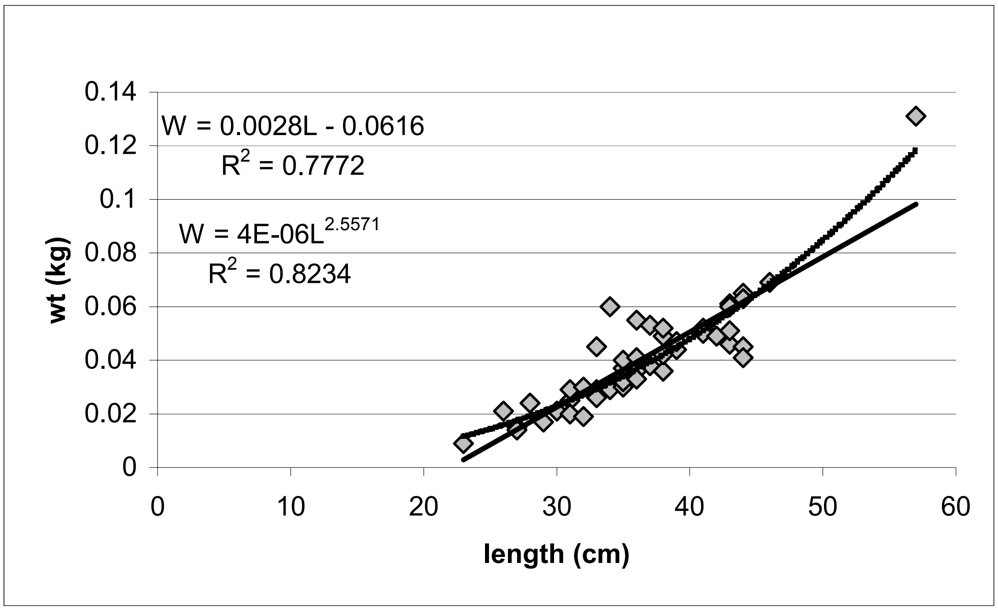



**Figure E28 - Hagfish length-weight relationship from 2002 NEFSC survey data (n=49)**

*Source: NEFSC 2002 Gulf of Maine surveys*
*Length in centimeters; weight in kilograms*

Martini et al. (1997a) collected samples of Atlantic hagfish from the Bigelow Bight in the Gulf of Maine, approximately 25 km west of Jeffrey's Ledge and 50 km east of the New Hampshire coast between June 1989 and August 1992. A length-weight curve was constructed based on a random sample of 83 individuals (Figure E29). These data include a large number of specimens greater than 50 cm, which were primarily absent from NEFSC samples. Martini et al. present a very similar length-weight relationship for hagfish as that derived from the NEFSC survey data.

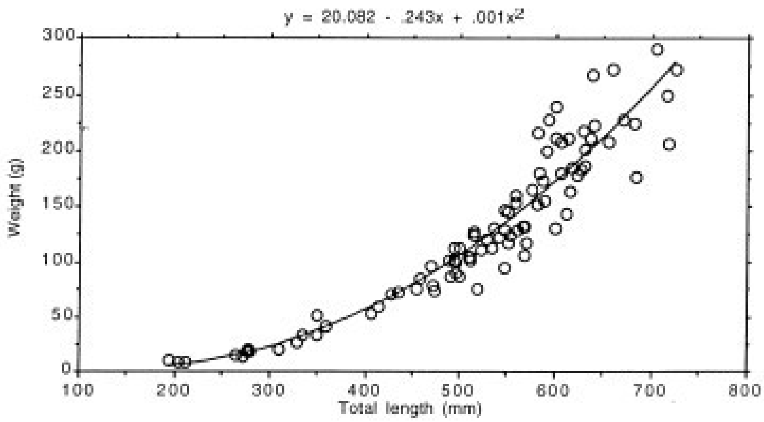



**Figure E29 – Hagfish length-weight relationship from Martini et al. 1997 (n=80)**

*Source: Martini et al. 1997a*
*Length in millimeters; weight in grams*
$W = 20.082 - 0.243L + 0.001L^2$

## 5.0 HISTORY OF THE FISHERY

### 5.1 Western Pacific Hagfish Fishery (Asia)

An active hagfish fishery originated in Japan and Korea, where hagfish were an historically important source of food for human consumption (Leask & Beamish 1999). After World War II, the skins of hagfishes (*Paramyxine atami* & *Eptatretus burgeri*) also became valued in Asia for their use as a soft, strong leather. During the late 1980s, South Korea annually exported "eelskin" (hagfish skin) leather products worth \$80 million. By 1986-1987 the Korean fleet had grown to about 1,000 vessels which sold their catch to approximately 100 shore-side processing plants (Martini & Flescher in Collette & Klein-MacPhee 2002). By 1995, Koreans consumed nearly 5 million pounds of hagfish meat each year. Because of depletion of the stock, exports had dropped to about \$20 million by 1992 and a new source of high quality skins was sought in the western Atlantic. Overfishing in Korea had caused the collapse of the hagfish fishery there and created an opportunity for such a fishery to be developed in the United States (Maine/New Hampshire Sea Grant Press Center 1995).

### 5.2 Eastern Pacific Hagfish Fishery (North America)

A North American hagfish fishery began in 1987, when Korean buyers began purchasing Pacific hagfish (*Eptatretus stoutii*) from the Monterey area of California (Martini & Flescher in Collette & Klein-MacPhee 2002). By 1989 an active west coast fishery was established in the United States and Canada. Korean traps – 24" long and 5" in diameter with one entrance funnel on one end – were used in west coast fisheries with one exception in 1992 when 5-gallon plastic traps were used experimentally in British Columbia (Benson et al. 2001, Leask & Beamish 1999).

### 5.2.1 Canadian Fishery

An experimental fishery for hagfish existed in British Columbia from 1988-1992. In addition to basic management measures for this fishery, participating vessels were required to collect biological information in specific areas (Leask & Beamish 1999). (See Section 7.1 for more information on the experimental fishery.) In Canada, patterns of CPUE suggest there may be biological factors such as seasonal movements or spawning periods that affect catch rates (McCrae 2002).

### 5.2.2 U.S. Fishery

The Oregon fishery began in 1988 and peaked in 1992 with 16 vessels landing over 750,000 lb (Table E6). Catch-per-unit-effort (CPUE) for Oregon vessels using small Korean traps ranged from 0.8 - 1.4 kg per trap (McCrae 2002).

| Year | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|
| Landings | 0 | 0 | 0 | 0 | 25.8 | 344.2 | 167.5 | 274.5 | 751.2 | 332.8 |
| Number of vessels | 0 | 0 | 0 | 0 | 2 | 7 | 12 | 12 | 16 | 5 |

**Table E6 – Annual harvest of Pacific hagfish in Oregon, 1984-1993**

*Landings in thousands of pounds*
*Source: McCrae 2002*

In the late 1980s, California, Oregon and Washington initiated a permit requirement for the hagfish fishery in state waters. The states also established regulations on the fishery, including limited entry, trap limits, and specific gear requirements. These measures are discussed in greater detail in Section 7.2. The Pacific 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 (McCrae 2002).

## 5.3 Western Atlantic Hagfish Fishery (North America)

### 5.3.1 Canadian Fishery

A small Atlantic hagfish fishery was developed in Nova Scotia, Canada during the mid-1990s. Hagfish landings in the Scotian fishery, as reported by the Nova Scotia Department of Agriculture and Fisheries, diminished from a high of 1.1 million pounds in 1995 to 33,000 pounds in 1997, and increased again to about 858,000 pounds in 1999. Since 2000, no hagfish landings have been reported to the Nova Scotia Department of Agriculture and Fisheries. It has been suggested that activity has diminished in this region due to the absence of shore-side infrastructure for processing and exporting hagfish (Cho pers. comm. 2003). The Department of Fisheries and Oceans in Atlantic Canada does not conduct a formal stock assessment for hagfish. The fishery is managed through a Joint Project Agreement (JPA) which requires industry participants to collect length and weight data on hagfish, similar to the experimental fishery for hagfish in British Columbia (Stobo pers. comm. 2003).

### 5.3.2 U.S. Fishery

A Saltonstall-Kennedy Fishery Development Grant stimulated development of the Atlantic hagfish fishery in Georges Bank and the Gulf of Maine in the early 1990s (Allen 2001). A 1996 report by the New England Fisheries Development Association on the result of this effort indicated that while Atlantic hagfish leather has been successful in both the domestic and export markets, it had been difficult to create a domestic market for hagfish meat because of the difficultly in preparing it for consumption and the aversion of American consumers to the texture of the flesh (Hultin et al. 1996). Revenues from the hagfish fishery in New England more than doubled in the second year of its development. However, this rapid increase in exploitation led R.B. Allen (2001) to write:

> The experience of the hagfish fishing fleet in the Gulf of Maine tends to corroborate experience with other hagfish resources. As early as 1996, fishermen were already seeing classic signs of resource stress. In just two years, fishermen noted a diminishing marketable catch level per trap. One fisherman reported that two summers of fishing one area revealed an impact on the eels' average size (Hall-Arber 1996). Since 1995 hagfish vessels have experienced fairly rapid local depletions with a corresponding need to continually shift fishing grounds to maintain catch rates (Nippert personal communication).

Today, the primary market for hagfish is the meat for human consumption. Small slime eels, which were previously unmarketable because of the small size of their skins, are now accepted by buyers because of their suitability for consumption.

## 6.0 CHARACTERIZING THE NEW ENGLAND COMMERCIAL HAGFISH FISHERY

### 6.1 Data Sources and Caveats

*Data Sources:*

- NMFS Commercial Fisheries Databases (WODETS/CFDETS)
  - NMFS Dealer Database
  - NMFS Vessel Trip Report (VTR) Database
- Industry phone interviews (March 2003)

The number of active hagfish vessels was determined by counting the number of distinct vessels, identified by hull number, with documented landings of hagfish in the NMFS Dealer database for each year. Aggregate records representing activity by multiple vessels provided no information on number of individual vessels. The total number of active vessels may be higher than the numbers reported. Where "UNK" is indicated in Table E9, *all* hagfish landings for that year were reported as aggregate records. The number of individual vessels landing these fish, however, is unknown.

Hagfish landings are underreported. Because there are no requirements for reporting landings of hagfish, documentation of landings and revenues generated in this fishery has not been consistent or complete. Due to a normal lag in data processing, 2002 data are especially incomplete.

### 6.2 Gear

The directed hagfish fishery in New England uses specialized traps for capturing hagfish which are different in size and structure from Korean traps (described in Section 5.2). While hagfish have been caught incidentally in lobster pots, eel traps, otter trawls, gill nets, and sea urchin dredges, in New England they are caught predominantly using specialized hagfish gear. Fifty-five gallon plastic barrels with 3-6 entrance funnels and several rows of approximately 3/8" escape holes are used to trap hagfish. The traps are attached to ½" Polysteel groundline and set 25-35 fathoms apart, with ½" polypropylene/polydacron anchor and buoy lines at either end (Nippert pers. comm. 2002).

### 6.3 Fishing Practices

For both large and small vessels, the soak time for the gear is from 6-24 hours. Small boats fish 20-40 traps in a string, hauling several times per trip. Larger vessels fish 80-200 traps in a string, hauling 1-2 times per day (Nippert pers. comm. 2002, Boulay pers. comm. 2003). One Gloucester captain of an 85 foot hagfish boat reported that he sets and hauls 1,000 traps (5 sets of 200 traps) on each 5 day trip (Boulay pers. comm. 2003). Gear is deployed to depths of 50-155 fathoms (in 1993, some vessels successfully fished in 18-22 fathoms outside Boston harbor) (Nippert pers. comm. 2002). Bait used is herring, tuna racks and occasionally mackerel (Nippert & Boulay pers. comm. 2002). Incidental catch of other species in hagfish traps is extremely low. One fisherman reported that in seven years of slime eeling, he has seen a single juvenile cod individual, around a half dozen juvenile hake and several dozen shrimp in the hagfish traps. Bycatch only occurs when an entrance funnel is damaged (Nippert pers. comm. 2002).

One hundred percent of the hagfish landed in New England are frozen whole and shipped to Korea. The current price per pound for hagfish is 36 cents. Processors get $1.60 per kilo, or about 75 cents per pound from Korean buyers (Cho pers. comm.).

### 6.4 Dealer Data – Landings and Revenues

The Atlantic hagfish fishery was developed in the early 1990s, with the first landings reported at just over 1 million pounds in 1993 (Table E7). Landings increased dramatically from 1.1 million pounds in 1993 to 4.3 million pounds in 1996, with an average annual increase of 66% during that period (Figure E30). Landings declined about 26% from 1996-1998, and doubled from 1998 to 2000. About 6.8 million pounds were landed in 2000, more than a six-fold increase since 1993. According to the NMFS Dealer database, landings declined dramatically in 2001, to around 1.5 million pounds, increasing only slightly in 2002 to 2.9 million pounds.

There is considerable uncertainty regarding the actual level of hagfish landings. According to a hagfish dealer/processor in Gloucester who contributes 70-75% of the total landings to the market each year, his personal records show that total landings for 2001 and 2002 were much higher. He estimates his 2001 landings to be between 2.3-2.4 million pounds, nearly 1 million pounds more than the *total* reported in the NMFS Dealer Database for that year. The dealer, who reports all landings to NMFS at least 2-3 times per month, provided a detailed record of 2002 trip reports by vessel to NEFMC staff in March, 2003. Total landings by vessels that sold the product to this dealer were 4.4 million pounds, 1.5 million pounds more than total landings reported by NMFS. Using the information provided by the dealer (March 2003), total landings for 2001 and 2002 are estimated to be 3.2 million pounds and 6.0 million pounds, respectively. The following formula was used to calculate these estimates:

Calculated total landings = (Dealer's landings) / (Dealer's expected percent contribution to total landings)

Dealer's expected percent contribution to total landings: 73% (between 70 and 75 percent)
Estimated landings in 2001 (according to dealer): 2.35 million pounds
Calculated total landings: 3.2 million pounds

Dealer's expected percent contribution to total landings: 73%
Exact landings in 2002 (Dealer's records): 4.4 million pounds
Calculated total landings: 6.0 million pounds

Approaching this calculation from a slightly different angle leads to a similar estimate. According to the dealer, 145 containers of landed hagfish were filled (105 by this dealer, 40 by other processors) in 2002. With about 42,500 pounds per container, the total landings were around 6.2 million pounds.

This new estimate of 2001 landings was half the level of the reported landings in 2000. From 2001 to 2002, landings (newly estimated) nearly doubled, reaching around 6 million pounds (Figure E31).

A NMFS port agent suggested that landings currently absent from the database were likely unreported to the National Marine Fisheries Service (Mason pers. comm. 2003). The database is currently being corrected for these errors. Because these data are incomplete, whether they are accurate enough to provide a basis for management is an issue. Landings data will only improve through the implementation of a permitting system requiring vessels and dealers in the hagfish fishery to report landings.

Revenues exhibited a similar trend to landings from 1993 to 2002 (Table E8, Figure E30). The ex-vessel price for hagfish remained relatively stable throughout the 1990s at 28 cents per pound, and recently increased to 36 cents per pound. Total revenues in 2000 were 1.9 million dollars.

| | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|
| **ME** | 182,510 | 64,537 | 0 | 904,075 | 922,259 | 1,929,874 | 2,907,644 | 1,199,474 | 0 | 0 |
| **MA** | 869,386 | 2,372,037 | 3,133,716 | 3,415,107 | 2,745,943 | 1,261,403 | 2,344,004 | 5,602,082 | 1,514,277 | 2,886,773 |
| **NH** | 0 | 0 | 0 | 0 | 8,196 | 0 | 0 | 0 | 0 | 0 |
| **CT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 70 | 0 |
| **RI** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,280 |
| **TOTAL** | **1,051,896** | **2,436,574** | **3,133,716** | **4,319,182** | **3,676,398** | **3,191,277** | **5,251,648** | **6,801,556** | **1,514,347** | **2,890,053** |

**Table E7 - Total hagfish landings by state of landing, 1993-2002**

*Landings in pounds.*
*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

| | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|
| **ME** | $88,272 | $19,941 | $0 | $267,179 | $234,778 | $586,028 | $755,988 | $408,275 | $0 | $0 |
| **MA** | $252,186 | $716,769 | $906,384 | $955,942 | $758,578 | $328,650 | $667,811 | $1,449,016 | $384,198 | $982,201 |
| **NH** | $0 | $0 | $0 | $0 | $2,141 | $0 | $0 | $0 | $0 | $0 |
| **CT** | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $10 | $0 |
| **RI** | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $479 |
| **TOTAL** | **$340,457** | **$736,710** | **$906,384** | **$1,223,121** | **$995,496** | **$914,678** | **$1,423,799** | **$1,857,290** | **$384,207** | **$982,680** |

**Table E8 - Total hagfish ex-vessel revenues by state of landing, 1993-2002**

*Revenues expressed in 1999 dollars.*
*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

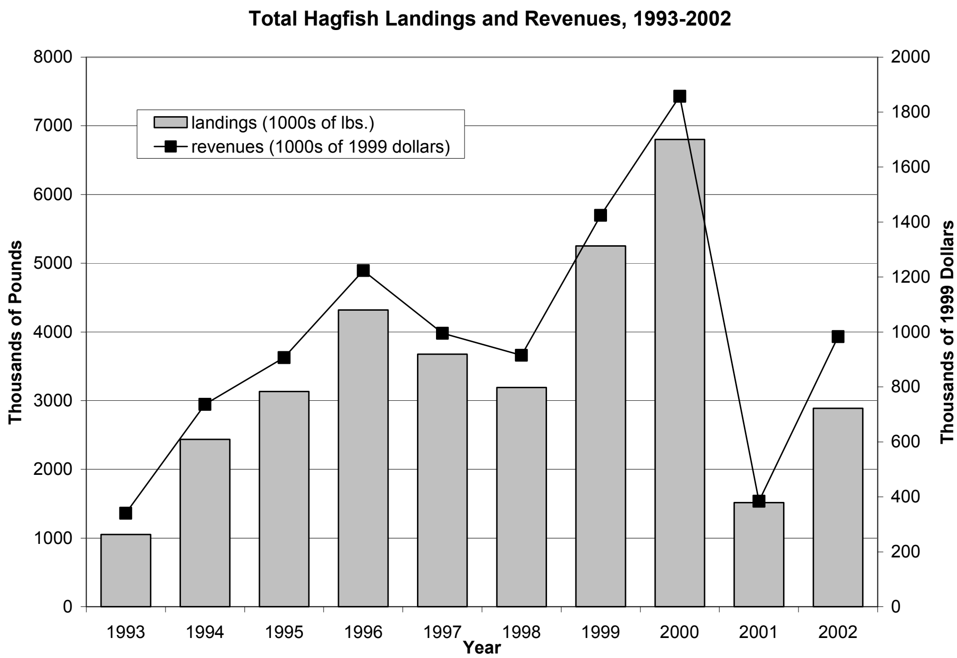



**Figure E30 - Total hagfish landings and revenues, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

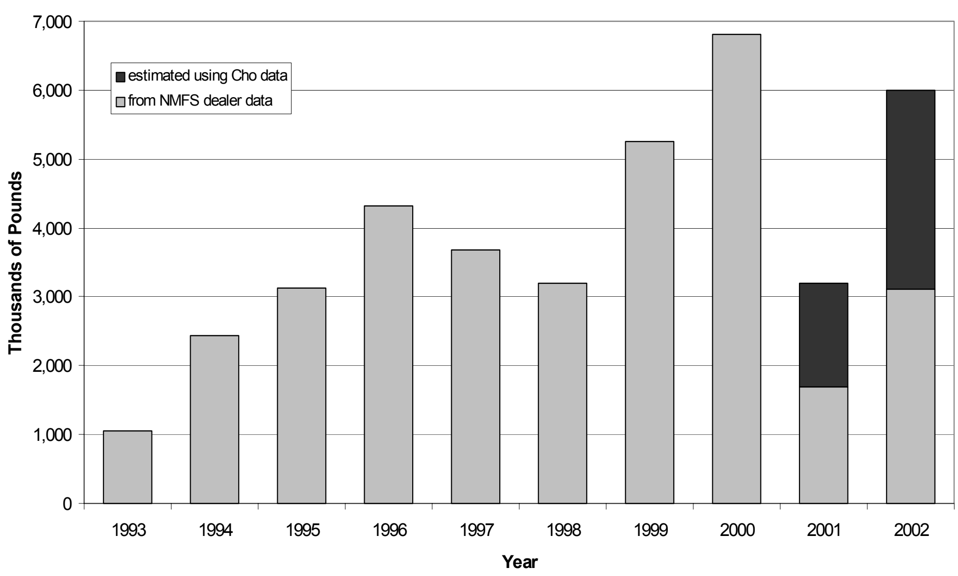



**Figure E31 - Total hagfish landings and revenues adjusted in 2001 and 2002 based on individual dealer records, 1993-2002**

*Data Sources: NMFS Dealer Database (WODETS/CFDETS); Yang Cho, personal communication*

### 6.4.1 Reporting of Landings

Dealers with federal fishery permits are required to report landings of all species to the National Marine Fisheries Service. In recent years, hagfish dealers have made efforts to report all landings to NMFS, although the database may be incomplete due to unreported or unrecorded landings. The total live or frozen weight of the catch landed by fishermen is discounted by 10% to account for the slime and water associated with the catch and is reported at this discounted rate in dealer and vessel trip reports (Boulay, Cho, Chu, Nippert pers. comm. 2003). This reported weight is also the paid weight, or the weight for which fishermen receive payment from the dealer. The weight of the catch that may be lost in this calculation is referred to as "shrinkage," and the extent to which this practice may be misrepresenting the actual level of landings is unknown. The formula is an industry standard used by dealers both for vessels that freeze their catch at sea and those which land a live catch in RSW tanks or barrels. Simple tests comparing live weight and frozen weight of a sample of hagfish may illuminate potential disparities in the reporting of live hagfish and hagfish frozen at sea.

