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# Review of the fisheries and biology of the Pacific Hagfish (*Eptatretus stoutii*) in British Columbia, with recommendations for biological sampling in a developmental fishery.

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## ABSTRACT

A review of the biology of hagfish in general and *Eptatretus stoutii* in particular is presented. Hagfish are one of the most studied fishes in the laboratory, but one of the least studied in its natural environment. Food and commercial fisheries in Asia and North America are described and historical landings presented. The fishery and associated biological sampling program that took place in British Columbia from 1988 to 1992 is reviewed. Fishing hagfish at harvest levels similar to those in the earlier fishery are considered to be possible, provided adequate monitoring and assessment are carried out.



## RÉSUMÉ

La biologie de la myxine, en général, et de *Eptatretus stoutii* en particulier, est passée en revue. La myxine est l'un des poissons les plus étudiés en laboratoire, mais les moins étudiés dans son milieu naturel. Les pratiques de la pêche pour la consommation humaine et de la pêche commerciale en Asie et en Amérique du Nord sont décrites, et des données sur des débarquements historiques sont présentées. La pêche et le programme d'échantillonnage biologique qui ont été effectués en Colombie-Britannique entre 1988 et 1992 sont examinés. Avec un contrôle adéquat et des évaluations appropriées, il serait possible d'obtenir des niveaux de capture similaires à ceux obtenus durant les débuts de la pêche de la myxine.

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# I. INTRODUCTION

Two species of hagfish, *E. stoutii* and *E. deani*, were harvested commercially in British Columbia during 1988-1992. The fishery was considered experimental throughout it's duration since little of the biological information required for developing a stock assessment was available (Beamish and Neville, 1993). The fishery was managed by restricting effort through limiting the number of vessels, traps per vessel, areas open to fishing, trap design, and a market driven minimum size limit. A biological sampling program was conducted throughout the fishery that provided information on length, sex, and egg condition of samples taken in the commercial harvest and from designated sample sites.

Interest in a fishery has recently developed in response for a demand to supply a market for hagfish meat to Asia. The policy outlined by the seafood diversification board for new and developing fisheries in the Pacific region recommends a precautionary approach that proceeds through three phases of development (Perry *et al.*, 1999). This report represent 'Phase 0': a review of the available biological and fisheries information on the target species, and from similar species elsewhere, from a variety of sources. This information will provide a baseline for assessing alternative management options and to identify areas where information is required.

The objectives of this report are:

1) to provide a review of the hagfish fishery that took place in British Columbia from 1988 through 1992, from harvest logbook records;

2) to provide an analysis of the biological sampling program that proceeded with the fishery in British Columbia;

3) to present a review of the fishery related biology of hagfish in general, and Pacific hagfish, *E. stoutii* in particular, and to review the history of hagfish fisheries in the world;

4) to make recommendations for management of future fisheries.

# II. BIOLOGY

Pacific hagfish, *Eptatretus stoutii* (Lockington, 1878 in Hart, 1973) belong to what many consider the most primitive class of extant fishes, the Myxini (Nelson, 1994). *Eptatretus* is one of 5 (Fernholm, 1998) or 6 (Nelson, 1994) genera in the "agnathan" family Myxinidae. The unique taxonomic position of hagfishes in evolutionary biology has lead to the generation of a considerable body of knowledge regarding their physiology and biochemistry, however little is known about their reproductive biology, ecology, and the mechanisms that regulate their abundance (for a review see: Jørgensen *et al.*, 1998). Hagfishes and their closest living relatives, the lampreys, form a group known as the cyclostomes owing to the presence of a round, suctorial mouth that is unique to these fishes. They share a cylindrical eel-like body, with a single nostril, and lacking jaws, ribs, and paired fins and girdles. The skeleton is cartilagenous, the teeth are keratinous cusps, and the body does not contain any calcareous structures. The body also lacks scales and a cloaca. Despite these similarities lamprey are thought to be more closely related to the jawed fishes, Gnathostomes, than to the hagfishes (Nelson, 1994). Unlike lamprey, all species of hagfish are strictly marine and can be found inhabiting the deep ocean benthic communities between a few metres and over 2400 m deep, in the semi-tropical and temperate oceans of the world. Also unlike lamprey, all the life stages of hagfish are thought to be free living, scavenging on dead or moribund animals or predating on invertebrates. Hagfish are commonly known as slime eels because of the copious amounts of slime they secrete from mucous pores along their sides when agitated.

*E. stoutii* are bottom dwelling fish occupying depths of 15 to 800 m and are distributed from Baja, California to southern Alaska. Barss (1993) noted that underwater observations and logbook data from hagfish fisherman in Oregon found Pacific hagfish to be most common at 119 to 219 m. In their natural environment hagfish are thought to occur predominately on mud and other soft substrates into which they may form shallow, temporary burrows or depressions. Under laboratory conditions they have been observed to prefer to rest among piles of rocks (Worthington, 1905), and some underwater observations have indicated that up to 30% of the hagfish were found in areas of mixed substrates like sand and gravel or sand and boulders, while 15% occupied massive granite formations (Cailliet, 1991, in Martini, 1998), and sometimes partially under rocks and sponges (Barss, 1993). Off the coast of Oregon, hagfish were found primarily on a bottom of mud were also found in lower numbers on rock and cobble substrate (Pearcy *et al*., 1989). Hagfish were ranked the 14$^{th}$ most abundant non-schooling fish observed on the submarine bank, Hecate Bank (Pearcy *et al*., 1989). Burrowing behaviour of *E. stoutii* occurs less often and the burrows are more poorly defined than has been observed in the Atlantic species, *Myxine glutinosa*. Studies performed in Barkley Sound, British Columbia, found *E. stoutii* primarily on silty bottoms, where the water temperatures did not rise above 10$^{o}$C, and the salinity was 31-32 ppt, even though the surface waters into which they occasionally swam might reach 24 ppt (McInerney and Evans, 1970). Another species, the Black hagfish, *E. deani*, has a similar distribution to *E. stoutii*, but resides at greater depths of 156 to 1070 m (Hart, 1973).

The genus *Eptatretus* was known as *Polistotrema* (Clemens and Wilby, 1961*)*, and Worthington (1905) used the scientific name *Bdellostoma dombeyi* Lac. to describe the hagfish she worked on that were taken from Monterey Bay, California, and it has been presumed by subsequent authors that she referred to *E. stoutii.*

Hagfish generally have an elongate, cylindrical body that is laterally compressed at the posterior end and lacks fins. The body is grey to dark brown in colour, possibly with a blue or purple tint, and is generally lighter ventrally. *E. stoutii* may reach a length of 63.5 cm according to Hart (1973), but samples from British Columbia reached 73 cm (Beamish and Neville, 1993). *E. deani* may grow to similar lengths as *E. stoutii* but the colour is dark prune, often with light spots. *E. stoutii* has a relatively short head with a pointed snout and barbels around the single nostril and mouth. The mouth contains a rasping organ comprised of horny plates, with cusps on the roof of the mouth and the tongue. Gill pores form a line along either side of the anterior third of the body posterior to the head. The number of gill pores varies within species and between species, and the variability within a distinct range but number of gill pores is one of the characteristics used to distinguish the order Myxiniformes (ie., 10 to 14 along each side) to which *E. stoutii* belongs, from the order Petromyzoniformes (ie., 7 on each side), to which lamprey belong. The distance from the snout to the first gill opening may be used to distinguish *E. stoutii* from *E. deani.* The darker skin colour of *E. deani*, and consequently the greater contrasting tissue of the lighter eyespots, can also be used to discriminate between the two species (G. Gillespie, pers. comm.). The pair of rudimentary eyes is sensitive to light and lie beneath a thin layer of the epidermis of the head. Hagfish do not respond to sound (Worthington, 1905), but have keen senses of smell and touch (Jensen, 1966).

The flexible nature of the cartilagenous skeleton of the hagfish allows it to tie itself into a knot. This behaviour is thought to have several purposes; the hagfish pulls itself through the knot in order to remove itself from a body of slime that would otherwise suffocate it, or the knot can be used as leverage for tearing meat from a carcass (Jensen, 1966). A hagfish swims in snake-like fashion usually slowing along the sea bottom, but bursts of speed up to 1 m $s^{-1}$ have been recorded for *M. glutinosa* (Foss, 1968). Along with the assumption that hagfish swam only slowly, lethargically, and without direction, was the belief that hagfish populations were fairly localised. Some studies have shown that hagfish may migrate over a wider range than previously thought and for various reasons, ranging from food availability to spawning behaviour (Martini, 1998). A study on tagged hagfish*, M. glutinosa*, were found 2 km from their release site (Walvig, 1967). Bait parcels placed at 1310m, a depth well below that common for *E. deani*, attracted peak densities of over 100 *E. deani* $m^{-2}$ after 10-24 hours (Smith, 1985). Hagfish have been observed to feast on a carcass for only about an hour before moving off a few metres to form burrows (Smith, 1985).

Little is known about the reproductive behaviour of any species of hagfish, beyond the recognition of low fecundity that ranges from 1 to 30 eggs per female. Although mature adults of the Japanese hagfish, *E. burgeri*, have been shown to migrate seasonally to spawn in deeper waters (Kobayashi *et al.,* 1972), no seasonality has been recognised in the gonad maturation of adults of any other hagfish species (Walvig, 1963; Patzner, 1998). Therefore, since it has not been shown that most species of hagfish spawn annually, the accepted fecundity of 1 to 30 eggs may not be attributed to a single year period.

In a study of 552 female *E. stoutii* caught in the Oregon fishery in 1988 and 1989, some females were found to contain over 200 eggs longer than 1 mm, but the greatest number of eggs over 5 mm in length was 76, and the average number of eggs over 5 mm long was 28 (Barss, 1993). The greatest egg length was 32 mm, and the average length of eggs over 5 mm long was 14.3 mm. Often up to 3 size ranges of eggs were identified macroscopically in the gonad of a single female; ie., one group less than 1 mm long, one group 1 to 4 mm long, and a third group 19 to 22 mm long (Barss, 1993). Although females containing large or empty egg capsules were found throughout the year, females containing eggs with hooks were noted only during July. In the Oregon study females were considered to be mature if the ovary contained an egg class with a minimum size of 5 mm, and males were considered mature if the testis was a minimum of 1mm diameter, the size at which obvious colour or physical change was likely to occur (Barss, 1993). In 1988, 26% of the Pacific hagfish sampled (both male and female) were mature, and all of these were caught in October and November. In 1989, 69% were mature and only 19.5% were caught in October and November, while 56% were caught in July and August (Barss, 1993). This points to the late summer months as being a period with high potential for spawning activity.

Breeding behaviour and developing eggs have never been observed in their natural environment even though investigations have been conducted in submersible vessels down to 300 m in Monterey Bay, California and Barkley Sound, British Columbia (Gorbman, 1997). The only successful collections of fertilized *E. stoutii* eggs occurred in Monterey Bay, California at the turn of the century and were obtained from mature females being caught by line fishing with baited hooks from July through October and always on mud bottom (see Gorbman, 1997; Worthington, 1905). Some of the fertilized eggs collected by Worthington (1905) were found in the guts of male hagfish, and 3 recently hatched hagfish were collected in September. The mode of fertilization is thought to be external since no copulatory organ is found in males and females lack any appropriate sperm receiving organ (Gorbman, 1997). Gorbman (1997) has recently proposed that the slime extruded by hagfish may play a role in reproduction by providing a medium through which the relatively sparse sperm might contact the egg. Following fertilization, the mucous component of the slime would disintegrate leaving behind a 'nest' of slime threads protecting the developing embryos. Juvenile hagfish have been observed to hatch directly from the large eggs, omitting a larval period, appearing very much as smaller versions (6 to 8 cm) of the adult (Worthington, 1905).

Sexes are separate and sexual determination is considered by Gorbman (1990) to be "juvenile progynous hermaphroditism", since the single, long gonadal fold of post-hatching free-living individuals begins developing ovarian tissue in the anterior portion. In larger animals, the posterior region may begin differentiating testicular tissue, at which time the ovarian anterior region begins to involute resulting in a male fish. Some early stage hermaphroditism was found in specimens between 20 and 25 cm and rarely, fully developed hermaphrodites were observed at 29 cm or greater (Gorbman, 1990). Barss (1993) noted a 0.2% incidence of hermaphroditism in 788 *E. stoutii* sampled from the Oregon hagfish fishery.

**Sex Ratios**

Unequal adult sex ratios are generally observed in hagfishes, although the ratios are smaller in Pacific hagfish than in Atlantic hagfish where males may not have been collected at all from some populations (Gorbman, 1990). Typically females are collected in greater numbers than males and this has been attributed by some to a loss of feeding behaviour in adult males during breeding. Gorbman and Dickhoff (1978) found that females predominated even in juvenile *E. stoutii* and proposed that epigenetic factors may affect sex differentiation in hagfishes.

Johnson (1994) suggested that unequal sex ratios and age or size partitioning may be depth specific. Large male *E. stoutii* were most common at shallower depths while large females predominated at lower depths, and small hagfish were most common at intermediate depths of around 250 m (Martini, 1998). Johnson (1994) also suggested that the partitioning of habitat by sex and age may reduce intraspecific competition, and depth migration by adults may precede spawning.

