M.Sc.

Marine Sciences Centre

Michael Brennan

SHORT TITLE

Biology of A. rostrata - Reference to Commercial Fishery

As turning the logs will
make a dull fire burn,
so change of studies a dull brain.

Longfellow - Driftwood

# THE BIOLOGY OF <u>ANGUILLA ROSTRATA</u>, WITH REFERENCE TO THE COMMERCIAL FISHERY

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## ABSTRACT

The feasibility of establishing a commercial eel (*Anguilla rostrata* Le Sueur) fishery on the west coast of Newfoundland is determined and recommendations submitted. Fishing techniques are evaluated and holding and transporting procedures for live eels are described. The largest concentrations of eels were found in brackish water areas. Highly significant differences in fat content and total mercury were found between broad-nosed and sharp-nosed eels. Whether the differences between these two types are genetically or environmentally determined is discussed. Analysis of variance of fat content between five colour types of eels resulted in a significant F value. Bronze eels were found to have a significantly higher fat content than all other colour types. A method of handling, freezing and storing frozen eels designed to achieve and maintain a high quality frozen product, is described. A smoking technique is described that produces a smoked eel product acceptable to most European tastes.

M.Sc. Marine Sciences Centre

Michael Brennan

La Biologie d'*Anguilla rostrata* et sa Pêche Commerciale


RESUME

On a étudié les possibilités de la pêche commerciale à l'anguille (*Anguilla rostrata* Le Sueur)sur la côte ouest de Terre Neuve; et on a soumis certaines recommandations. Les techniques de pêche sont évaluées et les moyens de conservation et de transport des anguilles vivantes sont décrits. Les plus grandes concentrations d'anguille se trouvent dans les régions d'eau saumâtre.

On a trouvé des différences très significatives dans le taux de graisse et le mercure total entre les anguilles à museau large et celles à museau effilé: on se demande si ces différences sont dues à des causes génétiques ou écologiques. On mesura la variabilité du taux de graisse chez des anguilles de 5 types de couleurs; les résultats obtenus donnèrent une valeur F significative. Les anguilles bronzées ont un taux de graisse beaucoup plus élevé que les autres.

On a décrit une methode de traitement, de congélation et de stockage des anguilles congelées en vue d'obtenu et de conserver un produit de haute qualité. On a décrit également un procédé de fumage, qui donne des anguilles fumées au goût de la plupart des européens.

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## I PURPOSE OF STUDY

The project was conceived by the author and fellow graduate student, Dean McKenzie. The aim was to determine the feasibility of establishing a commercial eel fishery on the west coast of Newfoundland. Stephenville was selected as a base of operation because of available processing facilities and ready access to road, water and air transportation. An eel fishery had already been established with a 1972 catch exceeding 32 600 kg. The vast majority of this catch was not however processed in the area, but trucked live to New Brunswick. Economically and logistically Stephenville was considered a prime area to establish a processing facility that could export live, frozen and fresh smoked eels to the ready market in Europe.

The prime fishing areas had to be determined and the various fishing techniques and gear evaluated. Procedures for holding large quantities of live eels had to be considered and sorting and freezing techniques developed to produce the most economical top quality frozen eel. Testing various containers for shipments of live eels was undertaken and experimentation with smoking recipes and techniques carried out to produce a smoked eel product acceptable to the European market.

Biological data pertinent to a commercial fishery were collected and analysed to assess the area's potential yearly production of immature and mature eels as well as a comparative assessment of their market quality.

## II HISTORICAL INTRODUCTION

Throughout recorded history, the eel has been a culinary delight to man and an enigma to many of the scientists who speculated upon the mysterious method of eel reproduction.

Aristotle, some 350 years before Christ, contended that eels were born from earthworms, Lumbricus terrestris, which, in turn, were produced spontaneously from mud and soil. About 400 years later, the Roman scholar Pliny the Elder expressed the belief that young eels were produced from fragments rubbed off by the adults against the rocks. In 1555, Rondelet maintained that young eels were produced from putrified matter and also by eggs produced by the copulation of the male and female. Marcello Malpighi ( 1628 - 1694 ) failed to identify the ovaries of eels correctly, believing them to be deposits of fat. Many observers, seeing "young eels" inside the adults expressed belief in their viviparity. Some of the more imaginative explanations were reproduction from dew, and spontaneous generation from horse hairs that had fallen in water while the horses were drinking.

Francisco Redi, in 1684, refuted the theory that eels were born from decaying matter and also showed the "young eels" to be intestinal worms. He firmly contended that eels reproduced by the spawning of eggs. Christian Frary Paulleni agreed with Redi but neither had observed the eggs or sperm within the eels.

It was not until 1777 that the ovary was correctly identified by Carlo Mundini, professor of anatomy at the University of Bologna.

Some 96 years elapsed before the spermatic organs of the eels were described by Syrski, Director of the Museum of Natural Science at Trieste and professor of the University of Lemburg.

The confirmation that eels were oviparous led to speculation on where they breed. It had long before been recognized that in the fall of the year adult eels migrate downstream and in the spring great numbers of tiny eels (6 - 7 cm) appear in coastal waters and begin swimming upstream into the fresh water. Smaller eels had never been seen. In 1896, Grassi and Calandruccio reported that after keeping alive a specimen of the peculiar ribbon-like fish described by Kaup in 1856 as Leptocephalus brevirostris, it changed into a young eel. They concluded that this Leptocephalus was the larva of the European eel. Since young larvae had never been found inshore, they stated that the eel must spawn at great depths, where the leptocephali live and develop.

Professor Johannes Schmidt first caught specimens of Leptocephalus in 1904 while fishing for cod-fry to the west of the Faeroes. Schmidt speculated that the source of supply of these larvae, the breeding place of A. anguilla, was further to the west. Because of the importance of the commercial freshwater eel fishery to Denmark, and because fears of overfishing the eel stocks existed, the International Commission for the Exploration of the Sea fully supported and encouraged Schmidt's investigation.

After 20 years of extensive observations, Schmidt's 1925 publication, "The Breeding Places of the Eel", appeared, the first thorough systematic scientific paper on eel breeding. Schmidt separated the larvae of the European eel ( A. anguilla L. ) from the American eel ( A. rostrata Le Sueur ) on the basis of the numbers of vertebrae, and proposed separate breeding locations in the Sargasso Sea. He stated that, "In the case of the American eel, the pelagic stage is terminated in about one year; consequently the larvae have not time to make the journey to Europe, the distance being more than they can cover in that period. It is otherwise with the European eel, which takes nearly three times as long over the larval development, as a result of which practically all A. anguilla larvae are far away from the western (American) portion of the Atlantic when the time comes for them, as elvers, to seek the coasts.

"We can thus indicate both a geographical and an ethological cause for distribution of these two species of freshwater eels. The former lies in the fact that A. rostrata has its centre of production somewhat further west and south than A. anguilla. The latter is the different duration of the pelagic migratory stage. These two facts, in conjunction with the ocean currents as an aid to transport, and later - once the earliest stages of development are passed - the active movements of the larvae themselves, must be regarded as the causes which lead the two Atlantic species of eels to find each its own side of the ocean, despite the close proximity of the breeding grounds."

Schmidt's conclusions were not disputed until Tucker (1959a) published his article on "A New Solution to the Atlantic Eel Problem". Schmidt's assumption that the European eel ( A. anguilla ) returns to the Sargasso Sea is rejected by Tucker ( p.496 ) and he proposes: "That the European eel need not and do not succeed in returning to the ancestral spawning ground area, but perish in their own continental waters; 2) That the American and European eels are not distinct species, but merely eco-phenotypes of A. anguilla, their apparent distinguishing characters being environmentally determined ( in the manner of numerous precedents ) by demonstrable differences in the temperature conditions encountered during the ascent from different parts of the American eel's spawning area to the surface, and their distribution by demonstrable co-incident differences in the subsequent transport of the surface-water masses; 3) That the populations of the so-called 'European' eels, A. anguilla, are therefore maintained by reinforcements of larvae of American A. rostrata 'parentage'."

Bruun (1963) pointed out that Tucker founded his hypothesis on only part of the existing literature without any new observations of any kind.

Tucker cites the difference in the number of vertebrae as the only distinguishing morphological difference between the two species. Schmidt made a much more thorough study of the taxonomy of the genus Anguilla Shaw using numerous morphological characters to show consistent differences between A. anguilla and A. rostrata. These data were brought together in a monograph by Ege (1939) after Schmidt's death.

In stating his belief that A. anguilla is unable to migrate to the spawning area, Tucker overlooks the population of A. anguilla in the Azores ( Schmidt 1909 ). The migratory distance that the eels from the Azores would have to cover is roughly 2000 miles, or approximately the same distance that A. rostrata from Canada must cover.

Tucker states (1959a, p. 496) that "Differences between morphological and physiological states of the European and American eels on their descent to the sea are remarkable in a context quite apart from taxonomy. The European eel is already well advanced towards being a reproductive oceanic fish, and this despite the long journey which supposedly lies before it. The American eel, with a much smaller distance/time to go, is yet relatively retarded. The two conditions are the reverse of what any reasonable consideration of adaptive characters and natural selection would predict."

In support of this, Tucker, citing only Vladykov (1955), claims that the American eel is, on the average, larger and four times heavier than the European eel, although he considered it more retarded.

To make the statement quoted above, Tucker must have used Vladykov's data for adult females ( by far the larger of the sexes ) from the province of Quebec (where the largest eels in North America are caught). Tucker's choice of comparative data (Vladykov (1955) ), was from an atypical population and not valid for comparison. Bruun (1963), on the other hand, uses more typical populations of _A. rostrata_ resulting in a close similarity of sizes between the European and American eel.

In the European eel, there are marked changes that occur during the transformation of older yellow eels to silver eels, besides the noticeable change in coloration. These include a thickening of the skin, accumulation of fat, reduction in the production of mucus, enlargement of the eye, alteration of body flexibility and locomotion behaviour, pointing and narrowing of the pectoral fins, development of the gonads, increased endocrine activity, cessation of food consumption, reduction of the digestive tract, increased numbers of chloride cells in the gills and changes in osmoregulatory capacity (D'Ancona, 1960).

This transformation has not been studied extensively for the American eel. Similar changes probably occur in A. rostrata although the parallel is not exact. The most noticeable difference between the two species is in coloration of the migrating adults. The American eel does not show the same degree of macrophthalmia and displays a bronze rather than silver ( A. anguilla ) hue (Vladykov, 1955). He has suggested that a more apt term for migrating adult (A. rostrata)eels would be "bronze eels". Nevertheless it should not be considered that only the bronze coloration occurs in A. rostrata. I have observed numerous male and female silver adult migrating eels ( A. rostrata ) caught on the west coast of Newfoundland and female silver eels from the province of Quebec. The bronze coloration is however, predominant (82% of the migrating eels sampled from the south-west coast of Newfoundland).

Vladykov (1955) assumes that the bronze eel stage in North America corresponds to that of the European silver eel. A bronzy-black coloration has occasionally been observed in the migrating European eel (A. anguilla) but it is rare compared to the silver migrant (D'Ancona, 1959). As stated above this situation is the reverse for the American eel (A. rostrata), the bronze coloration being dominant. Bruun (1963) stated that after having examined ten live bronze eels from Canada, the egg diameters ranged from 0.20 to 0.35 mm while those of the European silver eels very rarely exceed 0.20 mm. Bruun concluded: "that they ( the bronze eels from Canada ) are certainly more advanced than the European silver eel".

Comparing the fat content of silver and bronze eels from Newfoundland, I found bronze eels to have a significantly higher mean fat content (15.9 vs 12.1 %), ( see section on Fat Content below). McCance (1944) found the fat content of silver European eels ( A. anguilla ) to be 26 - 30%, considerably higher than bronze eels ( A. rostrata ) from Newfoundland. It is reasonable that the migrating European eels would require more stored energy to complete the longer migration. These facts add support to Bruun's (1963) belief that the bronze North American eel is more reproductively advanced than the silver European eel. This contradicts one of Tucker's key points in his theory, that the silver European eel is the more reproductively advanced, and therefore less likely to survive the longer migration.

It is my opinion that the differences in egg diameter and fat content, already cited, lead one to conclude that the silver European eel is not as advanced reproductively as the bronze American eel and that this physiological difference would increase its chance of returning to the Sargasso spawning area.

Criticisms of Tucker's hypothesis were published by D'Ancona (1959), Jones (1959), Deelder (1960) and by Bruun (1963), who submitted the most thorough and best substantiated objection. Tucker replied to his first three critics in subsequent publications (1959b, c, 1960). Although Tucker's "New Solution" is not generally accepted, he did show that many of Schmidt's assumptions concerning the spawning areas were based on circumstantial evidence rather than proven facts ( Vladykov 1966 ).

Nevertheless Schmidt's conclusions appear to be preferable to the Tucker view.

Vladykov (1966) raises no objection to Schmidt's findings on the duration of the larval stages, on distribution, on migration of A. anguilla leptocephali nor to his outline of the presumed spawning area of A. anguilla, but he questions Schmidt's proposed spawning area of A. rostrata. The presence of adult A. rostrata as far south as Trinidad and the Guianas make it difficult to imagine how leptocephali could reach this southern area from the spawning area proposed by Schmidt. The likelihood that leptocephali can cover 900 miles in a southerly direction and cross the South American equatorial current is remote. Vladykov (1964) therefore suggests that the true spawning place for A. rostrata is much further to the South (5°N) than Schmidt had suggested.

The fresh water part of the life cycle of the European eel, A. anguilla, is well documented, mainly because of the importance of the commercial eel fishery. Although the American eel, A. rostrata, is widely distributed, its commercial importance is minor and the details of its biology have been little studied. Useful information on the biology of the American eel can be obtained in Bigelow and Schroeder (1953), Smith and Saunders (1955), Bertin (1956), Wise (1959), D'Ancona (1960) and Eales (1968).

Whether A. rostrata spawns where Schmidt (1925) suggests, or further south as suggested by Vladykov (1964), spawning is generally believed to occur in midwater at a depth of about 400 m. Eales (1968) suggests that females can produce up to 15 - 20 million eggs of about 1 mm diameter. After fertilization the eggs develop into transparent ribbonshaped leptocephali with small pointed heads and long teeth. These leptocephali are very weak swimmers and are carried passively by the ocean currents towards the coast of North America. After about a year of planktonic life, they reach 6.35 - 7.0 mm ( 2.5 - 2.75 inches ) in length, at which time they arrive at the edge of the continental shelf. The slow metamorphosis to the glass eel begins during the early winter months. Glass eels resemble a non-pigmented small eel. As the glass eels approach the littoral regions, pigmentation develops. At this stage they are called elvers.

The elvers either migrate upstream or populate estuarine areas (tidal marshes, brackish-water ponds, harbours, areas behind barrier beaches) or live in the vicinity of eelgrass ( Zostera ) (Bigelow and Schroeder 1953 ). This migration occurs at different times depending on the area. I noted the beginning of the elver migration during the first week of June along the south-west coast of Newfoundland, in the Stephenville area. Most of the elvers entered during the first three weeks of June.