### 6.4.2 Discards

There are two major sources of discards in the hagfish fishery: at-sea culling of small slime eels and landed catch that is rejected by dealers due to quality concerns. The portion of the catch that is rejected at port is returned to sea by the fishermen who landed the catch or by a boat hired to dispose of the discarded hagfish.

The discard rate is unknown and is likely to vary widely among individual vessels. Producing a marketable catch in the hagfish fishery requires a great deal of skill and experience because of the challenges of maintaining freshness, locating large aggregations of hagfish and handling the live slime eels. Vessels with more experienced captains and crew tend to generate fewer discards than new entrants.

We have no current estimate of discards – total landings reported may be much lower than total removals from the hagfish stock. Estimating the volume of hagfish discarded at sea is difficult because sorting occurs continuously and at a rapid rate as traps are returned to the deck. The proportion of the catch that is rejected by the dealer and later discarded at sea is not measured. Most fishermen report only the landed catch accepted by the dealer on their vessel trip reports (VTRs).

### 6.4.3 Number of Active Vessels in the Fishery

It is difficult to establish a definitive count of vessels in the hagfish fishery because of the absence of permits and reporting requirements. However, the known number of active vessels (vessels reporting landings of at least one pound of hagfish in a given year) was derived from the NMFS Dealer Database and may be used to estimate total number of active vessels and observe trends in participation since 1993 (Table E9). The number of participants in the hagfish fishery has fluctuated since the early 1990s (Figure E32). In part, this is a result of the unique challenges to success in this fishery. Hagfishing (slime eeling) requires very specialized gear (see description in Section 6.2) and is technically difficult because of the nature of the fish. Many who enter the fishery in the hopes that it will provide a good alternative to other fisheries find the copious amounts of slime produced by the hagfish to be repulsive and difficult to handle. In addition, there is little movement in and out of other fisheries by those committed to slime eeling since it is difficult to convert vessels designed for trawling and dredging to boats capable of slime eeling and vice versa. The number of participants generally increased from 1993 to 1997, achieving a maximum of 31 vessels. This number dropped in 1998 to around 6 vessels and is currently about 16 boats.

| Year | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|
| **ME** | UNK | 1 | 0 | 8 | 16 | 3 | 4 | UNK | 0 | 0 |
| **MA** | 7 | 14 | 7 | 11 | 13 | 3 | 10 | 6 | 4 | 13 |
| **NH** | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| **RI** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| **CT** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **TOTAL** | **7** | **15** | **7** | **19** | **31** | **6** | **14** | **6** | **5** | **16** |

**Table E9 - Total number of known active hagfish vessels, 1993-2002**

*UNK = unknown greater than zero*
*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*
*Number of vessels is an approximation, probably lower than actual number. [see Data Caveats discussion]*

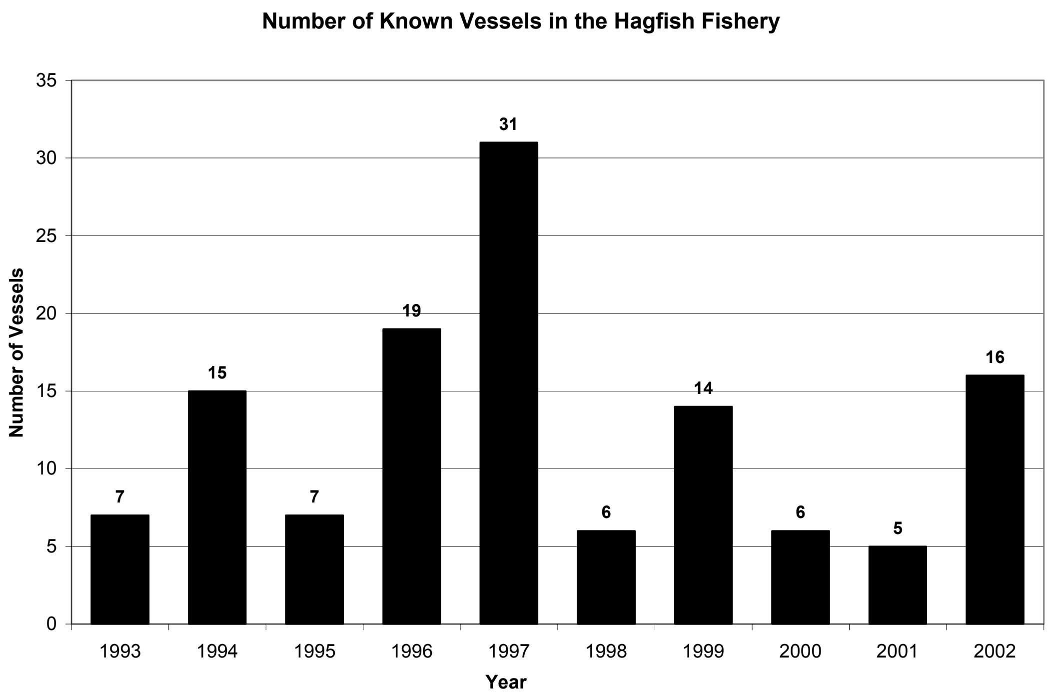



**Figure E32 – Active hagfish vessels reported by dealer records, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

### 6.4.4 Size Composition of Active Vessels

For vessels for which tonnage was reported in the NMFS Dealer Database, the size composition of active vessels was examined. Tonnage is reported by ton class in the database. Four ton classes were represented by hagfish vessels:

- Ton Class 1 – 1-4 tons
- Ton Class 2 – 5-50 tons
- Ton Class 3 – 51-150 tons
- Ton Class 4 – 151-500 tons

Figure E33 and Figure E34 show the percentage of trips made by vessels in each ton class out of the total number of trips taken in each fishing year from 1993 to 2002. In general, the size of vessels has increased throughout this period. Vessels in the 1-4 ton range were absent from the fishery after 1994 in Massachusetts and Maine (with the exception of 1999). In Maine, the smallest vessels accounted for 100% of the trips in 1993 and 1994. In Massachusetts, trips by vessels 5-50 tons made up at least 50% of the total from 1993 to 1997. From 1997 to 2001, about 60-95% of trips by Massachusetts vessels were made by those in the 51-150 ton range. In 2002, 40% of the trips by Massachusetts vessels were made by large vessels in the 151-500 ton range. There is no direct correlation between vessel tonnage and vessel length. However, vessels in Ton Class 4 (largest) generally correspond to those with lengths in the 80-120 foot range, while those in Ton Class 2 (small-mid sized) generally range from 30-60 feet. As a point of reference, the majority of currently active permitted groundfish vessels are 30-50 feet in length. Because larger vessels tend to take fewer, longer trips, these data would more accurately represent distribution of effort by vessel size if the number of trips was weighted by the average length of a trip for each ton class before determining the percent composition of total trips. However, the following visual analyses provide a rough estimate of size composition of the fleet and demonstrate a general trend towards larger vessels, consistent with information recently provided by current industry participants.

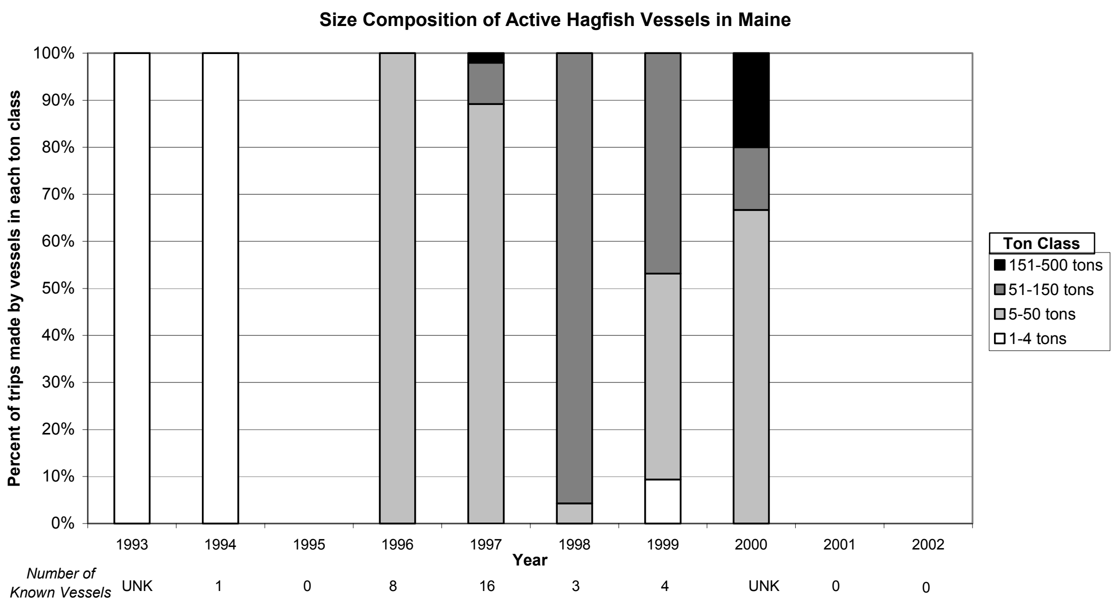



**Figure E33 - Size composition of active hagfish vessels in Maine, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

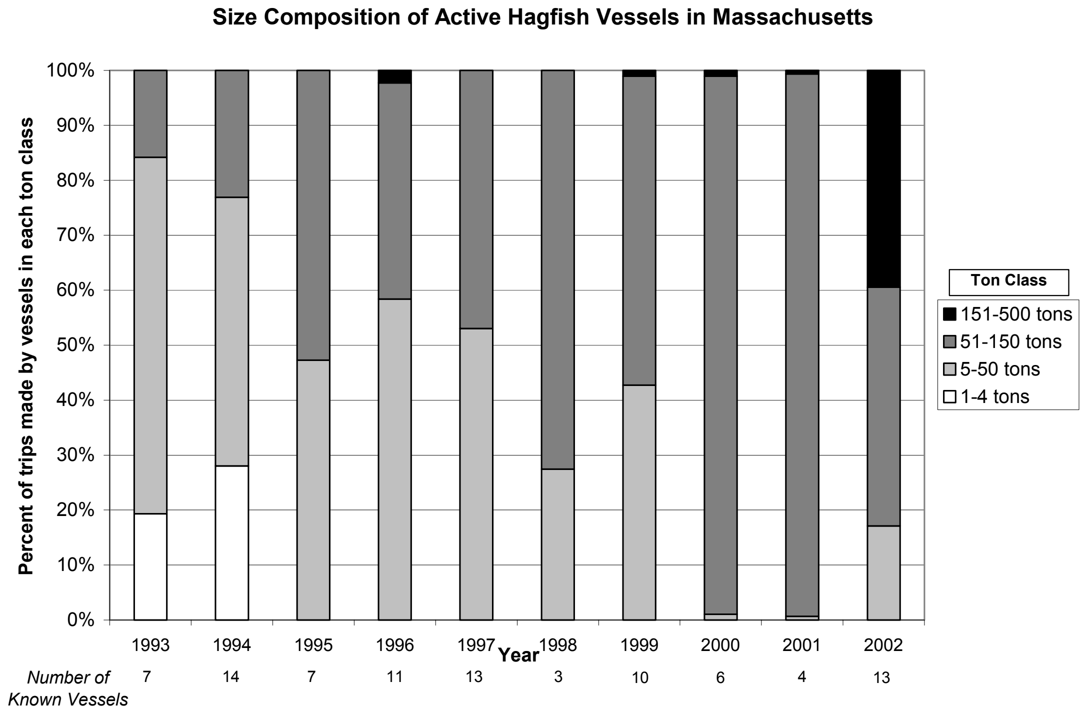



**Figure E34 - Size composition of active hagfish vessels in Massachusetts, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

Based on the Cho 2002 data, six of eleven active hagfish vessels fell into Ton Class 4, the large vessel category. Between one and two vessels were in Ton Class 2 and 2-3 in Ton Class 3. In just one year, hagfish vessels have extended their capabilities to allow for longer trip duration and more effective handling of the product at sea. Less than one year ago, a Gloucester hagfish fisherman noted that the larger vessels in the fishery ranged from 65-90 feet and made trips of 4-5 days in length (Boulay pers. comm. 2002). Now, in March 2003, he considers his 85 foot vessel (which takes 5-6 day trips) to be on the "small side" (Boulay pers. comm. 2003). Since the winter of 2002, at least four vessels between 145 and 165 feet entered the fishery. Two of these, each 165 feet, remain active participants while two 145-foot boats left hagfish to pursue other fisheries (P. Chu pers. comm. 2003). Currently, two new vessels around 160 feet are making preparations to begin slime eeling in April 2003 (Y. Cho pers. comm. 2003).

There are several categories of hagfish vessels which differ in their means of at-sea processing and storage of the product and, to some extent, size. Up until the winter of 2002, the two major types of hagfish vessels were:

- "barrel" vessels – 36-65 feet, carrying 10-20 traps per trip
- "tank" vessels – 65-90 feet, carrying 80 traps per trip; there are a limited number of these vessels over 150 feet

The larger, "tank" vessels have refrigerated sea water (RSW) systems on board which allow for increased freshness of the product. Some also have processing and sorting capabilities which may aid fishermen in discarding small juvenile hagfish at sea. The smaller "barrel" vessels do not hold RSW tanks and transport the hagfish back to port in barrels on deck (Boulay and Cho pers. comm. 2002).

Traditionally, all vessels were "barrel" boats which transported hagfish back to port in barrels on deck (Cho pers. comm. 2002). Now, many larger vessels use alternative storage facilities on board in order to ensure greater freshness of the product. Freshness is a major concern in this fishery, particularly during hot summer months when hagfish stored in barrels on deck can literally boil in their own slime, diminishing the quality of the skins and meat. The nature of the fishery has changed dramatically over the past few years. Even since last spring (2002) vessels' fishing capabilities have expanded and vessel size increased. Today, vessels under 80 feet are considered "small" and many more boats over 150 feet have entered into the fishery. "Tank" vessels now use a variety of means of processing and storing the fish on board. While most tank boats use RSW, some of the largest vessels have freezing capabilities on board. At least one utilizes a blast cooling system. To a large extent, sorting and discarding of small slime eels occurs at sea on tank boats equipped with sorting tables on deck. Limited deck space on barrel boats inhibits the crew's ability to sort at sea.

On average, small to mid-sized (less than 80 feet) vessels bring in about 3,000 – 20,000 pounds per trip for 1-4 day trips while larger vessels land 40,000 – 75,000 pounds per trip for 5-6 day trips (Cho landings data, 2003).

### 6.4.5 Landings by Vessel Ton Class

The highest total landings across the time series are attributed to fishing activity by vessels in Ton Classes 2 and 3 (5-50 tons and 51-150 tons, respectively) (Figure E35). Vessels in Ton Class 3 had slightly higher landings than those in Ton Class 2. Both vessel classes exhibited local maxima for landings in 1996 and 2000. Data for the years 2001 and 2002 should be regarded as incomplete, for the reasons previously discussed (Section 6.4). Assuming that the omissions in data for these latter years discriminate equally against all size classes, it is possible to examine relative landings for hagfish vessels, even if the absolute levels are unknown. In 2001, landings for Ton Class 3 vessels were substantially higher than those for other ton classes. In 2002, landings by Ton Class 4 vessels (151-500 tons) exceeded landings by smaller vessels.

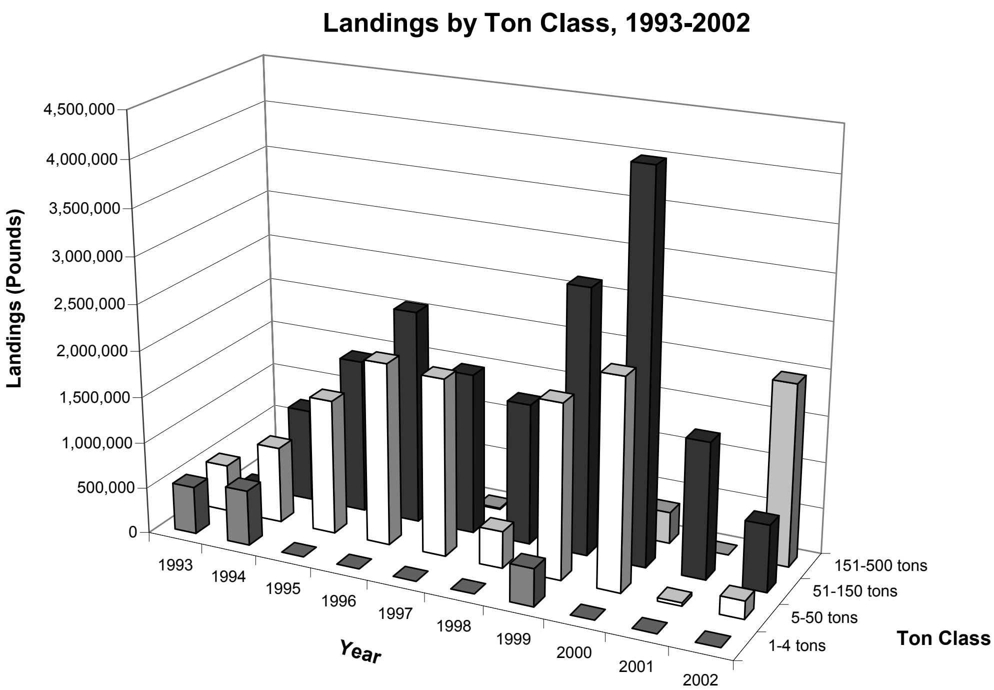



**Figure E35 – Total hagfish landings by ton class, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

The average landings per trip were examined for the four ton classes (Figure E36). Trip duration is not accounted for in determining averages. The highest landings per trip for all size classes occurred between 1998 and 2001. In 2000, 5-50 ton boats exhibited the highest average landings per trip over the time period from 1993 to 2002. With this exception, trips on 151-500 ton boats consistently landed the highest average landings per trip in 1999 and 2000, the years of highest *reported* landings overall. Boats between 51-150 tons demonstrate the most consistency in landings per trip from year to year. Consistency in average trip landings may be related to increased operator skill.

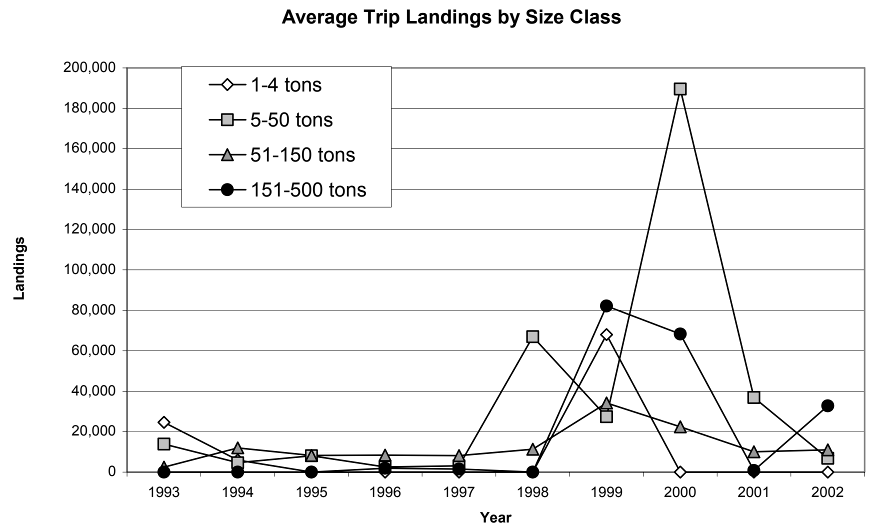



**Figure E36 – Average landings per trip by size class, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

The highest number of trips occurred in 1996 and 1997, with the majority of these trips made by 5-50 ton vessels (774 trips in 1996 and 636 trips in 1997). 51-150 ton boat landings followed, exhibiting two local maxima, at 277 trips in 1996 and 187 trips in 2000. Figure E37 shows the number of VTR records in the NMFS Dealer Database from 1993 to 2002. Across all years in the time series there was a relatively low number of trips for the smallest (1-4 ton) and largest (151-500 ton) vessels. This is likely due to low numbers of vessels in the smallest ton class in all years and in the largest ton class during the early years of the time series. In later years when the number of very large vessels increased, a low number of trips for these vessels relative to the smaller size classes is likely due to longer trip duration.