**Growth**

The only species of hagfish for which a growth rate has been suggested is the Japanese hagfish, *E. burgeri*. Patzner (1978) used the correlation between ovarian development and annual increase in body length, in this the only species of hagfish to exhibit a regular spawning period, to calculate an annual growth rate of 4 to 5 cm. The mean length of females containing a single generation of postovulatory follicles was found by Tsuneki *et al*., (1983) to be 44 cm, and females with one generation of postovulatory follicles were on average 3.4 cm longer than females lacking postovulatory follicles. It would appear then that if juvenile hagfish hatch at approximately 6.5 cm length (Worthington, 1905) and if the growth rate thereafter is estimated at 4 cm per year, then on average it may take about 9 or 10 years for a female hagfish to bear her first brood.

**Trophic Relationships**

Pacific hagfish have been observed to feed on the muscles and viscera of large fishes such as cod, dogfish, blackcod, lingcod, perch, flounders, and salmon (Hart, 1973). Their preference for newly dead or moribund fish is what has made them a pest to commercial bottom fisheries. Although hagfish have traditionally be designated as scavengers, it has been suggested that scavenging at the depths in which they inhabit might be opportunistic with their diet primarily being derived from predation on various invertebrates (Martini, 1998). A study performed on both *E stoutii* and *E. deani* from Monterey Bay, California, found that their diets were predominantly made up of mesopelagic organisms, such as sergestid shrimp, cephalopods, euphausiids and small fishes, as well as, a large portion of benthic polychaetes (Johnson, 1994). In areas where a considerable by-catch is discarded by fishery activities, hagfish may play a significant role in recycling and maintaining the sea bottom by scavenging and burrowing through the substrate (Martini, 1998). The effect that these large single event feedings might have on local hagfish populations is unknown but has been speculated upon by Fernholm (1974) regarding the Japanese hagfish in Koajiro Bay, Japan, and by Martini (1998) in reference to Atlantic hagfish and the North Sea trawling fleet. *E. stoutii* have been reported to comprise a portion of the diets of Harbour seals (Hanson, 1993, and Oxman,1995, in Martini, 1998) and other hagfish species have been reported to be the prey of numerous marine fish and mammals including cod, dogfish, seals, porpoises, sea lions, dolphins, as well as, cormorants and octopus (Martini, 1998). Male hagfish are often found to have unfertilized eggs in their guts, and have been one source of the eggs used in embryo studies (Worthington, 1905).

### Abundance and Biomass Estimates

Some measures of hagfish density and biomass have been estimated. Black hagfish populations on the continental slope off of central California have been estimated by underwater observations to range from 0 to 592 000 km$^{-2}$, with an average year round density of 325 000 km$^{-2}$ at depths of 600 to 800 m (Wakefield, 1990 in Martini, 1998). In one particular area at a depth of 600 m the density was estimated from underwater observation to be 176 300 km$^{-2}$ and the biomass at 11 800 kg km$^{-2}$, while trawling in the same area lead to the calculation of a biomass estimate of 700 kg km$^{-2}$ (Wakefield, 1990, in Martini, 1998). Both measures of biomass were considered to be underestimates due to the burrowing behaviour of the hagfish, which may have had a more pronounced effect on the trawling estimate. Peak densities of Atlantic hagfish in the Gulf of Maine were estimated from underwater observations at bait stations to be 500 000 km$^{-2}$ (Martini *et al*., 1997). The average density at several sites was 59 700 km$^{-2}$ and the biomass was 8 119 kg km$^{-2}$.

## III. FISHERIES

Historically, hagfish have been of little economic importance to North America or Europe except as a pest in ground fisheries. They have traditionally been a food item in Japan and Korea and it was due to shortages of materials brought about by the Second World War that the skins began being used as a soft leather in Japan (Honma, 1998). For more information on Asian fisheries see Appendix 1.

The fishery for hagfish began in North America on the west coast in 1987 with a shipment from California to Korea (South). By 1989, fishers in Oregon, British Columbia, and Nova Scotia were landing hagfish for the Korean 'eel skin' market. Interest was also generated by fishers in Washington, Alaska and New Brunswick but few commercial landings were made in these regions. The demand for a North American supply of hagfish to be shipped primarily to South Korea for tanning was precipitated by a decline in the supply of hagfish from the waters of Southeast Asia (Gorbman *et al*, 1990). Korea imposed trade restrictions on all hagfish imported for processing in the eel skin industry such that all hagfish meat required a stamp indicating that it was not fit for human consumption. This was due to the use of anaesthetics by some fisherman to relax the animals while aboard ship thereby reducing the incidence of bite marks in the skins. Korea exported eel skin leather products worth about $80 million per year in the late 1980's but this had dropped to about $20 million by 1992 (Sea Grant Media Center, www.seagrantnews.org). Instability in the Korean market and variable product quality and fishing effort may have contributed to price fluctuations (Neville and Beamish, 1992). A drop in demand and inability of the fishers to meet market quality requirements lead to reduced effort and catch rates and finally to a close of the fisheries of British Columbia and Washington in 1992. Landings continued but at a lower rate in California and Oregon than in previous years. The fishery in Nova Scotia has continued to land Atlantic hagfish throughout the period and the New England states of Maine, New Hampshire, and Massachusetts began fisheries on George's Bank in 1993.

There is renewed interest in developing a fishery for Pacific hagfish off the west coast of Vancouver Island. Until recently, the market for hagfish meat, 5 million pounds annually in Korea, has been closed to North America due to trade restrictions. Now that these restrictions have been removed, and with it the cost associated with re-exporting the hagfish meat from Korea, the financial return on hagfish for North American fishers is expected to increase. As was the case during the previous experimental fishery for hagfish in British Columbia, there is a lack of knowledge regarding abundance, individual and population growth rates, fecundity, migration behaviour, individual ages and mortality rates. Even though fishing has continued for some 10 years on the east coast of Canada and 5 years in the New England states, biological information is just beginning to become available on Atlantic hagfish in the Gulf of Maine (Martini, 1998) but the fundamental questions of abundance and growth and mortality rates are still unanswered for any of the commercially fished species of hagfish. For more detailed information on North American fisheries see Appendix 1.

## IV. BRITISH COLUMBIA EXPERIMENTAL FISHERY, 1988-1992

The fishery for hagfish in British Columbia was considered experimental throughout its duration from 1988 through 1992 (Beamish and Neville, 1993). This fishery and the associated biological sampling program have been described and the results analysed by Neville and Beamish (1992) and Beamish and Neville (1993). Most of the following description has been taken from this document.

Although fishing occurred throughout Pacific Fisheries Management Areas, PFMA, 3-4, 23-27, and 123-124, effort and biological sampling were concentrated in Areas 23, Barkley Sound Inside Waters, and Area 123, Barkley Sound Outside Waters. No quotas were set, and effort was restricted by limiting the number of vessels, traps per vessel, areas open to fishing, and the number of boats fishing in a particular area at a given time. Fishermen were required to maintain logbooks and to participate in a biological sampling program. However, there was only minimal research dedicated to understanding the biology and the impacts of fishing. Permits were required for the fishing of hagfish from October 1988 through 1992 and from 0 to 11 permits were issued and active during any month. No commercial quantities of hagfish were landed in the North coast areas 3 and 4 during 1988 through 1990. Fishing occurred in Area 23 in a total of 7 months between May of 1990 and June of 1992, although biological sampling occurred in 13 of those months (Table 3). Only one vessel fished at any one time in a particular area from June 1990 to the end of the fishery in 1992.

Cylindrical Korean style traps, with a single entry tunnel at one end, were used in all years of the fishery except for a trial in 1992 using 5-gallon traps. The cone ends of all traps were fitted with biodegradable escape ports covered in cotton tape or string to prevent continued fishing by lost traps. Escape holes were required in the traps to decrease the catch of unmarketable small hagfish. In 1990, the required size of escape holes was changed from 1.5 cm to 3.0 cm. There are no data available that shows whether this change was more effective at reducing the by-catch of small hagfish. Trap limits per vessel were set at 2000 when fishing inside waters and 3500 in offshore waters. Soak times varied from 18 to 72 hours, but were generally 24 hours. Traps were fished at depths ranging from 35 m to 200 m; but most fishing effort was directed at 70 m to 120 m depths. No size limit was imposed by fisheries managers but a market limit of not less than 30 cm was in place throughout the fishery. Small hagfish and by-catch were sorted onboard and discarded overboard. By-catch was recorded as minimal, consisting of the occasional snail or starfish. Hagfish catches were primarily comprised of *E. stoutii*; with catches of unwanted *E. deani* avoided by selecting the shallower fishing depths inhabited predominantly by *E. stoutii*.

**Biological Sampling Program**

Permit holders were required to undertake and fund a biological sampling program employing qualified personnel from the Pacific Biological Station. Biological samples were collected monthly by vessels active in the fishery in PFMA 23 and 123 (Table 3) (Beamish and Neville, 1993). The sample locations were designated from PFM sub-area 23-7, Kirby Point and PFM sub-area 123-5, Amphitrite Point. Length measurements were to be taken from 1000 randomly sampled fish. Approximately 200 fish were sub-sampled randomly from the larger sample and these were subsequently analysed for sex and egg condition. A stratified sample of up to 5 fish from each 10 mm hagfish body length interval was sometimes taken to determine the total length by sex of the samples. Weight of the total catch was determined for estimation of CPUE, and the 1000 fish sample, and the 200 fish sample were weighed to determine the average weight per fish.

**Catch and Effort**

Catch (kg) and effort (number of traps) were obtained from the logbook records (Tables 3, 4, and 5, Figs. 1, 3, and 5). Catch and effort declined in all areas from the initial effort in the 'fishing up' period in 1988/89 (Figs. 1, 3, and 5). Catch per unit effort, CPUE, was calculated as kg per trap. CPUE generally began high, decreased after a peak in effort and catch, and increased slowly after a period of no fishing (Figs 2,4, and 6). The decline in catch and effort was less noticeable in PFMA 25, Nootka Sound, where the CPUE remained fairly consistent throughout the fishery, but effort was sporadic (Fig. 5 and 6). Effort in the fishery for any given area ranged from 0 to 50 000 traps. Catch for PFMA 23, Barkley Sound Inside Waters, reached a total of 211 tonnes in the first 5 months of the fishery, Oct 1988 through February 1989. This constituted 57.8 % of the total for the entire fishery in this area (Table 3, Figure 1). During this time, CPUE declined from a high of 1.1 kg/trap in November of 1988 to a low of 0.4 kg/trap in March 1989 (Fig. 2). CPUE remained at an average of 0.4 kg/trap for the remaining years of the fishery, with an unusual peak of 0.8 kg/trap in May of 1992. The greatest effort was expended in January of 1989 when 104,522 traps landed the highest monthly landing of 86,554 kg (CPUE 0.8 kg/trap). This represented 23.7% of the total landings for the fishery in this area that took place from October 1988 through May 1992.

CPUE for PFMA 123, Barkley Sound Offshore Waters, dropped from a high of 1.1 kg/trap in May of 1989 to a low of 0.3 for February 1990 (Table 4, Figure 3). CPUE continued to drop, reaching a low of 0.1 in July of 1990. Following this decline in CPUE, another peak of 0.9 kg/trap was recorded for April of 1991 (Fig. 4). The greatest effort took place in September of 1991 when 84,574 traps landed 54 tonnes of hagfish. The highest landings were recorded for the month of August 1991 when 58 tonnes of hagfish were landed with 82,651 traps. In these 2 months, 112 tonnes of hagfish were landed representing 24.4% of the landings for the entire fishery which extended from January of 1989 to May of 1992.

Peak effort and landings in PFMA 25, Nootka Sound were recorded for the month of September 1989, when 88,302 traps landed 34,343 kg of hagfish (Table 5, Figure 5). Although the CPUE was only 0.4kg/trap, the landings represented 21% of the total landings of the fishery that occurred April 1989 through May 1992. Monthly CPUE fluctuated from a high of 0.7 kg/trap (August, 1989 and February 1992) to a low of 0.4 kg/trap that was recorded many times through the fishery including May 1989 and May 1992, the second and last months of the fishery, respectively (Fig. 6). A low of 0.2 kg/trap that was recorded for the first month of the fishery, in April 1989, was explained by the fisherman to be due poor site selection for setting traps.

We examined the trend in CPUE by excluding the initial ‘fishing up’ period of 5 months. The CPUE for PFMA 23 (Fig. 2) declined only slightly from 0.45 to 0.40 kg/traps over this 27 month period. Effort also declined (Fig. 1) so it is difficult to determine a precautionary level of effort. However, an effort equivalent to the early months in 1990 may be an appropriate level for an experimental fishery. In PFMA 123, the CPUE declined from 0.54 to 0.45 over the 25 month period (Fig. 4). Interpreting the change in CPUE is difficult as only a few vessels were involved and there was no “controlled” fishing area. For example, in PFM25, CPUE actually increased (Fig. 6). Associated with changes in CPUE were changes in length. It could be expected that length would decline as the larger, and presumably older, hagfish were fished. The actual trends (Figs. 7, 8, 9) appear to be less than expected, however, in the absence of age and growth data, and a method of standardising fishing impacts (such as an experimental fishing area), it is difficult to interpret fishing impacts accurately.