Generally eels tend to prefer shallow warm water lakes to cold water lakes or streams. Standing crops of eels in Maritime lakes are extremely variable. Smith and Saunders (1955) reported estimates of standing crops of eight Maritime lakes varied from 0 to 70.8 pounds per acre ( 79.3 kg/hectare ).

Miles (1968) showed in laboratory experiments that elvers displayed a stronger positive rheotaxis to freshwater than to salt water, and the attractiveness to various types of stream water was found to differ greatly. The attractiveness of the fresh water was due to dissolved and particulate organic matter, that he found to be bio-degradable, heat stable, and non-volatile. Mile's report that the attractiveness of a water sample increased if adult eels had been placed in the water for a time, and the presence of elvers made it less so, is very interesting. Unfortunately he did not include brackish or salt water samples in the above tests, but it is probable that the attractiveness of brackish and salt water would show similar results. This suggests that elvers may evaluate a variety of "clues" and show a preference when confronted with a choice of water types.

The above findings are insufficient to show that elvers display a homing tendency. Sufficient evidence has been given demonstrating the homing ability of transplanted European eels (Tesch 1967, Deelder and Tesch, 1970). Tesch (1967) tagged and transplanted 1,538 eels from the German Bight in different areas of the southern North Sea during June - August 1966. Five percent of the eels were recaptured, 64% of these captures were made over the home area. Transplanted eels have returned to their home area from as far as 200 kilometers ( Deelder and Tesch, 1970 ).

The homing ability of the American eel (A. rostrata) has been demonstrated by Vladykov, 1971. These transplanted eels were forced to discriminate between the river of release ( Kouchibouguacis ) and the home stream ( Shediac River ) seemingly utilizing a keen olfactory perception.

It should be noted that the Kouchibouguacis River (transplanted area) and the Shediac River (home area) are separated by eight rivers and at least four brooks.

The explanation of how eels transported from their home range to new areas relocate their home water is not very clear. Tesch (1967) speculates that the homing tendency of the eels is probably based on long-term non-genetic adaptation to the environment at the home area, and concludes " the successful re-migrations observed cannot be explained on the basis of the eel's olfactory capacity alone; other sensual abilities such as salinity preferences, sensitivity to light, and magnetic compass-orientation may be involved." It is clear from the above statements that Tesch considers the sensual knowledge of the home area observed in eels to be "learned" from their presence in the home area.

It would be necessary for this sensual knowledge of the home area to be transferred genetically to the egg, to enable elvers to home. In this case the larval distribution would be predestined rather than random. The possibility of this seems remote and it is more likely a case of the leptocephalus larvae arriving randomly in a coastal area and then as elvers selecting, on some unknown basis, one of the available freshwater or brackish water areas which will then become their home area for the duration of the trophic stage.

Vladykov (1966) found that the size of elvers and the number of females in the population increase from south to north. Of six eels examined from southern Greenland (Jenson, 1937) all were found to be females. Gray and Andrews (1970) found 93.7% of the eels they examined from Newfoundland waters to be female.

As the wide distribution of A. rostrata ( 5°N to 62°N ) would indicate, eels seem to readily adapt to a wide range of environment which, as elvers, they find themselves.

During the growth stages of the American eel, there exist several colour phases. Bertin (1956) states that four kinds of pigments, carotenoids, flavones, melanins and guanins, are present in the eel. Eels can display a yellow, green, brown, bronze or silver coloration, or, as is most often the case, a combination of colours. These different manifestations of colour are related to maturity and can be simply grouped, especially for commercial purposes, into the following two categories.

Yellow-stage: Body pigment is dull, does not glisten. Upper parts (above lateral line) are grey, brownish or greenish. Sides (below lateral line) are usually yellowish. The belly portion is dull white or grey and often mottled with yellow. These eels are sexually immature and their whole activity is devoted to feeding.

Silver-bronze stage: A glistening layer exists underneath the skin. This causes the whole body to have a metallic glint or glisten, especially the sides and belly. Upper parts are usually greyish (silver eels) or brownish with a purple sheen (bronze eels). Along the lateral line, dark pigment develops, resembling a black line. The pectoral and caudal fins darken and the diameter of the eye enlarges considerably. The silver-bronze eels are sexually mature and have generally ceased feeding. In the fall they will begin their catadromous migration to the Sargasso Sea. This metamorphosis from yellow (immature) to silver-bronze (mature) entails many other changes which are described for A. anguilla by D'Ancona (1960).

Bertin (1956) describes two characteristic variations in the shape of the head found in the immature yellow-stage of the European eel. These two types, broad-nosed and sharp-nosed eels, also exist in the immature yellow-stage of the American eel, A. rostrata. Recorded here for the first time, the physical differences can be summarized for A. rostrata as follows:

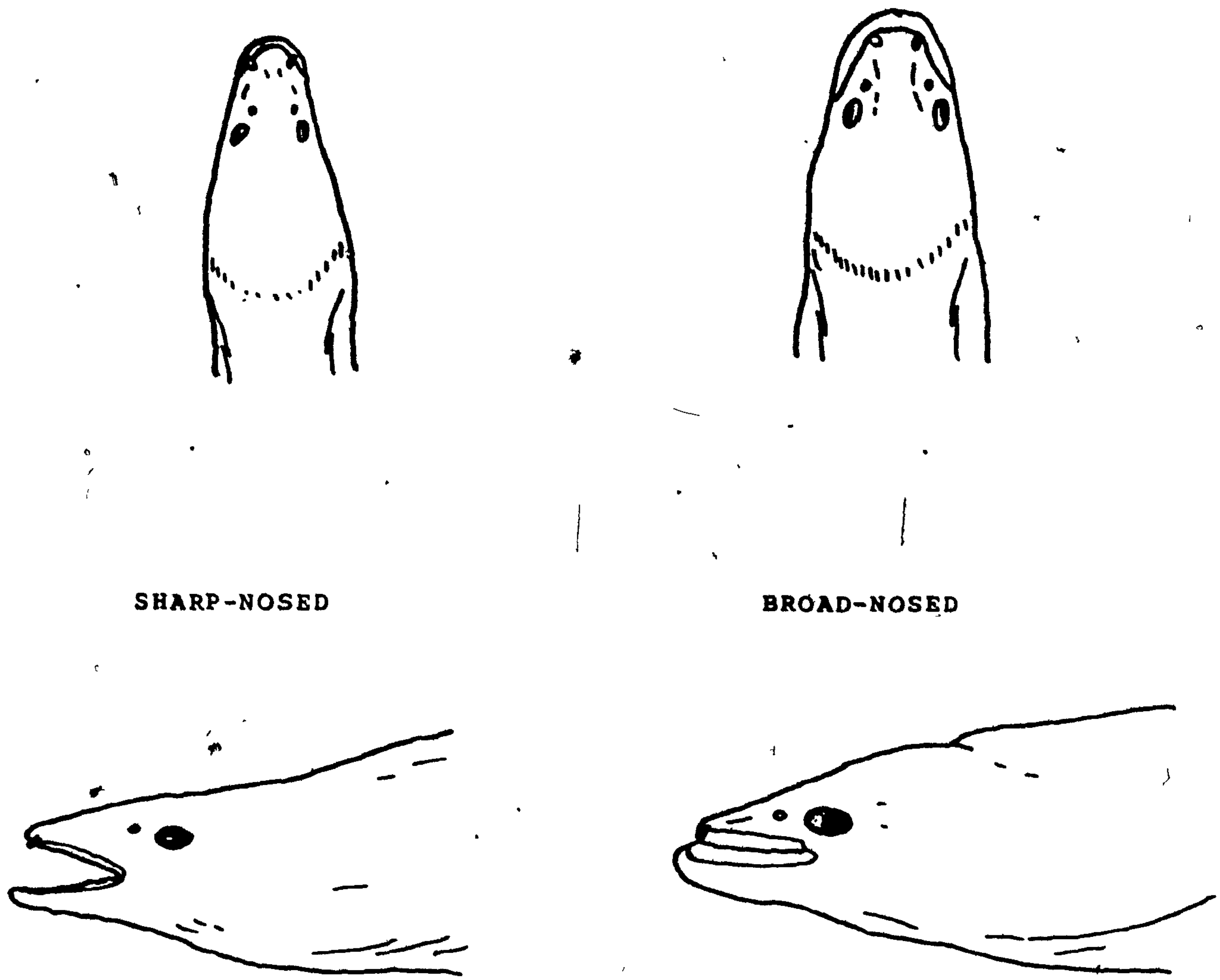
| Broad-nosed | Sharp-nosed |
|---|---|
| 1) short, blunt muzzle | 1) long, narrow muzzle |
| 2) eyes and nostrils wide apart | 2) eyes and nostrils close together |
| 3) pronounced lower lip | 3) small lower lip |
| 4) bump behind eyes | 4) smooth contour of the head |

Physiologically, the broad-nosed eel is distinguished from the sharp-nosed eel by its slower growth and by the larger size it can attain in the course of a longer existence (Bertin 1956). The fat content of the broad-nosed eels from Flat Bay was found to be significantly lower than that of the sharp-nosed eels (see Fat Content).

I have not seen one specimen of a silver or bronze eel ( A.rostrata) with a broad nose, nor have any observations of this been noted in the literature for either A. anguilla (D'Ancona 1960) or A. rostrata. A further discussion of this appears below, (Section V - Fat Content).

Since the details of the growth period of A. rostrata, whether it be in fresh or brackish water, are poorly documented, and since these will probably vary with location, information on this stage will be discussed in "Behavioural Characteristics of the Local Eel Populations", p. 65

Figure 1: Different head configurations of the Sharp-nosed and Broad-nosed members, immature (yellow stage) of <u>Anguilla</u> <u>rostrata</u>.



## III PRESENT EEL FISHERIES AND METHODS

### Introduction

The Europeans have maintained an active eel fishery for hundreds of years. It is natural then that most of the fishing techniques used in Canada are identical to or modifications of the European methods. The fishing techniques are usually conceived to utilize a facet of the eels' behaviour. Eels are captured in commercial quantities as elvers, yellow eels (immature) and as migrating silver or bronze eels. These three stages have distinct behavioral characteristics ( see Section V - Biological Observations ). Fishing for each type requires different fishing gear and techniques.

In Europe, the emphasis is on catching the migrating silver eels and the elvers. In Eastern Canada by comparison, only the Province of Quebec has a fishery geared for the capture of migrating bronze or silver eels. The eel fisheries in the Maritime Provinces are generally poorly organized and less intense, with the majority of the catch being yellow immature eels. There is, however, a well organized basically yellow eel fishery in New Brunswick operated by Rivers and Nolan.

To date there has been no commercial harvest of elvers in Canada (Eales 1968). The Europeans and Japanese have shown sporadic interest in obtaining Canadian elvers. The capture of large quantities of elvers for export is not looked upon favorably by the Provincial and Federal Governments.

Fishing Methods

Descriptions, photographs and drawings of the various fishing gear and techniques appear in Eales (1968).

A summary of fishing methods appears below.

| FISHING GEAR | BEHAVIOUR |
|---|---|
| **ELVERS** | |
| a) purse seins | migrating up stream |
| b) dip nets | (late June and July) |
| **YELLOW EELS** | |
| a) baited pots | |
| b) baited hooks | |
| c) baited traps | |
| d) unbaited traps | - actively feeding in |
| i) fyke nets | lakes, slow moving |
| ii) wing nets | rivers, barachois and |
| e) beam trawling | estuaries (June - Sept.) |
| f) electrofishing | |
| g) spearing | |
| **SILVER OR BRONZE EELS** | |
| a) river weirs | |
| b) hoop nets | actively migrating down |
| c) estuary weirs | streams or out of barachois |
| d) portable traps | or estuarine areas |
| i) St. Lawrence box trap | (Sept. - Nov.) |
| ii) Swedish box trap | |

The provincial governments and the Federal Department of the Environment, Fisheries Service, control the regulations concerning the commercial eel fishery.

In Newfoundland, nets cannot be fished in designated salmon rivers. River weirs, traps and hoop nets could not, therefore, be used in the rivers from Fox Island to Port aux Basques ( Fig. 7 ). A quantitative assessment of the downstream migration of silver or bronze eels was impossible.

Hoop nets were permissible outside the mouths of these rivers. The Fisheries Service set markers to designate the fishing boundaries and controlled the number of nets in each area.

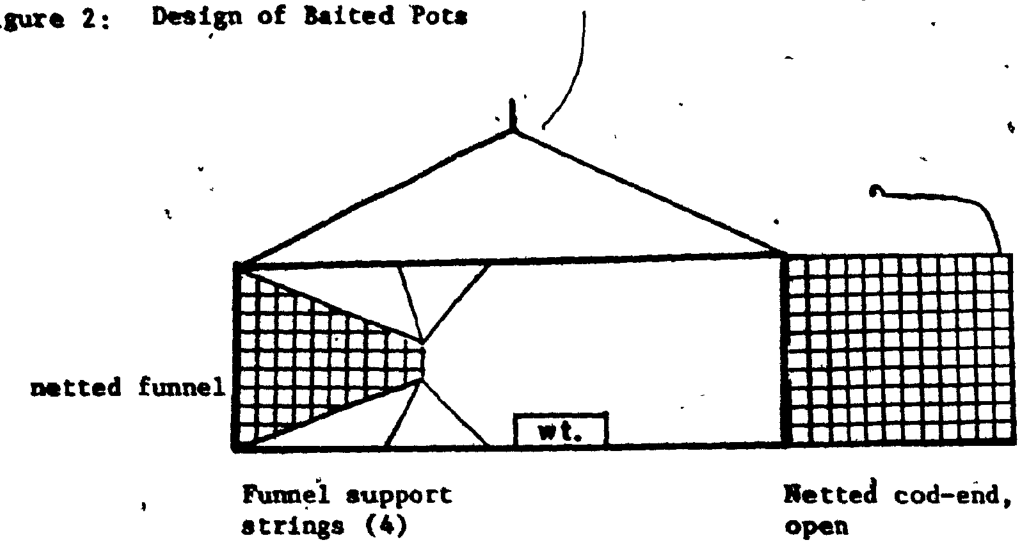
The success of baited eel pots in the Maritimes ( Eales, 1968 ) and specifically in the Grand Bank area of Newfoundland ( Axelson, personal communication ) warranted their use in this project to obtain spring and early summer samples of yellow eels.