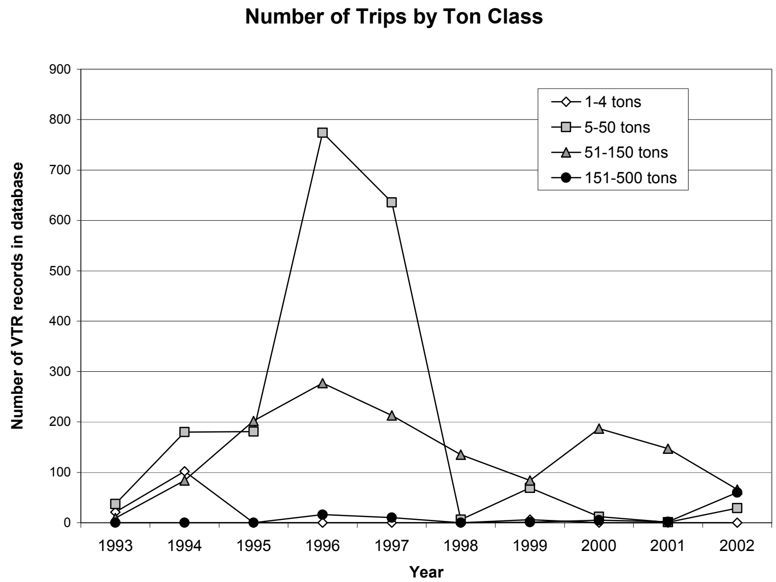



**Figure E37 – Number of trips by ton class, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

### 6.4.6 Ports and Shoreside Processing Facilities

From 1993 to 1997, between about 75% and 100% of the total hagfish landings in New England were brought in by vessels landing their catch in Massachusetts (Table E7 and Table E8). In 1998 and 1999, 40-45% of the total was landed in Massachusetts, while 55-60% of the total was landed in Maine (Figure E38 and Figure E39). Landings in Massachusetts increased in 2000 to 82% of total landings. In 2001 and 2002, 100% of the total hagfish landings were landed in Massachusetts. Less than 0.1% of the total hagfish landings in each year were reported in other states. Between 1993 and 2002, very low landings were reported in New Hampshire (8,196 pounds in 1997), Connecticut (70 pounds in 2001), and Rhode Island (3,280 pounds in 2002).

In 1995 the Maine/New Hampshire Sea Grant Press Office reported that the hagfish fishery is centered around the ports of Gloucester, MA, Portsmouth, NH and Stonington, ME which were “equipped with the freezing and packing facilities required to send the frozen product to Korea, where most of the skinning, tanning and meat processing is still being done” (ME/NH Sea Grant Press Office 1995). From 1993 to 2000, landings were reported in Gloucester (MA), Chatham (MA), Portsmouth (NH), Portland (ME), Camp Ellis (ME), South Bristol (ME), Cundys Harbor (ME), Stonington (ME), and Lincoln County (ME). The primary ports in which hagfish were landed during this period were Gloucester and Portland, with very low landings in other ports. In 2000, 92.7% of the total hagfish landings in New England were landed in Gloucester, MA, with 7.3% of the total in Portland, ME. Since 2000, however, a directed fishery for hagfish has ceased to exist in Maine. Currently, 100% of the catch is landed in Gloucester, Massachusetts. There are two major buyers in New England, all with processing facilities located in Gloucester.

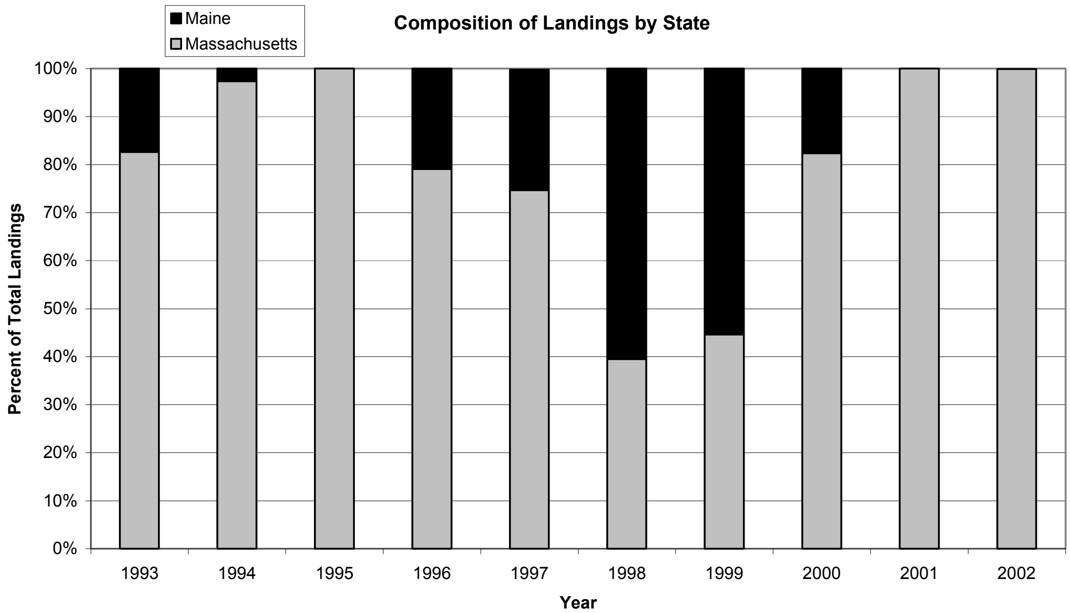



**Figure E38 - Composition of hagfish landings by state**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*
*States with less than 0.1% of total landings are not included.*

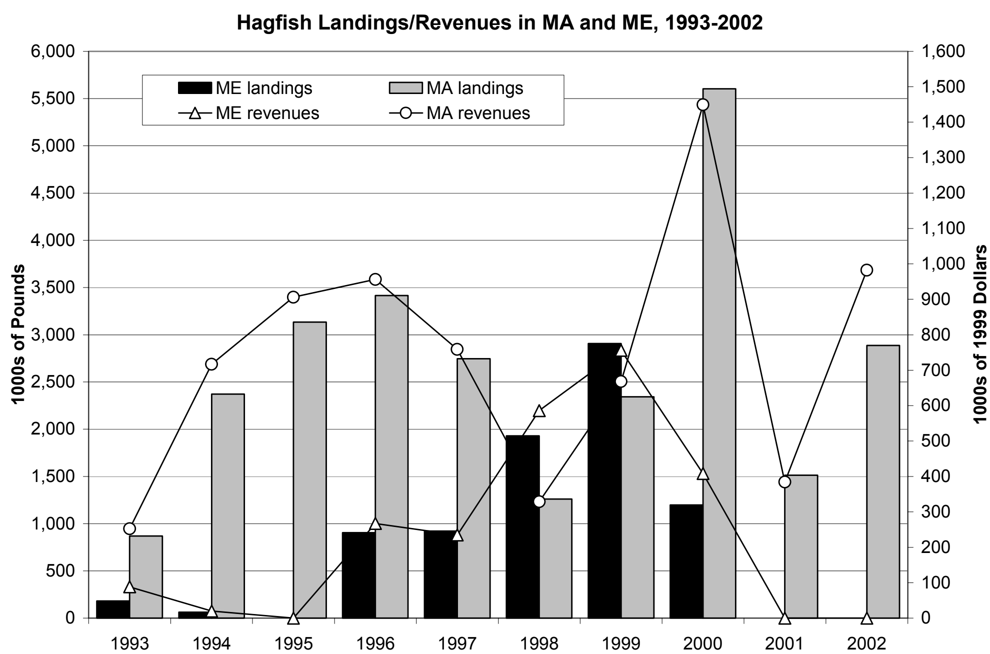



**Figure E39 - Hagfish landings and revenues in Massachusetts and Maine, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

### 6.4.7 Spatial and Seasonal Fishing Effort

Vessels fish for hagfish within a 40-130 mile radius of Gloucester throughout the Gulf of Maine and out to the Hague line as weather permits. In 1993-1994, these vessels fished within a 63 mile radius of Gloucester (6-7 hours of steaming time plus 8 hours hauling). With a diminishing marketable catch (smaller slime eels), these vessels moved their operations to a 63 mile radius out of Portland (Nippert pers. comm. 2002). In 1996, these vessels targeted hagfish in the Western Gulf of Maine groundfish closed area, an area with open access for certain non-groundfish fisheries. At that time, 3-4 larger boats fished the eastern boundaries of the closed area and smaller inshore boats fished the western boundaries. In March, 2002, one of the smaller vessels was fishing about 10 hours off Cape Cod and another in Closed Area 1 (Nippert pers. comm. 2002). Fishermen have noted that hagfish have diminished in size since the early 1990s and that it has become increasingly difficult to find large abundances of the fish in the inshore Gulf of Maine (Boulay, Hill, Nippert, Palumbo, pers. comm. 2003).

Over time, trips have grown longer and vessels have moved further offshore in search of marketable catches. One fisherman gave a detailed report of how hagfish fishing grounds have shifted over the past few years (Boulay pers. comm. 2003). In 2000 and 2001, he made all of his trips to Wilkinson Basin, Franklin Swell, Franklin Basin and Mayo Swell (50-125 nautical miles off Gloucester). During 2001, a few trips were also made to Jordan Basin (150-200 nautical miles off Gloucester). By 2002, it had become necessary to fish almost exclusively in Jordan Basin, out to the Hague line. During the winter of 2003, a particularly difficult season due to harsh weather and sea conditions, he fished from Eastport, ME to Cape Cod, MA in search of large aggregations of hagfish and met with limited success. A few trips off New York and Virginia yielded a low number of hagfish but the individuals captured were very large (up to 4 feet).

Average landings of hagfish exhibit a seasonal trend, with the highest landings occurring from May to September (Table E10 and Figure E40). Fishermen have indicated that they land the greatest abundance and largest sized hagfish from late spring through November, when waters are warmer (Nippert pers. comm. 2002). Hagfish tend to “herd” or aggregate when water is warmer. Dense aggregations of active feeding hagfish are captured in summer months, resulting in “choker” barrels packed full of slime eels. When the waters cool in late fall and winter, hagfish seem to scatter and become dormant, becoming more difficult to capture (Boulay pers. comm. 3/17/03).

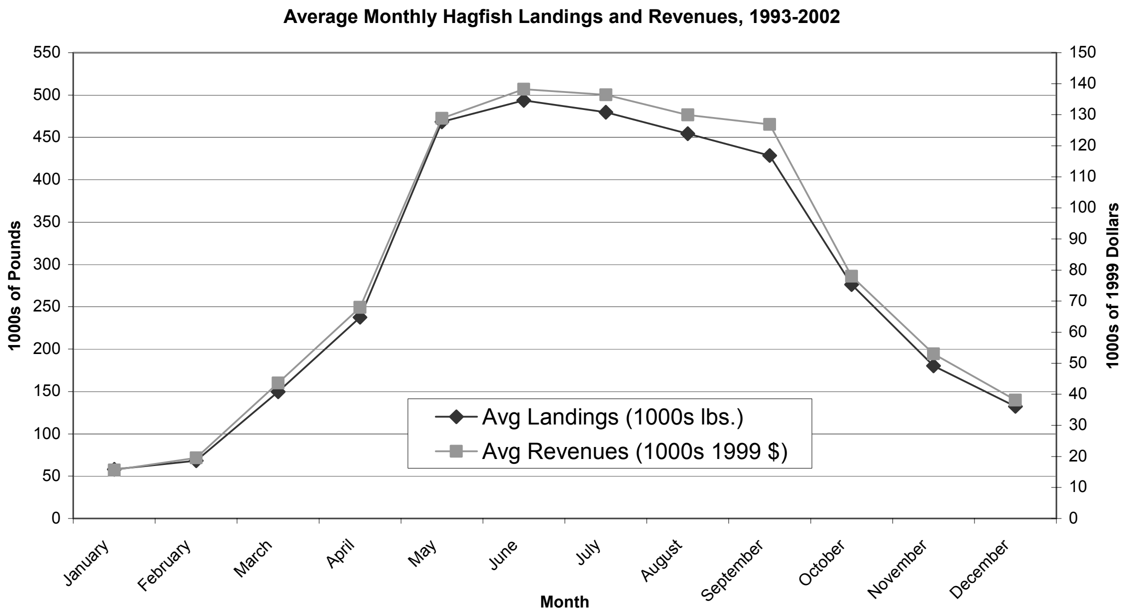



**Figure E40 - Average monthly hagfish landings and revenues, 1993-2002**

*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

| | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Monthly Landings (Pounds) | 58,080 | 68,131 | 149,659 | 237,473 | 468,223 | 493,544 | 479,565 | 454,434 | 428,497 | 276,323 | 180,420 | 132,317 |
| Average Adjusted Monthly Revenues (1999 Dollars) | $15,603 | $19,569 | $43,688 | $67,995 | $128,879 | $138,237 | $136,423 | $129,981 | $126,919 | $77,989 | $53,034 | $38,103 |

**Table E10 - Average monthly hagfish landings and revenues, 1993-2002**

*Landings in pounds. Revenues expressed in 1999 dollars.*
*Data Source: NMFS Dealer Database (WODETS/CFDETS)*
*Note: 2002 data may be incomplete*

### 6.5 Vessel Trip Report (VTR) Data – Landings and effort trends

#### 6.5.1 Objectives

From the working group meeting on March 28, two topics related to analysis of commercial landings data were assigned for further investigation.

1) Couple VTR data with dealer data to look at spatial distribution of hagfish trips and calculate LPUE if possible.
2) Couple VTR data with spatial component of surveys to look at localized depletion/relative abundances of hagfish from one area to the next over time, also incorporating bottom temperatures, if possible.

Feedback from commercial fisherman at the working group meeting indicated that, while hagfish landings from vessels without groundfish permits were not required to be reported through the VTR program, a substantial number of trips are reported either on a voluntary (the vessel has no other federal permits requiring logbook reporting) or mandatory basis (Nippert pers. comm., Boulay pers. comm. 2003). Furthermore, this feedback indicated that due to the nature of the hagfish fishery, the landed weight reported per VTR trip is likely to match closely if not exactly with the same trip's landings reported through the dealer database system. For this reason, it was not instructive to couple VTR and dealer data for analysis consistent with the first objective, described above.

Due to tight time constraints, survey data was also not coupled with VTR data in meeting the second objective. Bottom temperatures were not available from VTR data and therefore are not included as a variable for the purposes of this portion of the investigation.

These two caveats did not prevent a thorough analysis of available VTR data, however. Spatial distribution of the hagfish fishery, regional and temporal LPUE estimates, and the potential of localized depletion are investigated below. These data are often noisy, and the relatively short time series does not often reveal meaningful trends, but a few broad conclusions may be reached. Spatial analysis of VTR data indicates that, on average, vessels are moving farther off shore for their hagfish trips (+27 statue miles per trip from 1995 to 2002). Consequently, days absent reported via VTR are increasing, from 1.1 days absent in 1994 to 1.7 days absent in 2002 per average trip reported. The fishery is becoming more geographically diffuse; the number of ten minute squares attributed annually to VTR landings is increasing, while the average landed weight of hagfish from a ten minute square is decreasing.

In general terms, nominal LPUE estimates fluctuate in an almost cyclical pattern both seasonally and annually; no trends emerge. When standardized for vessel size (gross tonnage), LPUE estimates fluctuated, with a slightly declining trend.

#### 6.5.2 Commercial Trip Data

Logbook (vessel trip report, or VTR) data is used for this analysis. Hagfish logbook data are available from 1993 – November 2002 but due to changes in data structure between 1993 and 1994, 1994–2002 data are used here. Trips not landing hagfish were filtered. Logbook data were merged with vessel permitting data, yielding one dataset with variables describing vessel landings, trip locations and vessel characteristics. Table E11 contains the variable names that were used to form the hagfish trip dataset. Table E12 summarizes data from the hagfish VTR dataset.

| 1994-2002 VTR Dataset | |
|---|---|
| year | Calendar Year |
| tripid | Individual trip ID |
| ves_name | Vessel name |
| permit | Vessel permit number |
| gearqty | Number of traps |
| nemarea | Statistical area fished |
| lat_degree | Latitutude - degrees |
| lat_minute | - minutes |
| lon_degree | Longitude - degrees |
| lon_minute | - minutes |
| nhaul | Number of hauls |
| depth | Water depth |
| tenmsq | Ten minute square ID |
| haglb | Lbs of hagfish landed |
| hagdisc | Lbs of hagfish discarded |
| month | Month landed |
| day | Day landed |
| da | Days absent |
| crew | Number of crew |
| port | Port landed |
| hport | Vessel home port |
| len | Vessel length |
| gtons | Vessel gross tonnage |
| vhp | Vessel horsepower |

**Table E11 – Variable names for Hagfish VTR dataset.**

| Variable | Sum | Mean | Std Dev | Minimum | Maximum |
|---|---|---|---|---|---|
| Pounds landed | 25,302,836 | 5,456.73 | 5,163.71 | 85 | 122,295 |
| Number of traps | 363,185 | 78.32 | 49.35 | 0 | 500 |
| Number of hauls | | 9.65 | 17.67 | 0 | 312 |
| Days absent | 5,603 | 1.21 | 0.88 | 1 | 20 |
| Water depth | | 72.66 | 30.16 | 0 | 514 |
| Number of crew | | 2.56 | 0.68 | 0 | 11 |
| Vessel length | | 51.37 | 12.17 | 28 | 96 |
| Vessel gross tonnage | | 39.63 | 28.36 | 4 | 258 |
| Vessel horsepower | | 336.34 | 77.10 | 120 | 1,200 |

**Table E12 – Statistics for all trips landing hagfish (n=4,637).**

### 6.5.3 Landings and vessels

As evident in both the dealer and VTR data, the hagfish fishery expanded greatly between 1993 and 1996 as landings and the number of participating vessels both increased (Figure E30, Figure E32, Figure E41 and Figure E42). Vessels reported historically high landings during the period from 1999 to 2001 after a brief dip in VTR landings in 1998, while numbers of reporting vessels declined from 1999-2002. General trends in landings and number of active vessels from the VTR data were similar to trends seen in the dealer data (Section 6.4). However, there were some discrepancies between the two data sets. Reported landings from the VTR data were lower than dealer-reported landings in all years except 2001, when VTR landings exceeded dealer landings by over 100%. It is expected that the total VTR-reported landings would be lower than dealer-reported landings, as only vessels with federal permits in other fisheries are required to report via VTR and many, if not most, hagfish vessels do not possess permits for other federal fisheries. Therefore, much of the VTR reporting is voluntary. The anomalously low dealer records in 2001 yield the need for further investigation into the reporting process for hagfish. Total numbers of active vessels also differed between dealer reports and VTRs. Numbers of vessels reporting via VTR would, in some years, be lower than dealer-reported vessels due to individual vessels opting to not report. In other years, though, the number of active vessels reporting by VTR may be higher due to the reporting of aggregate records by dealers, in which a single trip record is not associated with a particular vessel and may represent landings by several vessels. There is no discernable pattern in the differences between numbers of active vessels reported in dealer and VTR databases.

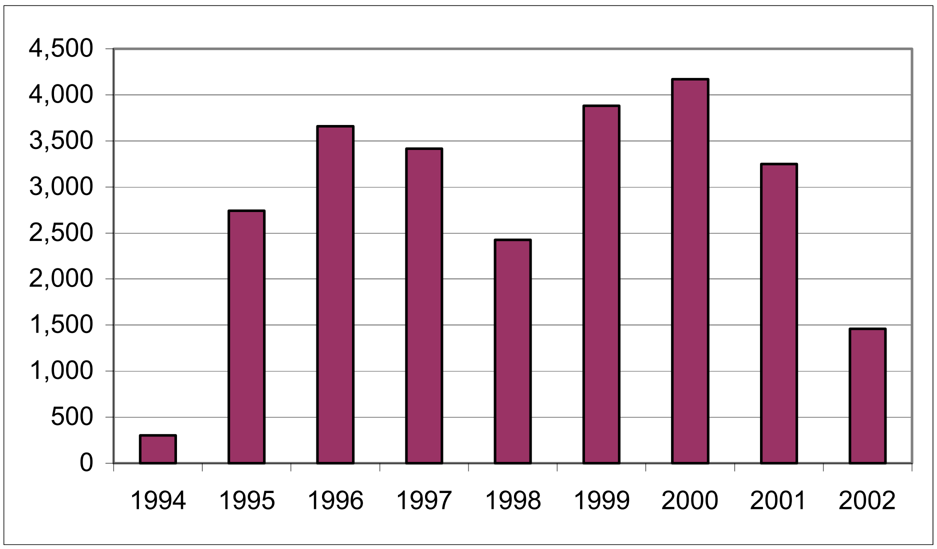



**Figure E41 – Hagfish landings (1,000 lbs.) by year reported via VTR.**

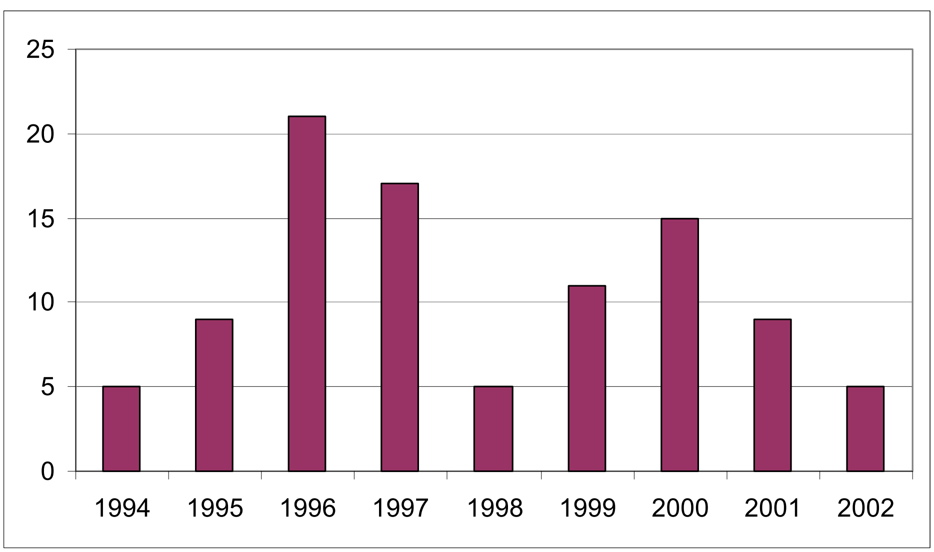



**Figure E42 – Number of vessels reporting via VTR, 94-02 (total # vessels = 48).**

### 6.5.4 Spatial distribution of the hagfish fishery

The hagfish fishery is generally prosecuted from Atlantis Canyon (70nm south of Nantucket) to the south, the eastern seaboard from Cape Cod to Downeast Maine to the west and north, and the Hague line to the east. Figure E43 shows that the majority of landings came from statistical areas 513 and 514, with 515 and 521 also contributing significantly.