**Weight and Length Frequencies**

The average weight calculated for all of the hagfish sampled was 0.11 kg, and this was only slightly higher than the average Pacific hagfish (0.102 kg) caught in the Oregon fishery samples studied by Barss (1993). Length frequencies fluctuated monthly throughout the sample period. A gradual decline in mean lengths was observed for hagfish sampled from PFMA 23-7, while a slight increase was apparent for hagfish sampled from PFMA 123-25 (Figs. 7 and 8). Mean lengths ranged from 30.4 cm to 48.3 cm in PFM sub-area 23-7. The largest specimen was 72 cm. This is greater than the maximum length of 63.5 cm noted in Hart (1973). The smallest hagfish reported was 16 cm long. It was collected in July of 1990, and 2 other minimum lengths of less than 20 cm were recorded in June of 1989 and June of 1990. The mean lengths of hagfish measured from PFM sub-area 123-5 ranged from 38.7 cm to 47.8 cm in total length. The largest fish recorded was 73 cm long, and the smallest was 17 cm in total length. Hagfish smaller than 20 cm in total length were collected in February, April and May of 1990 in PFM sub-area 123-5.

**Sex ratios**

The number of females exceeded the number of males in samples of hagfish collected from PFMA 123 and in PFMA 23 (Tables 9 and 10). For most samples, the ratio of female to male hagfish ranged between 1 and 3. Very high ratios (4.4 and 3.7) of female to male hagfish occurred when the percentage of unidentified individuals was also high and may reflect inaccurate recognition of sex. A smaller proportion of females to males was observed in August through October of 1989 and again in May and June of 1990 in PFMA 23 only. The changes in sex ratios did not show trends for the duration of each year or the entire fishery (Fig. 9).

**Egg condition**

Egg condition data exhibited high variability between months and no particular trends that would indicate seasonality of breeding (Tables 9 and 10). The average length of female to reach at least stage 4 (Table 11) egg condition was 42.8 cm (min. 39.0 cm) in PFMA 23 and 44.2 cm (min. 35.0) in PFMA 123.

An egg condition index was calculated as the percentage of the females containing eggs in stage 4 or later, divided by the percentage of the females that measured 40 cm in total length or greater. The available data is scanty and no seasonality is apparent, but it appears that this index fluctuates similarly to CPUE. High variability exists between collection sites within the same area. For example, in October of 1989 the egg condition index for a random sample from a random site in Area 23-7 was 0.23 while during the same month a random sample collected from Kirby Point in Area 23-7 had an egg condition index of only 0.08. Stages 6 and 7 were introduced in the description of samples collected in Area 123 for August and October of 1989 only. Whether this is a reflection of inconsistent evaluation of egg condition or a real sign that later stages of maturity occurred only rarely, is unknown.

## V. DISCUSSION

The hagfish fishery in British Columbia started in 1988 and was effectively finished by May of 1992. The sporadic nature of the sampling program and the very poor understanding of the biology make it difficult to assess the impacts of fishing.

**Catch and Effort**

Catch and effort data must continue to be collected, but with greater consistency and uniformity than in the past. This will allow comparison with catch and effort data that were recorded during the previous fishery and will show how the stocks responded after the fishery stopped in 1992. In the absence of estimates of absolute abundance, catch per unit effort data related to true abundance by a catchability coefficient could be used to develop surplus production models (Walters and Hilborn, 1976). Furthermore, Woodby *et al.* (1993) developed a conservative application of a surplus production model for populations about which information is lacking.

**Length and Weight**

Total body lengths should be measured and length frequencies collated for hagfish from populations in the two of the PFM sub-areas designated for biological sampling in the previous fishery. Mean length frequencies can provide some immediate information of the impact of a fishery on a population. Consistency in the sampling schedule (i.e., monthly, or bimonthly at the most) is required in order that the large variability in the data can be reduced or explained. Taking some other measurements, such as circumference and individual weight, would make the data more comparable to other recent studies on hagfish (Martini *et al*., 1998; Wisner and McMillan, 1995).

**Sex Ratio and Egg Condition**

A regular schedule of sampling is required to determine if there is migration to spawn. Possible 'breeding grounds' could be identified and a sampling program designed to determine how hagfish reproduce. The possibility of migratory behaviour has been suggested by fishermen.

The fact that females containing advanced stages of egg development were so rarely found in samples taken in the previous fishery, and the lack of collection of very large or fertilized eggs, suggests that the method of harvesting is biased against finding these samples. The very mature females and embryos collected at the turn of the century were caught by hook and line. Considering that a female hagfish may contain up to 30 maturing eggs at one time, and when fully mature these eggs may each measure some 31 mm in length and 8 mm in width (Dean, 1900, in Walvig, 1963), it is possible that very ripe females may not be able to pass through the small entrance cones of the traps. Sampling methods designed to further studies of reproduction may need to be developed.

**Ageing**

*E. stoutii* does not possess any of the bony structures typically used for age determination, but it does contain a number of small statoliths. These structures may prove useful in determining age, and growth rate, by a method similar to that used in lamprey (Beamish and Northcote, 1989).

**Tags**

Mark and recapture programs can also be used to determine the growth rates and can provide evidence of migratory behaviour. Success with implantation, retention and recovery of coded-wire tags, (CWT) in muscle tissue of Pacific hagfish was reported in California by Nakamura (1994). The possibility of running some preliminary trials with CWT's in Pacific hagfish in order to prove their efficacy should be considered. Marks may also be applied using coloured latex injections.

**Traps**

In 1992, at the end of the previous fishery, a modified trap was introduced to the fishery. More recently a trap was developed that has been further modified to prevent continued fishing of lost traps and to reduce the by-catch of small hagfish. These different models of traps need to be fished, in a controlled fashion, to calibrate new and historical data.

**Habitat**

Estimates should be made of the area of ocean bottom that is the habitat for hagfish. Designate as a reserve a section containing good hagfish habitat in each PFM Area proposed to be fished. The reserve area would be used to study the biology and behaviour of hagfish. In particular, information is needed on reproductive timing and rates, as well as, age and growth.

**Management Alternatives**

Direct limitation of effort by licence limitation and gear limits as was advocated in management of the previous fishery could be implemented effectively in any new fishery. Time and area closures could also be enforced in order to restrict the extent and level of exploitation. Dictating size limits on a fishery requires confident estimates of size at maturity for evaluation of the effectiveness of the limitations. Determining TAC, total allowable catch, estimates requires knowledge of stock size, and ongoing assessment of the effectiveness of enforced exploitation rates and evaluation of the response of the stock to these rates.

**Management Considerations**

A limited and monitored fishery for hagfish is an effective way to acquire information needed to assess impact of future fisheries. A small fishery in the areas fished in the past will provide important data needed to begin to understand recruitment and productivity characteristics. Science, however, cannot be used to assess sustainable removal levels or assign quotas to particular bottom habitats. The biology and life history patterns of hagfish are simply too poorly understood to expect the survey results and monitoring will provide this information. This means that management strategies need to be adaptive as well as realistic. There also needs to be a balance in the effort and resources used to monitor and report on fishing activities and those used to discover new information about this species. Fisheries currently exist for species where understanding of the mechanisms that affect recruitment are poorly known (i.e. geoduck). Thus, we do not have to wait until such aspects of the dynamics have been worked out. There is not a method of ageing hagfish other than a crude analysis of length frequencies. It would be helpful to know the age at first maturity and the average length of life. However, fisheries can be allowed now so that we can observe changes in size with time and effort and we can look for ways of ageing hagfish. The cost and time involved to carry out these biological studies can be estimated once some attempts have been made to collect samples.

In the interim we recommend that a fishery, not exceeding the annual harvests of the past fishery (in this report, Tables 4), be allowed and that it be monitored for (1) the type of trap used, (2) the number of traps used, (3) the catch per trap, (4) the total length of 2 samples of 50 fish selected randomly each day, (5) the length, sex and maturity of one sample of 50 fish every three days of fishing. (6) the area of Kirby Point, Barkley Sound PFM area 23-7, be designated a sample grid of stations, to be fished once each month and that a random sample of 100 fish be sampled for length, sex, and maturity, and (7) all other areas can be fished according to the conditions in 1 through 5.

After one year of fishing, a risk analysis will be developed that will be based on the ration of effort to changes in average size of catch. If size is stabilised, the level of effort would be assumed to be acceptable for an additional year. If the average size of catch is declining, the rate of decline would be used to determine the level of effort or to close the particular area.

## VI. RECOMMENDATIONS

Information collected from the previous fishery and the associated sampling program provide a baseline from which an understanding of the population dynamics of Pacific hagfish can be developed. In light of the current interest by industry in re-instituting a hagfish fishery, the following recommendations are made:

- Allow an experimental fishery as it is possible, even desirable since it will provide information on the response of the population to a period of no fishing. This experimental fishery should be structured such that data requirements for managing the fishery are met with industry support.
- Effort and total catch per unit area should be less than past levels until the impact of fishing is better understood.
- Monitor the fishery through logbooks and sales slip receipts. Sample catch, length, weight, sex and maturity, by a method comparable to that used in the previous program but which incorporates a structure that will provide information for estimates of stock assessment.
- It is desirable to have a controlled fishing area that can be used to standardise fishing impacts. Participants in the fishery would be required to carry out standardised fishing operations in this area to collect biological information.
- Funding must be made available for collection and analysis of information.
- After 1 year, a risk analysis be developed that will be based on the ration of effort to changes in average size of catch.

## VII. ACKNOWLEDGEMENTS

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## IX. TABLES AND FIGURES

Table 1. Landing statistics for hagfish (Pacific, Black, and Atlantic) in North America. Landings in metric tonnes. Values are taken from F&O and NMFS statistics.

| YEAR | BC | WA | OR | CA | Pacific + Black | NS | ME | MA | NH | Atlantic |
|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 66.2 | | 11.7 | 313.3 | 391.2 | | | | | |
| 1989 | 625.6 | | 156.1 | 1,198.6 | 1980.3 | 117.1 | | | | |
| 1990 | 167.0 | 35.9 | 76.0 | 2222.9 | 2501.8 | 88.7 | | | | |
| 1991 | 63.8 | | 124.5 | 137.5 | 325.8 | 86.5 | | | | |
| 1992 | 45.1 | 19.1 | 340.8 | 183.9 | 588.9 | 204.5 | | | | |
| 1993 | | | 150.9 | 0.3 | 151.2 | 7.2 | 82.8 | 394.4 | | 484.4 |
| 1994 | | | | 0.6 | 0.6 | 107.7 | 29.3 | 1075.9 | | 1213.0 |
| 1995 | | | 1.0 | 0.4 | 1.4 | 503.0 | | 1421.4 | | 1924.4 |
| 1996 | | | 17.4 | 82.7 | 100.1 | 268.7 | 410.1 | 1549.1 | | 2227.8 |
| 1997 | | | | 0.03 | 0.03 | 15.0 | 418.3 | | 3.7 | 437.0 |
| 1998 | | | 3.7 | 0.2 | 3.9 | na | 875.4 | 572.2 | | 1869.5 |

Table 2. Summary of Atlantic hagfish landings and value in the Nova Scotia (Scotia Fundy DSAB) fishery.

| Year | Number of Licence holders | Total Landings[1] (kg) | Total landed Value ($) |
|---|---|---|---|
| 1989 | 3 | 117117 | 127000 |
| 1990 | 3 | 87699 | 90000 |
| 1991 | 3 | 86465 | 69000 |
| 1992 | 3 | 204527 | 203000 |
| 1993 | 3 | 7198 | 7000 |
| 1994 | 7 | 107734 | 107000 |
| 1995 | 6 | 50300 | 496000 |
| 1996 | 6 | 268738 | 251455 |
| 1997 | 6 | (preliminary )5806 | 5440 |

[1] Data from F&O Statistics, in '1998/99 Hagfish (*Myxine glutinosa*) Interim Conservation Harvesting Plan', Scotia Fundy Fisheries, Maritimes Region, Fisheries and Oceans Canada. These figures differ substantially from hagfish purchase data provided by a regional buyer for 1995 (643,928 kg) and 1996 (749,052 kg).