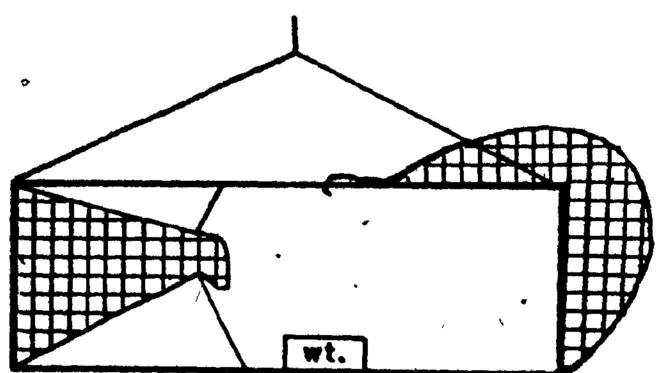
General descriptions of these two fishing methods appear below. For detailed specifications see Design and Materials ( Section IV-A, p. 30 )

Baited Pots

Baited eel pots are used in the Maritime Provinces and occasionally in Quebec. Bait is used to attract the eel to the pot. Entry is via a wide funnel which narrows rapidly to a small orifice and leads the eel to an enclosure containing the bait. The eels enter readily to feed and have difficulty finding the exit. Occasionally, two funnels are used in making the chances of escape more remote.

**Figure 2: Design of Baited Pots**




Funnel with two support strings and "loose-sock" end

Most pots are homemade and extremely variable in design ( Eales,1968 ). Pots are constructed of wood, barrels, baskets, sacks and nets. The choice of design and material is generally due to personal preference, cost and availability of materials.

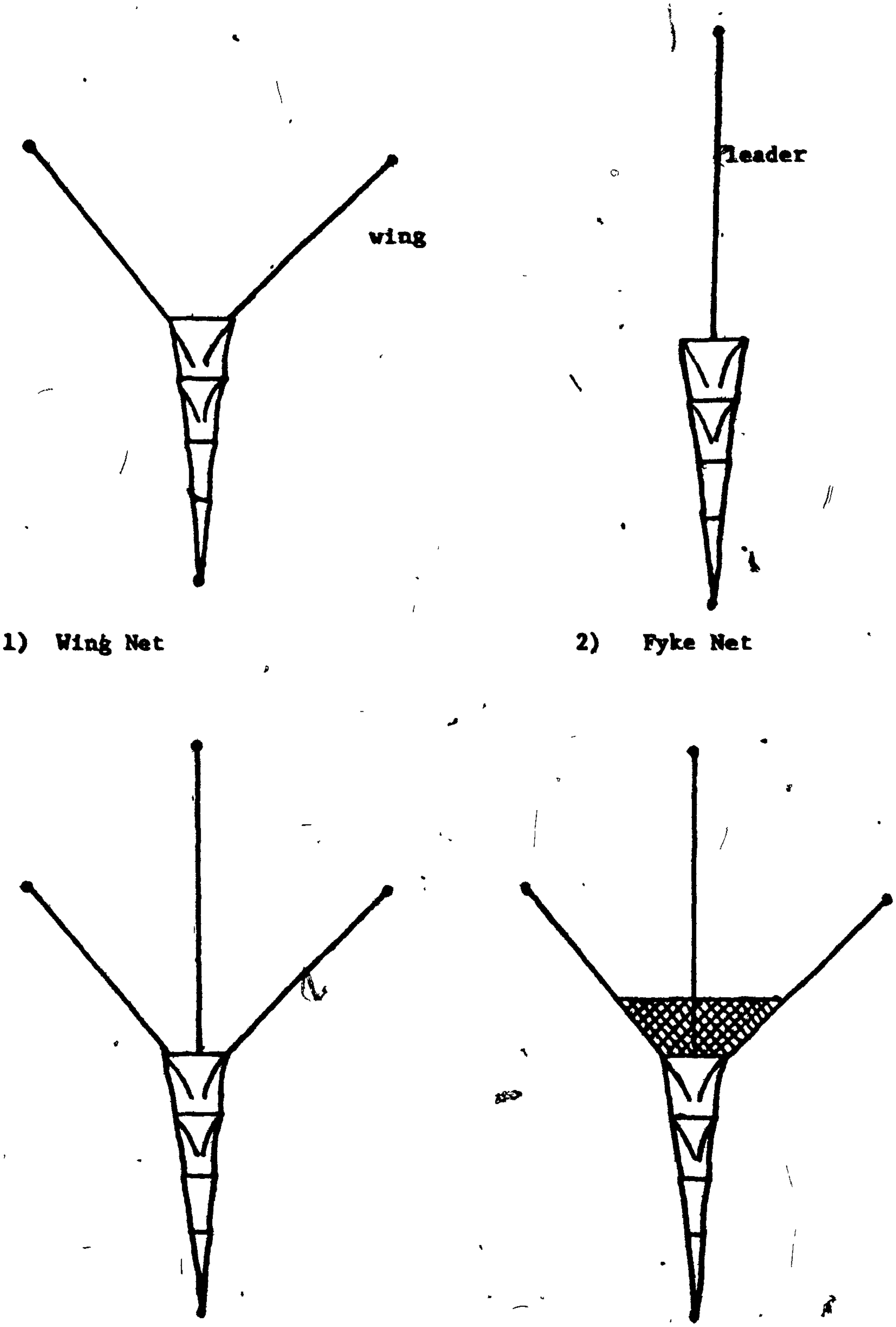
Hoop Nets

Hoop nets are typically, gradually tapering cones with various types of supports and a number of interior funnels made of netting. The lengths and diameters vary considerably. They are made of either one mesh size or decreasing mesh size from mouth to cod end. Hoop nets can be set in "wing" or "fyke", "fyke-wing" and "hooded" styles.

Wing nets usually have wings over 2.44 meters ( 8 feet ) in length which are attached to the primary (first) hoop. They are usually set to form a 90° angle at the mouth ( Figure 3-1 ). A knowledge of the local eel habits is essential in successfully fishing these nets. In estuaries and barachoises the eels tend to run with the tides, usually close to shore. Wing nets are set singly or often in series to guide moving eels into the cones ( Figure 4 ).

Fyke nets have a single leader attached to the primary ring of the hoop net instead of two wings. These are generally set at right angles to the shore, but this may vary with local eel habits and current conditions ( Figure 3-2 ). The leader and hoop nets are held in place by stakes. The leader is weighted to lie snuggly on the bottom. The leader blocks the passage of eels up or down stream. The eels will try to go around the leader and eventually follow the leader to the mouth of the hoop net.

Figure 3: Four designs of hoop nets




1) Wing Net

2) Fyke Net

3) Wing-Fyke Net

4) Hooded Wing-Fyke Net

Figure 4: Wing-nets set in series.

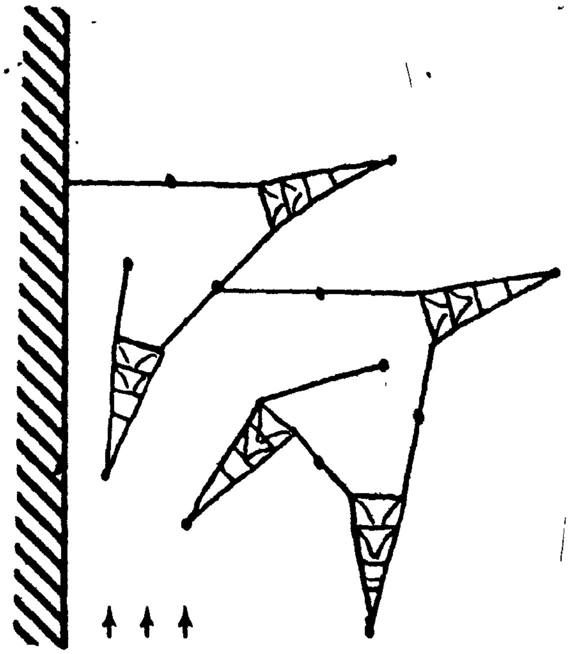
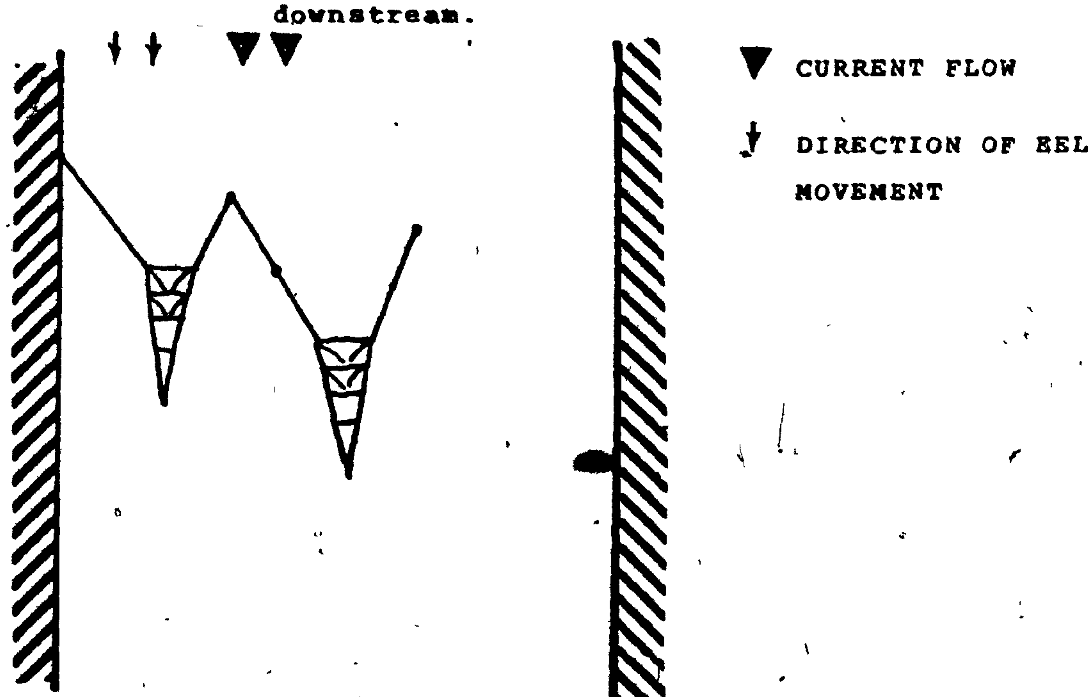


Figure 5 : Wing-nets set to fish eels migrating downstream.



A combination of two wings and a leader is often used to improve fishing efficiency ( Figure 3-3 ). More elaborate hoop nets often have a "hood" of netting attached to the wings and leader on the top and bottom ( Figure 3-4 ). This hood reduces the chance of eels swimming over the top of the hoop net and is useful in deeper water.

EEL MARKETS

A market survey of the major eel importing countries in Europe was undertaken in April 1972 by the Department of Industry, Trade and Commerce, Fisheries and Fish Products Division of Agriculture, Fisheries and Food Products Branch. The information compiled can be obtained from them entitled "Eel Market Analysis 1972". This report was intended to assist the eel industry by evaluating the export market potential, market requirements and preferences and to indicate how Canadian exporters could successfully increase export sales to the major eel consuming countries.

To summarize briefly, the overall world decline in eel landings, especially the high quality Baltic Sea Silver eels coupled with an increasing consumer demand, increased the export potential and price for Canadian eels. Germany, orway, France, Switzerland, The Netherlands, Britain, Sweden, Denmark and Italy are all now potential importers of Canadian eels. In order of national consumption, the eel connoisseurs of Europe are the Germans, Dutch, Danes and Swedes. Japan is the largest producer of eels mainly due to its tremendous output of farmed eels, which accounts for over 85% of its total production. The Japanese, however, are "buyers" and have shown interest in live elvers, young eels and live bronze eels from Canada, but the shipping logistics to Japan from Eastern Canada have caused considerable problems. The fact that the Canadian and European catches peak at roughly the same time reduces the demand for live Canadian eels when the European fishery is at its height. Canadian processors can either freeze a proportion of their catch or hold the catch live until the market demand improves again near the middle of December. Holding large quantities of live eels during the early winter months can, in Canada, however, be rather risky. Over 50% of the European importers that this author contacted requested frozen eels. Some of these European buyers were hesitant to purchase Canadian frozen eels because of previous experience with very poorly frozen eels from some Canadian suppliers ( see Freezing, Introduction ). The European seasonal production peaks require the utilization of frozen eels to assure year-round continuity of eel products. It is felt that the profit potential for the Canadian exporter is approximately equal for both frozen and live eels if they are of consistently high quality.

The potential also exists to export fresh smoked eels and canned smoked eels to Europe. Experimentation would be required to achieve a smoked eel product acceptable to the various European markets.

An eel market analysis, by country, from Anon (1972) appears in Figure 6.

**Figure 6: Summary of Eel Market Analysis 1972 (from Anon 1972)**

| COUNTRY | GERMANY | HOLLAND | ITALY | DENMARK | FRANCE | U.K. | SWEDEN |
|---|---|---|---|---|---|---|---|
| Live Quantity | 5.0 Million | 2.7 Million | 6.6 Million | 3.6 Million | .9 Million | .2 Million | .4 Million |
| Price | Not Stated | 1.05 Brown<br>1.20 Silver | 1.05 Brown<br>1.20 Silver | 1.05 Brown<br>1.20 Silver | .80 Per Lb. | .63 - 1.10<br>Per Lb. | 1.08 - 1.60<br>Per Lb. |
| Size | 1 - 7 Lbs. | ½ - 2 Lbs. | 1 - 7 Lbs. | ¾ - 3 Lbs. | 2 - 3 Lbs. | 1 - 1½ lbs. | All Sizes |
| Season | Cdn. Season | Cdn. Season | Sept to Mar | Cdn. Season | Cdn. Season | Apr - Dec. | All Year |
| Frozen Quantity | 5.0 Million | 4 Million | | .3 Million | .8 Million | .8 Million | .35 Million |
| Price | | .85 Per Lb. | | | | | 1.25 Per Lb. |
| Size | | ½ - 2 Lbs. | | 2½ - 3 Lbs. | 2 - 3 Lbs. | ¼ - ¾ Lb. | All Sizes |
| Season | | Cdn. Season | | | | Apr - Dec | All Year |
| Type Preferred | Silver | Silver | Silver | Silver | Silver | Silver | Silver |
| Remarks | Have no real preference for live eels. Frozen eels are completely acceptable. Majority of consumption is for smoking. | High consumption of smoked eels. Also for export. | Peak Xmas to New Year. Price in Milan Jan/72 was $3.50 per K. | Silver eels for smoking preferred. | Discontinued imports from Canada because suppliers unable to meet commitments. | Silver eels worth as much as .60¢ more per lb. than brown for top quality silver eels. | New Zealand eels inferior to Baltic and Canadian silver but New Zealand prices much lower .66 to .77 per lb. |