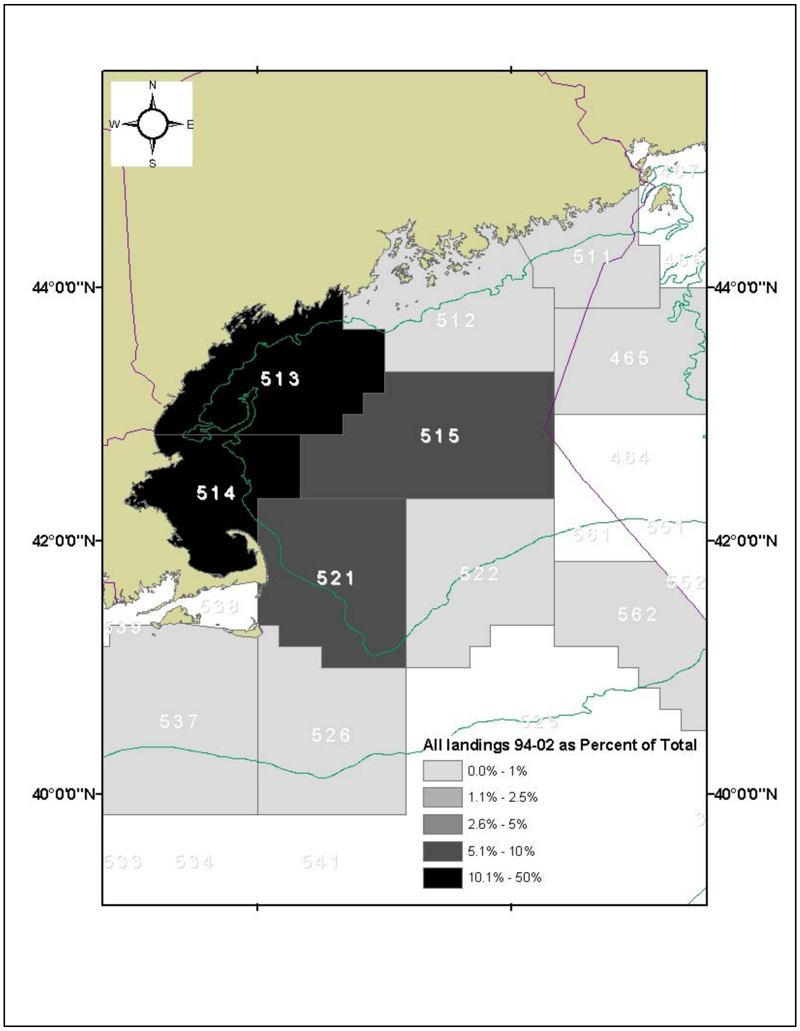



**Figure E43 – Hagfish landings per statistical area, as a percent of total (1994-2002 VTR data, n=4,637).**

The vast majority of trips occur in the deeper water (greater than 40 fathoms) in the Gulf of Maine, within a 60nm radius of Gloucester, MA. Figure E44 provides some detail for the spatial distribution of landings and their magnitude. Figure E45 shows the differences in landings in greater detail, revealing that the majority landings from hagfish trips reporting their positions (latitude and longitude) were prosecuted in the Wilkinson Basin area. Two large trips in the Jordan Basin (northeast corner of the fisheries' range) are the exception to this rule.

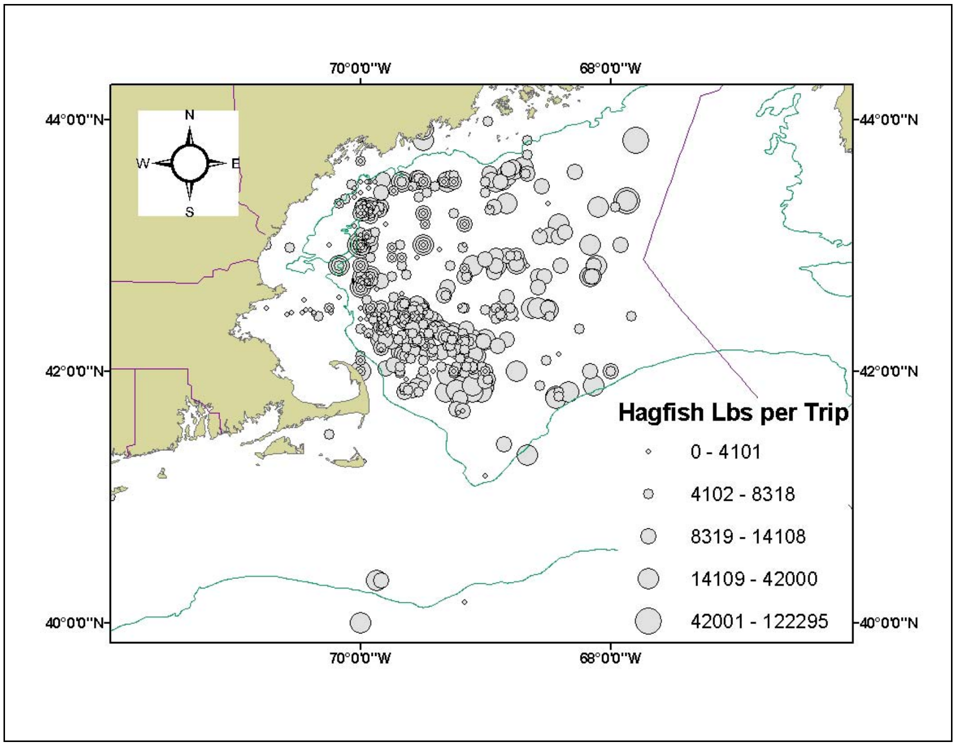



**Figure E44 – Point estimates for hagfish landings based on reported trip lat/lon (1994-2002 VTR data, n=1,571).**

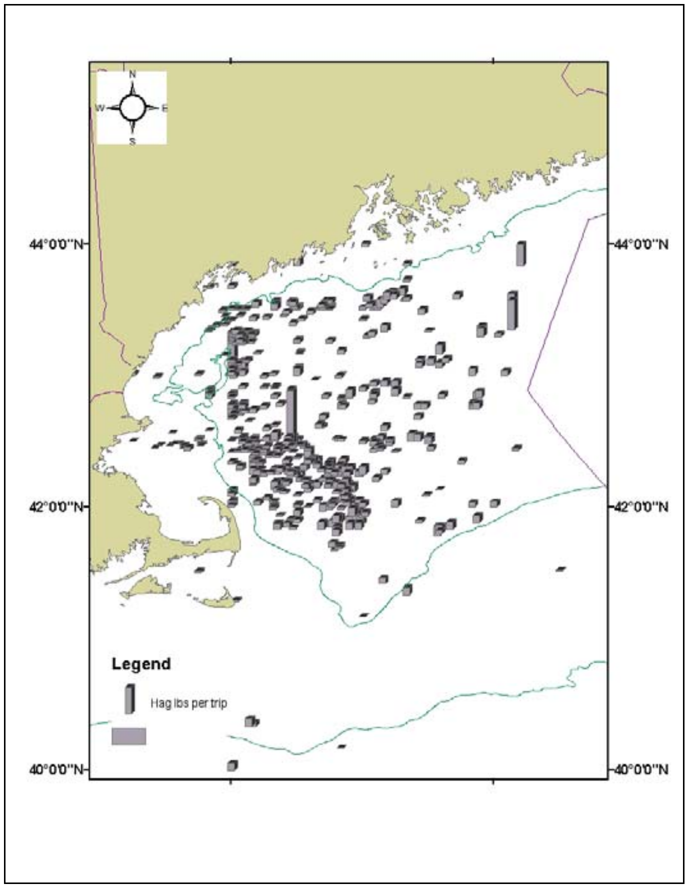



**Figure E45 – Bar chart of point estimate hagfish landings (1994-2002 VTR data, n=1,571).**

| NEMAREA | Sum haglb | Mean haglb | Mean GEARQTY | Mean NHAUL | Mean da | Mean DEPTH | Mean CREW | Mean LEN | Mean GTONS | Mean VHP | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 13,110 | 3,278 | 21.3 | 2.0 | 1.3 | 5.0 | 2.5 | 44.5 | 18.5 | 275.8 | 4 |
| 513 | 12,556,379 | 6,195 | 91.6 | 7.8 | 1.1 | 74.8 | 2.8 | 56.1 | 48.6 | 345.6 | 2,027 |
| 514 | 7,629,682 | 3,885 | 62.8 | 11.3 | 1.1 | 62.9 | 2.3 | 43.9 | 23.8 | 319.2 | 1,964 |
| 515 | 2,419,937 | 8,897 | 100.2 | 8.5 | 1.7 | 94.0 | 2.6 | 59.2 | 57.3 | 365.2 | 272 |
| 521 | 2,446,929 | 7,529 | 75.5 | 11.4 | 1.7 | 102.0 | 3.0 | 59.2 | 58.1 | 335.1 | 325 |
| 522 | 42,538 | 3,545 | 45.2 | 22.8 | 5.7 | 98.0 | 4.1 | 72.5 | 124.3 | 543.3 | 12 |
| 526 | 980 | 245 | 40.0 | 34.5 | 6.8 | 106.5 | 4.5 | 58.5 | 70.0 | 397.5 | 4 |
| 612 | 844 | 211 | 1.0 | 3.0 | 1.0 | 26.3 | 2.0 | 60.0 | 77.0 | 365.0 | 4 |
| All other areas | 192,437 | 8,337 | 72.6 | 10.4 | 2.5 | 71.5 | 3.6 | 58.4 | 75.3 | 485.3 | 25 |

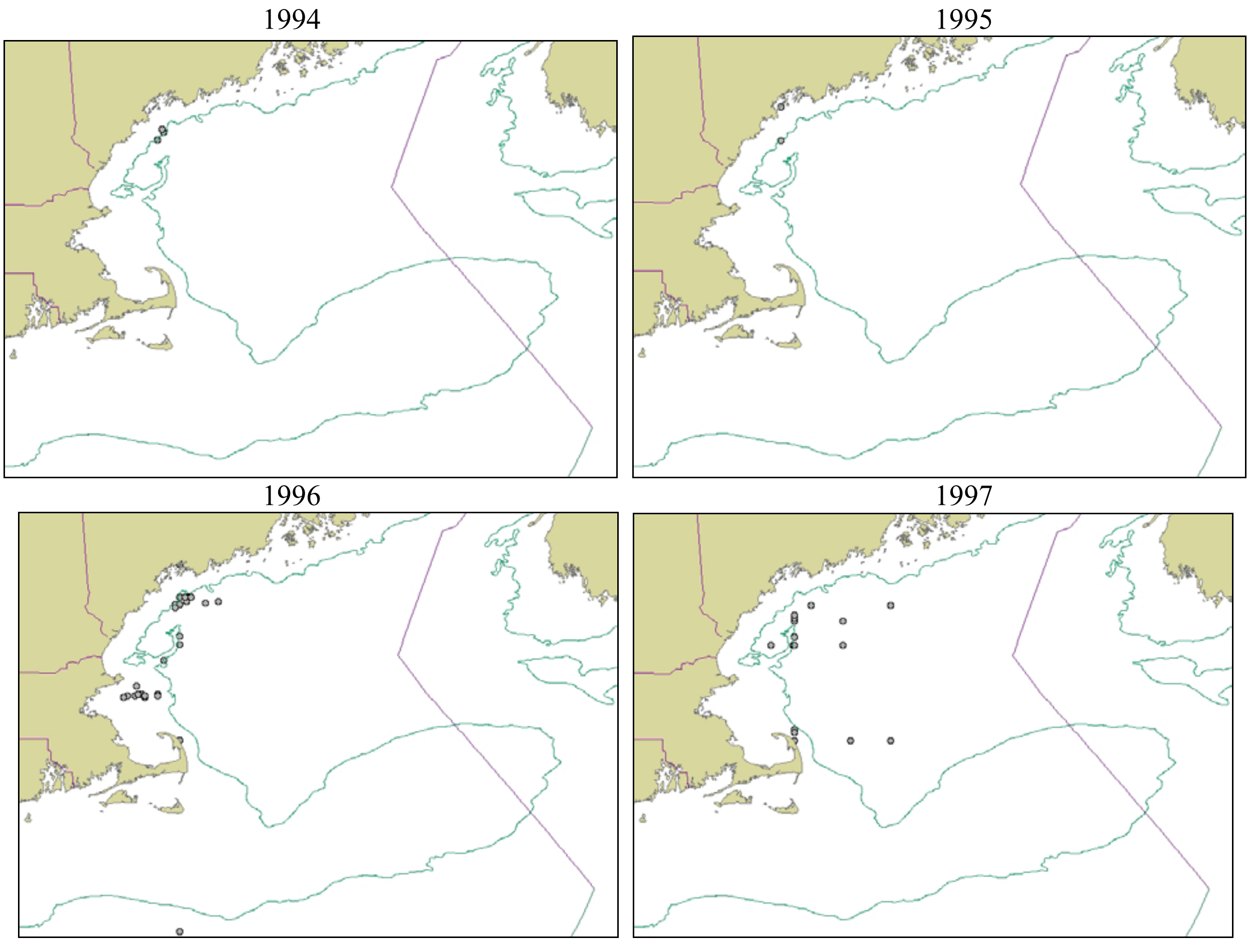
**Table E13 – Statistics for all trips landing hagfish, by statistical area (1994-2002 VTR data, n=4637).**

Clearly the bulk of landings stem from areas 513, 514, 515 and 521. These areas tend to see shorter trips by, on average, smaller vessels. Larger vessels making longer trips have landed hagfish (eg. in Areas 522 and 526) but this mode of fishing has not, to this point, become overly popular.

### 6.5.5 Spatial and temporal trends within the hagfish fishery

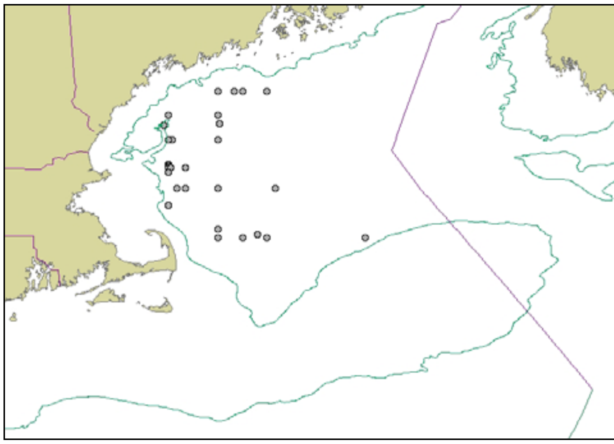
#### 6.5.5.1 Spatial distribution

Map E1 shows the reported position of trips on an annual basis. These figures show that vessels reporting trips have tended to move further and further offshore. These trips have also trended southward, with a cluster of trips in the coastal Maine area occurring in 1998-2000, while the bulk of the fishing trips shifted southward off of Cape Cod along the southern reaches of Wilkenson Basin in 2001-2002. This brings to light the possibility that vessels are moving farther from their traditional fishing grounds in search of better fishing. The concept of localized depletion will be investigated in a subsequent section of this document.

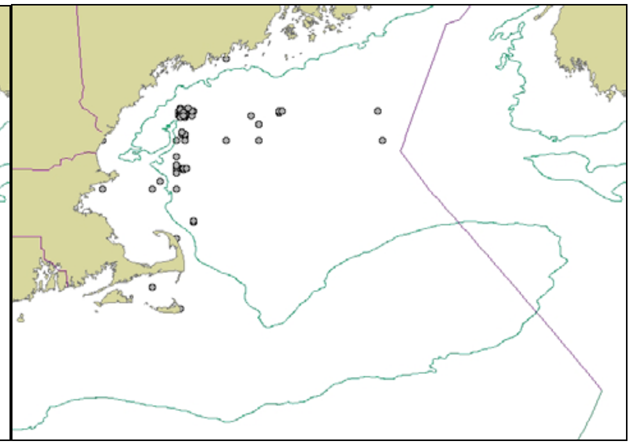



**Map E1 - All trips reporting via VTR, 1994 - 2002.**

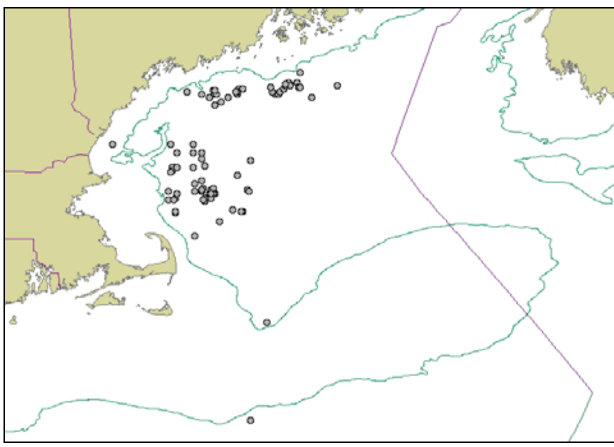
1998



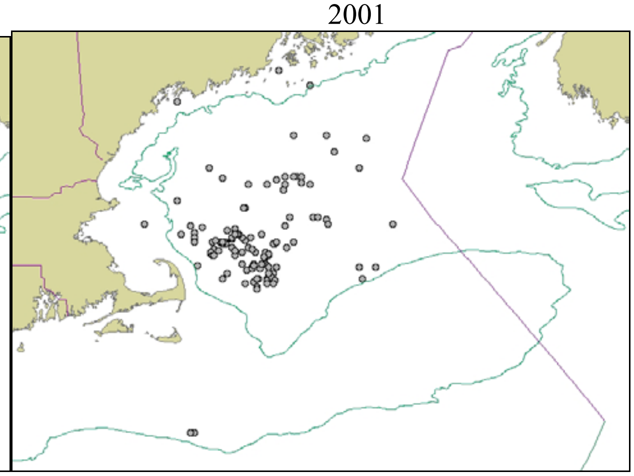
1999



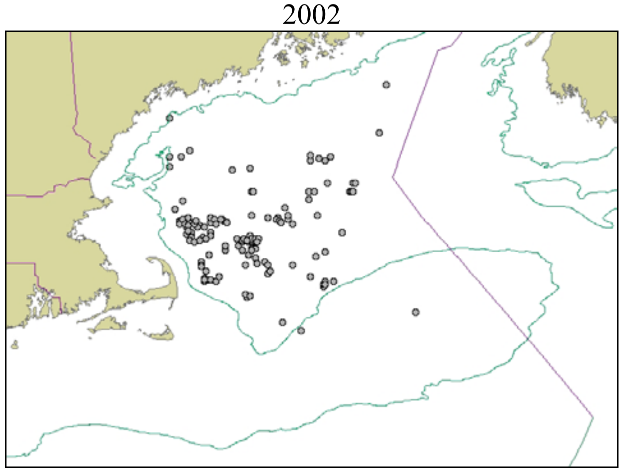
2000



2001



2002



**Map E1 - All trips reporting via VTR, 1994 – 2002.**

(continued)

#### 6.5.5.1.1 Spatial distribution measures

In addition to the eastward and southward expansion of the hagfish fishery's range, it is also becoming more geographically diffuse. A Lorenz curve, plotting cumulative landings (*X*) versus cumulative area (*Y*), is applied to the VTR data for trips where the "ten minute square" variable is available (n=2,646). Area is defined by the number of ten minute squares found within the demonstrated range of the fishery; landings are summed for each ten minute square and a cumulative distribution is computed. If the density of landings was the same across all ten minute squares, i.e. both effort and abundance were uniformly distributed, the Lorenz curve would be a straight line from the origin to (1, 1). Figure E46 shows the Lorenz curves for the hagfish fishery from 1994 through 2002.

The Gini coefficient is a measure typically used to quantify dispersion of wealth. Here it is used to demonstrate the spatial diffusion of the hagfish fishery. It is essentially the sum of the differences between the Lorenz curve and the identity function (equal distribution of landings). Figure E47 shows that reported hagfish fishery landings are becoming more spatially diffuse over time.

Another measure of spatial distribution is mean geographical distance. A simple algorithm (SAS macro) is used to compute the distance from landed port for each trip reporting a position (latitude and longitude). Figure E48 shows that the mean distance from landed port for reporting trips is increasing.