Table 3. Commercial fishery and biological data available on Pacific hagfish in Pacific Fisheries Management Areas 23 and 123 (L=logbook, B=biological sample).

| YEAR | MONTH | AREA 23 | AREA 123 | YEAR | MONTH | AREA 23 | AREA 123 |
|---|---|---|---|---|---|---|---|
| 1988 | October | L | | 1991 | January | L B | L B |
| | November | L | | | February | | L B |
| | December | L B | L | | March | B | L |
| 1989 | January | L | L | | April | | L |
| | February | L B | L | | May | B | L B |
| | March | L | L | | June | | |
| | April | L | L | | July | L B | L B |
| | May | L | L B | | August | L B | L B |
| | June | B | L B | | September | | |
| | July | L B | L B | | October | | |
| | August | B | L B | | November | | |
| | September | | L | | December | B | L |
| | October | L B | L B | 1992 | January | | L |
| | November | LB | L B | | February | L B | L B |
| | December | L B | | | March | L B | L B |
| 1990 | January | L B | L B | | April | L | L |
| | February | L B | L B | | May | L B | L B |
| | March | L B | L B | | June | | |
| | April | L B | L B | | July | | |
| | May | B | L B | | August | | |
| | June | B | L | | September | | |
| | July | B | L B | | October | | |
| | August | B | L B | | November | | |
| | September | | | | December | | |
| | October | B | | | | | |
| | November | | | | | | |
| | December | | | | | | |

Table 4. Landing statistics for Pacific hagfish in PFMA 23, Barkley Sound Inside Waters.

| YEAR | MONTH | LANDINGS (kg) | EFFORT (# of traps) | CPUE (month) (kg/trap) | TOTAL LANDINGS Annual | CPUE Average Annual |
|---|---|---|---|---|---|---|
| 1988 | October | 3653 | 4200 | 0.9 | 66192 | 1.0 |
| | November | 32797 | 28647 | 1.1 | | |
| | December | 29742 | 36275 | 0.8 | | |
| 1989 | January | 86554 | 104522 | 0.8 | 206009 | 0.6 |
| | February | 57822 | 81175 | 0.7 | | |
| | March | 12926 | 34000 | 0.4 | | |
| | April | 9763 | 26478 | 0.4 | | |
| | May | 4558 | 12896 | 0.4 | | |
| | June | a | | | | |
| | July | 12355 | 21504 | 0.6 | | |
| | August | a | | | | |
| | September | a | | | | |
| | October | 15085 | 27900 | 0.5 | | |
| | November | 6942 | 13850 | 0.5 | | |
| | December | 20914 | 33077 | 0.6 | | |
| 1990 | January | 25096 | 52542 | 0.5 | 62341 | 0.4 |
| | February | 17522 | 39940 | 0.4 | | |
| | March | 18997 | 53422 | 0.4 | | |
| | April | 725 | 2100 | 0.3 | | |
| | May | a | | | | |
| | June | a | | | | |
| | July | a | | | | |
| | August | a | | | | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1991 | January | 4550 | 10900 | 0.4 | 6879 | 0.3 |
| | February | a | | | | |
| | March | a | | | | |
| | April | a | | | | |
| | May | a | | | | |
| | June | a | | | | |
| | July | 23 | 300 | 0.1 | | |
| | August | 2306 | 7596 | 0.3 | | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1992 | January | a | | | 2610 | 0.5 |
| | February | 136 | 400 | 0.3 | | |
| | March | 272 | 600 | 0.5 | | |
| | April | 477 | 1450 | 0.3 | | |
| | May | 1725 | 2099 | 0.8 | | |
| TOTAL | | 364974 | | | | |

a – No fishing occurred.

Table 5. Landing statistics for Pacific hagfish in PFMA 123, Barkley Sound Outside Waters.

| YEAR | MONTH | LANDINGS (kg) | EFFORT (# of traps) | CPUE (month) (kg/trap) | TOTAL LANDINGS Annual | CPUE Average Annual |
|---|---|---|---|---|---|---|
| 1988 | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1989 | January | 2400 | 2505 | 1.0 | 322817 | 0.7 |
| | February | 12700 | 17368 | 0.7 | | |
| | March | 4550 | 5490 | 0.8 | | |
| | April | 27800 | 26740 | 1.0 | | |
| | May | 48206 | 42232 | 1.1 | | |
| | June | 42875 | 73725 | 0.6 | | |
| | July | 35683 | 46786 | 0.8 | | |
| | August | 57810 | 82651 | 0.7 | | |
| | September | 54461 | 84574 | 0.6 | | |
| | October | 26678 | 42872 | 0.6 | | |
| | November | 9654 | 17544 | 0.6 | | |
| | December | a | | | | |
| 1990 | January | 4932 | 10633 | 0.5 | 82831 | 0.3 |
| | February | 21404 | 69735 | 0.3 | | |
| | March | 19575 | 49134 | 0.4 | | |
| | April | 10772 | 29518 | 0.4 | | |
| | May | 12442 | 59325 | 0.2 | | |
| | June | 5482 | 29362 | 0.2 | | |
| | July | 745 | 7453 | 0.1 | | |
| | August | 7479 | 25278 | 0.3 | | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1991 | January | 14009 | 21857 | 0.7 | 51283 | 0.6 |
| | February | 682 | 1197 | 0.6 | | |
| | March | 15727 | 22463 | 0.7 | | |
| | April | 10247 | 10992 | 0.9 | | |
| | May | 3205 | 3839 | 0.8 | | |
| | June | a | | | | |
| | July | 4971 | 29561 | 0.2 | | |
| | August | 2261 | 6580 | 0.3 | | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | 181 | 800 | 0.2 | | |
| 1992 | January | 1232 | 3000 | 0.4 | 3037 | 0.5 |
| | February | 114 | 200 | 0.6 | | |
| | March | 1328 | 4295 | 0.3 | | |
| | April | 136 | 350 | 0.4 | | |
| | May | 227 | 350 | 0.6 | | |
| TOTAL | | 459968 | | | | |

a – No fishing occurred.

Table 6. Landing statistics for Pacific hagfish in PFMA 25, Nootka Sound Inside Waters.

| YEAR | MONTH | LANDINGS (kg) | EFFORT (# of traps) | CPUE (month) (kg/trap) | TOTAL LANDINGS Annual | CPUE Average Annual |
|---|---|---|---|---|---|---|
| 1988 | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1989 | January | a | | | 96794 | 0.5 |
| | February | a | | | | |
| | March | a | | | | |
| | April | 4251 | 23982 | 0.2 | | |
| | May | 14544 | 33828 | 0.4 | | |
| | June | 2943 | 6446 | 0.5 | | |
| | July | 10250 | 22256 | 0.5 | | |
| | August | 16625 | 24557 | 0.7 | | |
| | September | 34343 | 88302 | 0.4 | | |
| | October | 9525 | 17985 | 0.5 | | |
| | November | 1589 | 3447 | 0.5 | | |
| | December | 2724 | 5500 | 0.5 | | |
| 1990 | January | a | | | 21812 | 0.4 |
| | February | a | | | | |
| | March | a | | | | |
| | April | 19769 | 49521 | 0.4 | | |
| | May | 2043 | 5916 | 0.4 | | |
| | June | a | | | | |
| | July | a | | | | |
| | August | a | | | | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1991 | January | a | | | 5590 | 0.6 |
| | February | a | | | | |
| | March | a | | | | |
| | April | a | | | | |
| | May | a | | | | |
| | June | a | | | | |
| | July | a | | | | |
| | August | a | | | | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | 5590 | 9673 | 0.6 | | |
| 1992 | January | a | | | 39491 | 0.5 |
| | February | 7173 | 9992 | 0.7 | | |
| | March | 14119 | 24890 | 0.6 | | |
| | April | 9014 | 21893 | 0.4 | | |
| | May | 9185 | 20888 | 0.4 | | |
| TOTAL | | 164086 | | | | |

a – No fishing occurred.

Table 7. Length frequency of Pacific hagfish from PFMA 23-7, Barkley Sound Inside Waters. Sample station Kirby Point.

| Year | Date | Mean Length (cm) | Min. Length (cm) | Max. Length (cm) |
|---|---|---|---|---|
| 1989 | June | 36.6 | 19.0 | 62.0 |
| | July | 48.3 | 32.0 | 63.0 |
| | August | | | |
| | September | | | |
| | October | 44.1 | 29.0 | 61.0 |
| | November | 45.6 | 26.0 | 68.0 |
| | December | 45.8 | 27.0 | 69.0 |
| 1990 | January | 38.9 | 27.0 | 63.0 |
| | February | 44.3 | 29.0 | 64.0 |
| | March | 40.5 | 30.0 | 58.0 |
| | April | 41.4 | 20.0 | 64.0 |
| | May | 46.2 | 24.0 | 64.0 |
| | June | 38.1 | 18.0 | 59.0 |
| | July | 33.5 | 16.0 | 57.0 |
| | August | 45.6 | 23.0 | 72.0 |
| | September | | | |
| | October | 44.0 | 27.0 | 66.0 |
| | November | | | |
| | December | | | |
| 1991 | January | 45.6 | 26.0 | 65.0 |
| | February | | | |
| | March | 46.3 | 23.0 | 72.0 |
| | April | | | |
| | May | 43.7 | 24.0 | 65.0 |
| | June | | | |
| | July | 41.1 | 26.7 | 62.1 |
| | August | 30.4 | 21.2 | 63.3 |
| | September | | | |
| | October | | | |
| | November | | | |
| | December | 37.8 | 20.4 | 56.2 |
| | January | | | |
| 1992 | February | 41.2 | 21.2 | 60.2 |
| | March | 34.9 | 23.1 | 60.4 |

Table 8. Length frequency of Pacific hagfish from PFMA 123-5, Barkley Sound Outside Waters. Sample station Amphitrite Point.

| Year | Month | Mean Length (cm) | Min. Length (cm) | Max. Length (cm) |
|---|---|---|---|---|
| 1989 | May | 45.0 | 24.0 | 68.0 |
| | June | 42.1 | 22.0 | 61.0 |
| | July | 45.4 | 22.0 | 65.0 |
| | August | 47.8 | 24.0 | 67.0 |
| | September | | | |
| | October | 44.0 | 23.0 | 69.0 |
| | November | 41.7 | 22.0 | 61.0 |
| | December | | | |
| 1990 | January | 39.5 | 22.0 | 61.0 |
| | February | 42.4 | 19.0 | 68.0 |
| | March | 43.8 | 20.0 | 66.0 |
| | April | 38.7 | 17.0 | 60.0 |
| | May | 42.9 | 19.0 | 60.0 |
| | June | | | |
| | July | 43.9 | 23.0 | 67.0 |
| | August | 44.6 | 21.0 | 67.0 |
| | September | | | |
| | October | | | |
| | November | | | |
| | December | | | |
| 1991 | January | 42.5 | 24.0 | 61.0 |
| | February | | | |
| | March | 44.5 | 22.0 | 73.0 |
| | April | | | |
| | May | 45.8 | 25.0 | 72.0 |
| | June | | | |
| | July | 47.2 | 21.8? | 61.2 |
| | August | 43.9 | 22.2 | 62.3 |
| | September | | | |
| | October | | | |
| | November | | | |
| | December | | | |
| 1992 | January | | | |
| | February | | | |
| | March | 46.3 | 20.4 | 64.9 |

Table 9. Egg condition and ratio of female to male Pacific hagfish in PFMA 23-7, Barkley Sound Inside Waters.

| YEAR | MONTH | Females % | Males % | Unidentified % | Female/ Male ratio | Egg condition index[1] |
|---|---|---|---|---|---|---|
| 1989 | May | a | | | | |
| | June | 68.7 | 15.7 | 15.7 | 4.4 | 0.36 |
| | July | 48.3 | 44.0 | 7.7 | 1.1 | 0.21 |
| | August | 40.9 | 49.8 | 9.3 | 0.8 | |
| | September | a | | | | |
| | October | 41.7 | 58.3 | 0.0 | 0.7 | 0.23 |
| | November | 45.6 | 51.8 | 2.6 | 0.9 | |
| | December | 43.7 | 32.0 | 24.3 | 1.4 | 0.09 |
| 1990 | January | 74.3 | 25.7 | 0.0 | 2.9 | 0.23 |
| | February | 53.3 | 46.7 | 0.0 | 1.1 | 0.02 |
| | March | 55.3 | 44.7 | 0.0 | 1.2 | 0.25 |
| | April | 53.7 | 46.3 | 0.0 | 1.2 | 0.25 |
| | May | 35.0 | 60.0 | 5.0 | 0.6 | 0.30 |
| | June | 35.7 | 48.0 | 16.3 | 0.7 | |
| | July | 47.6 | 45.9 | 6.5 | 1.0 | |
| | August | 56.3 | 41.5 | 2.2 | 1.4 | |
| | September | a | | | | |
| | October | 57.1 | 33.8 | 9.1 | 1.7 | 0.43 |
| | November | a | | | | |
| | December | a | | | | |
| 1991 | January | 70.4 | 29.6 | 0.0 | 2.4 | |
| | February | a | | | | |
| | March | 62.1 | 33.8 | 4.1 | 1.8 | |
| | April | a | | | | |
| | May | 62.7 | 37.3 | 0.0 | 1.7 | |
| | June | a | | | | |
| | July | 62.1 | 35.7 | 2.2 | 1.7 | |
| | August | 58.2 | 36.9 | 1.9 | 1.7 | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | 65.5 | 34.5 | 0.0 | 1.6 | |
| 1992 | January | a | | | | |
| | February | 58.2 | 36.8 | 5.0 | 1.6 | 0.21 |
| | March | 62.8 | 34.1 | 2.9 | 1.8 | |

[1]Egg condition index is calculated as the % of the females containing eggs in stage 4 or later, divided by the % of the females that measured 40 cm in total length or greater.