## IV METHODS: A. FISHING OPERATION

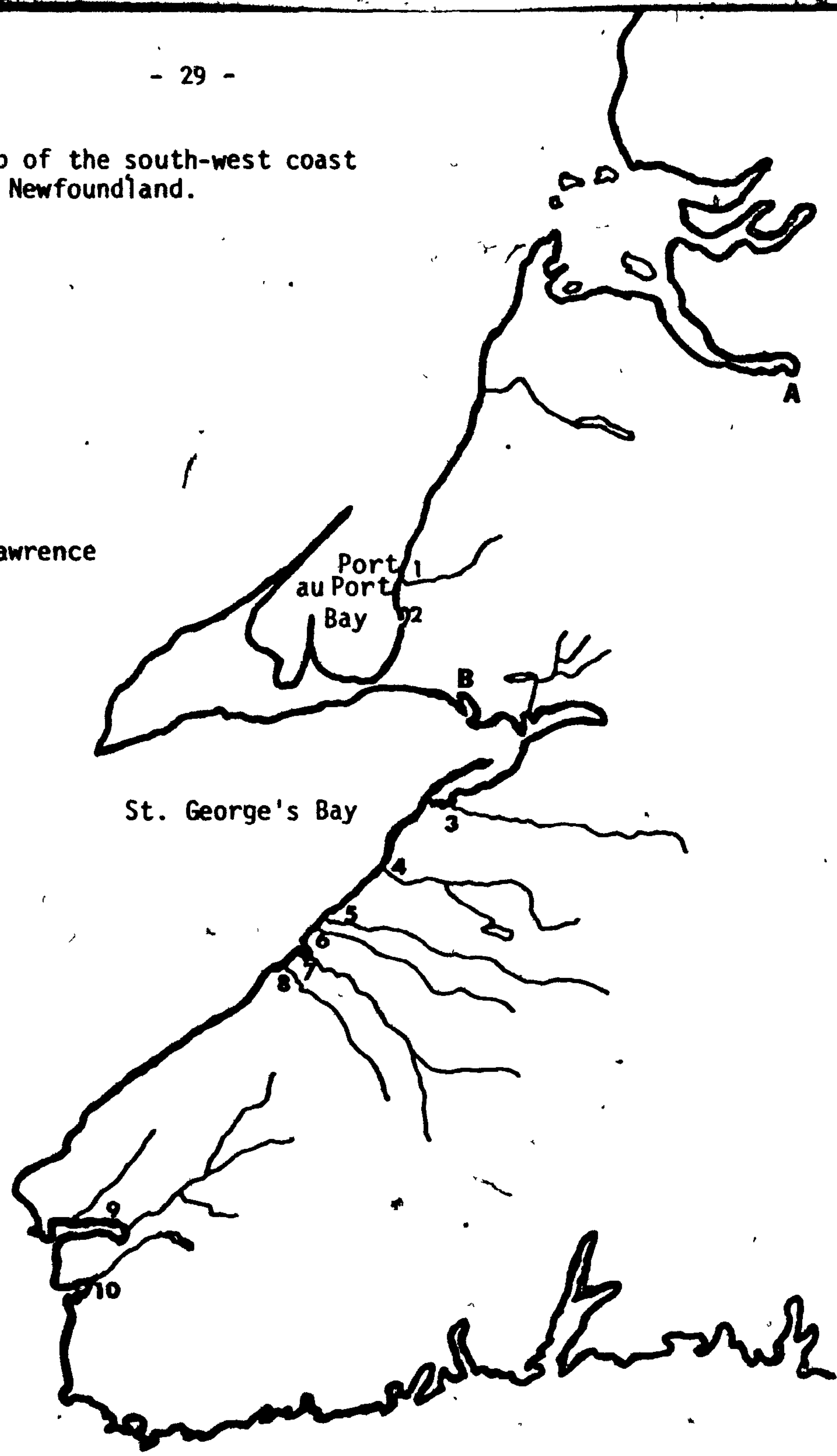
### PRE-OPERATIONAL PROCEDURES

A partnership under the name of Anguilla Enterprises Registered was legally established and registered in March, 1973 in the Province of Quebec. Marketing information was obtained from the Federal Department of Industry, Trade and Commerce. Contacts were made with Canadian fish brokers as well as direct communication with European buyers concerning the marketing of the expected catch. The project was financed jointly by the author and Dean McKenzie.

In Stephenville, freezing and processing facilities were leased from Jan Strangeland (Canada) Limited. All eel fishermen in the area were contacted and arrangements made to purchase their catches. The local Fisheries Inspection Officer, Mr. Jim Cheeseman, was notified of the proposed operations and arrangements finalized to have all stages of the processing inspected. Mr. Ken May, Department of the Environment, Fisheries Service, St. George's, was informed of the company's plans and activities throughout the fishing season. Permission was obtained from Mr. Ben Alexander, Manager of the Harmon Corporation, to use a small pond adjacent to the fish plant, for the storage of live eels.

A Jeep wagoneer was chosen as a work vehicle because of the relatively high load capacity and four wheel drive traction. A 10' x 4' trailer with hydrolastic suspension was used to transport both fishing gear and live eels. A 4.57 meter (15 foot) Gruman aluminum boat equipped with a 10 H. P. Mercury outboard motor was used to rob pots and fyke nets.

Figure 7. Map of the south-west coast of Newfoundland.




A. Cornerbrook
B. Stephenville
1. Fox Island River
2. Two Guts Pond
3. Flat Bay Brook
4. Fischells Brook
5. Robinson's River
6. Barachois Brook
7. Crabbes River
8. Highlands River
9. Grand Codroy River
10. Codroy River

## DESIGN AND MATERIALS

### Baited Pots

Eel pots were constructed of ½ inch (1.27 cm) mesh 16 gauge wire screening. The pots were cylindrical, measuring 36 inches (91.4 mm) in length and 12 - 14 inches (30.5 - 35.6 cm) in diameter (Figure 2). A 2 inch (5 cm) overlap was used to make the wire cylinders and 1 inch (2.54 cm) wire U nails used to crimp the edges together. This gauge of wire screening was chosen because it would hold the cylindrical shape without further supports. The cod end and funnels were made of ½ inch ( 1.27 cm) stretch nylon netting. The cod ends were 18 inches (45.7 cm) long, cylindrical, and equipped with a drawstring closure that looped over the top of the pot and hooked tightly to the wire mesh. The funnels were 15 - 18 inches (38 - 45.7 cm) long, tapering to 2½ inches ( 6.4 cm) in diameter and suspended by nylon cords. Cod ends and funnels were tied securely to the cylinder of wire screening. Marker floats were attached and rock weights tied to the interior of the pots to facilitate handling and storage.

The preliminary fishing trials revealed some flaws in design. Eels were observed escaping, tail first, by spreading the drawstring closure at the cod-end. A half-hitch knot, tied with the drawstring around the cod-end, and hooked tightly, prevented these escapes.

The funnel support strings were also modified. The tapered ends of the funnels were originally supported by four nylon cords attached to the end of the funnel netting and tied tautly to the wire screening. This resulted in a clear entrance and exit to the pot of between 2 and 2.5 inches ( 5 to 6.4 cm) in diameter ( Figure 2 ). The number of supporting cords was reduced to two, which were tied 2 inches ( 5 cm ) back from the end, leaving a "loose sock" effect (Figure 2). It was observed that the eels in the pots tended to stay on or near the bottom. The funnels were re-designed to "pour" into the upper portion of the pot, further reducing the possibility of escape, (Figure 2). The eel fishermen stated that any bulge in the lower part of the funnel reduced fishing efficiency. It is suggested that the eels' poor eyesight ( Bertin 1956 ) causes them to bump the bulge frightening them away. On this advice, care was taken to ensure a smooth surface on the lower portion of the funnel netting.

A comparison of the fishing efficiency of the "original" and "modified" pot designs was undertaken. Twelve pairs of pots were set at twelve locations in Two Guts Pond and fished for seven consecutive nights. The twelve pairs consisted of eight pairs with one pot of each design, and two "control" pairs of each design. The paired pots were set parallel, one meter apart, facing the same direction. Each pot was baited with 1 kilogram of frozen chopped herring.

The "modified" pots outfished the "original" pots by 30 percent during the trial fishing period. Differences in catch within the control pairs of "original" and "modified" pots were 5.4 and 6.6 percent and 11.2 and 7.9 percent, respectively.

A total of 80 pots were constructed at a unit cost (materials and labor) of $4.25.

## Hoop Nets

Two sizes of hoop nets were purchased from J. P. Forgie Limited, Moncton, New Brunswick. The smaller net, #30/18, had a primary ring 30 inches ( 76.2 mm ) in diameter followed by 4 tapered rings with two net funnels suspended inside. The hoop net was 18 feet ( 5.49 m ) long, with 2 6-foot (1.83 m ) wings and a 50-foot (15.24 m) leader extending out from the primary semicircular ring. The netting used for the hoop net was 1 inch (2.54 cm) stretch nylon and the leader and wings 1½ inch ( 3.8 cm) nylon netting.

The larger net #40/22 had a 40-inch (1.02 m) diameter primary semicircular ring followed by 4 tapered rings with two inside funnels. The net was 22 feet ( 6.7 m ) in length and was equipped with an 8-foot (2.44 m) hood and 50-foot ( 15.24 m ) leader. The hoop net was made of 1 inch (2.54 cm ) stretched nylon and the leader 1½ inch ( 3.8 cm ) nylon netting. Both nets were dyed black and treated.

The funnels in these nets were modified to ensure a smooth lower portion ( described above in baited pots ). Five-foot sections (1.5 m) were added to the cod-end of the nets to increase their catch capacity.

## Holding Traps

Two sizes of floating holding traps were constructed. The larger traps, with a volume of 48 cubic feet ( 1.34 $m^3$) measured 4 feet ( 1.2 m) in length, 4 feet (1.2 m) in width and 3 feet ( 0.91 m) deep. The smaller traps had a volume of 24 cubic feet ( 0.67 $m^3$ ) and were 4 feet x 2 feet x 3 feet ( 120 x 61 x 91 cm ). Six traps of both sizes were built. These traps had a frame of 3" x 3"

( 7.6 x 7.6 cm ) lumber with tops and bottoms of ½ inch (1.27 cm) plywood. The top had a hinged 2 feet x 2 feet ( 61 x 61 cm ) trap door with a lock latch. The sides were 1/2 inch ( 1.27 cm ) galvanized 16 gauge screening. These holding traps were placed in locations where water exchange would be greatest. The traps could safely hold a maximum of 700 and 350 pounds ( 317 and 159 kg ) respectively.

SPRING FISHING

Baited eel pots were the only fishing method used in the spring due to a late delivery of the hoop nets. Twenty baited pots were initially set during the last week of May, 1973 in the back of the following locations: Two Guts Pond, Fox Island River, Stephenville Crossing and off St. George's. The pots were hauled daily and baited with 1 kilogram of frozen herring. Fishing depths ranged from 1 to 6 meters. Empty pots were moved daily attempting to determine the areas of highest eel concentrations.

The cod-end closure cord ( see Design and Material p.30 ) was always hooked to a specific row of the wire mesh frame, so any incident of tampering or theft could be recognized. The theft of eels from one-third of the pots set in Stephenville Crossing and St. George's was observed on the 10th of June. Fishing was terminated in the above areas on June 16th after continued theft of eels and pots. Fishing was terminated in Fox Island River on the 27th of June due to insufficient catches. Fishing effort was concentrated in Two Guts Pond until the 14th of July. Five baited pots were set from June 18th - 28th in the following fresh water areas: Noels Pond, Gravels Pond, Gull Pond and three unnamed small ponds east of Noels Pond ( Figure 10 ).

On June 16th, fifty eels of various sizes were weighed and measured and placed in a holding trap in Two Guts Pond. The objective was to obtain estimates of weight loss over several months' starvation. These eels were stolen from the holding trap on the 14th of July along with nine pots. The remaining eels being held in Two Guts Pond were transported to the pond adjacent to the fish plant ( Figure 10 ) and fishing terminated. These eels were subsequently used in the various processing trial runs.

FALL FISHING ACTIVITY

To avoid any conflict of interest with the nine local eel fishermen we participated in the fall fishery as buyers and not as fishermen. Hoop nets and holding traps were loaned to the fishermen. As previously described, this fall fishery was basically catching yellow eels moving into the mud holes to over-winter.

The author and Dean McKenzie attempted to persuade the fishermen to set their nets to catch bronze or silver eels migrating downstream. None of the eel fishermen had seen a silver or bronze eel nor did they really believe they existed. This was understandable due to their lack of knowledge of the life history of the eel and because nets were set to catch yellow eels going upstream. Only the occasional bronze or silver eel would be caught by these nets and would go unnoticed by the fishermen. About fifty bronze and silver eels were caught by chance at Crabbes River. These were held live to show the fishermen the distinguishing differences between bronze or silver and yellow eels.

The importance of fat content was explained and the significance of the fat content data clearly demonstrated by the author to the fishermen.

The fishermen were offered double the price for silver and bronze eels as further incentive, but only one set his net to fish downstream migrating eels. The second night of fishing resulted in approximately 18 kilograms of high quality bronze and silver eels. The next night was the beginning of the large yellow upstream migration and the net was re-set.

The fall fishing began during the middle of August when the fishermen set a few nets to indicate the beginning of the fall run. The three main fishing areas were Grand Codroy River, Crabbes River and Muddy Hole in Flat Bay ( Figures 13, 11, 9 ).

## FISHING RESULTS

### Spring Fishing Results

Few eels were caught until the end of the first week of June. The 20 baited pots set in Two Guts Pond were the first to catch any quantity of eels. Two Guts Pond was the shallowest area fished with a maximum depth of 2.5 meters and an average depth of 1.25 meters. Tidal fluctuations were approximately 45 cm. The bottom was mostly muddy with near shore concentrations of eel grass and other vegetation. Two very small streams fed into the pond ( Figure 8 ).