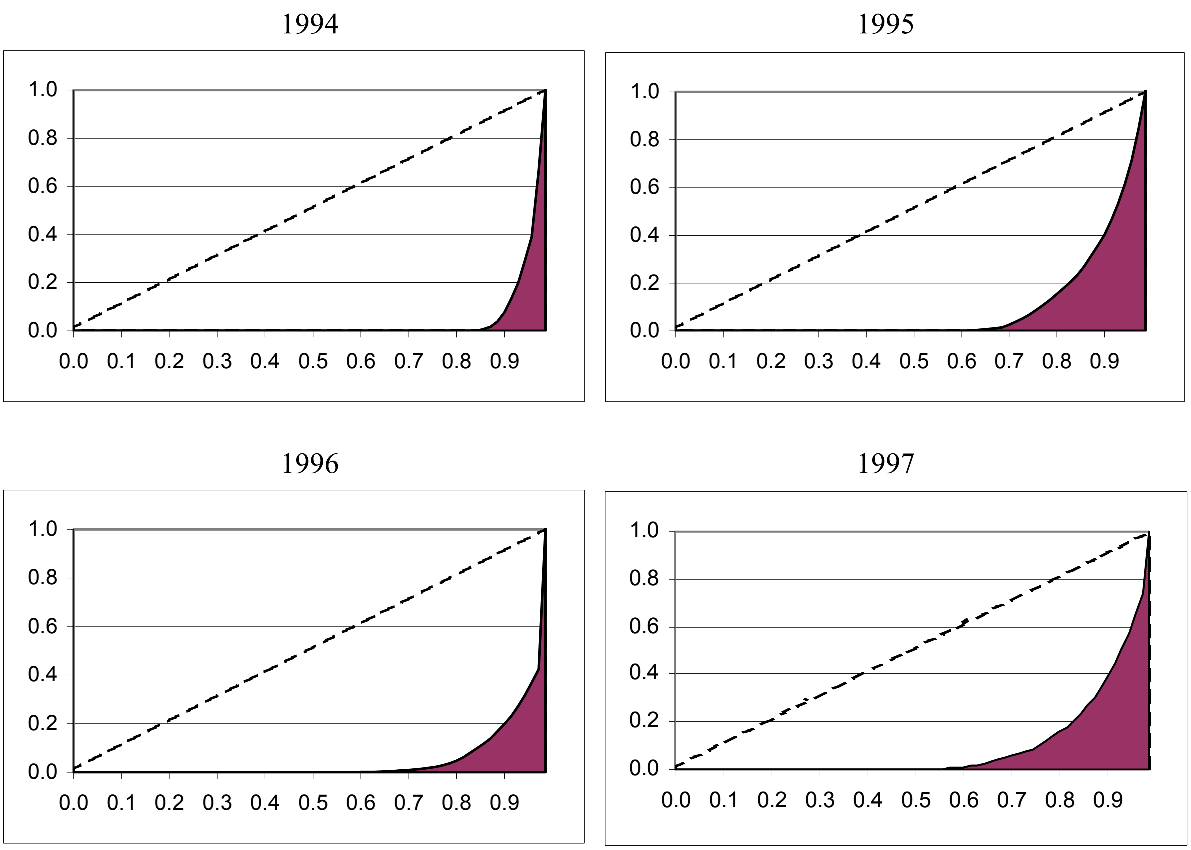



**Figure E46 - Lorenz curves for reported hagfish landings (94-02 VTR, number of trips = 1,571).** *Cumulative % landings is on the X axis and cumulative % area is on the Y axis. Greater curvature indicates a greater spatial concentration of landings. The dashed line represents what would be expected if landings were equally distributed across the range of the fishery.*

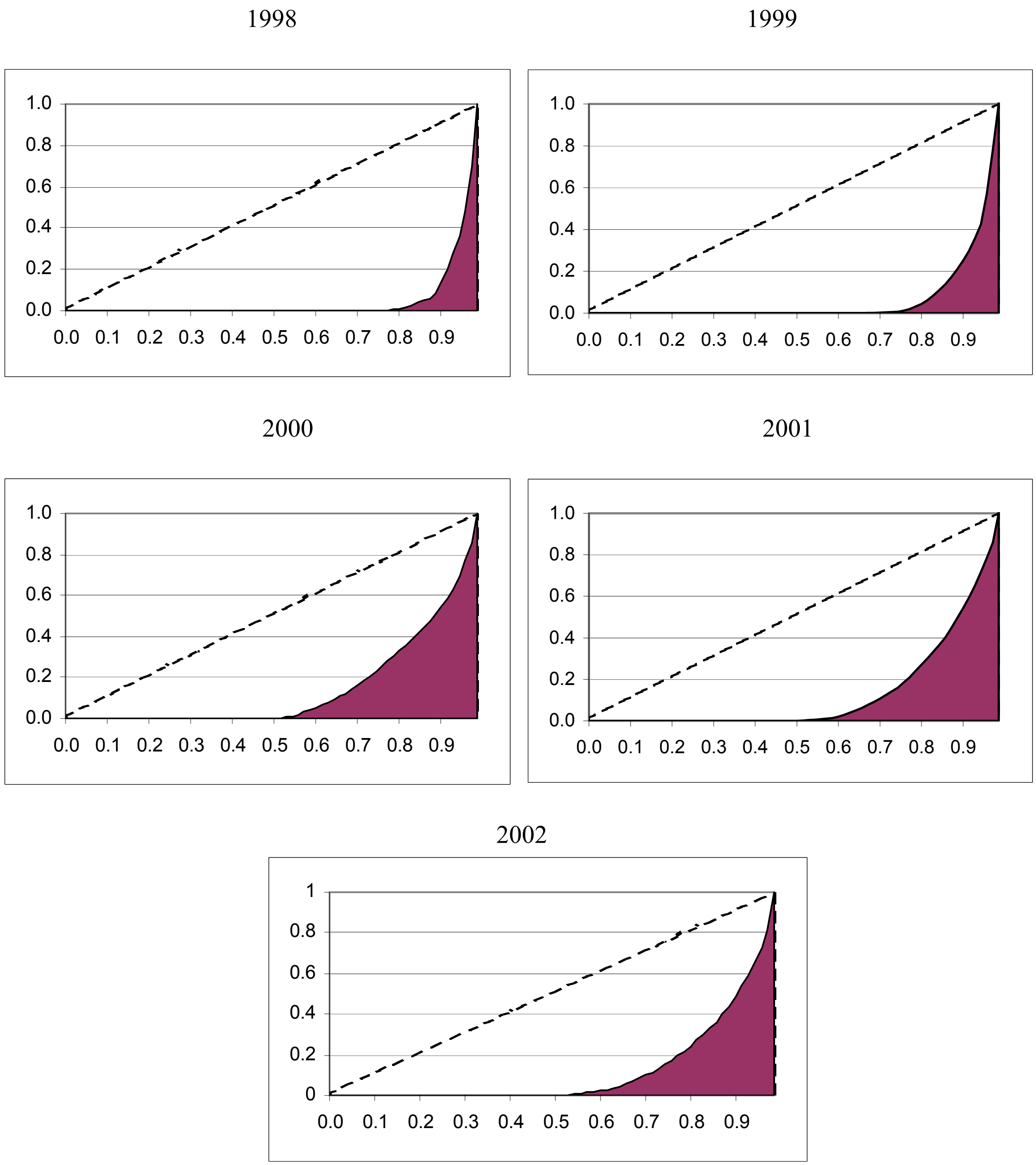



**Figure E46 – Lorenz curves for reported hagfish landings (94-02 VTR, number of trips = 1,571).**

*Cumulative % landings is on the X axis and cumulative % area is on the Y axis. Greater curvature indicates a greater spatial concentration of landings. The dashed line represents what would be expected if landings were equally distributed across the range of the fishery.*

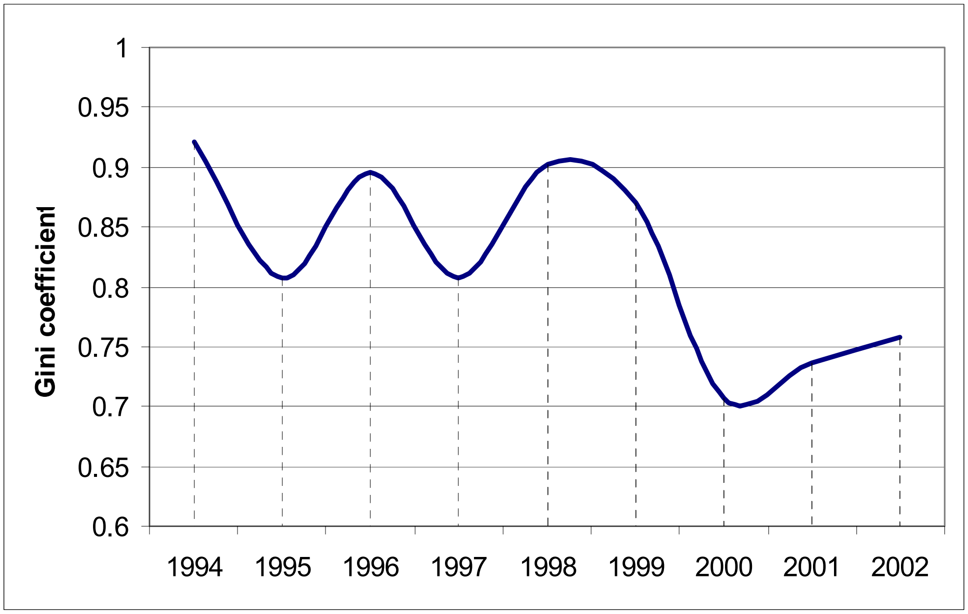



**Figure E47 – Gini coefficients for the hagfish fishery (all VTR trips reporting lat/lon, n = 1,571).**

*A coefficient of zero would represent equal distribution of landings across the range of the fishery.*

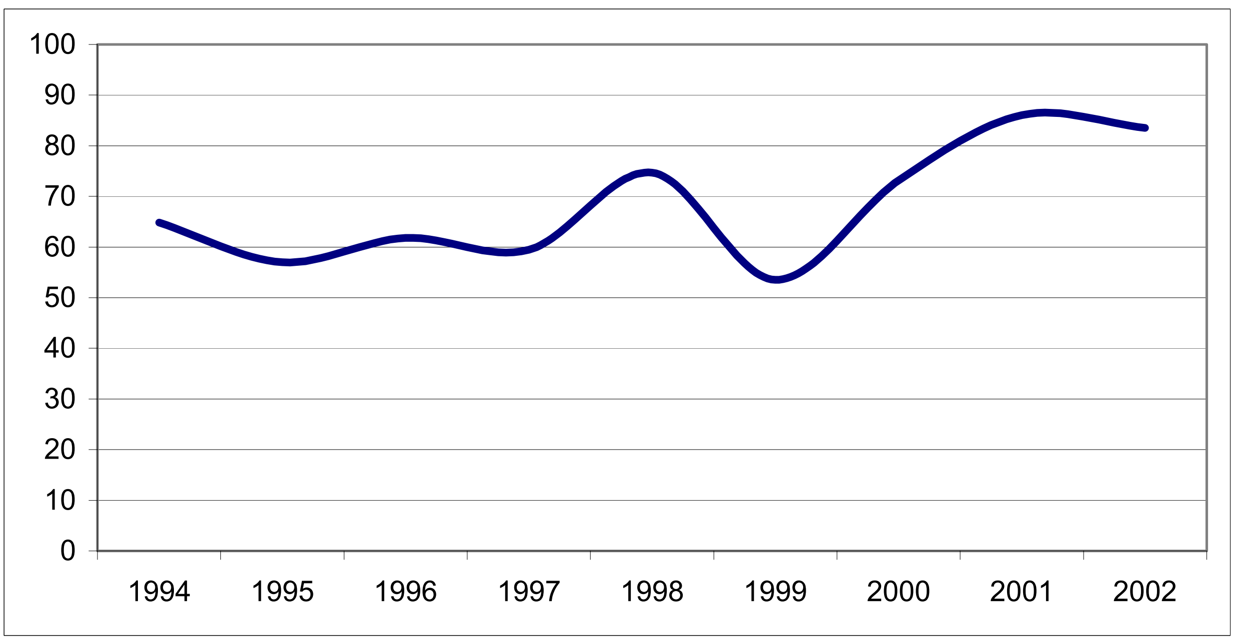



**Figure E48 – Mean distance (statute miles) from landed port per trip, VTR 94-02 (n=1,571).**

### 6.5.5.2 Changes in fishing practices

In addition to the geographic changes noted above, changes in fishing practices over time have been observed. As the mean distance from landed port has increased with time, so too has the mean number of days absent and the number of traps used per trip (Figure E49).

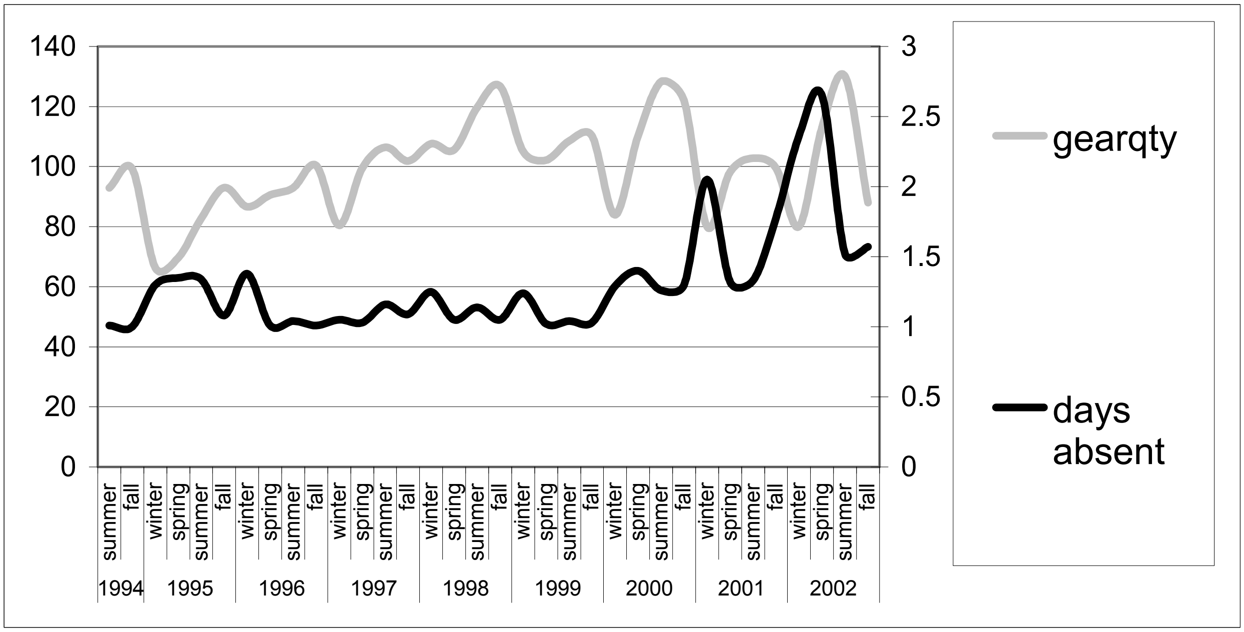



**Figure E49 – Mean number of traps employed and days absent per trip (n=3,410).**

### 6.5.5.3 Seasonal trends

Landings tend to be significantly higher in the spring and fall months, peaking in summer (Figure E50). This trend is very similar to that which emerged from monthly dealer landings data (Figure E40). Reported trips tended to occur in the northern areas of the fisheries' range in the summer and fall months, and in the southern areas in the winter and spring.

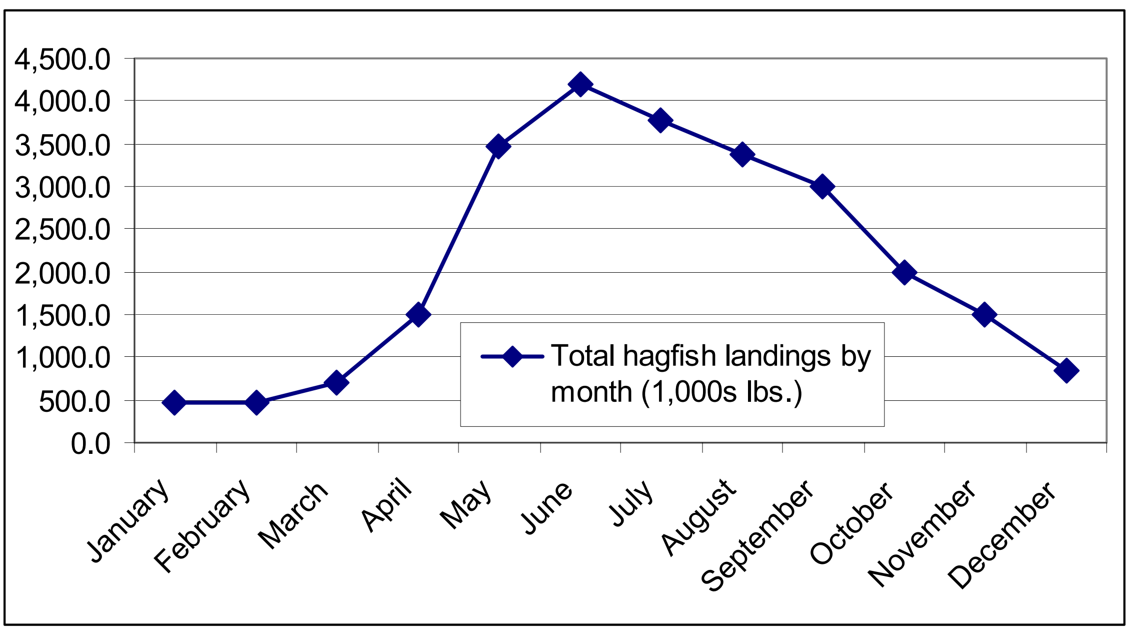
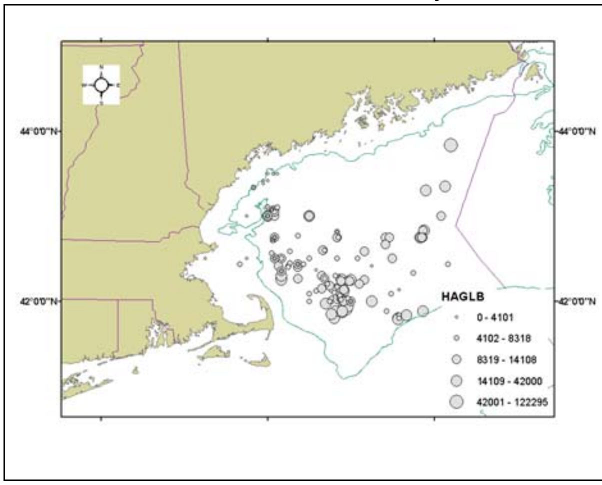
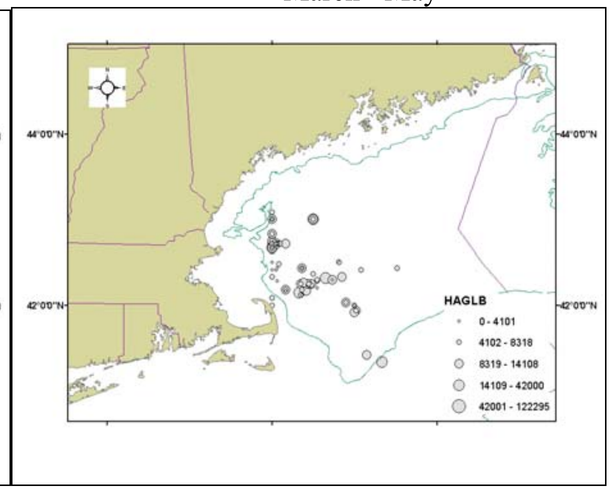



**Figure E50 – Season total landings as reported via VTR.**

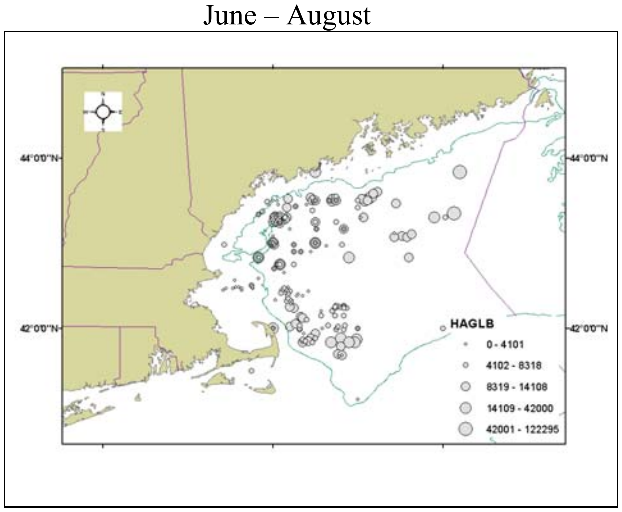
December – February



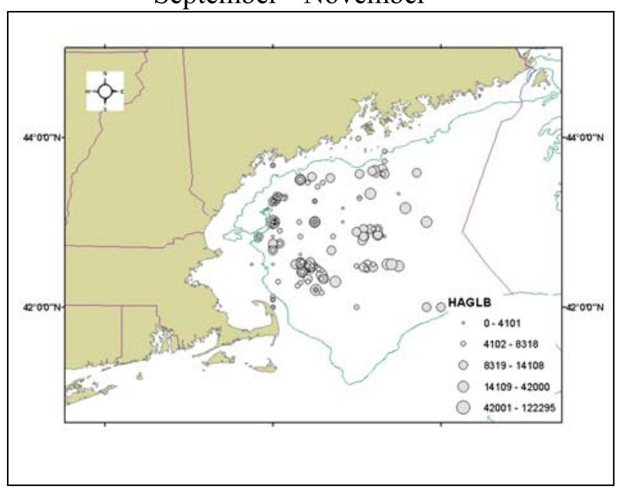

March - May




June – August




September - November




**Map E2 – Seasonal distribution of trips reported via VTR, 1994-2002 (n=1,571).**

### 6.5.6 Landings per unit Effort

Fishing effort refers to the ability of fishing vessels to translate inputs (vessel, gear and crew) into outputs (pounds of fish, dollars). In trap fisheries, number of traps or number of trap-hauls often function as a proxy for effort inputs (Briand 2001, DFO 2002, Benson 2001, DFO 2002). As trap fisheries tend to focus on a small array of species, pounds of fish is the most common output. These conventions are used here.

In these analyses, landings per unit of effort (LPUE) were examined. Because the weight of the catch reported by VTR is, in nearly all cases, identical to the landed (paid) weight reported by the dealer, it is not possible to accurately estimate catch per unit of effort (CPUE). Measures of LPUE underestimate true effort because they do not include discards and other possible reductions in true landed weight (e.g. "shrinkage").