Table 10. Egg condition and ratio of female to male Pacific hagfish in PFMA 123-5, Barkley Sound Outside Waters

| YEAR | MONTH | Females % | Males % | Unidentified % | Female/ Male ratio | Egg condition index[1] |
|---|---|---|---|---|---|---|
| 1989 | May | 56.3 | 28.1 | 15.6 | 2.0 | |
| | June | 66.5 | 26.0 | 7.5 | 2.6 | |
| | July | 58.0 | 40.5 | 1.5 | 1.4 | |
| | August | 67.0 | 33.0 | 0.0 | 2.0 | 0.47 |
| | September | a | | | | |
| | October | 69.0 | 28.0 | 3.0 | 2.5 | |
| | November | 68.0 | 18.2 | 13.5 | 3.7 | |
| | December | a | | | | |
| 1990 | January | 48.0 | 50.0 | 1.9 | 1.0 | 0.43 |
| | February | 61.6 | 37.9 | 0.5 | 1.6 | 0.37 |
| | March | 62.8 | 37.2 | 0.0 | 1.7 | 0.34 |
| | April | 65.7 | 33.3 | 1.0 | 2.0 | 0.33 |
| | May | 71.0 | 29.0 | 0.0 | 2.4 | 0.35 |
| | June | a | | | | |
| | July | 58.0 | 36.0 | 6.0 | 1.6 | |
| | August | 66.4 | 31.0 | 2.6 | 2.1 | |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1991 | January | 70.4 | 29.6 | 0.0 | 2.4 | |
| | February | 64.7 | 30.6 | 4.7 | 2.1 | 0.42 |
| | March | a | | | | |
| | April | a | | | | |
| | May | 62.7 | 37.3 | 0.0 | 1.7 | |
| | June | a | | | | |
| | July | 68.4 | 30.4 | 1.2 | 2.2 | |
| | August | 64.9 | 34.7 | 0.4 | 1.9 | 0.53 |
| | September | a | | | | |
| | October | a | | | | |
| | November | a | | | | |
| | December | a | | | | |
| 1992 | January | a | | | | |
| | February | a | | | | |
| | March | 64.3 | 33.5 | 2.2 | 1.9 | |

[1] Egg condition index is calculated as the % of the females containing eggs in stage 4 or later, divided by the % of the females that measured 40 cm in total length or greater.

Table 11. Egg condition stages defined for Pacific Region biological sampling program for Pacific hagfish.

| Stage Number | Description |
|---|---|
| 1 | Eggs small and cylindrical. Usually located near liver or along dorsal ridge of gut cavity. Often difficult to locate. |
| 2 | Eggs oblong and white. Resemble rice in shape and size. Usually quite abundant. |
| 3 | Eggs similar to #2 except yellow or orange in colour. Approximately 0.5 cm in length. |
| 4 | Eggs enlarged and yellow or orange. No spicule formation on egg. |
| 5 | Eggs similar to #4 except that spicules are present or forming on ends of oblong egg. |
| 6 | Females released eggs. Stages #2 and # present. Evidence of tissues from #5 eggs also present. |

**Figure 1. Catch and effort for the hagfish fishery in British Columbia, PFMA 23, Barkley Sound Inside Waters.**

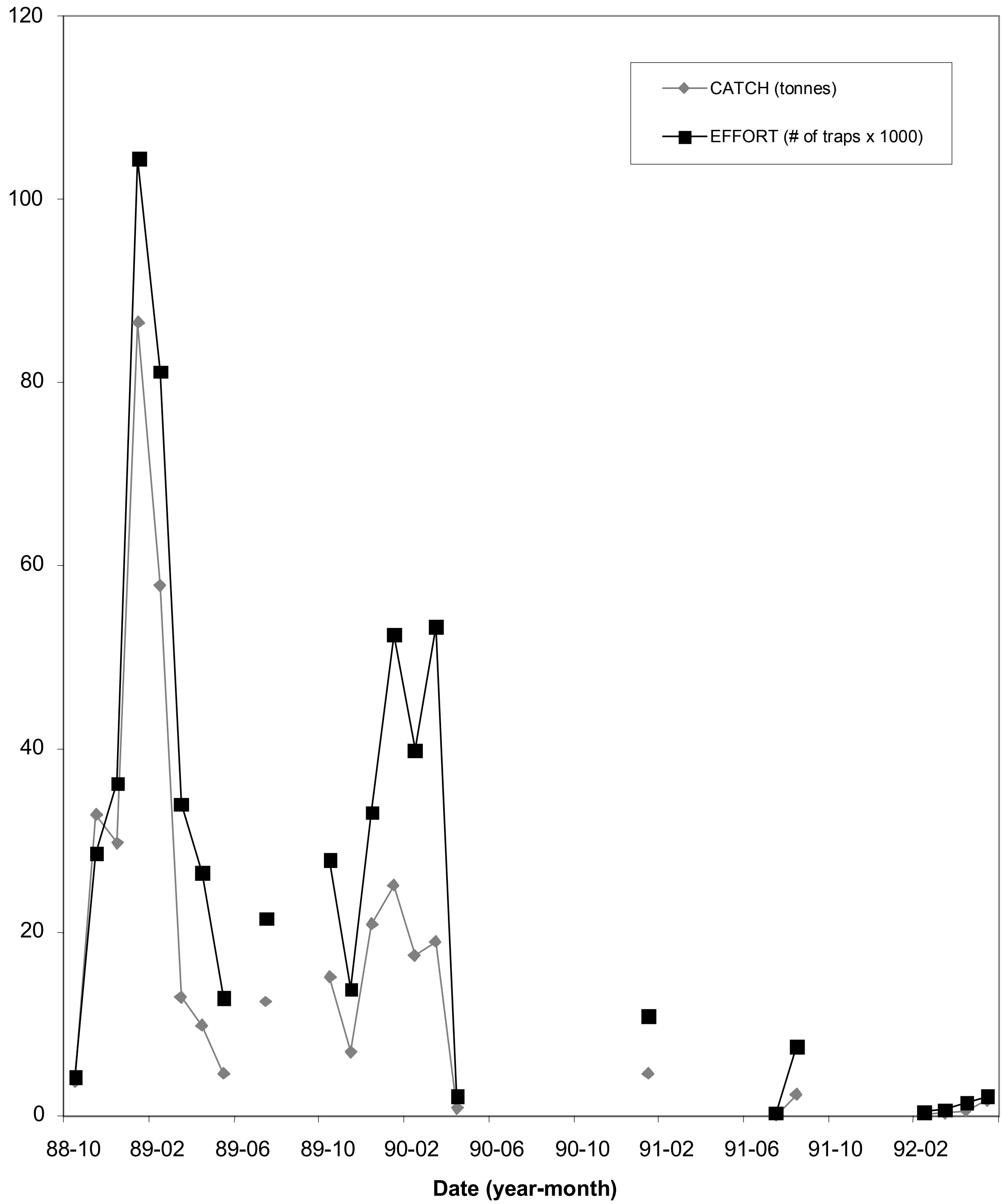


**Figure 2. Monthly catch per unit effort (CPUE) in the hagfish fishery in British Columbia, PFMA 23, Barkley Sound Inside Waters. With linear regression analysis only of values reported after February, 1989.**

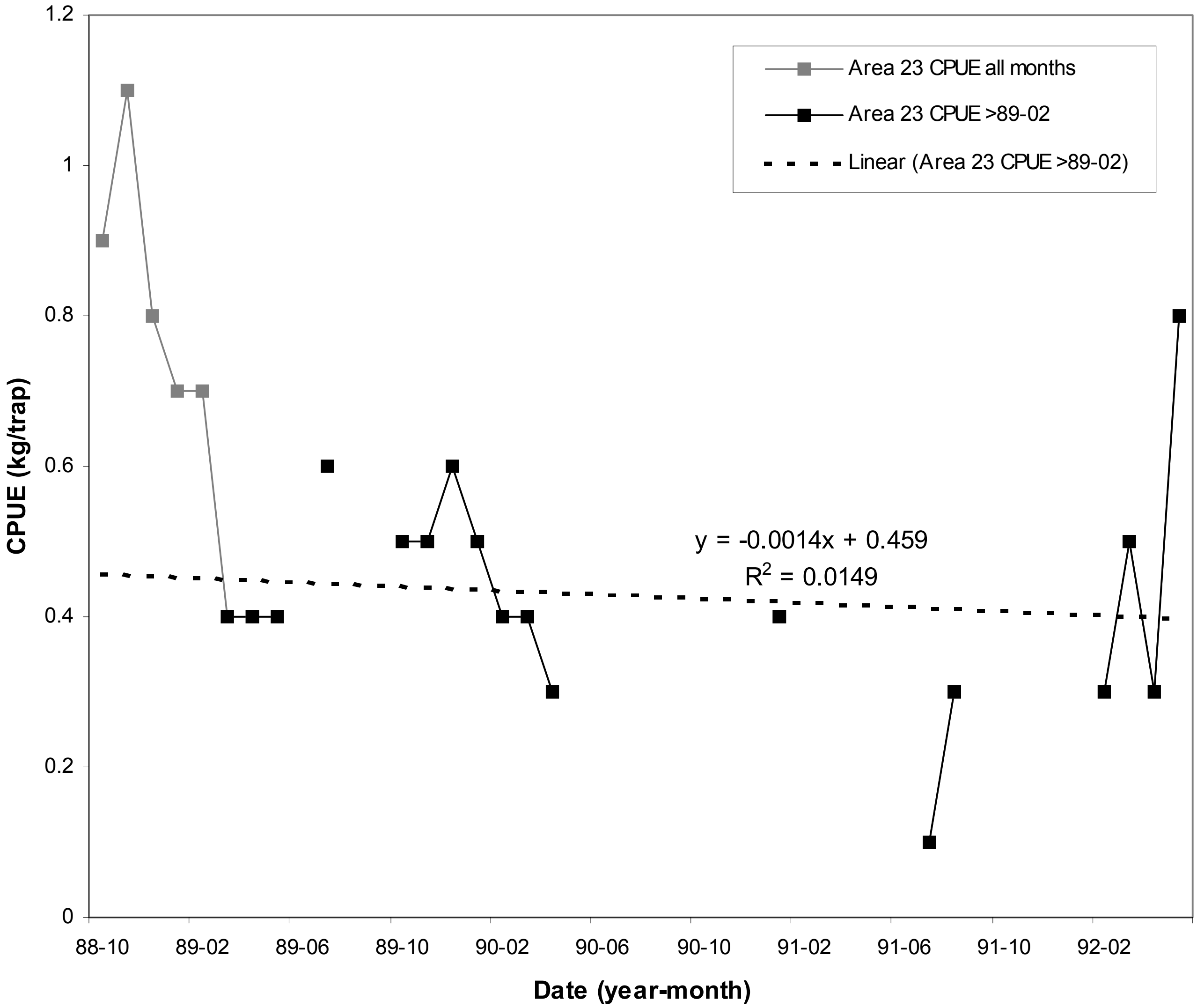


**Figure 3. Catch and effort for the hagfish fishery in British Columbia, PFMA 123, Barkley Sound Outside Waters**

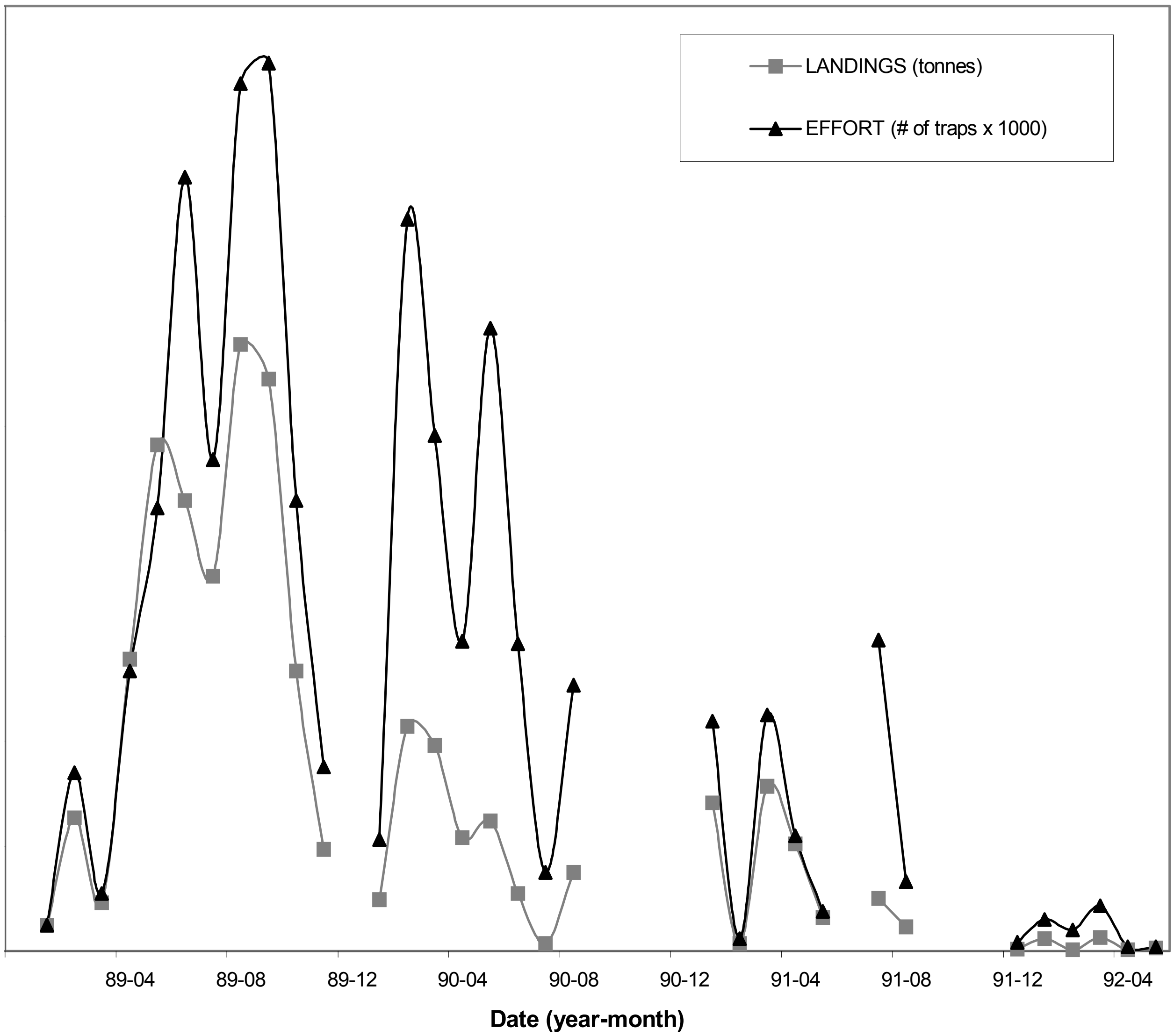


**Figure 4. Monthly catch per unit effort (CPUE) in the hagfish fishery in PFMA 123, Barkley Sound Outside Waters, with linear regression analysis performed on CPUE only after May 1989.**