Coincident with the gradual rise in water temperature eel activity and catches increased. The catch data for Two Guts Pond can be summarized as follows:

The greatest weekly catch averaged 2.3 kg/pot/day. The largest single day catch averaged 3.7 kg/pot. The greatest daily catch by a single pot was 10.12 kilograms. The total catch during

Figure 8: Map of Two Guts Pond

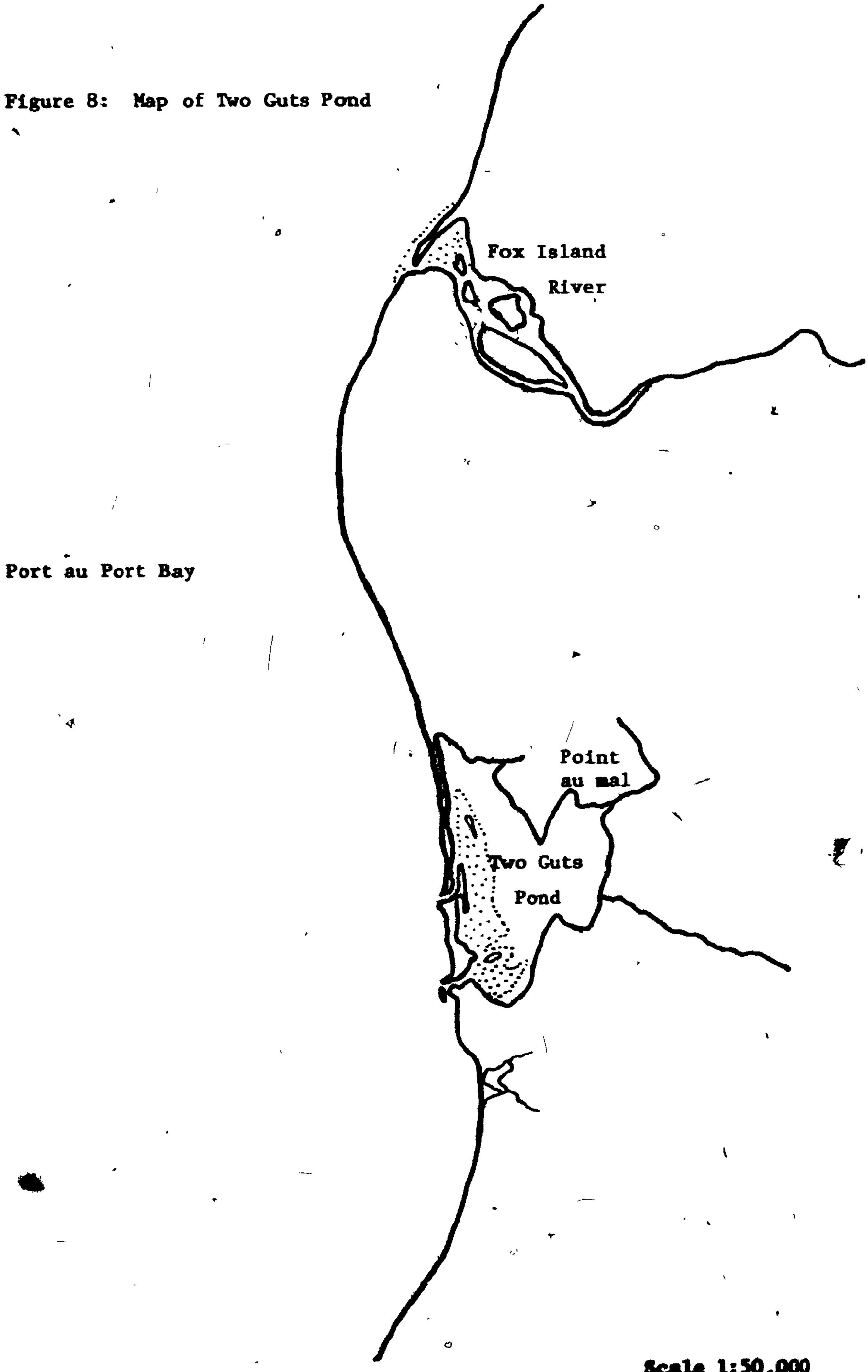


Figure 9. Map of Flat Bay.

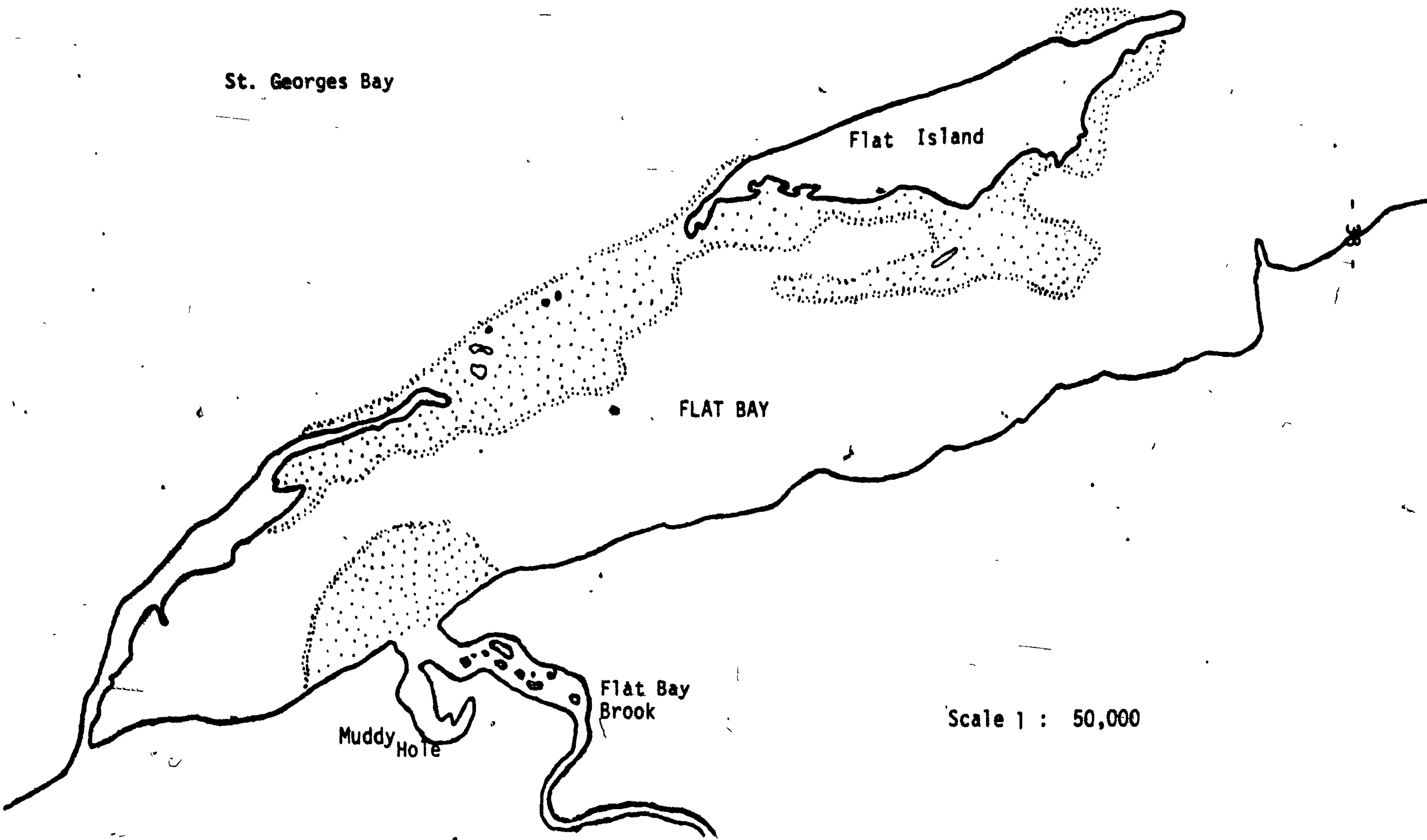
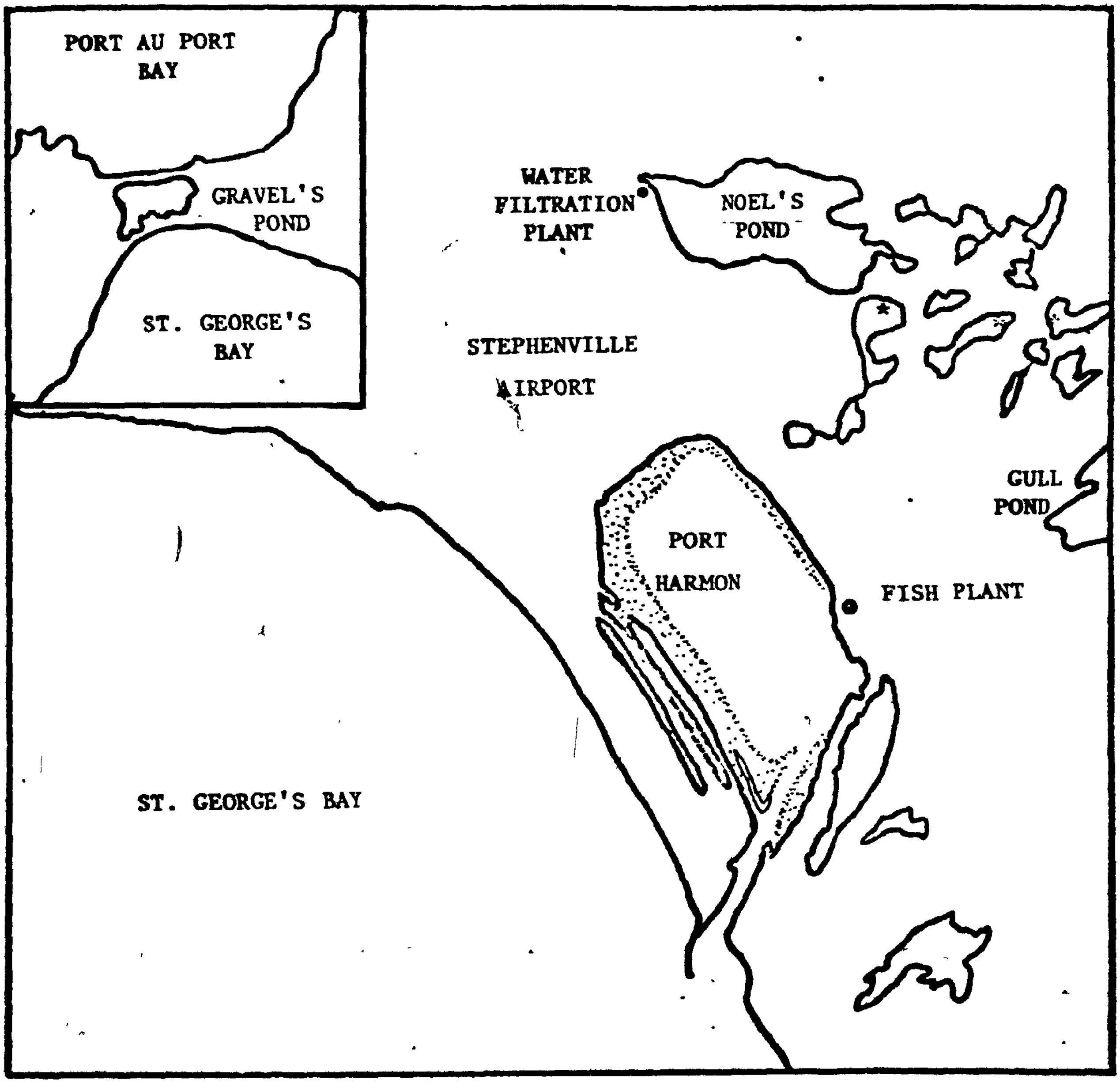


Figure 10: Map of fish plant location and ponds sampled




SCALE: 1:50,000

* Three small ponds east of Noel's Pond

the fishing period was 849.96 kilograms.

Fox Island River produced only 3.9 kilograms of eels during the fishing period. The catch data from Stephenville Crossing and St. George's are not comparable because of the continued incidence of theft and subsequent short fishing period. The total catches in Gull Pond and Noels Pond were 3.4 and 2.6 kilograms, respectively. No eels were caught in Gravels Pond, or the three ponds east of Noels Pond. ( Figure 10 ).

## Fall Fishing Results

The catch data for the fall fishery appear in Table A-13. The first area to produce sizeable catches was Crabbes River (Figure 11). During the last week in August and the first two weeks of September approximately 906 kilograms of eels were caught per week. The catch dropped sharply to 86 kilograms during the third week of September. Fearing the run was over in Crabbes River, the two fishermen moved their nets to Muddy Hole.

The two fishermen fishing Grand Codroy River first set their nets during the last week of August, catching 169 kilograms in three nights. These men were game wardens and because of their work had to stop fishing for two weeks. Five nights of fishing during the third week of September resulted in 164 kilograms. The catch peaked the following week to over 1 630 kilograms and then dropped the first week of October to approximately 272 kilograms. Small catches were made during the second and third weeks of October at the end of which fishing was terminated.

Figure 11: Map of Robinson's River and Crabbes River

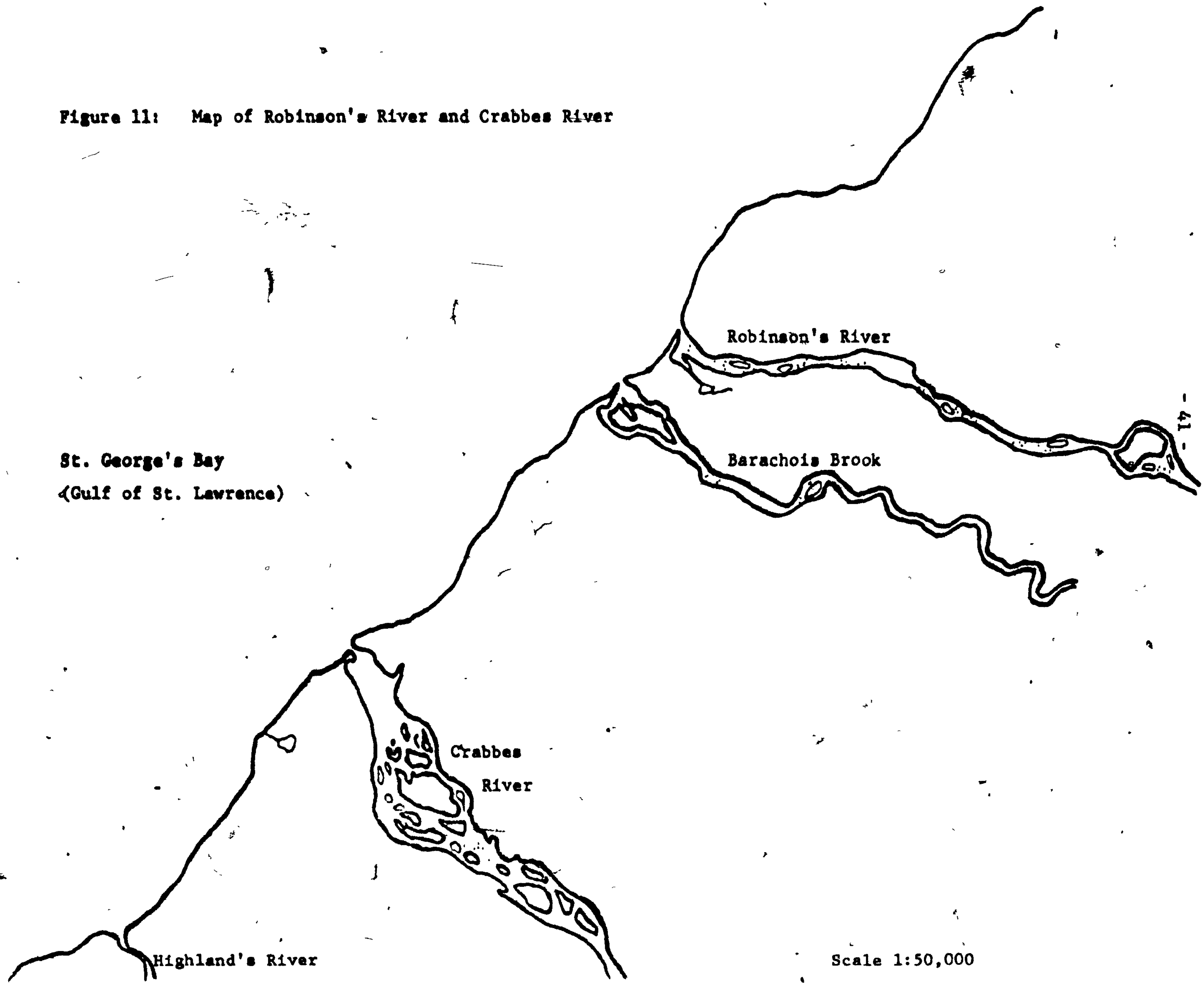


Figure 12: Histogram of weekly catches of eels from the three major fishing areas.