To further focus the data, exclusion rules were employed as follows:

- days absent less than 1 were assigned a value of 1, with subsequent days absent employing partial days
- trips reporting more than 30 days absent were deleted
- trips reporting more than 60 hauls were deleted
- trips landing less than 75 lbs of hagfish were deleted
- trips reporting less than 15 traps were deleted

This reduced the size of the dataset from 4,637 trips to 3,410 trips.  Days absent refer to days absent from port.

#### 6.5.6.1 Nominal LPUE

Nominal landings per unit effort is measured here as pounds of hagfish per trap per reported day absent. Number of hauls was investigated as an input variable but found to be less reliable due to inconsistencies in the way data were recorded—some captains listed 1 haul per day, while others listed as many as 100 hauls per day.  Due to this inconsistency, number of hauls was not used in estimating LPUE.

Figure E51, below, shows nominal LPUE for the hagfish fishery.  The days absent variable is also listed as an indicator of total fishing effort.  As LPUE has declined, total days absent have declined as well.  An obvious seasonal trend emerged as well, and Figure E52 shows nominal LPUE per season.

LPUE tended to hold steady throughout much of the late 1990s, but began to decline after the spring of 2001.  All season-specific LPUE estimates have trended down since 2001, and all are currently between 30 and 50 percent of their historic highs (Figure E52).

At smaller spatial scales, nominal LPUE varied cyclically with a generally declining trend across years in all areas except 514.  Effort, measured in days absent, has recently increased in Area 514, with historically high LPUEs for much of 2000 and 2001 (Figure E54).

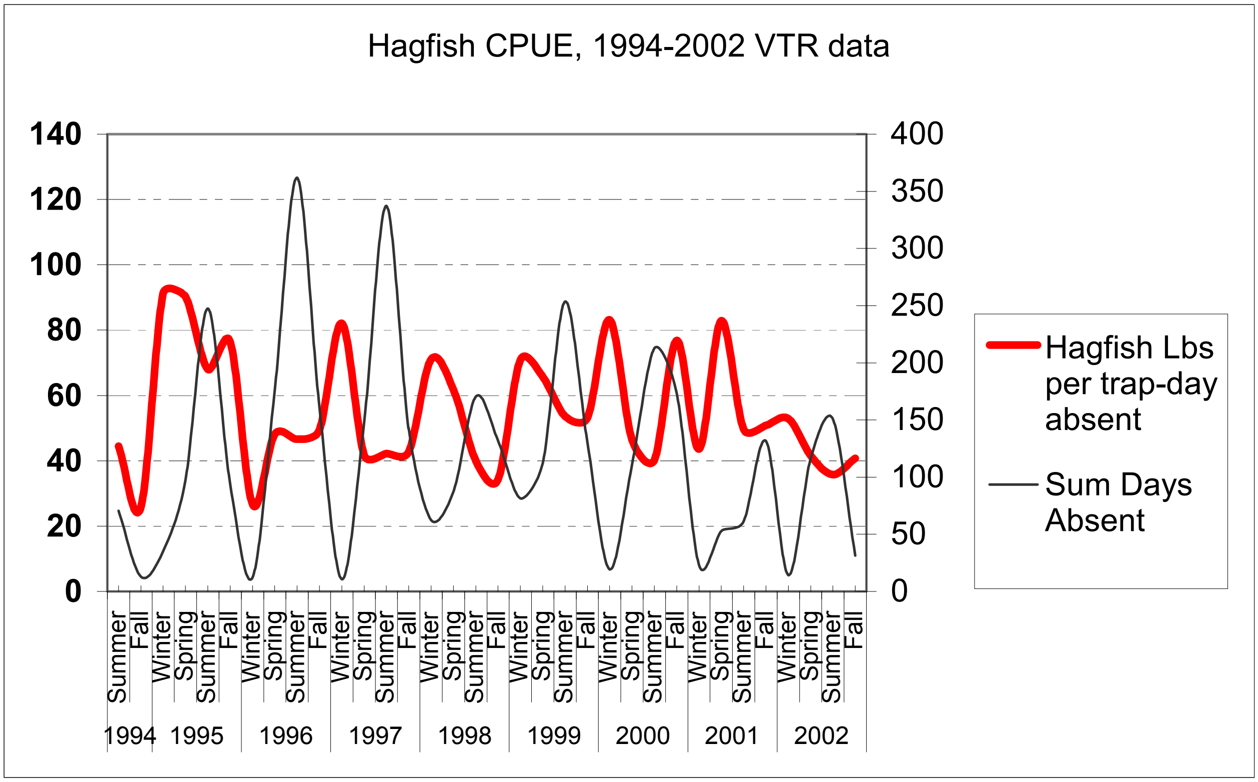



**Figure E51 – Nominal LPUE for trips reported via VTR, 94-02 (n=3,410).**

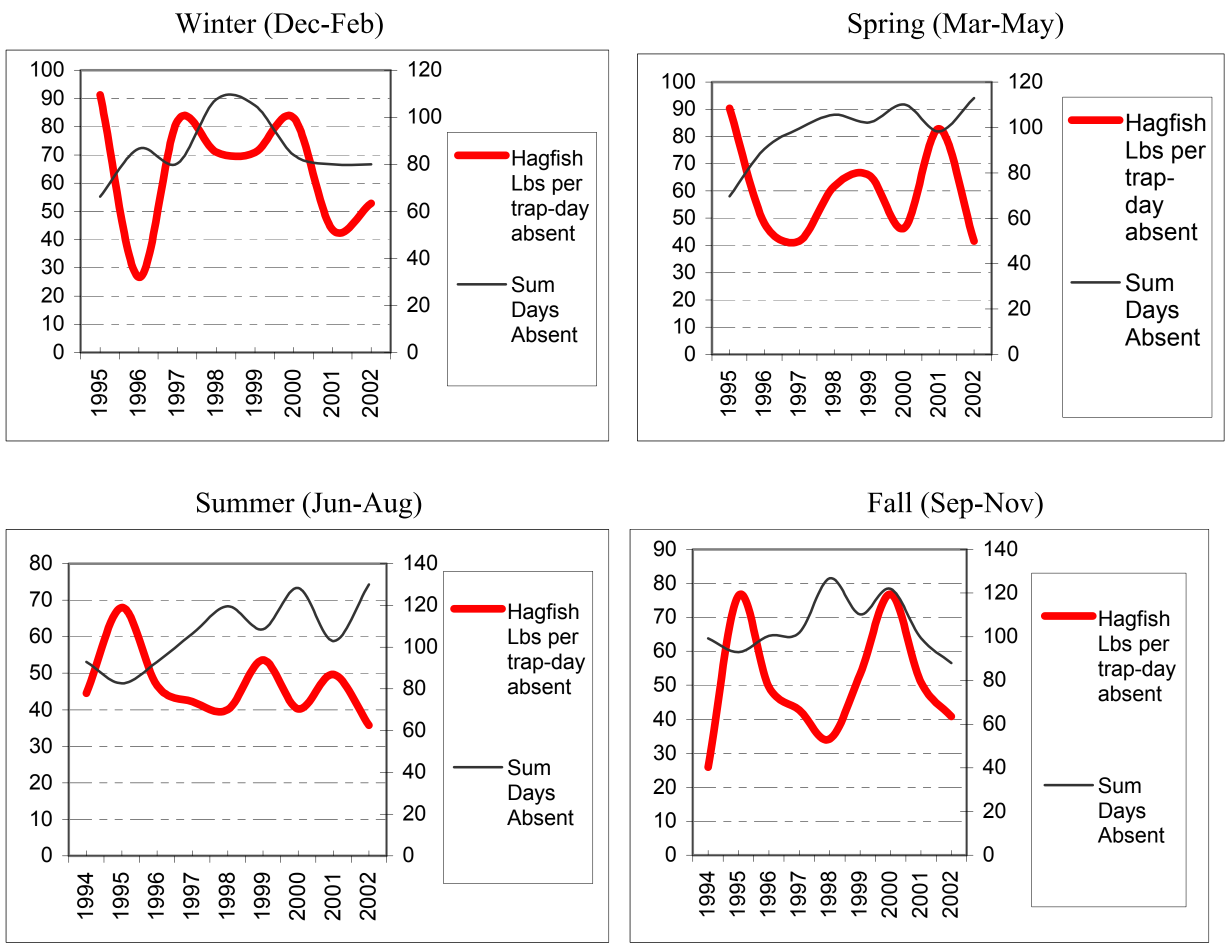



**Figure E52 – Seasonal trends in nominal LPUE (VTR data, n = 3,410).**

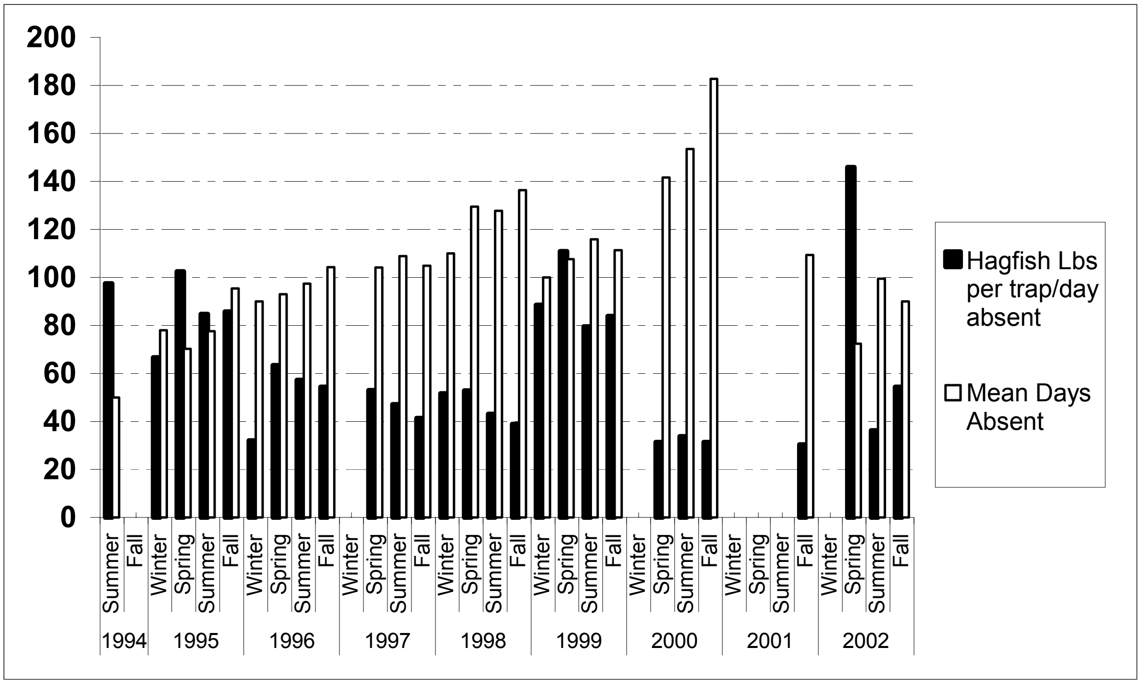



**Figure E53 - Nominal LPUE for Area 513 (1994-2002 VTR data, n=1,687).**

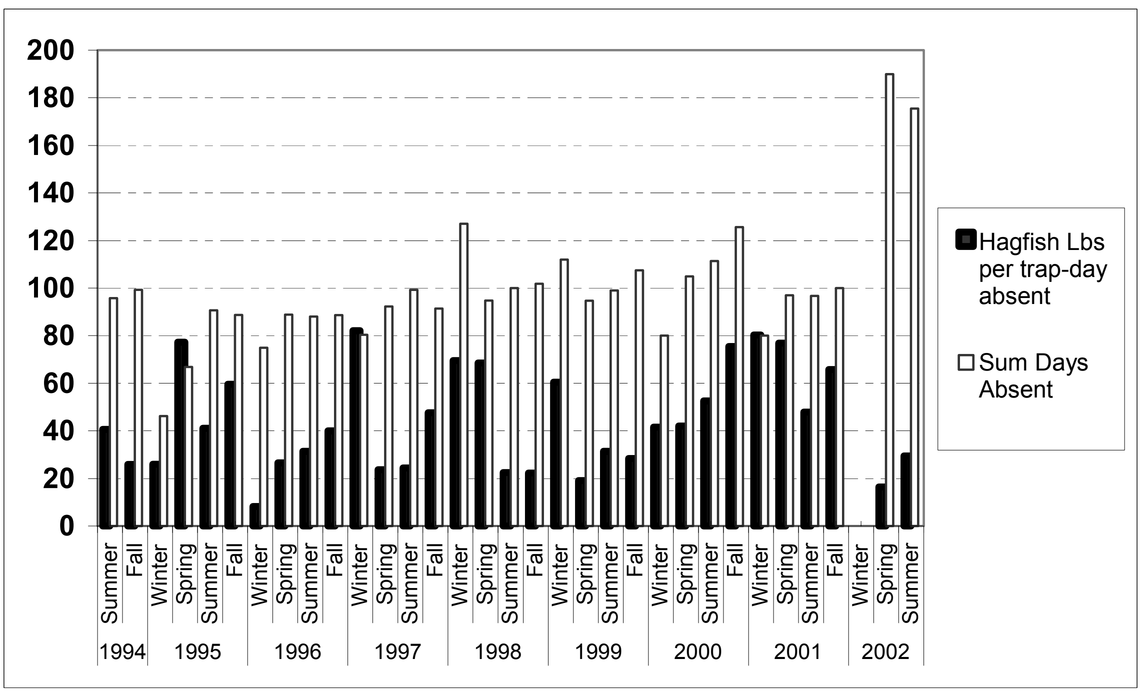



**Figure E54 - Nominal LPUE for Area 514 (1994-2002 VTR data, n=1,190).**

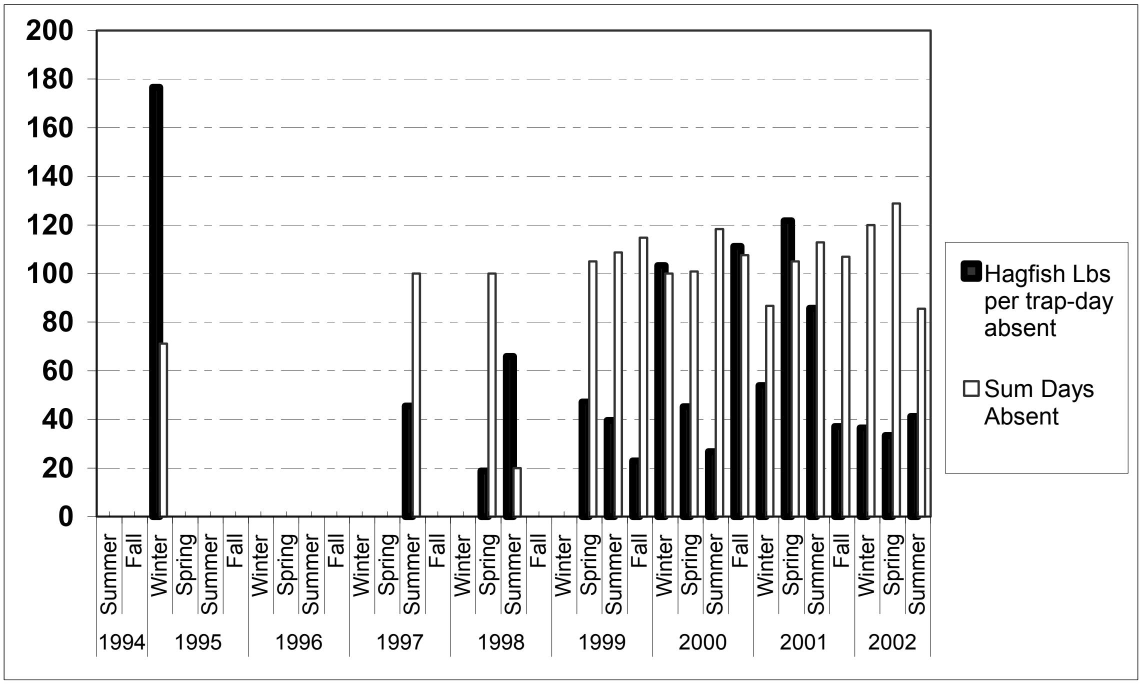



**Figure E55 - Nominal LPUE for Area 515 (1994-2002 VTR data, n=254).**

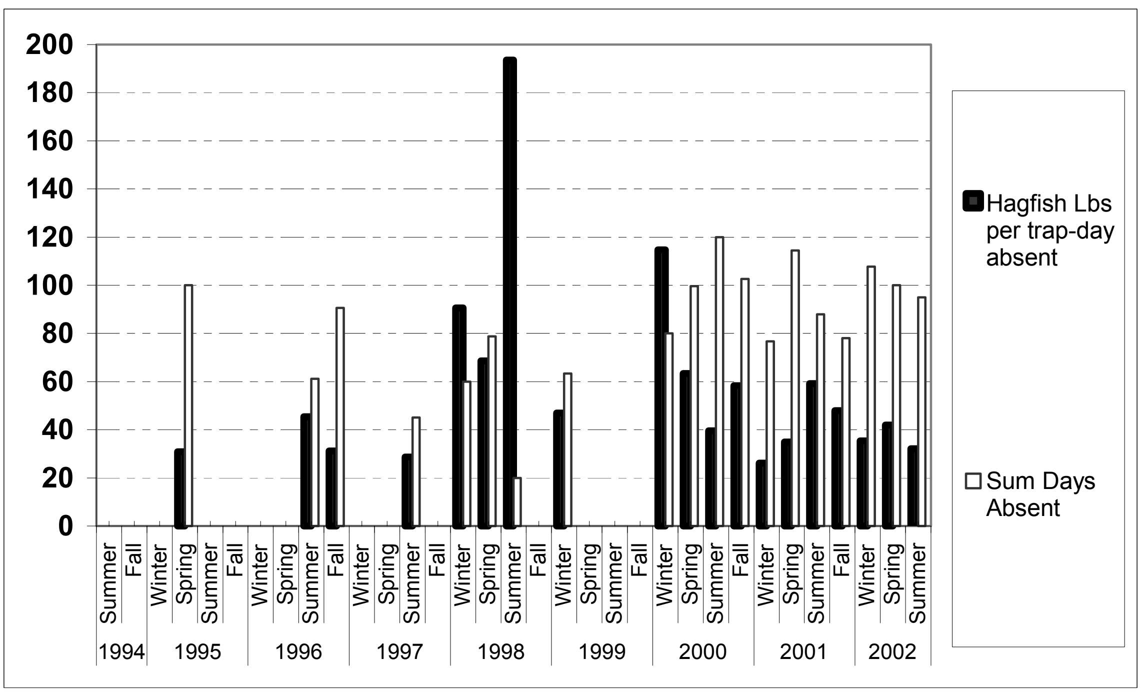



**Figure E56 - Nominal LPUE for Area 521 (94-02 VTR, n=256).**

#### 6.5.6.2 Standardized LPUE

Nominal LPUE inputs were not found to be comprehensive predictors of actual landings. LPUE was modeled using a generalized linear approach to test for vessel-specific variables that may contribute toward actual fishing effort. Specifically the crew, length, gross tonnage and horsepower variables were modeled (Table E14).

| Variable | Parameter Est | St Error | t Value | Pr > \|t\| |
|---|---|---|---|---|
| Intercept | 18.15641 | 8.63073 | 2.1 | 0.0355 |
| Number of crew | 2.75166 | 1.45549 | 1.89 | 0.0588 |
| Vessel length | 0.54475 | 0.16135 | 3.38 | 0.0007 |
| Vessel gross tonnage | 0.38779 | 0.08465 | 4.58 | <.0001 |
| Vessel horsepower | -0.05878 | 0.0115 | -5.11 | <.0001 |

**Table E14 – Regression statistics with nominal LPUE as the dependent variable (LPUE mean = 52.18, df = 3,409).**

The crew variable was not significant at the P > 0.05 level (though just barely), and multicolinearity was observed between the gross tonnage, length and horsepower variables. A modified ad-hoc step-up procedure was used to fit the best models, and the number of crew, horsepower, and length variables were eliminated. LPUE was then standardized for vessel gross tonnage using a generalized linear model.

Standardized LPUE trended down in all areas, with declines on the order of 50% from historical highs (generally in the 1994-1996 time frame) being common.