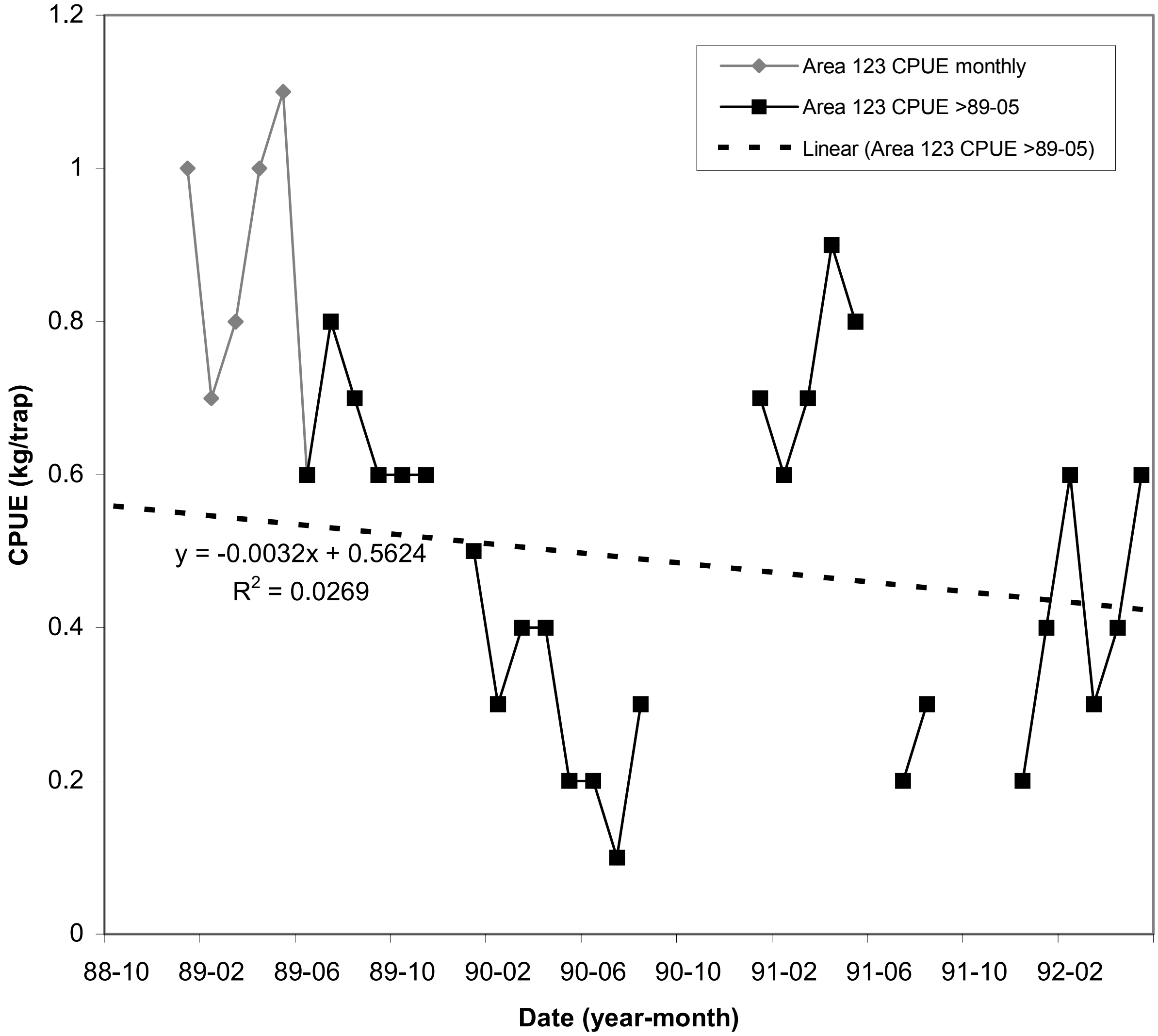


**Figure 5. Catch and effort in the hagfish fishery in British Columbia, PFMA 25, Nootka Sound Inside Waters**

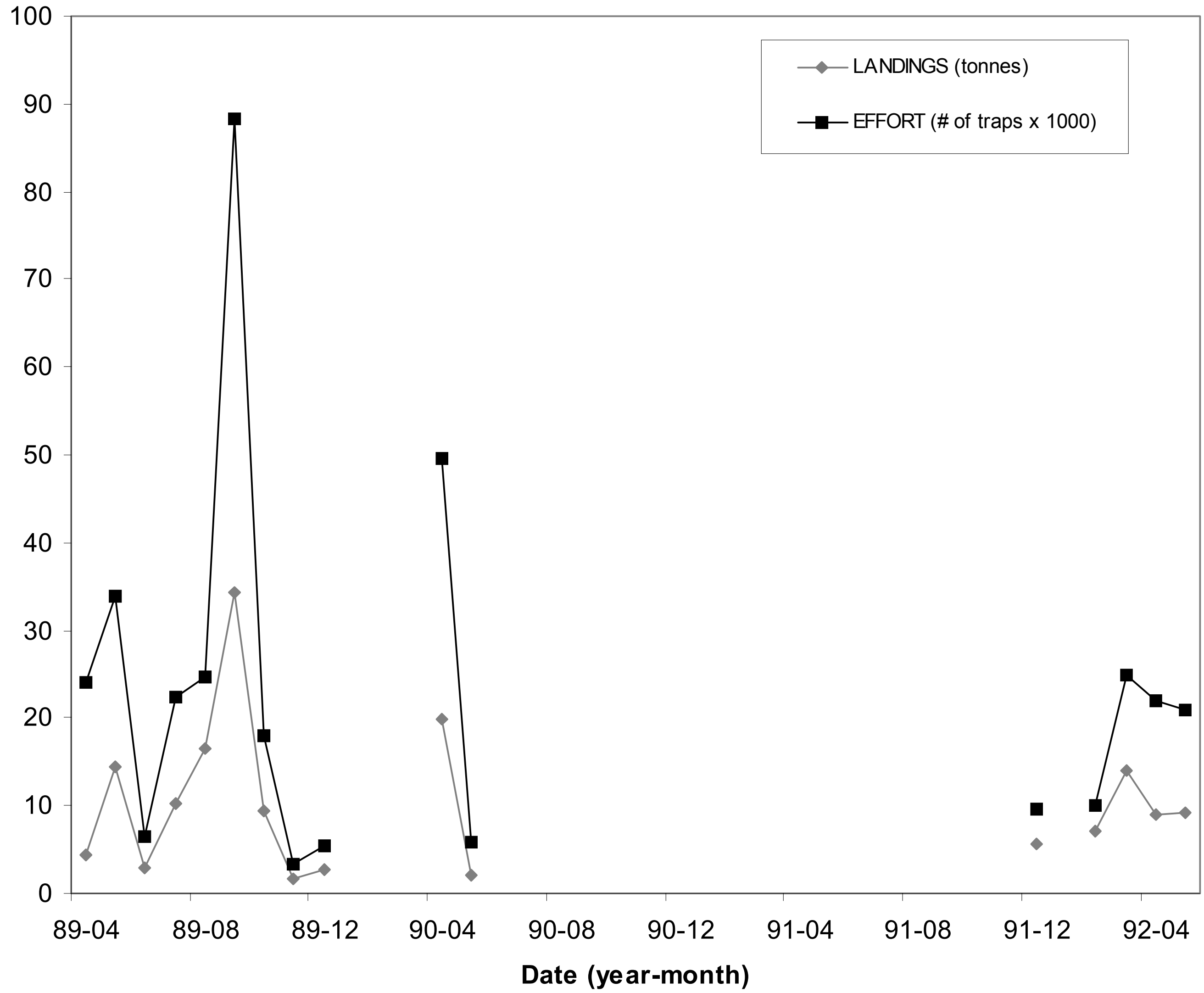


**Figure 6. Monthly catch per unit effort (CPUE) in the hagfish fishery in PFM 25, Barkley Sound Outside Waters, with linear regression analysis performed on CPUE after May 1989.**

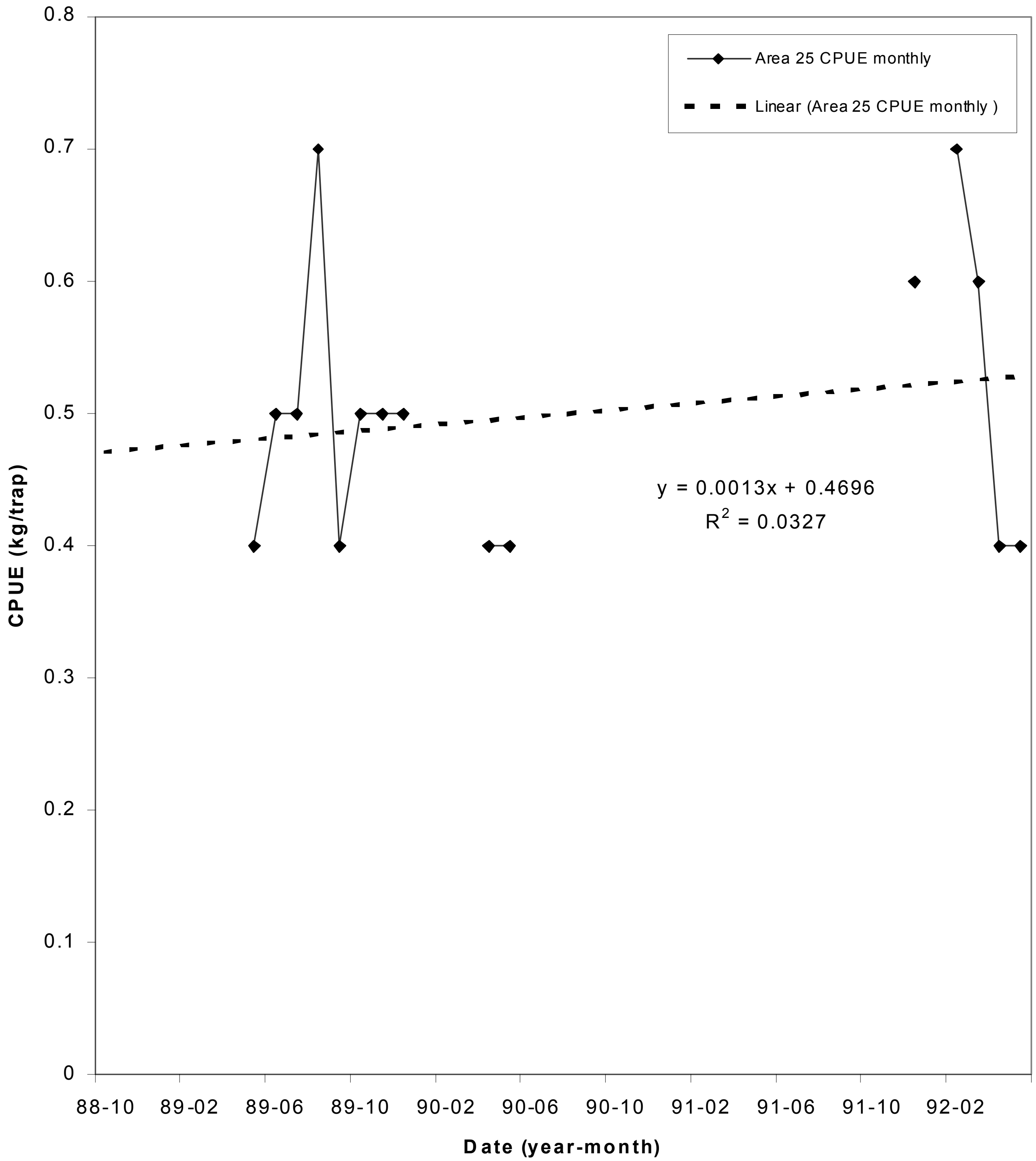


**Figure 7. Length frequencies of Pacific hagfish in PFMA 23, Barkley Sound Inside Waters, with linear regression analysis of the mean length frequencies.**