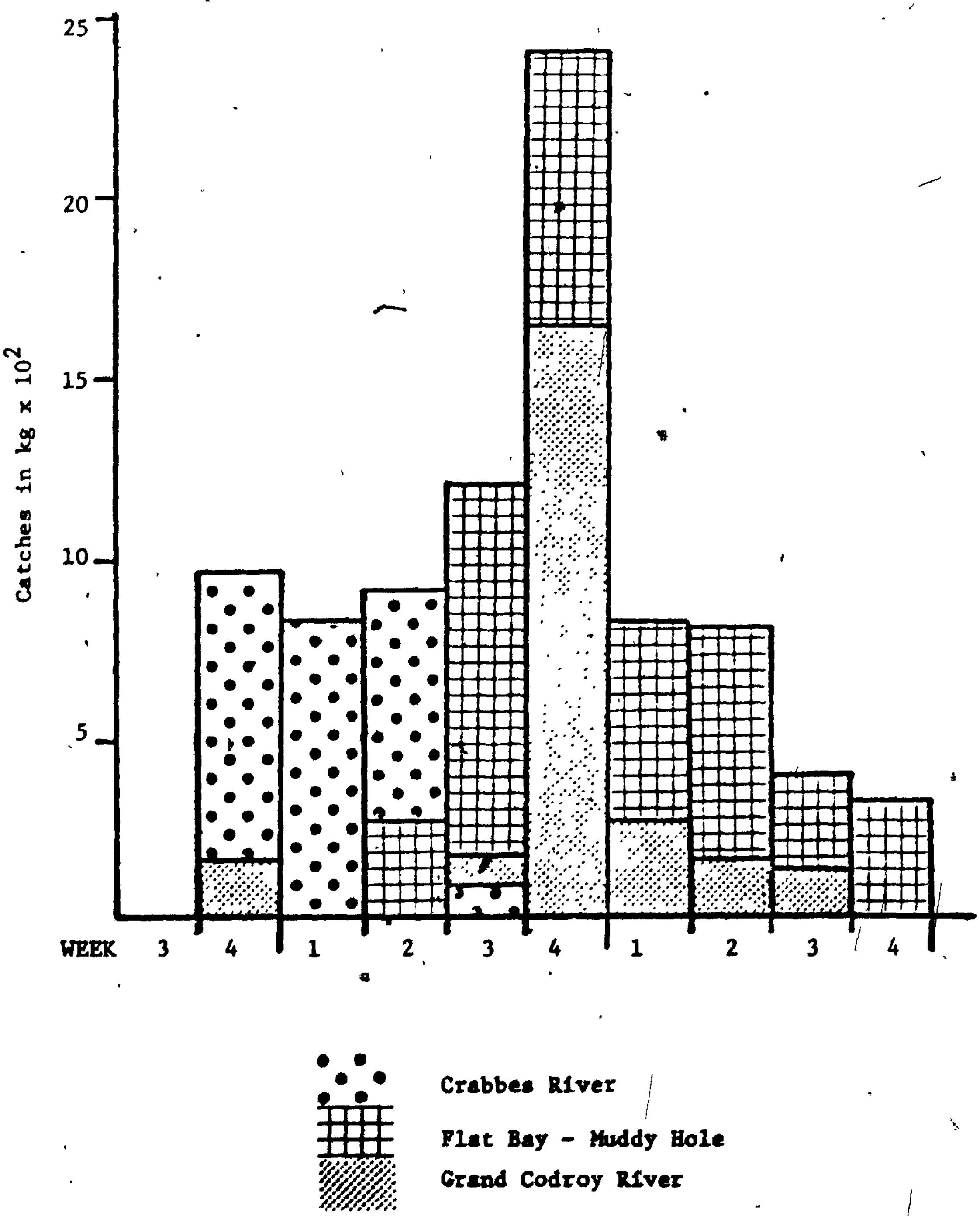
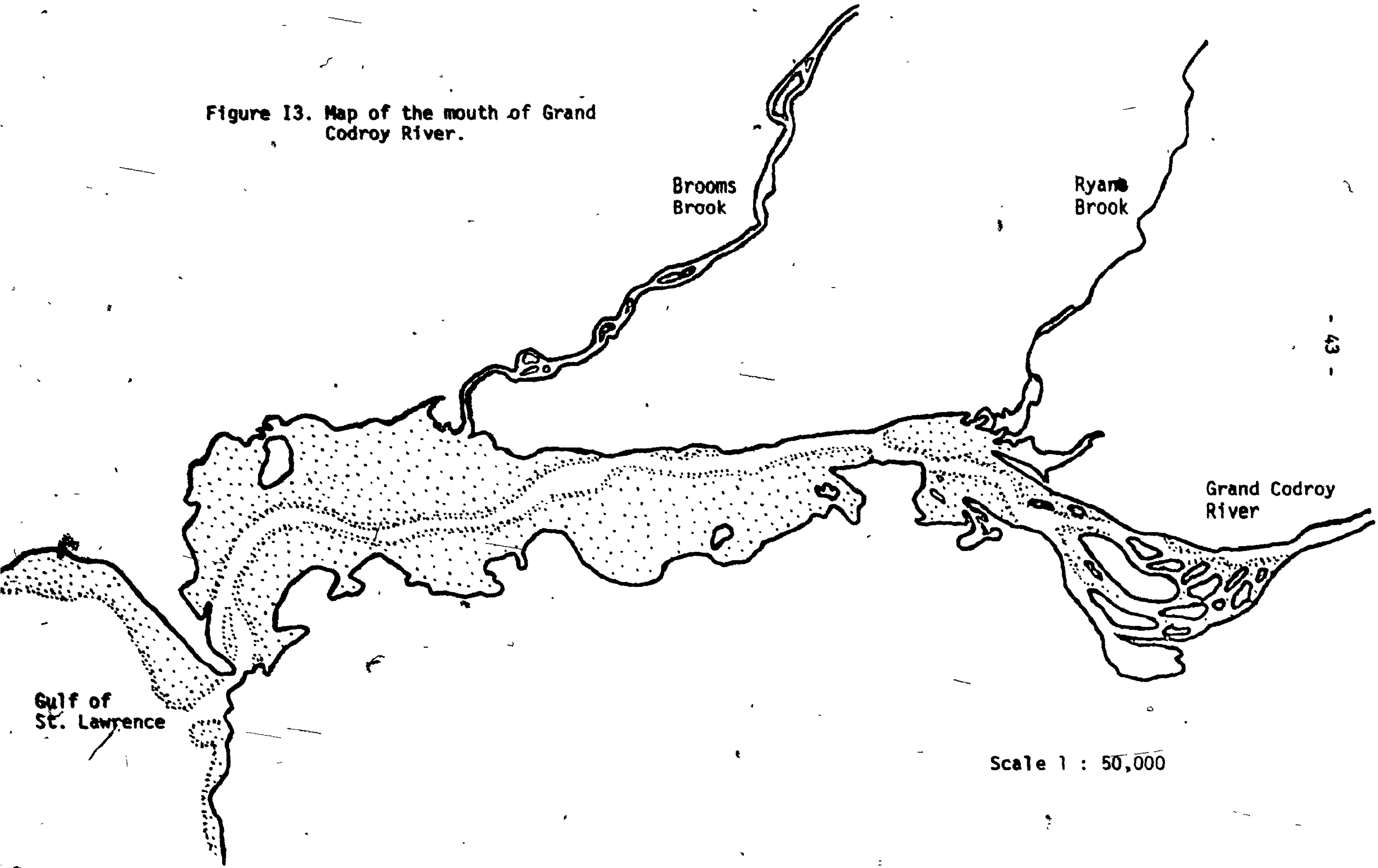


Figure I3. Map of the mouth of Grand Codroy River.



Initially, three fishermen had nets in Muddy Hole. The catch for the second week of September was only 272 kilograms. This figure increased to 1 223 kilograms the following week and peaked the fourth week of September to 2 400 kilograms. During this week there were five fishermen in the small area fishing 31 hoop nets. Fifty nets were fished the first and second weeks of October but the weekly catch fell to approximately 815 kilograms. Fishing was terminated at the end of October when only 317 kilograms were caught.

The fishermen expressed concern over the seemingly higher percentage of small eels ( under 200 gm ) in the 1973 catch. The abundance of small eels and a reduction in large eels is an indication of overfishing and parallels the Dutch situation ( Deelder, 1965 ). The yearly catch statistics for the years 1971 - 72 - 73 were 16 300.0, 22 650.0 and 10 420.0 kilograms, respectively. Fishing effort and intensity increased steadily over these three years.

The data suggests that the area could only support an intense yellow eel fishery for three to four years before being "commercially" fished out. Once this occurs the area must be allowed to replenish itself through natural elver recruitment.

A yellow eel fishery was operated by the Bonavista Cold Storage Company Limited in the Grand Bank area from 1962 - 65. The yearly catches were 16 300.0, 35 790.0 and 2 983.0 kilograms, respectively. No eel fishing was attempted in 1966 because of insufficient eels available in the shallow warm-water barachois to which the fishery was confined. The above data indicate that the Bay St. George eel fishery will follow a similar pattern.

Gray (1971) found the average age of silver eels sampled from Conception Bay to be 12.3 years. His data also suggests that yellow eels between 150 - 200 grams would have an approximate age of 6 years. Any eel smaller than 200 grams would not be of commercial size and would be thrown back. It would therefore require approximately 6 - 7 years for a fished out area to theoretically recover its original eel standing crop.

The data presented seems to indicate strongly that the Flat Bay, St. George's Bay area has already been doomed to this recovery period and the prospects for the eel fishery in the near future would be considered poor.

## HOLDING LIVE EELS

### Introduction

Generally, eels swimming in the wild are of top quality and great care must be taken by the fishermen and processor to keep them in perfect condition.

The fish should be kept in holding tanks for a minimum of 7 to 8 days before attempting to freeze or ship live eels. Eels must have an empty gastrointestinal tract before being frozen. This "swimming" allows the eels to void their stomachs and intestines and reduce the quantity of digestive juices in their system. Eels that are not swum or slowly frozen will have badly stained abdominal cavities due to the stomach digesting itself. This greatly reduces the market quality of the eels. A further advantage of the swimming process is that eels become tame very quickly and this facilitates handling and for live shipments greatly increases the survival rate.

Weak, diseased, or injured eels will usually die during this "swimming period" serving as a preliminary culling before shipment or processing. It is therefore necessary to swim all eels including the silver or bronze migrating eels, which are presumed to have stopped feeding.

Although processors should adhere to this swimming period, it is also advantageous for the fishermen to hold their catch for a few days. Freshly caught eels that are trucked immediately to the fish plant also tend to have a greater mortality rate ( 4% vs 1-2% ) than eels that have been swum for a short period. This can cause a shortage of holding tank space for the fishermen especially during peak landings, but adequate foresight and planning will keep mortality to a minimum.

## Description of Method Used

Four large holding tanks designed to hold catches of herring were available from Jan Strangeland Limited in September and October. The building housing these tanks was 46 meters from the leased cold storage and freezing facilities. These tanks were semicircular steel structures, 18 meters long, 3.5 meters in diameter and sloped to feed into a common cement trough which fed the processing lines with herring. Each tank had a 3-inch (7.6 cm ) diameter fresh water line entering at the back. Large plywood doors were constructed to block the sluice troughs of each tank leading into the concrete trough. These doors were constructed so that the minimum depth at the shallow end was 1.5 meters. Wire screening, 30 cm high at the top of the doors, allowed the overflow to escape into the trough. A 1½ inch (3.8 cm ) diameter hose with a ½ inch (1.27 cm) wire mesh bucket inside of the tank allowed water and debris on the bottom to leave the tanks. This system allowed fresh water entry at the rear of the tanks and removal at both the top and bottom at the front of the tanks. Depending on water pressure fluctuations, total water replacement times varied between one and two hours. Each tank could hold approximately 3 200 kilograms of live eels.

Eels were transported by the fishermen to the fish plant in converted lobster holding boxes. These boxes measured 3' x 1' x 2' ( 91.4 x 30.5 x 61 cm) with ½" (1.27 cm) wire screening at both ends. These were stacked in back of their truck, and wetted down. The holding boxes were then covered with a heavy canvas to reduce drying by wind or sun. If the distance was over 50 kilemeters, the fishermen would stop at a stream and rewet the eels. Upon arrival, the eels were weighed and placed in the cement trough. The cement trough was equipped with a fresh water intake so the eels could be kept there for many hours without danger or stress. The eels were allowed to "rest" a few hours in the trough before being dip netted into the appropriate holding tank.

When the eels had been "swum" for at least seven days, the fresh water intake was turned off and the water level allowed to drop to about 18 inches ( 45.72 cm ). At this water level the doors could be pulled away from the wall of the tank and the eels allowed to flow into the cement trough. They were then dip netted into 1.8 cubic meter aluminum bins and transported by fork lift truck to the processing line.

This holding tank set-up worked quite well, requiring only one man to drain a tank and dip net eels into the aluminum bins as they were needed by the processing line for freezing.

Results

Thirteen percent of the eels died while being "swum" in these tanks. This extremely high figure requires an explanation. The fish plant was supplied with water from the Harmon Filtration Plant. Normally the chlorine content in the water at the fish plant was negligible due to its distance from the water treatment plant. A shortage of chlorine resulted in a considerable reduction in chlorine treatment for a period of two weeks. When the late shipment of chlorine arrived, an excessively large dose was administered to "clear out the system". This caused the death of 1270 kilograms of eels. The dead and sick eels displayed a loss of slime, greying of the skin and severe contraction of body muscles, especially in the abdominal region. Dr. P. Montreuil, of the Montreal Aquarium, confirmed that these symptoms are indicative of chlorine poisoning.

An arrangement had been made with the manager of the water works for notification to be given prior to any increase in chlorine treatment. An alternate salt water system was available to supply water to the tanks but no warning was given, nor was it admitted that this action had been taken until one month after the incident.

Swimming mortality was 1-2% other than this accident. The only other noticeable single cause of death was a minor incidence of "red disease" that occurred during early September. This bacterial disease mainly affects large eels and occurs when water temperatures are 18°C or higher. This disease causes the fins and body to become raw and red and, internally, the instestines, liver and kidneys are affected ( Usui, 1974 ).

TRANSPORTING LIVE EELS

Live eels can be successfully transported long distances by air, land and by sea.