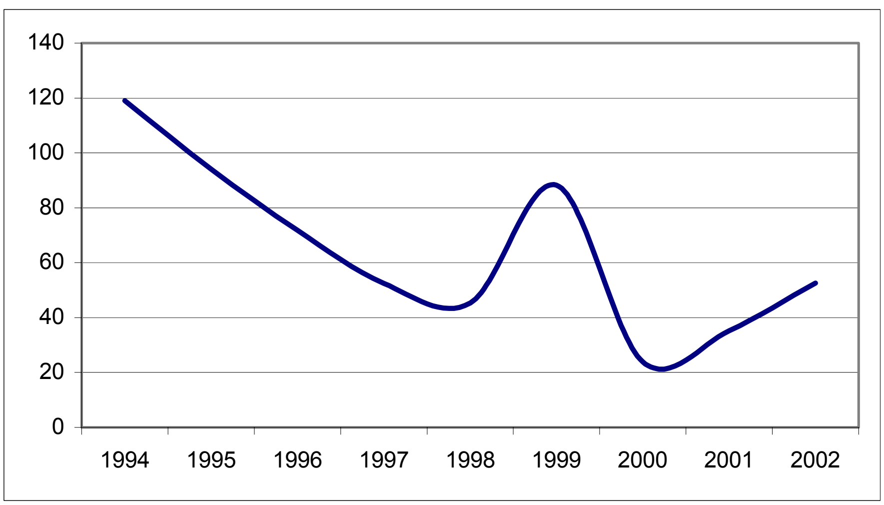



**Figure E57 - Standardized LPUE for area 513 (VTR 94-02, n=1,670).**

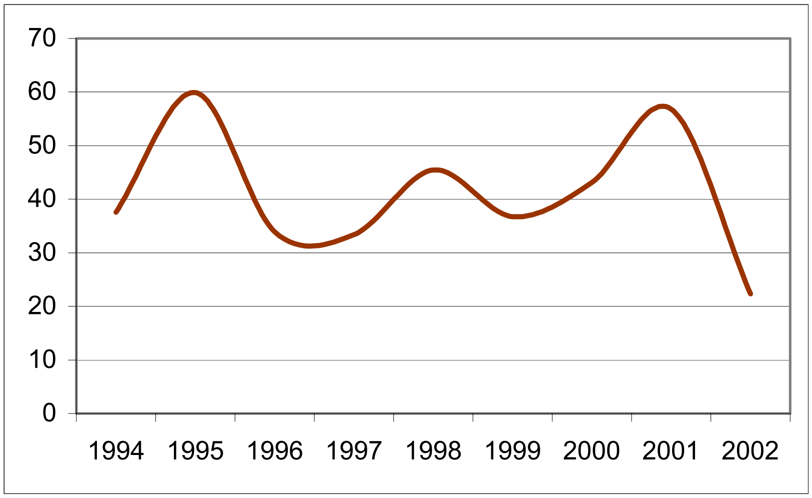



**Figure E58 - Standardized LPUE for area 514 (VTR 94-02, n=1,190).**

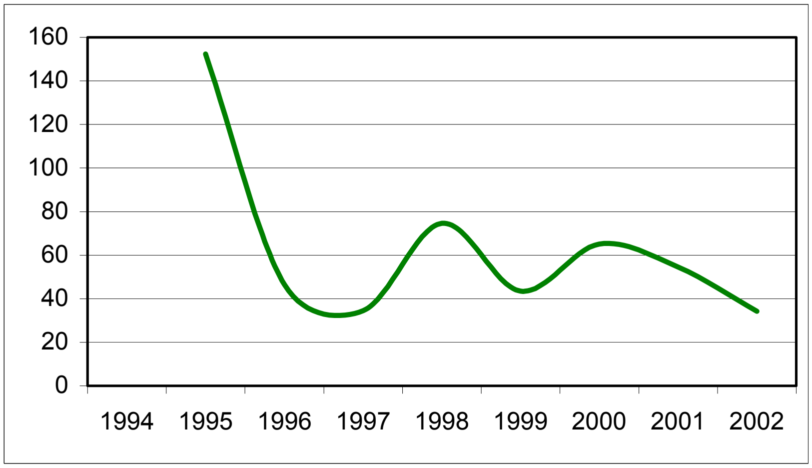



**Figure E59 - Standardized LPUE for areas 515 and 521 (VTR 94-02, n=510).**

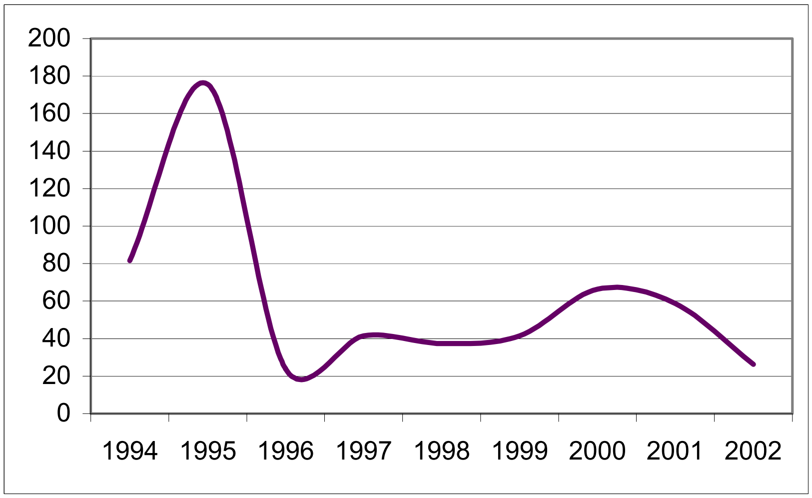



**Figure E60 - Standardized LPUE for all other areas (VTR 94-02, n=277).**

#### 6.5.6.3 Vessel-specific LPUE

A relatively large number of vessels have entered and exited the hagfish fishery, targeting hagfish for only a short time. To eliminate the influence of short-time operators on LPUE, standardized LPUE was computed for the top five hagfish landing vessels, each of which remained in the fishery for more than 2 years. After an initial "fishing up" period in 94-95, and another again in 97-98 as new long-term (greater than 2 years) operators entered the fishery, LPUE estimates declined as they have on nearly every spatial and temporal scale investigated (Figure E61).

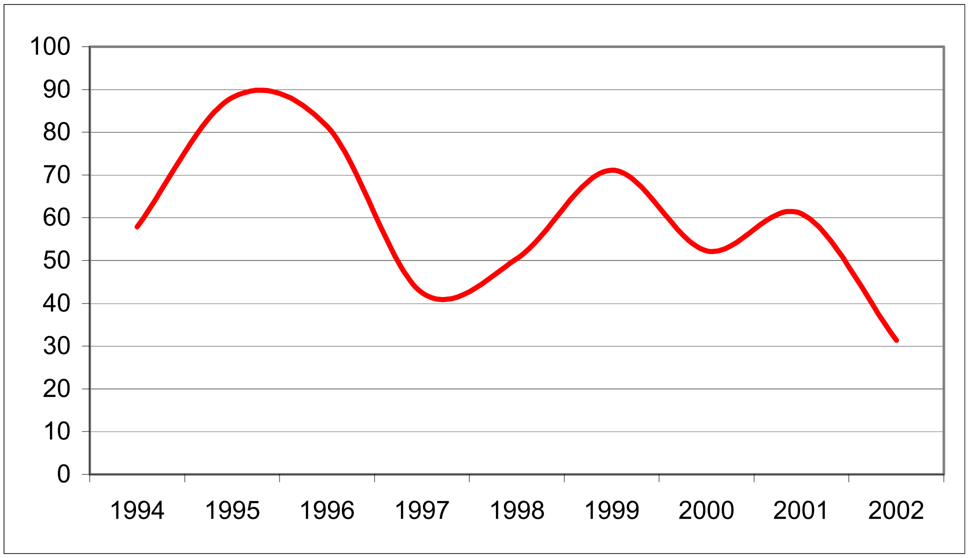



**Figure E61 - Standardized LPUE for the top 5 landing vessels (VTR 94-02, n=2,176).**

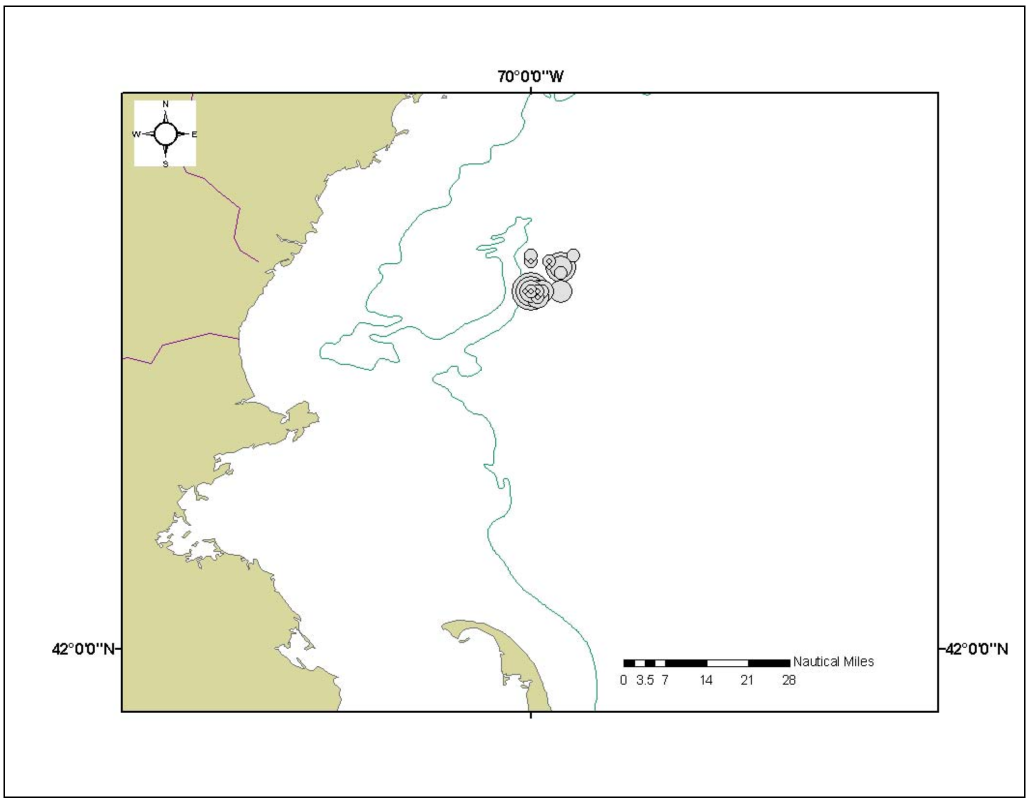
### 6.5.7 Localized Depletion

The trends noted above, specifically the increasing diffusion of fishing effort and increasing mean distance from landed port, call to mind the potential that hagfish may be targeted intensely on a small spatial scale, potentially leading to localized depletion. To investigate this, small spatial areas with numerous trips reported were sought. Three such areas were identified through geo-statistical analysis using ArcGIS. The first two clusters were comprised of trips by only one or two vessels and analysis results cannot be shown due to data confidentiality. The third cluster, described in Table E15 and shown in Map E3, contains 411 trips by more than three vessels. Table E16 shows the regression statistics for modeling standardized LPUE for this cluster. Note that all trips in this cluster were made between 1996 and 2000.

Analysis shows two periods of sharply declining LPUE. These declines are somewhat consistent with those observed in statistical area 513 (in which this cluster resides). Further investigation is required to differentiate the localized declines in LPUE from those of the region. The important fact here is that localized concentrations of fishing effort are available in these data and, while the time series is too short to reach any conclusions, the potential for further investigation using more savvy statistical tests exists.

| Variable | N | Mean | sd | Minimum | Maximum |
|---|---|---|---|---|---|
| HAGLB | 411 | 8459.1 | 5416.62 | 300 | 82522 |
| LPUE | 408 | 82.3 | 87.43 | 3 | 1363.25 |
| GEARQTY | 411 | 110.6 | 22.28 | 0 | 180 |
| NHAUL | 411 | 11.5 | 5.57 | 0 | 100 |
| DA | 411 | 1.0 | 0.16 | 0 | 2 |
| DEPTH | 411 | 72.7 | 27.29 | 0 | 144 |
| CREW | 411 | 3.0 | 0.21 | 0 | 3 |
| GTONS | 411 | 57.4 | 9.20 | 17 | 63 |

**Table E15 - Descriptive statistics for identified cluster**




**Map E3 - Location of identified cluster (symbols proportional to pounds landed per trip, VTR 94-02, n=411).**

| | | | | | |
|---|---|---|---|---|---|
| Intercept | 1 | -75.8379 | 36.44146 | -2.08 | 0.0381 |
| GTONS | 1 | 1.99975 | 0.48068 | 4.16 | <.0001 |
| 1996 | 1 | 65.20874 | 21.50996 | 3.03 | 0.0026 |
| 1997 | 1 | 16.13869 | 23.01507 | 0.7 | 0.4836 |
| 1998 | 1 | 10.05016 | 22.37558 | 0.45 | 0.6536 |
| 1999 | 1 | 55.59023 | 23.07742 | 2.41 | 0.0165 |

**Table E16 - Modeled regression statistics for identified cluster (cluster mean gross tonnage = 57.43, df = 410).**

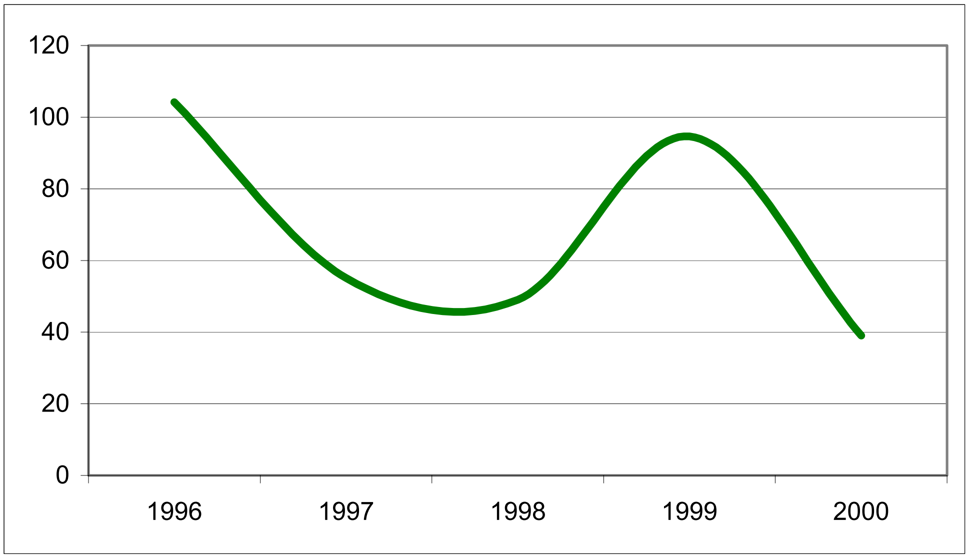



**Figure E62 - Standardized LPUE for identified cluster (VTR 94-02, n=411).**

## 7.0 MANAGEMENT HISTORY

### 7.1 British Columbia, Canada

In British Columbia, the commercial fishery for Pacific hagfish (*E. stoutii*) and Black hagfish (*E. deani*) was classified as experimental from 1988 to 1992 (Leask & Beamish 1999). During this time, the fishery was managed by limiting participation in the fishery and establishing differential trap limits based on area fished, of either 2000 Korean traps or 3500 Korean traps per vessel (Benson et al. 2001). There was no minimum size established but a market limit of 30 cm was in place for the duration of the fishery. The most critical element of the management program was the requirement for active vessels to participate in a biological sampling program, recording length, weight, sex, and presence/absence of eggs of a random sample of 1,000 landed hagfish each month. Catch and effort were also recorded for each set (Benson et al. 2001). Gear fished was required to have biodegradable fastenings for entrance funnels to prevent ghost fishing of lost gear (Leask & Beamish 1999).

### 7.2 Western U.S.

In the Pacific U.S. hagfish are managed in state waters only. In Oregon, hagfish were harvested using traps with a required biodegradable escape panel and no incidental catch was allowed. Before the traps were approved for the hagfish fishery, experimental gear permits were issued for their use. By fall 1990, 52 permits had been issued (McCrae 2002).

California also required a biodegradable panel in each trap. Gear studies in California demonstrated that larger fish could be selected for using traps with larger escapement holes (0.48 inches) and allowing for longer soak times (12 hours) (McCrae 2002). The most efficient trap design had more than one entrance funnel, escapement holes only in the area around the funnel, and shorter funnels made of solid material (McCrae 2002). California set a trap limit of 1,200 Korean traps or 300 plastic bucket traps (5 gallons or less in capacity). In addition, any vessel with hagfish gear on board is prohibited from possession of species other than hagfish. As in all California trap fisheries, a trap permit is required for hagfish (CA Regs. FGC §§9000-9024).

### 7.3 New England

There is currently no management plan for Atlantic hagfish and the fishery has not been managed by federal or state agencies since its inception in 1993. The following is a timeline describing the development of management for Atlantic hagfish in New England.

- **November 2001:** The New England Fishery Management Council ("Council") received a letter and petition signed by 13 members of the Gulf of Maine hagfish industry requesting that the Council take action to conserve the Atlantic hagfish resource and prevent overcapitalization of the fishery. The petitioners sought expedient implementation of a control date and the development of a Fishery Management Plan (FMP) for hagfish.

- **January 2002:** The Council tabled a motion to establish a control date for the hagfish fishery and moved to ask state directors to develop regulations for managing the fishery and report back to the Council within a six-month period. (The states have not provided this requested information to the Council). While there was disagreement about the merits of establishing a control date for hagfish, there was overwhelming consensus among Council members and industry representatives alike that more information on the biology and ecology of hagfish and the character of the fishery is essential to making sound management decisions.

- **April 5, 2002:** A Federal Register notice announced a petition to the Secretary of Commerce requesting emergency rulemaking for the Atlantic hagfish fishery.

- **April 2002:** The Northeast Region Coordinating Council tentatively placed the review of a hagfish assessment on the agenda for the 37$^{th}$ Stock Assessment Review Committee (SARC) workshop in June, 2003.

- **August 28, 2002:** *Control Date Published*— In response to public comment on the proposed emergency rulemaking, NMFS Northeast Regional Office established a control date for the Atlantic hagfish fishery and urged the Council to begin development of a Hagfish FMP.

- **November 2002:** The New England Fishery Management Council considered development of an Atlantic hagfish FMP in their discussion of priorities for 2003. They decided to wait for the results of the June SARC and completion of a Stock Assessment and Fishery Evaluation (SAFE) report before beginning development of a plan. The Council formed a hagfish committee which has not yet met.
- **March 28, 2003:** A working group met to (a) evaluate and discuss existing fishery and biological data and to highlight remaining data needs, and to (b) discuss and consider survey and assessment methods for hagfish. This report is the result of the group's efforts to address informational needs of the SARC.

## 8.0 FUTURE RESEARCH

### 8.1 Informational Needs

The working group identified specific data and information needs for management of the hagfish fishery and resource. The following is a list of the most essential research foci.

- estimate abundance based on existing data and new studies
- determine the level of discards in the hagfish fishery
- determine survivability of discarded hagfish
- collect more detailed information on spatial distribution of fishing effort and changes in effort over time
- develop studies to collect information on reproduction, growth and development, including age at maturity; growth rates; lifespan; and timing, condition and location of reproduction and egg deposition
- highlight differences between hagfish in the Gulf of Maine and those south of New England as well as differences between the inshore and offshore populations
- describe the range of hagfish and determine the extent of movement and migratory behavior
- develop a more detailed habitat profile for hagfish in the Gulf of Maine

The group also discussed means of collecting these data, including biological sampling, surveying and tagging studies, described in further detail in the following sections.

### 8.2 Biological Sampling

#### 8.2.1 At-Sea Observer Program

In accordance with the NMFS federal observer program, placing observers on vessels fishing for hagfish is possible. There are three possibilities for funding and administration of such a program:

1. Vessels participating in the fishery could hire NMFS-certified observers on a per day/per trip basis and compensate the observer contractor directly. Costs could range from $700-$1000 per day depending on the timing, duration and extent of coverage.

This option may be useful at the present time in identifying data that should and can be collected, issues associated with processing samples, variability in observations, and so forth. It is not clear whether industry is willing to incur such costs.

2. There is a limited pool of observer sea days which were earmarked for supporting cooperative research projects. To date, projects which have tapped into those days have involved joint design and execution by teams of NMFS scientists, industry and other participants.

Typically, projects to date which have tapped into the cooperative research observer sea day pool have involved about as much lead time in terms of planning and review as a typical cooperative research proposal. Only a part of the non-marine mammal observer days are associated with cooperative research. Most of these days are reserved for observer coverage in the New England groundfish fishery, as mandated by a federal court order.

3. A specific cooperative research proposal could be funded which would explicitly provide an appropriate level of coverage to the hagfish fishery.

In all cases, the data that should be collected, the precision necessary to draw inferences from the data and the variability in observations of those data must be determined prior to the specification of a sampling regime. A pilot study may be necessary to determine the relationship between precision and sample size.

### 8.2.2 Port Sampling

Taking length and weight measurements of random samples of landed hagfish at port is also a possible source of fishery data. The potential for implementing such a program is currently being examined by the National Marine Fisheries Service Northeast Regional Office.

## 8.3 Fishery Investigation

The working group discussed ways in which fishermen could provide more detailed information about spatial distribution of fishing effort. A relatively simple means of acquiring more explicit information on fishing patterns would be to conduct chart surveys with fishermen willing to disclose their personal logbook data. By plotting the positions of trips recorded in their logbooks and the catch levels associated with these specific areas, it may be possible to look at localized changes in harvest rates over time.

The New England Fishery Management Council staff is also working with the Canada Department of Fisheries and Oceans to obtain landings and revenues data for the Canadian Atlantic hagfish fishery and further information about the management of the hagfish fishery in Nova Scotia and New Brunswick. Information sharing between the U.S. and Canada may aid the New England Fishery Management Council in developing management approaches for the hagfish fishery.

## 8.4 Tagging Studies

Hagfish pose a number of logistical problems for researchers interested in monitoring their movements. Tagging studies could provide measures of spatial range, migration, and estimates of growth rates. However, these studies are complicated because of the burrowing lifestyle of the hagfish and its anatomy. For example, long streamers are likely to be tangled or torn away, and holes in the skin cause potential problems not only with infection but also with disturbances in fluid balance since over most of the animal the skin covers a capacious vascular/lymphatic sinus. The skin is also too thin for freeze-branding to be a viable option, and peritoneal tags, inserted through the cloaca, are likely to be ejected. An additional concern is whether tagged animals are likely to be returned by fishers, given the challenge of identifying tags during the sorting of a large volume of fish.

The literature contains very few reports of successful tagging attempts. Foss (1963) reported some success with small plastic tags (20 x 4 x 0.2 mm) that were originally designed for tagging juvenile herring. The tags were attached by a short length of monofilament line sewn through the dorsal midline about halfway along its length. Walvig (1967) described the problems associated with both external tags and peritoneal tags, and felt that neither was suitable for large-scale studies. He used two tagging methods successfully; both required anesthetizing the animals in cold seawater. The first method involved the injection of undiluted India ink into the subcutaneous tissue of the ventral fin fold using a small syringe. Black, blue, carmine, and green ink were used, with black felt to be most satisfactory. The marks persisted for at least 4 years. The second method involved making a small incision in the ventral fin fold and introducing a smooth plastic tag into the fin fold.