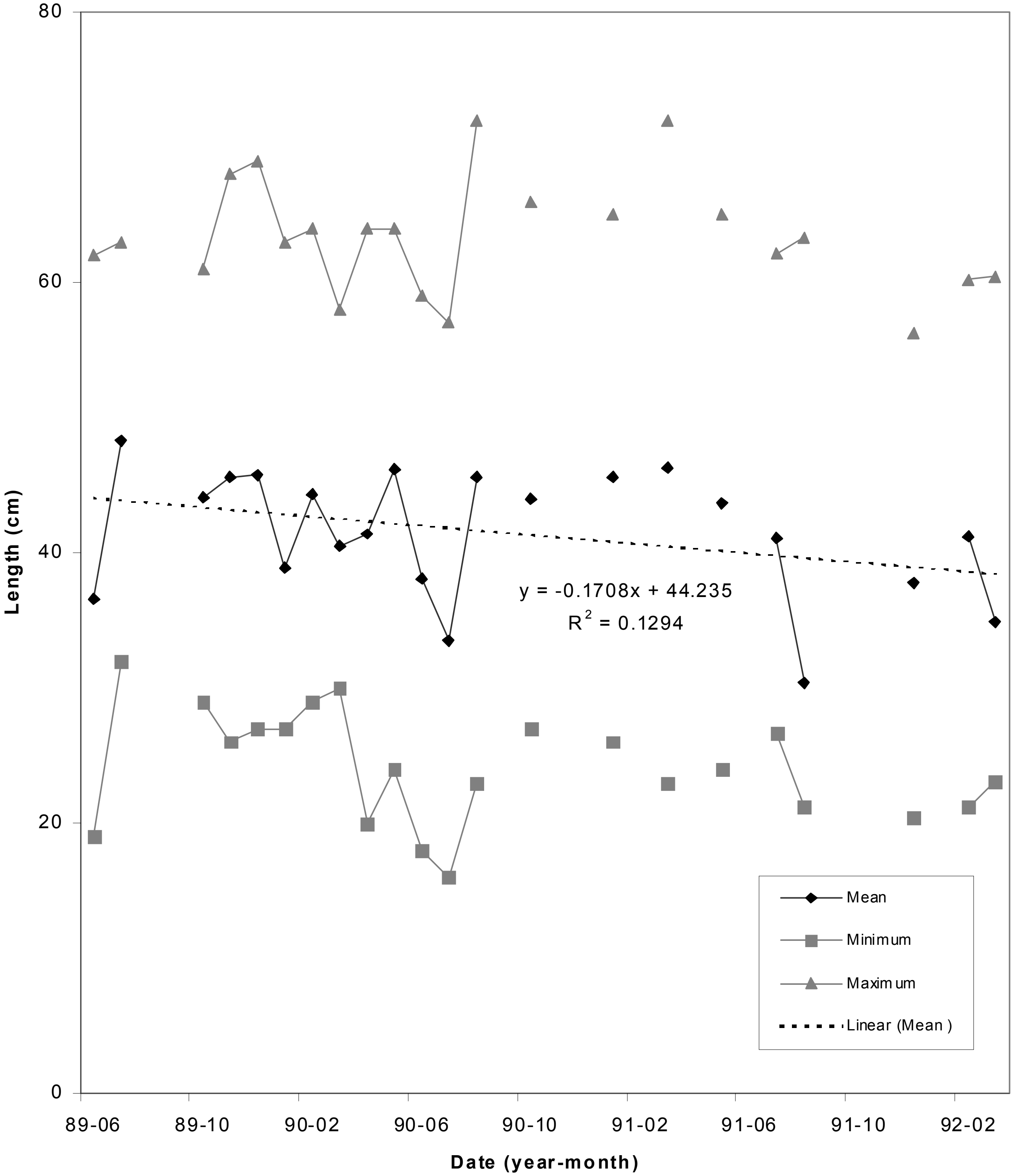


**Figure 8. Length frequencies of Pacific hagfish in PFMA 123, Barkley Sound Outside Waters, with linear regression analysis of mean length frequencies.**

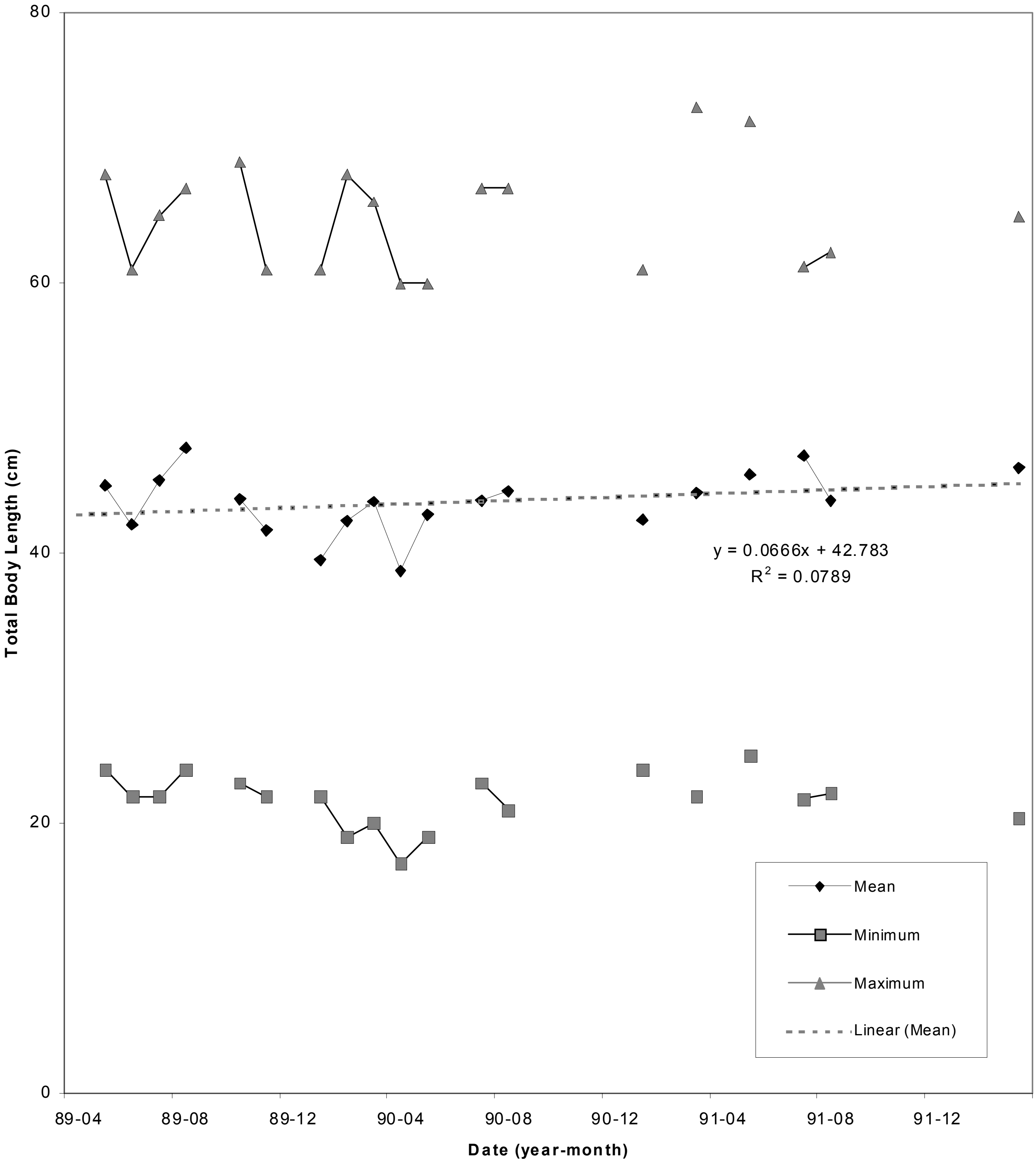
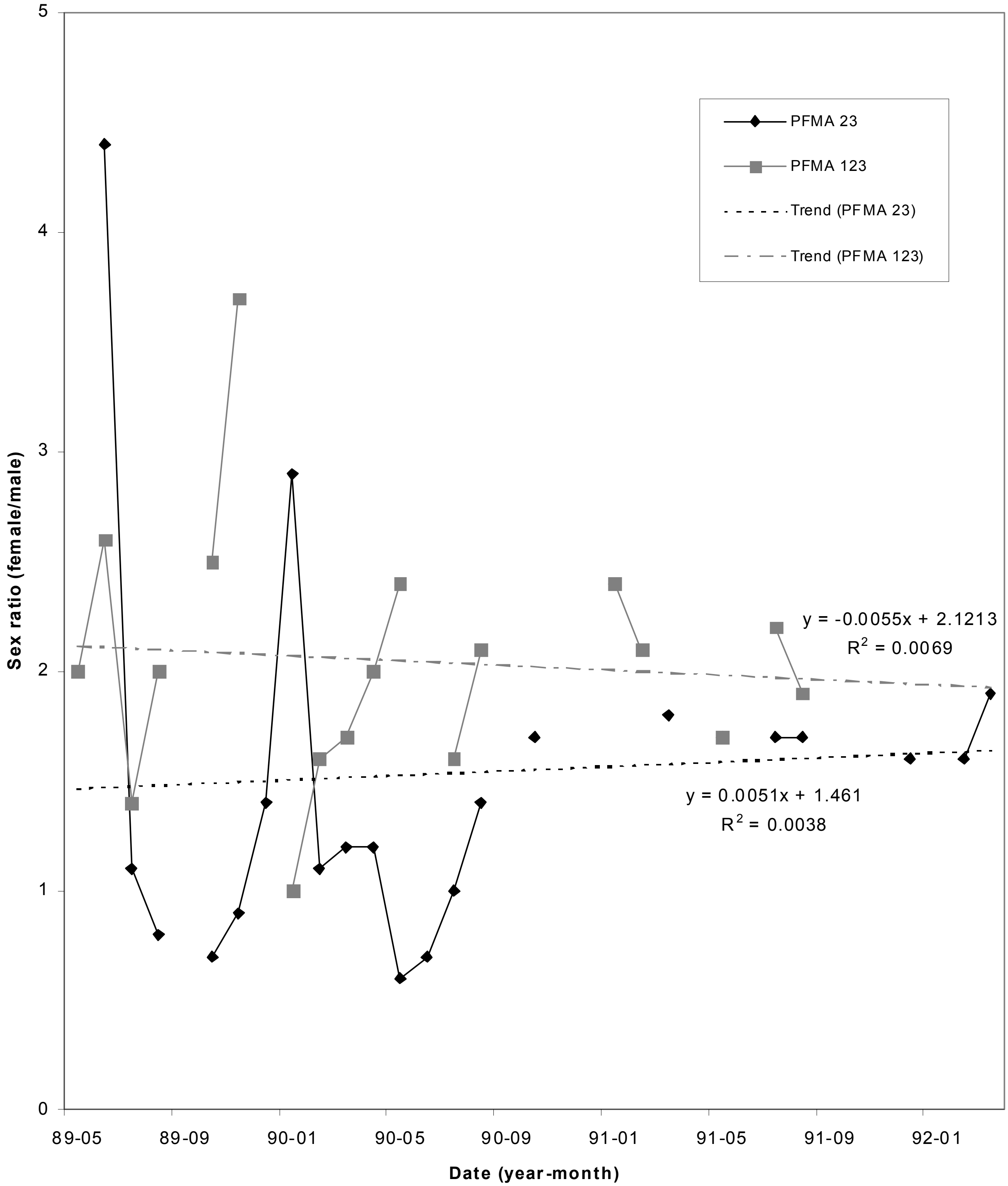


**Figure 9. Ratio of female to male Pacific hagfish in PFMA 23, Barkley Sound Inside Waters and PFMA 123, Barkley Sound Outside Waters, with linear regression analysis.**



## X. APPENDIX 1

**Asian Hagfish Markets and Fisheries**

Hagfish have traditionally been of minor importance as a food fish in Japan and Korea (South). After the Second World War the uses of hagfish, primarily *Paramyxine atami*, were expanded to include the skins as leathercraft and the slime as a cleaning substance (Honma, 1998). The demand for hagfish harvested for their skins has increased considerably over the past 40 year (Gorbman *et al.*,1990). Hagfish leather products such as wallets, purses, and boots, were manufactured primarily in Korea, and were considered to be worth approximately $100 million per year in the late 1980's (Gorbman *et al.*, 1990). Catch records for the Asian fisheries have been difficult to access, but it is apparent that a decline in the supply of hagfish in Korean waters lead Korean fisherman to move to sources offshore of Japan. Korean fisherman make up the majority of the fishers for hagfish in the region, but some records were available from Japan that gave an indication of the state of the new industry (Gorbman *et al.*, 1990). The hagfish stocks in one area of Japan that had traditionally served as a source of hagfish as food no longer sustains a viable commercial fishery. *P. atami* was the primary species fished and depletion of the stock has been blamed on overfishing, although pollution is also suspected. Another area in Japan has supported a exploitation by both Japanese and Korean fisherman for about 30 years without apparent deleterious effects on catch rates, however catch rates were only available up to 1982, and the local industry only began supplying the eel skin market in 1984. A third area was described by Gorbman *et al.* (1990) where a new fishery for hagfish began in 1984, principally for the leather market. Within 4 years the total annual catch had decreased from 2 732 tonnes to 65.6 tonnes, and the number of boats involved in the fishery dropped from 41 to only 2. The seasonal catch rate per boat was thought to have remained stable, the decline in landings attributed to the declining effort in terms of the number of boats. Why the numbers of boats involved in an industry would decrease at a time when that industry was being forced to look for international sources for product is not explained. *E burgeri* and was the species preferred for leather and was the predominant species fished in this area, while *Myxine garmani* was taken primarily in the apparently sustainable food fishery that occurred in the second area described above (Gorbman *et al.*, 1990). Although the catches of *E. burgeri* and *M. garmani* remained relatively constant, the decline in catches of *P. atami* may have been due to differences among species in terms of fecundity or other population growth rate parameters, or to a difference in the length of time for which sustained fishing pressure had been applied. A potential difference in population growth rate parameters begs for caution in the application of life history information from one hagfish species to another.