Eels can simply be put in wooden boxes lined with wet sacking or seaweed for short journeys of one to three hours in cool climate.

Ice should be added to keep metabolic activity low, if the travel time is longer ( up to 6 hours ).

In Japan, live eels are sent from the culture ponds at Hamanako to Tokyo and Osaka by truck. The eels are placed in double polyethlene bags with ice and filled with oxygen, then packed in cardboard boxes ( Usui, 1974 ). Packed in this way eels can easily survive for 30 hours.

Tanker trucks are used to carry live eels within Europe and Canada. These trucks were originally designed by the Dutch eel firm of Joh Kuijten of Spaarndam. The most modern trucks weigh 15 000 kilograms empty and carry 15 000 kilograms of live eels swimming in 15 000 kilograms of water. A compressor (with back-up system) supplies air bubbles continuously into each tank, the water serves, more or less, only to keep the eels wet. For long trips the water is replaced every 3 to 4 days. Using this method, trips of 14 days are possible. Holding densities in the tanks vary with the temperature, for example: 485 kg/m$^3$ at 13°C, and 243 kg/m$^3$ at 20°C.

Special barges with perforated sides and bottoms are used (especially in Holland and England) to store and transport live eels (Eales, 1968; Usui, 1974 ). This method is very susceptible to various "pollution kills" and its use has been reduced.

In the early 1960's, live eel shipments to Europe were attempted by boat from Canada but high mortalities occurred. Initial efforts to ship live eels by air in 1969 also met with poor results with mortality rates in some cases 100%. Inadequate containers and the poor handling methods employed were the causes of the high mortality.

Through the efforts of the Department of Industry, Trade and Commerce, eels exporters and a carton manufacturer, a cardboard container, economically priced, was developed to transport live eels by air. Air Canada, realizing the potential freight business, analysed their ground handling and aircraft storage methods to provide the safe handling and carriage of the eel traffic. Through this combination of action, mortality rates in air shipments have been reduced to approximately 1%.

The cartons are oblong, fully telescopic and measure 28" x 12½" x 8" ( 71 x 32 x 20 cm ). The bottom fiberboard section is wax impregnated. For further protection, a 3 mil polyethylene liner is placed inside the bottom section of the carton. These cartons hold approximately 14 kilograms of live eels and 0.5 - 1 kilograms of fresh water crushed ice.

With regular flights to most major European cities, air transportation is now the best means of shipping live eels overseas.

IV.B PROCESSING PROCEDURES

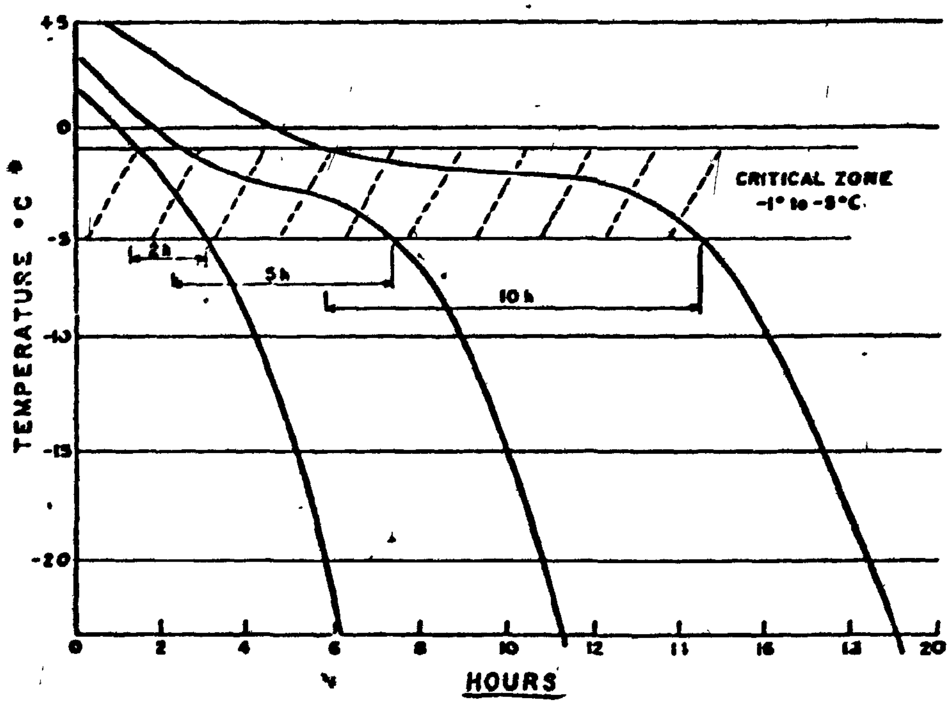
FREEZING EELS

Introduction

The concensus of opinion of scientific investigators is that freezing rates used commercially appear to have little effect on quality, providing they are not unreasonably slow (Dyer, 1971). Investigations by taste testing have found it impossible to distinguish any differences in quality in fish frozen to -5°C in the centre in eight hours or less (Dyer and Dingle, 1961; Fennema and Powrie, 1964; Connell, 1964; Lane, 1964 ; Love, 1966). Greater freezing times than this result in a lowering of quality in texture and appearance due to the formation of larger ice crystals (Dyer, 1971).

The freezing process in fish is gradual because as water is removed as ice, the concentrations of dissolved organic and inorganic salts increases gradually, lowering the freezing point. The "critical freezing zone" occurs when most of the water is frozen and is usually between -1° and -5°C. The length of time to pass through this critical zone varies greatly ( See Figure 14 from Dyer, 1971 ).

Figure 14: Typical freezing curves for fish products (from Dyer, 1971)




*. Typical freezing curves for fish products (centre of pack). The time taken to pass through the critical zone, −1° to −5°C (30° to 23°F) is shown for three rates of freezing.*

Liberation of relatively large amounts of heat when water changes its form to ice crystals causes the slow freezing through the critical zone. Once this is passed, the temperature drops quite speedily in all cases because the sensible heat liberated in cooling the ice once it is formed is comparatively much less.

Rapid freezing causes small crystals to form both inside and between the cells. By comparison, in slow freezing the ice crystallizes first outside the cells and the crystals grow by accretion from the water which diffuses out from the cells. This process causes the cell to be pushed in by the crystals, leaving a mass of dried protein and salt solution in the cell (Dyer, 1971). The degree of damage to the water-holding capacity of the protein determines the degree of re-hydration on thawing. Slow freezing should thus be avoided because of the increased dehydration and subsequent thaw drip. Reay et al (1950) using panel assessment found that little loss of palatability occurred unless freezing time was longer than 4 - 10 hours. For subsequent smoke curing, this investigation found that the time through the critical zone has to be less than 2 to 3 hours for best quality. The smoking quality of eels is thus very sensitive to slow freezing rates and since the majority of the world's eel catches are smoked, this is highly significant to the eel processor.

Eels are frozen by many different methods with varying degrees of quality control in Eastern Canada. The majority of the buyers of Canadian frozen eels request that eels be frozen whole and live. The benefits of this are: 1) minimum surface area exposed to freezer "burn" or dehydration, 2) a thin layer of protective slime is secreted as the eel is frozen, 3) the gutting procedure is easier using thawed vs fresh eels, and 4) the buyers are more assured of a quality (fresh) product.

Processing techniques differ as do freezing rates. Dyer (1971) describes three general categories of freezing rates:

1) slow or sharp - room ( or coils )
2) quick or rapid - plate ( or blast )
3) ultra-rapid - liquid nitrogen, etc.

Live eels are generally first culled (damaged or injured eels discarded), graded (yellow or silver-bronze), weighed, and de-slimed before being frozen. Common freezing methods are: pan, block, plate and stick freezing. The essential difference in these methods (aside from the appearance of the frozen product) is the rate at which the eels are frozen. Freezing is achieved in 20-30 hours when eels are block frozen and in 6-8 hours when pan frozen. Due to these slow freezing rates neither method is suggested, although they are in common use in small fish plants in Eastern Canada.

The stick freezing technique was developed by the Japanese. Eels are killed by electrocution or heavy brine, elongated, blast frozen and glazed. Freezing and thawing times are rapid. Disadvantageous aspects are: 1) damage through tail breakage, 2) easier breaking of the glaze, leaving spots of skin unprotected during storage) and 3) more difficult and bulky packaging requirements. The quality is excellent if the above can be avoided.

Contact plate freezing rates are very short, approximately 2 hours. Live eels are packed in aluminum pans and placed in a contact plate freezer. For complete details of this method see below ( Description of Freezing Method ).

Proper storage of frozen eels is also important. If cold storage temperatures are allowed to fluctuate between -12oC and -30oC, ice crystals can enlarge to the detriment of the frozen fish. This occurs because the small ice crystals formed during quick freezing are more unstable due to a higher surface energy; temperature changes thus cause re-crystallization, increasing crystal size (Kietzmann,1969). Under these conditions an increase in evaporation can also occur. If temperature fluctuations are great, the very rapid heat transfer in the frozen product allows it to warm very quickly to the critical freezing zone (Fennema,1966). If this occurs, deteriorative reactions reach their maximum rate (Dyer,1967).

The fact that eels are a "fatty" fish further dictates proper storage procedures. The rate of fat oxidation is temperature dependent. Although fat oxidation cannot be eliminated at temperatures normally occurring in commercial cold storage facilities (Kietzmann,1971), a constant temperature in the -30 to -40oC range will retard this detrimental process considerably.

Description of Freezing Method

A system of electrically stunning live eels was developed so they could be easily handled for sorting, weighing and packing. After much experimentation with voltage and amperage levels, fresh water versus saline and duration of shock versus duration of effect, the following procedure was developed. A 4' x 3' x 1' ( 122 x 91 x 30 cm) plastic container was filled with fresh water. Two 20 cm long, 9 mm diameter, stainless steel electrodes were placed in diagonal corners. Approximately 12 kilograms of live eels were dip netted from holding bins and placed in the plastic bin, remaining in the dip net. An entering electrical current measuring 440 volts at 2.5 amps was held "on" for 20-30 seconds. The eels remained stunned for 10-20 minutes, depending on their size, the smaller eels recovering more rapidly.

The stunned eels were then de-slimed using high pressure water guns. They were then weighed individually and placed in one of the following weight categories:

1) 230 grams and under
2) 230 grams - 500 grams
3) 500 grams and over

Two Toledo over and under type balances, Model 3021, were used. The eels were then placed, by weight group, in aluminum freezing pans measuring 108 cm long, 25 cm wide and 5 cm deep. These pans were lined with overlapping sheets of 1.5 mil polythene. A minimum net weight of 13 kilograms was placed in each pan. A Stathmos, Type 326, scale was used to weigh the full pans. Cold water was then added to each full pan to provide a glaze and subsequent uniform rectangular frozen block. The polythene sheets were then folded over the eels and the pans placed in an Amero contact plate freezer with a 1400 kilogram capacity. Freezing time was approximately 2 hours at -40°C. The frozen blocks were removed from the freezing pans and two frozen blocks placed in each master carton of corrugated cardboard. The size range and date were stamped on the cartons which were then stapled closed. These master cartons were stored on wooden palettes in the cold storage. The cold storage was a "thermos" design so air currents inside were negligible and the storage temperature kept at -38°C.

Summary

1. The rapid contact freezing technique reduced the probability of freezing damage and resulted in a consistently high quality frozen product.

2. The maintenance of a constant ( $\pm$ 3 °C) cold storage temperature reduced the detrimental effects of temperature fluctuations.

3. The procedure of "topping up" freezing pans with cold water just prior to freezing resulted in the following benefits:
   - I. covered eels with a protective glaze
   - II. resulted in a solid rectangular frozen block with square corners and uniform size, allowing tight packing ( few air spaces ) in the master cartons
   - III. reduced exposed surface area by having flat surfaces
   - IV. acted as a superstructure, reducing the effects of potential rough handling because water inherently freezes harder than the flesh.

4. Benefits of packaging material: polythene sheeting and corrugated cardboard master cartons:

I. prevented blocks from freezing together

II. protected frozen eels from light exposure, thereby preventing photochemical oxidation

III. reduced possible evaporation and dehydration

IV. left no surface of the frozen block directly exposed to air and possible gas vapour precipitation ( example: ammonia )

V. protected the surface from damage

VI. provided a surface for proper labelling of the information required for quality control.

SMOKING EELS

Introduction

The vast majority of the world's catch of eels is eaten smoked. Smoking techniques and national ( as well as regional ) preferences, such as type of smoke, texture and fatness differ greatly. For example, Joh Kuijten, the founder of the famous eel firm Joh Kuijten of Spaarndam, Holland, referring to smoked eel eating habits, describes the Dutch as "suckers" and the Germans as "biters". When a Dutchman eats a smoked eel he like to feel the oil trickling out the corners of his mouth and down his chin, while the German like to bite into something big and solid. A brief summary by country of the preferences from Anon (1972) appears in Figure 6. The silver European eel is considered best for smoking because of its high fat content.

There is a slight demand for smoked eels in Canada, usually where higher densities of European immigrants (German, Italian, Latvian and French) are located. The largest such area is Toronto, where it is estimated at least 68 000 kilograms of Canadian-caught and Canadian-smoked eels are consumed annually. Small amounts are smoked in Montreal and approximately 4 500 kilograms are smoked and consumed in Halifax and Vancouver. The author knows of no Canadian smoked eels that are exported to Europe.

The difference in price between frozen eels and smoked eels is enormous. For example, good quality smoked silver eels were retailing for $18 - $22 per kilogram in Hamburg in the fall of 1973. The Germans were buying frozen Canadian eels for approximately $1.30 to $2.20/kg at this time. The economic possibilities of smoking eels in Canada for export to Europe as fresh smoked or canned smoked eels is very promising. Export possibilities for these products also exist in the United States, especially to cities like New York where there are large European populations.

It is felt that a Canadian processor could under-sell European competition because of the following:

1) lower raw fish cost
(Canadian eel fishermen receive between $0.44 - $1.10/kg, while German and Danish fishermen receive $1.85 - $2.90/kg (1973 figures).
2) lower labor costs
3) reduction in the number of "middle men", thereby increasing profit margin
4) if Canada's rate of inflation remains lower than that of most of the European countries this will further widen the price advantage of Canadian export products.

Benefits to Canadian Eel Fishermen and Processors

1. More consistent year-round utilization of labour force.
   This is very significant in the Maritime Provinces, especially in Newfoundland, where there exists extremely high winter unemployment of small, independent fishermen. These men could be givem jobs as cutters, packers and general labourers.
2. Better year-round utilization of processing facilities.
3. Advantage of selling products when the market demand and price are greatest in Europe (December through to early summer).

4. Reduced shipping costs (roughly 40% due to weight lost in gutting and smoking).
5. Increase in market possibilities ( Canada, U. S., Europe and Japan ).

Processing Procedures for Smoking Eels

The following smoking procedure was developed by this author and Dean McKenzie. Twenty-six trial runs were conducted, using in excess of 1360 kilograms of eels.