A combination of these methods would seem to have the greatest potential for tagging animals in the New England fishery. The fin fold does not communicate with the subcutaneous sinus, and the black markings would be apparent to a fisherman sorting on deck. The black mark(s) would indicate a tagged animal that could be set aside with the collection information recorded. The plastic tag, which identifies the individual, could then be removed by the investigators shoreside.

Proper handling is essential if the animals are to survive the tagging process. They will need to be transferred into cold, full-salinity seawater containing the anesthetic in a dark/covered container immediately after arriving on deck. Once the tagging is done, animals will need to go into another darkened tank of cold seawater for recovery. The tagged animals must then be transported in that tank to the bottom and released there. During preliminary studies, Martini et al. built and tested an inexpensive 35-gallon release tank that could be lowered over the side and would "trip" automatically on contact with the bottom (Martini pers. comm. 2003). Given the sensitivity of these animals to exposure to low salinity surface waters, such a device is probably essential if the project is to succeed.

### 8.5 Laboratory Studies and Survey Considerations

Hagfish are fundamentally difficult organisms to work with and study because of their behavioral and physiological characteristics. Researchers have noted that hagfish tend to behave abnormally in captivity, refusing to eat, exhibiting very little growth and demonstrating no reproductive tendencies (Martini & Powell, WG meeting 2003).

Developing a more specialized survey for hagfish to supplement the traditional trawl survey is possible. The working group recommended that pilot projects be developed to examine the distribution of hagfish on more refined spatial scales than those covered in the NEFSC trawl survey in the Gulf of Maine. Among the techniques which may be used to determine localized abundance estimates of hagfish are trap studies which set baited, standardized traps at specific locations for timed periods to collect hagfish; tagging studies (described in detail in Section 8.4); and remotely operated vehicle (ROV) work, particularly to investigate areas in which it is suspected that there are a large number of very small slime eels. These types of projects are conducive to a collaborative process which would benefit substantially from research partnerships between scientists and fishermen.

### 8.6 Assessment Methodology

The working group considered the utility of existing survey data on hagfish for assessing the stock. There are at least two approaches to assessing the condition of the hagfish population. The first approach, which uses a generalized linear mixed effects models, is more exploratory and purely statistical, while the other approach, a modified DeLury model, is comparable to more traditional stock assessment methods. Given preliminary evidence of localized depletion of hagfish in the Gulf of Maine as well as uncertainty in vital rates and stock structure, both approaches may be required to fully comprehend changes in the stock.

### 8.6.1 Generalized Linear Mixed-effect Models

Data from one geographic location at one point in time are not independent from data from a proximate location at the same time or from the same location at a different point in time. For example, when localized depletion is occurring, abundance in one location might have a declining trend while that in other locations may exhibit no trend. Trends in abundance in locations close to the site of depletion may also decline, while those in distant locations may not. Mixed-effects models allow us to account for spatial and temporal correlations (Pinheiro and Bates 2000). Generalized linear mixed-effect models are used when such correlated data comes from a non-normal exponential family (Breslow and Clayton 1993). These models are similar to regression or generalized linear models (McCullagh and Nelder 1989) but directly account for correlated, repeated measures data.

For hagfish, locations could be defined simply by the NEFSC statistical areas, or they could be based on some combination of these statistical areas, distance contours radiating out from the known major hagfish ports, and depth contours. The primary assumption in defining these locations is to make them as internally homogeneous as possible with respect to the assumed distribution of hagfish. In other words, areas that were heavily fished during one period in time should not be lumped with areas in which little fishing occurred during that same period. Doing so will violate the assumption that the areas are homogenous with respect to hagfish distribution, and cloud whatever pattern may be occurring in that location. These locations are assumed to be repeatedly measured.

Besides accounting for the spatial and temporal correlation, mixed-effect models allow for direct estimates of population-wide trends (e.g., fixed-effects) as well as location-specific trends (e.g., random-effects). As in regression and generalized linear models, the response variable from the surveys for mixed-effect models could be either the amount of hagfish caught per tow or simply the presence or absence of hagfish in a tow. In most cases, a non-normal error (binomial, gamma, negative binomial, or even a delta-gamma) would be assumed and generalized linear mixed effects models used.

To execute the analysis, we could use S-PLUS 2000 (Mathsoft, Seattle, Washington, USA, 2000) and the GLME extension developed by Dr. Pinheiro for the NLME software (Pinheiro and Bates 2000) within S-PLUS 2000. The GLME extension implements the methods in Breslow and Clayton (1993). The significance of each fixed-effect, both main effects and interactions, would be tested in an ANOVA framework using marginal F-tests (Pinheiro and Bates 2000) with an $\alpha$-level of 0.05 for main effects and 0.10 for interaction effects (Sokal and Rohlf 1981). Pinheiro and Bates (2000:88) state that likelihood ratio tests for testing the significance of the fixed-effects variables in linear mixed-effects models are often "anticonservative" and thus should not be used for the fixed-effects portion of the model. Because the generalized linear mixed-effects model was fitted through a series of linear mixed-effects model approximations, the same problem with the likelihood ratio tests for the fixed effects is expected to occur. The significance of random effects, within-population serial correlation structures (such as autoregressive with lag one or autoregressive-moving average), and heterogeneous variance structures could be tested using likelihood ratio tests (Pinheiro and Bates 2000).

### 8.6.2 Modified DeLury Model (Chapman 1974)

When an unfished population is in equilibrium, the annual instantaneous rate of recruitment will be approximately equal to the annual instantaneous rate of natural mortality. Over short time periods, the instantaneous rate of natural mortality could be considered constant. It is assumed that these conditions hold in the early stages of exploitation for a species that is slow to reproduce. Under these conditions, the average population size during year j ( $\overline{N}_j$ ) can be written as:

$$\overline{N}_j = N_0 - \sum_{i=1}^{j-1} C_i (1-M)^{j-i} - \frac{1}{2} C_j$$

Where $N_0$ is the initial abundance, $C_i$ is the catch in year i, and $M$ is the instantaneous natural mortality rate. This population dynamics model can be fitted to an index of abundance $I_j$ by the following equation using regression techniques:

$$I_j = kN_0 - k\left( \sum_{i=1}^{j-1} C_i (1-M)^{j-i} - \frac{1}{2} C_j \right)$$

Where $k$ is constant of proportionality and the index of abundance would be derived from the survey data. The catch for a given year would be extrapolated from the various sources of catch data. Sensitivity tests should be performed on $M$ because that value is relatively unknown. If it is assumed that movement of individuals from one location to another is limited, this modified DeLury method may be combined with the generalized linear mixed-effects model to obtain spatially-explicit estimates of abundance over time.

## 9.0 DISCUSSION

Despite the rapid growth of the Atlantic hagfish fishery over the span of the last decade, there remain substantial gaps in basic information on fishery performance, as well as many fundamental unanswered questions on the biology and life history of the animal. The paucity of crucial data make assessing the hagfish resource extremely problematic.

This paper has discussed what is known about the region's hagfish fishery, the biology of hagfish and described some potentially useful approaches to stock assessment.

This concluding section attempts to focus discussion on data and information gaps by revisiting the working group objectives (Terms of Reference, Section 2.2). The goal then, using this structure, is to identify a set of high priority tasks or research recommendations that would allow for progress in determining the status of the hagfish resource and inform managers as to the need for formal fisheries management intervention.

To do this we review fishery dependent information, biological and ecological information, fishery independent information and stock assessment approaches and research needs. Key research issues are highlighted in the discussion below.

**Fishery Dependent Information (TOR 1, 2)**

Through discussions with industry participants and examination of NMFS dealer and logbook (VTR) data, the working group was able to describe landings and revenues, spatial distribution of trips over time, seasonal trends in landings, geographic range of the fishery historically and currently, fishery participants, and fishing practices. The working group was concerned about the discrepancies between dealer reports and NMFS dealer data for some years, including 2001 and 2002. Other data issues include underreporting by both dealers and fishermen and the affect of "shrinkage" on the reported catch. Anecdotal evidence suggests that discard levels may be quite high, depending on the vessel and season. The working group discussed this issue at length and recommends a closer examination of discarding in the hagfish fishery through formal programs, such as the at-sea observer program and port sampling, as well as the assistance of dealers and fishermen in reporting their discard levels. Measuring the mortality of hagfish culled at sea is also important in determining total fishing mortality for the hagfish stock.

**Biological and Ecological Information (TOR 3)**
Despite the ubiquity and recognized ecological importance of hagfish, there is still limited knowledge of the life history of these organisms and their adaptability and role in benthic marine ecosystems. The working paper summarizes what is known about the geographic range, habitat, preferred depth, temperature and salinity, feeding habits, ecological role, and reproduction and development of the Atlantic hagfish based on current research. The working group recommends pilot tagging studies in specific areas that are not heavily fished to attempt to measure growth rates of hagfish. In this discussion, the working group identifies potential issues involved in tagging hagfish. Remotely operated vehicles (ROVs) with accompanying video equipment have served as a useful tool in observing hagfish behavior in their natural environment, as well as estimating abundance in specific locations.

**Fishery Independent Information (TOR 4)**
The working group described and analyzed data collected in NEFSC groundfish bottom trawl and shrimp surveys. The NEFSC groundfish bottom trawl survey, conducted since 1963, is the most consistent long-term source of abundance data on hagfish. These data also provided length frequency curves for hagfish collected within the spatial range of the survey. The NEFSC surveys and sampling studies by Martini et al. provide sufficient data to estimate length-weight curves for hagfish. In general, hagfish are poorly represented in traditional trawl surveys because of their morphology and burrowing behavior. The sample size of hagfish collected during trawl and shrimp surveys is not large enough to distinguish noise in the survey data from true changes in the population or to determine changes in localized populations over the period of the surveys. The working group recommends development of a specialized hagfish survey using standardized, baited traps deployed in random sampling locations. Additional observations on hagfish aggregations may be made using ROVs and towed video equipment.

**Stock Assessment Approaches and Research Needs (TOR 5, 6)**
The working group seeks additional guidance from the SARC on assessment approaches that are appropriate for hagfish given the data currently available. Two general modeling approaches were discussed – the use of a generalized linear mixed-effect model to standardize commercial catch rates and survey data, and a modified DeLury model which is used for a number of the invertebrate species in the Northeast. These models are limited by deficiencies in abundance and life history data for hagfish, and may be restricted in their potential for determining population trends. Data and research needs were highlighted repeatedly by the working group throughout their discussions and analyses of current data and have been described in the working paper and this summary. It may be appropriate for the SARC to discuss these issues in terms of recommendations for future research and/or data collection programs.

## 9.1 SARC Discussion

- Hagfish fisheries around the world have not been sustained and some have a history of overexploitation followed by fishery collapse. The level of a potentially sustainable fishery on Atlantic hagfish is uncertain.
- The working group has developed a set of data requirements necessary for stock assessment to determine the level of a sustainable fishery.
- Based on the life history information that is currently available, there is a strong argument for a management system that, at a minimum, would cap effort and protect juveniles (smaller than 40-45 cm).

## 9.2 SARC Research Recommendations

- Consider appropriate measures of "effective" fishing effort, including but not limited to soak time, number of traps, number of hauls per trip, and fishing power differences between large and small vessels, that are directly related to fishing mortality;

- Look at LPUE in conjunction with survey data and use density measures from the surveys to estimate CPUE;
- Establish biological sampling in ports (length and weight, by sex to the extent possible);
- Collect commercial length frequency data for size composition of catch; Seek additional information on the Nova Scotia hagfish fishery (landings, biological sampling data);
- Seek information on hagfish exports from NMFS trade specialists on the west coast who specialize in Asian exports and examine export data;
- Develop a study fleet with electronic reporting;
- Consider conservation engineering studies to minimize the catch of juveniles and the potential for ghost fishing;
- Conduct a directed population dynamics study, examining food web dynamics (stomach sampling data from survey), age and growth, maturation, fecundity and stock identification;
- Evaluate gillnet sea sampling data for evidence of hagfish eating gilled fish. (There may be spatial and temporal overlaps between discards in gillnet fisheries and hagfish that predate on the discarded fish).

## 10.0 LITERATURE CITED

Allen, Richard B. 2001. The Gulf of Maine Hagfish Fishery: Lessons from Science and History. Unpublished article. 5pp.

Benson, A.J., C.M. Neville, and G.A. McFarlane. 2001. An update for the British Columbia experimental fishery for Pacific hagfish (Eptatretus stoutii). Department of Fisheries and Oceans Canada, Pacific Biological Station, British Columbia, Canada. [on-line:web] URL: http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2001/RES2001_149e.pdf

Bigelow, Henry B. and William C. Schroeder. 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.

Boulay, Mark. Phone interview. Anne H. Beaudreau, interviewer. March 17, 2003.

Boulay, Mark. E-mail and personal communication. Anne H. Beaudreau, correspondent. Gloucester, MA. 2002.

Breslow, N.E., and D.G. Clayton. 1993. Approximate inference in generalized linear mixed models. Journal of the American Statistical Association 88(421): 9–25.

California hagfish regulations. 2001. Traps. §§FGC 9000-9024.

Chapman, D.G. 1974. Estimation of population size and sustainable yield of sei whales in the Antarctic. Rep. Int. Whale. Commn. 24: 82-90.

Cho, Yang. Phone interview. Anne H. Beaudreau, interviewer. March 4, 2003.

Cho, Yang. E-mail and personal communication. Anne H. Beaudreau, correspondent. Gloucester, MA.

Chu, Peter. Phone interview. Anne H. Beaudreau, interviewer. March 4, 2003.

Dean, B. 1899. On the embryology of *Bdellostoma stouti*. Fest. Schrift. fur Carl von Kupffer. Jena: 221-277.

Fernholm, B. 1974. Diurnal variations in behavior of the hagfish, *Eptatretus burgeri*. Marine Biology. 27: 351-356.

Fernholm, B. 1969. A third embryo of Myxine: Considerations on hypophysial ontogeny and phylogeny. Acta zool. (Stockh.) 50: 169-177.

Foss, G. 1963. Myxine in its Natural Environment. In A. Brodal and R. Fange, eds. The Biology of Myxine. Universitatsforlaget, Oslo, Norway. 42-46.

Hall-Arber, Madeline. 1996. Workshop probes hagfish processing potential in US: fishery discards worry fishermen. Commercial Fisheries News: 18B-19B. Stonington, ME.

Hill, Thomas. Phone interview. Anne H. Beaudreau, interviewer. March 19, 2003.

Holmgren, N. 1946. On two embryos of *Myxine glutinosa*. Acta Zoologica XXVII: 1-90.
Hultin, Herb, Stephen Kelleher, Sue Kuenstner, George Nardi. 1996. Harvesting the value-added potential of Atlantic hagfish. New England Fisheries Development Association, Inc. Saltonstall-Kennedy Grant, submitted to NMFS.
Leask, Karen D. and Richard J. Beamish. 1999. Review of the fisheries and biology of the Pacific hagfish (*Eptatretus stoutii*) in British Columbia, with recommendations for biological sampling in a developmental fishery. Department of Fisheries and Oceans Canada, Pacific Biological Station, British Columbia, Canada. [online: web] URL: http://www.dfo-mpo.gc.ca/csas/CSAS/DocREC/1999/pdf/99_205e.pdf.
Lesser, Michael P., Frederic H. Martini and John B. Heiser. 1996. Ecology of the hagfish, *Myxine glutinosa L.*, in the Gulf of Maine: I. Metabolic rates and energetics. Journal of Experimental Marine Biology and Ecology 208(1996): 215-225.
Maine/New Hampshire Sea Grant Press Center. March 24, 1995. Trade barriers lifted on hagfish exports to Korea: Earnings of developing New England fishery expected to double. [online: web] URL: http://www.seagrantnews.org/news/hagfish.html
Maine/New Hampshire Sea Grant Press Center. September, 1994. Fishery Developments: Disgusting slime eels just got more attractive. [online: web] URL: http://www.seagrantnews.org/news/maine2.html
Mangel, M. and P.E. Smith. 1990. Presence-absence sampling for fisheries management. Canadian Journal of Fisheries and Aquatic Sciences 47(10): 1875-1887.
Martini, Frederic. Personal communication. Anne H. Beaudreau, correspondent. May, 2003.
Martini, Frederic H. and Donald Flescher. 2002. Hagfishes, Order Myxiniformes. In Bruce B. Collette and Grace Klein-MacPhee, eds. Bigelow and Schroeder's Fishes of the Gulf of Maine. 3rd Edition. 9-16. Washington and London: Smithsonian Institution Press.
Martini, F. 2000. The evidence for and potential significance of cutaneous respiration in hagfishes <Abs.> The FASEB Journal 14(4): A436.
Martini, Frederic H., Michael P. Lesser, and John B. Heiser. 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. Fishery Bulletin 96: 516-524.
Martini, F., J.B. Heiser, and M.P. Lesser. 1997a. A population profile for Atlantic hagfish, *Myxine glutinosa (L.)*, in the Gulf of Maine: morphometrics and reproductive state. Fishery Bulletin 95(2): 311-320.
Martini, Frederic, Michael Lesser and John B. Heiser. 1997b. Ecology of the hagfish, *Myxine glutinosa L.*, in the Gulf of Maine: II. Potential impact on benthic communities and commercial fisheries. Journal of Experimental Marine Biology and Ecology 214(1997): 97-106.
Martini, F.H. and J.B. Heiser. 1989. Field observations on the Atlantic hagfish, *Myxine glutinosa*, in the Gulf of Maine. American Zoologist 29(4): A38-A38.
Mason, Don. NMFS Port Agent. Personal communication. Anne H. Beaudreau, correspondent. 2003.
McCrae, Jean. 2002. Oregon Developmental Species: Pacific Hagfish (*Eptatretus stouti*). Oregon Department of Fish and Wildlife. Hatfield Marine Science Center, Oregon State University. [online: web] URL: http://www.hmsc.orst.edu/odfw/devfish/sp/hagfish.html
McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. Second edition. Chapman and Hall, London, UK.
Nakamura, R. 1991. A survey of the Pacific hagfish resource off the central California coast, final report. Secretary of Environmental Affairs, Office of Environmental Protection, Marine Fisheries Impacts Program, #A-800-184.
National Marine Fisheries Service (NMFS) Commercial Fishery Databases (WODETS/CFDETS).
Nippert, Steve. 2002. A brief history of the New England hagfish industry. Unpublished report.
Nippert, Steve. E-mail and personal communication. Anne H. Beaudreau, correspondent. Gloucester, MA. 2002.
Nippert, Steve. E-mail interview. Anne H. Beaudreau, interviewer. March 20, 2003.

Nippert, Steve. Personal communication. Richard B. Allen, interviewer. 2001.
Nova Scotia Department of Agriculture and Fisheries. Marketing Services Division. Statistics: Nova Scotia Fish Landings. [on-line:web] http://www.gov.ns.ca/nsaf/marketing/statistics/landings
Palumbo, Bill. Phone interview. Anne H. Beaudreau, interviewer. March 4, 2003.
Palumbo, William R. Letter to NEFMC. November 30, 2001.
Patzner, R. A. 1982. Die Reproduktion der Myxinoiden. Ein Vergleich von *Myxine glutinosa* und *Eptatretus burgeri*. Zool. Anz. 208(3-4): 132-144.
Pinheiro, J. C., and D. M. Bates. 2000. Mixed-effects models in S and S-PLUS. Springer-Verlag, New York, New York, USA.
Powell, M. and S. Sower. Unpublished. Seasonal concentrations of reproductive steroids in the gonads of the Atlantic hagfish, *Myxine glutinosa*. Submitted to Journal of Experimental Zoology, January 2003.
Schuetzinger, S., H.S. Choi, R.A. Patzner, and H. Adam. 1987. Estrogens in plasma of the hagfish, *Myxine glutinosa* (Cyclostomata). Acta Zoologica (Oxford) 68(4): 263-266.
Sokal, R. R., and F. J. Rohlf. 1981. Biometry. Second edition. W. H. Freeman and Company, San Francisco, California, USA.
Sower, Stacia and Mickie Powell. E-mail and personal communication. Anne H. Beaudreau, correspondent. University of New Hampshire. 2002-2003.
Stobo, Wayne. Department of Fisheries and Oceans, Canada (Maritimes Region). Personal communication. Anne H. Beaudreau, correspondent. May, 2003.
Tsuneki, K. 1976. Effects of estradiol and testosterone in the hagfish Eptatretus burgeri. Acta Zoologica (Stockholm) 57: 137-146.
University of British Colombia (UBC), Department of Zoology. 2002. Hagfish slime research. [online: web] URL: http://www.zoology.ubc.ca/labs/biomaterials/slime.html.
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 p.
Walvig, F. 1967. Experimental Marking of Hagfish (*Myxine glutinosa*, L.). Norwegian Journal of Zoology. 15: 35-39.
Walvig, F. 1963. Gonads and the formation of sexual cells. In A. Brodal and R. Fange, eds. The Biology of Myxine. Oslo, Norway, Universitatsforlaget: 530-580.
Williams, Jon. Phone interview. Anne H. Beaudreau, interviewer. March 27, 2003.
Wisner, R.L. and C.B. McMillan. 1995. Review of the new world hagfishes of the genus *Myxine* (Agnatha, Myxinidae) with descriptions of nine new species. Fisheries Bulletin. 93:530-550.
Worthington, J. 1905. Contribution to our knowledge of the Myxinoids. The American Naturalist 39(465): 625-663.