At least 4 species of hagfish comprise the fishery in waters of Korea and Japan; *E. burgeri* and *P. atami* from the most commonly fished depths near 100 m, and *E. okinoseanus* and *M. garmani* from greater depths up to 500 m. The Korean hagfish fleet is comprised of over 1,000 boats, some of which travel long distances, for almost 2 weeks per trip, before returning with their live, iced, or frozen product to the industry centre of Pusan. Up to 500 baited traps may be clipped to a single line that stretches more than 8000 m, generally over the muddy bottoms that hagfish are known to frequent (Strahan, 1963). Traditionally and currently in use in parts of Japan are urn-shaped bamboo traps, approximately 66 cm tall, 33 cm wide, and 20 cm wide at the small end, and fitted with a conical, one-way entrance. Many fishers now use a cylindrical trap made of plastic resin and produced in Korea. These traps are smaller, at 56 cm tall by 13 cm wide, are perforated throughout for water exchange, and are fitted with a one-way entrance cone. Fishers generally set traps for only 4 hours saying that a longer soak period does not result in higher catches, and a shorter soak period allows the traps to be set in an adjacent area. (Gorbman *et al.*, 1990). Also, the most commonly caught hagfish species in some areas, *E. burgeri* has distinctly diurnal behaviour, being active mostly at night.

Traditionally, hagfish were landed live, and transported in holding tanks aboard the boats. The recent need for boats to travel longer distances and the subsequent length of time the fish might be aboard have forced the industry to develop new ways of transporting product. Live hagfish held in concentrated masses onboard for as long as two weeks showed signs of stress that manifested itself as increased biting and hence a higher incidence of bite marks in the skins. In the 1990's, processors still primarily demanded live product, therefore methods of slowing the animals using anesthetics and icing were tried (Gorbman *et al.*, 1990).

Despite a number of studies that have reported important findings about the diurnal nature of *E. burgeri*, and it's seasonal migration to deeper waters to spawn, little is know about the life history of this and other economically important species of hagfish in Japan and Korea. Knowledge is still required about growth rates, age determination, life span, and many aspects of the reproductive biology.

**North American Fisheries**

The North American fishery for hagfish began with a sample sent from California to the Republic of Korea in 1987 (Kato, 1990, in Barss, 1993). In 1988, British Columbia and Oregon joined California in supplying hagfish, primarily *E. stoutii*, to Korean hagfish skin buyers. Fisheries began on the east coast of the continent in 1989 when Nova Scotia began supplying Atlantic hagfish, *M. glutinosa*, to the same market. By 1993, the fisheries on the west coast were in decline and the fisheries of Maine and Massachusetts stepped in to maintain the supply to the Asian market. The highest recorded landings of hagfish on the continent was 2502 tonnes in 1990, mostly from the west coast fisheries (Table 1). Again in 1996, landings for North America peaked at 2328 tonnes, but this time the hagfish were primarily from the east coast fisheries. In 1994, New England Eel Processor, Inc., paid $460,000 for 1 million pounds (392 927 kg) of Atlantic hagfish. That's about $1.60 per kg in Canadian funds. The majority of the product is frozen and packed at facilities in New England and sent to Korea for skinning, tanning and meat processing.

With closure of George's Bank to many traditional fisheries, the search for alternative fisheries, and the rapid expansion of the fishery for hagfish, came a commitment to develop the fishery in a sustainable way. Rollie Barnaby, a Maine/New Hampshire Sea Grant Extension Agent expressed the following " The goal of the project is to have

science and supply, rather than demand, guide the development of the fishery." (Sea Grant News Media Center, www.seagrantnews.org). Although reference is made to research that is underway on the life cycle of hagfish and the extent of exploitable stocks, in the absence of this crucial stock assessment information, the fishery has landed approximately 6.8 million tonnes of Atlantic hagfish from 1993 to 1998 (NMFS Annual Landing, www.st.nmfs.gov).
All of the fisheries predominantly use baited traps to catch hagfish, either the Korean-type or local modifications of 5-gallon buckets or barrels of various volumes approved by Fisheries Managers. A few landings have been reported in some years in California as being caught by line, and some are reportedly harvested by Otter trawls (0.8 tonnes in 1995) and sea urchin dredges (27 tonnes in 1998) in Massachusetts (NMFS Annual Landing, www.st.nmfs.gov).

**Pacific US Fishery**

A fishery for hagfish has existed in California continuously since it began in 1988 and it has dominated the supply of Pacific hagfish. The size of the fishery has been far from consistent though; ranging from peak landings in 1990 of 2223 tonnes, to lows that continued from 1993 through 1998, at 0.3 tonne and 0.2 tonne, respectively (Table 1). How much of this decline was due to the poor quality of skins that were produced from the warmer Californian waters, or to declining abundance of hagfish in Californian waters, or to competition from the east coast fisheries is unknown. The fishery in Oregon has also continued from 1988 to the present, but no landings were reported for 1994 and 1997. Washington State only recorded landings in 1990 and 1992, and although a permit was issued for Puget Sound, landings were only ever made off the Pacific coast (Barss, 1993). Small landings were made in Alaska in 1989 but a commercial fishery never developed, partly owing to the domination of the catch by Black hagfish rather than Pacific hagfish. Black hagfish skins are less marketable since the skins are darker and thicker than those of Pacifics, and upon processing result in less soft skins that are difficult to dye and sew.

In his 1993 report on the Oregon commercial hagfishery, Barss suggested that a minimum size limit of 38 cm be imposed on the fishery rather than simply allowing the buyer preference of 36.5 minimum length to set the limit. This more conservative size limit would ensure that an appropriate part of both Pacific and Black hagfish populations would reach a size at which spawning was likely. He also proposed incentives to the fishing industry for the development of size selective traps. Limited entry and limiting the number of traps, the length of groundline, and the time of fishing were also recommended as measures that could be imposed on the fishery that would serve to reduce the possiblity of overcapitalization in the fishery, as well as reducing the potential for gear conflicts with other fisheries operating in the same fishing grounds. It was also noted that some buyers and fisherman recommended a short soak time of only about 4 hours to reduce the incidence of bite marks that were attributed to the stress of crowding.

In the early 1990s a study was conducted at Monterey Bay, California to develop size selective hagfishing gear and to develop recommendations for capturing and handling hagfish that would improve skin quality so that the new harvesting industry could develop a profitable and sustainable fishery for Pacific hagfish. (Melvin and Osborn, 1992). The study attempted to test a large number of variables in the techniques employed in the fishery, including trap types, soak times, fishing depths, type and quantity of bait, size and placement of escape holes, number of entrance funnels, anesthetics, density of live holding tanks, and risk of ghost fishing by lost traps. The fishing dates were not given so seasonal variability in the data could not be addressed. One of the two 100 m depth sites selected for most of the fishing trials had to be relocated due to low catch rates thought to be a result of the pressure of the experimental fishing. When the trap-type data were pooled and the soak time data were pooled separately, the mean length of male hagfish was found to be longer, 35.1 cm and 35.2 cm respectively, than the mean length of female hagfish, 34.1 cm and 33.5 cm, respectively, but only the length difference in the soak time data was significant. In a comparison of Korean-type, 5-gallon bucket-type and 30 gallon barrel-type, the 5 gal. bucket-type trap was preferred for since it caught the greatest number of hagfish per trap, the Korean-type traps had a greater incidence of slime indicating that the fish were stressed, and the 30 gal. barrel-type were large and unwieldy to handle. The mean number of hagfish per trap increased slightly, but not significantly, with increasing soak times (ie., 4, 8, and 24 hr). Mean length of the hagfish caught also increased with increasing soak time. The number of hagfish per trap decreased with increasing trap hole size (0.38, 0.42, 0.45, and 0.48 inches or 0.96, 1.06, 1.14, and 1.22 cm), but the average length of hagfish increased with increasing trap hole size and soak time. A longer soak time appeared to allow smaller fish to escape. A 5 gal. bucket-type trap with 0.48" (1.22 cm) escape holes, fished for 24 hr, caught on average 44 hagfish per trap and 90% of these were over 12" or 30.4 cm in length. If the same trap-type possessed the standard 0.38" (0.96 cm) escape holes it caught on average 104 hagfish per trap but only 51% of these would be over 12" (30.4 cm) long. A greater number of hagfish were caught per trap set for 12 hour soaks at night than in the day but the difference was not significant. Rockfish carcasses were found to attract a greater catch than did an equal amount of chopped mackerel, and a pound of bait per gallon of trap volume was recommended for optimum catch rates. Traps that were modified to have 2 entrance funnels and no side escapement holes caught significantly greatest numbers of larger hagfish. This and underwater observations of hagfish behaviour lead the authors to speculate that 2 entrance funnels enhanced access to the trap interior to large hagfish, while reducing access by small hagfish through the small escapement holes. More fish were caught in traps set at 100 m and 475 m, than at 225 m, 350 m and 600 m. In trials of various solutions for the live-holding of hagfish prior to off-loading to processing plants, iced seawater was recommended over freshwater, $CO_2$ bubbling, and MS222, for overall effectiveness in calming the fish and affordability. Preliminary experiments to determine the level of ghost fishing that might occur by lost traps found only a single hagfish in 12 baited traps fished for 24 hr and baited with dead hagfish.

**Maritimes Region**

A fishery for the Atlantic hagfish, *Myxine glutinosa ,* began in Nova Scotia in 1989 within the terms and conditions of the Underutilized Species Policy (1988, in Department of Fisheries and Oceans, 1998). Nova Scotia is the only province with access to Atlantic hagfish that has recorded landings in a commercial fishery. An exploratory fishery was conducted in Gulf of St. Lawrence in 1992 for biological sampling only but inconsistencies in the data collection prevented completion of the data analysis and hence publication of a report (T. Hurlbut, F&O, Gulf Region, Science Branch, pers. comm.). New Brunswick proposed an exploratory hagfish fishery for 1998 in the Bay of Fundy but activity has not yet been reported (T. Hurlbut, pers. comm.). The primary market for these fish has been in tanning for soft leather products and the price has fluctuated around $1.00/kg. Landings in the Nova Scotia fishery peaked in 1995 at 503.0 tonnes (or 1996, depending on source of data, see[1] in Table 2) but were low in 1993 at 7.2 tonnes and again in 1997 (15 tonnes according to Nova Scotia Department of Fisheries and Aquaculture landing statistics for 1996-1997 (www.gov.ns.ca/fish/marketing/landing). The decrease that occurred in 1993 may have been a result of increased competition from the New England states, particularly Maine (Table 1), while the drop in 1997 may have been due to the Korean currency crisis of that year.

Little biological information has been collected but some distribution information has been derived from annual groundfish surveys (Tom Hurlbut, pers. comm.). This information has not been used to estimate abundance or biomass since the burrowing activity of the animal precludes effective capture by survey trawls. Management of the fisheries is expressed in the 1998/99 Hagfish Interim Conservation Harvesting Plan by the Scotia Fundy Fisheries, Maritimes Region. The following information has been taken from this document. While fishing activity has generally taken place in the fall, to date the fishery has been open year round. Since a maximum soak time of 24 hours has been recognized by experienced fishers to procure the best catch rate (ie., less escapement) and quality of product (ie., lower incidence of bite marks and mortality), the poor conditions of winter precludes effective fishing since traps may be collected in a timely fashion. Two thousand Korean style hagfish traps were permitted for each fisher until 1995 when 30 gallon traps with Korean trap funnels were introduced. These new larger traps are allowed to be fished at 500 per fisher. Interest in the use of 45 gallon barrels has been expressed but Scotia Fundy Fisheries (Anonymous 1998) has warned that each change in gear type would translate into an extension of the period of stock assessment. In order to reduce the catch of undersized hagfish a minimum escapement hole size of 9/16" (0.56" or 1.42 cm) was required as of 1999 upon recommendation by the Scotia Fundy Hagfish Working Group after some experimentation. Corrodible metal ring clasps were required for attachment of lids to the barrels in order to prevent ghost fishing of lost traps. The substantial discrepancy between the landing statistics available to Fisheries and Oceans, Canada taken from weekly logbook submissions and the hagfish purchase data provided by a regional buyer in 1995 (643 928 kg) (Table 2) and 1996 (749 052 kg) lead to the enforcement of more stringent reporting and requiring participation in a dockside monitoring program as a condition of licence.

Scotia Fundy Fisheries, Maritimes Region of Fisheries and Oceans Canada has made the following recommendations in the 1998/99 Hagfish Interim Conservation Harvesting Plan. Harvest rates will take place at very low levels, during a prescribed season of 3 months duration. Catch rates (ie., number of fish/trap/hour) would be monitored for several season in order to determine the capacity for sustainability of a fishery and the potential for expansion. Although biological sampling was strongly recommended, industry representatives argued that the industry has too low a profit margin to support an observer program. Although other avenues for biological sampling are being investigated, to date no program has been implemented (T. Hurlbut, pers. comm.). It is thought that if standard trap type remains consistent and catch rates and biological samples can be collected, then an assessment period of three years minimum would be required prior to preparation of a Stock Status Report (Anonymous, 1998).