1. De-sliming

A. Live eels

a) stun eels electrically

b) de-slime with high pressure water guns ( cold water )

c) wipe clean with coarse towels

B. Frozen eels

a) thaw frozen blocks with cold water spray

b) de-slime with high pressure water guns ( cold water )

c) wipe clean with coarse towels and 1% ammonia solution (frozen eels are more difficult to de-slime; the ammonia solution facilitates slime removal).

2. Gutting

a) "pin" eel heads to the cutting board ( the use of coarse cloth or sawdust will improve the cutter's grip ).

b) slit open bellies from the throat to one inch beyond the anus (kidneys extend beyond the anus) with a knife.

c) scrape out guts with the back of the knife and be careful not to break the gall-bladder or cut the abdominal wall. The cut at the neck is made as small as possible to reduce the chances of the body falling away from the head during smoking.

d) carefully wash eels in cold water to remove all traces of blood and slime.

3. Brining

a) mix brine solution (270-300 gms of salt per litre of water)

b) immerse eels in brine for 10-15 minutes, depending on size.

4. Racking

a) thread brined eels on 0.5 cm diameter rods by pushing the pointed end of the rod through the throat from side to side.

b) dip eels for approximately 15-30 seconds in very hot water (90° - 100°C) to flare out belly flaps. This allows smoke to penetrate the body cavity more evenly. (Small lengths of stick can be used to keep belly flaps apart, but this was found to be time-consuming and the sticks had a tendency to fall out during smoking).

c) hang full rods of eels to drip dry, (approximately 30 minutes).

5. Smoking Procedure

a) hang the full rods of eels in the kiln and follow the temperature, time, smoke density schedule below:

| TEMPERATURE | SMOKE DENSITY | TIME |
|---|---|---|
| 35°C (95°F) | slight | 60 min. |
| 50°C (120°F) | medium | 30 min. |
| 73°C (170°F) | heavy | 20 min. |
| 73°C (170°F) | slight | 40 min. |

b) remove eels from kiln and allow to cool slightly before packing (reduces possibility of mold formation).

c) brush the eels lightly with edible oil and wrap in plastic film or vacuum pack in polythene bags.

Results and Conclusions

This gradual increase in temperature permits reasonably uniform drying throughout the thickness of the fish. If the temperature is allowed to rise too quickly, the eels may become "case hardened" ( skin becomes dry and hard but flesh remains wet), particularly when the fat content is low as with yellow eels. It is often difficult to accomplish proper drying on hot humid days if a traditional type kiln is used. Poor drying leads to a very undesirable "mushy" flesh. Smoking is thus more controllable during the winter months when the relative humidity is low.

Very sophisticated smoking kilns are available that allow total control of the internal kiln environment. Temperature, relative humidity and smoke density can all be time-programmed with some of these kilns. They are understandably very expensive.

Broad-nosed eels were found to be unsatisfactory for smoking due to their low fat content. The sharp-nosed eels smoked by this procedure had a good smoky flavour with a slight taste of salt and the flesh was firm, yet delicate, with a buttery texture.

Samples were taste-tested by fifteen Europeans (German, Danish, and Swedish), living in Stephenville. All stated that the texture, flavour and appearance were comparable to smoked eels they had eaten in their home countries. Their overall opinion was that the above process produced very good quality smoked eels, which would be acceptable in Europe.

Anyone considering smoking eels for export should carefully analyze the different regional preferences and determine which can most readily be duplicated. It is thought that the major difficulty will not be the problem of matching smoking techniques, etc., but rather the marketing aspects of the venture.

The aid of the Department of Industry, Trade and Commerce should be solicited to assess regional market potentials in the various European centres. The Department will make initial contact with potential buyers and arrange for meetings. It is strongly recommended that direct personal contact be made with potential buyers in Europe and the precise characteristics of the smoked eel product that they could retail be explicitly defined. A price advantage could exist if a purchase agreement could be consummated with a large retailer rather than a wholesaler or processor of smoked eels.

The main centres of eel buying and selling in Europe are, in order of importance: Spaarndam, Holland; Hamburg, Germany; and Copenhagen, Denmark.

## V. BIOLOGICAL OBSERVATIONS

### BEHAVIOURAL CHARACTERISTICS OF LOCAL EEL POPULATION

Information received from the eel fishermen of the area and my own observations indicate that the greatest concentrations of eels occur in the estuarine areas in the summer months ( see Spring Fishing ).

Night observations using spot lights and the spring fishing data indicate that eel activity in 1973 began during the first week of June. Active eels were first observed and caught in Two Guts Pond ( Figure 8 ). At this time, the range in surface water temperatures in the pond was 10 to 12°C. Dolan (1973) reported similar water temperatures and eel activity in the Matamek River, along the north shore of Quebec. Similarly, eels ( _A. japonica_ Temminck & Schlegel ) in Japanese culture ponds will not feed at water temperatures below 12°C (Usui,1974). This relatively high temperature requirement for the initiation of feeding is probably a reflection of the sub-tropical origin of the genus.

Seven night observations were made in Two Guts Pond during June 1973 by rowing a boat, fitted with two bow-mounted spot lights, along a 200 meter transect. Hourly observations were made between

1700 and 0500 hours. The lights provided a clear view, approximately 1.5 m in width, of the bottom area. Observations could not be made during heavy rain or when the water was choppy. The data appear in Table A-15.

The greatest number of sightings occurred between 1900 and 2300 hours, the mean value for this time period being 10.5 eels per hour. The majority of the eels spotted during this period were observed swimming, while fewer numbers were sighted lying stationary on the bottom vegetation. The mean number of eel sightings for the period 0100 to 0500 is 5.0 eels per hour. Eels spotted at these times were generally stationary, lying in amongst the bottom vegetation. Swimming eels were more readily visible than stationary eels, especially in the case of the latter.

These night observations suggest that feeding activity may be greatest between dusk and midnight. It was decided to verify these preliminary observations by fishing the baited eel pots at specific time intervals. The twenty pots could be hauled, eels counted and pots rebaited in one hour. This was done three times daily at 1600 - 1700 hours, 2300 - 2400 hours, and 0500 - 0600 hours. The fishing time is thus the time-period directly preceding each hauling time. This procedure was followed for seven consecutive days. A summary of the data appears in Table A-16.

The greatest number of eels were caught when the pots were hauled at 2300 - 2400 hours - a total of 1804 eels and mean nightly value of 257.7 eels. Mean values of 95.1 and 24.6 eels were caught at 0500 - 0600 hours and 1600 - 1700 hours, respectively.

These date indicate that during the fishing period the feeding activity was greatest from dusk to midnight and least during the daylight time. These observations are in agreement with Medcof (1966) and Eales (1968).

On June 12, while I was looking for elvers in Flat Bay, I observed many eels swimming downstream. Approximately 300 meters upstream from the mouth of the river an unusual sighting was made: a ball ( less than a meter in diameter ) of tightly interwoven eels was seen tumbling downstream in the main body of the current. A rock thrown at the centre of this ball quickly dispersed the mass of eels and they continued singly downstream. I can give no explanation for this behaviour. Mr. Ken May of the Fisheries Service in St. George's stated he had observed eels migrating downstream in rivers along the west coast and saw "balls" on two occasions, both in early June. A literature search revealed that fishermen in Nova Scotia had made similar observations (Medcof 1969). This downstream spring migration is not a typical behavioural characteristic of _A. rostrata_.

It is suggested that the eels migrate to the estuaries because these areas provide a greater availibility of food than do the rivers and lakes. The small drainage areas, ( less than 394 square kilometers ) of the rivers from Fox Island River to Grand Codroy River, suggest that such a migration to the estuaries would be a relatively simple procedure, probably requiring only 2 - 4 days.

Eels feed actively throughout the summer months on a variety of organisms: worms, crayfish, crustaceans, larval fish and small fish.

This is the trophic stage, during which eels undergo growth and sex differentiation. The growth of eels is strongly influenced by environmental conditions, especially by temperature and the availability of food and space (D'Ancona, 1960). Remarkable individual differences in growth have been observed among eels in the same environment (Frost, 1950). D'Ancona (1957) observed that the degree of voracity varied considerably, the extreme being cannibalism.

The feeding activity of eels, as previously stated, is known to vary with weather conditions. The largest weekly catch in Two Guts Pond ( 2.3 kg/pot/day ) occurred during a week characterized by five rainy days, continued cloudy conditions ( day and night ) and daily temperatures of 14 - 18°C. The largest single day catch (3.7 kg/pot/day ) occurred after an afternoon and evening of very heavy rain ( no thunder or lightning ). The smallest catches ( 0.0 to 1.1 kg/pot/day ) followed hot sunny days and clear nights.

In agreement with Eales (1968) and Fletcher and Anderson (1972), these observations suggest that feeding activity is greatest during cloudy, wet conditions.

The fall fishing data revealed another behavioural characteristic of the area's eel population. The immature eels display mass migrations to specific muddy areas for the purpose of overwintering. The best known of these areas is Muddy Hole, adjacent to Flat Bay Brook (Figure 9 ). Muddy Hole is approximately 17.4 hectares in area, and is shallow, with a bottom of deep mud.

The size of the pre-fishing migration was calculated by comparing the total catches, fishing pressures, estimates of the percentage of small eels released by the fishermen and estimates of the loss of migrating mature eels for the years 1970-73. The estimated weight of this pre-fishing migration is 90 600 kilograms. This is an enormous concentration of eels in such a small area, estimated at 5 207 kg/hectare. The fishermen state that random spearing in the mud through the ice anywhere in Muddy Hole throughout the winter will result in a catch of a barrel of eels in 30 minutes. This suggests that the eels remain buried in the mud throughout the winter.

Similar but smaller fall runs of immature eels are known to occur in the muddy areas of Grand Codroy River, Crabbes River and Robinson's River ( Ken May, personal communication ).

The fall run of yellow eels to muddy, overwintering areas appears to be temperature induced. The first two nights of frost occurred at the beginning of the fourth week of September, as did the mass yellow eel migration. The fishermen state that the peak catches of the previous three years coincided with the first frosts.

The Flat Bay fall fishing data revealed that the majority of the peak run was composed of eels over 250 grams. After the peak run of a week's duration, the majority of the eels caught were under 250 grams.

The size of the migrating population and knowledge of the factors affecting the migration of silver-bronze eels from this area are deficient at present. The departure of the maturing eels is believed to occur from mid-August until November. Details of the migrations of A. anguilla are available from Deelder (1954), Bostus (1967), Frost (1950) and Lowe (1952).

Factors affecting the upstream migrations of elvers are equally obscure. Elvers have been seen by river wardens in all the rivers of the west coast from Fox Island to Grand Codroy River but the largest concentrations observed are reported from Flat Bay Brook ( Figure 9 ). Information on the elver migrations of A. anguilla can be found in Lowe (1951) and Deelder (1952, 1958).

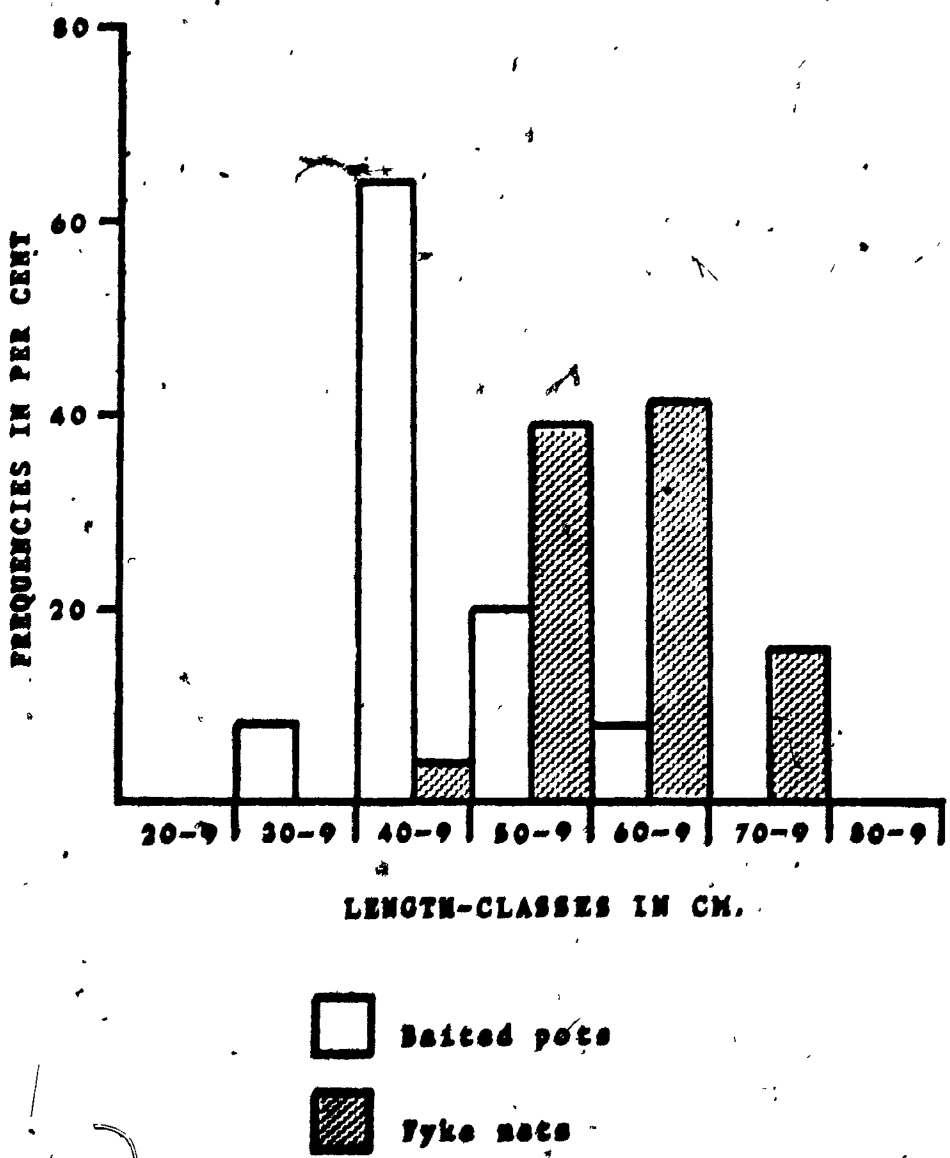
LENGTH-WEIGHT RELATION OF THE CATCH

Samples of eels ( over 300 mm ) were caught by the two fishing methods. Eels under 300 mm could escape because of the mesh sizes used, ( 0.5" vs 1" ) ( 1.27 vs 2.54 cm ) in the baited pots and fyke nets. Random samples from these catches were measured for total length (tip of lower jaw to the posterior end of the middle caudal ray ) and wet weight ( Table A-1 ).

The length-weight relationship was calculated from the exponential equation $W = al^n$, where a= constant, l = length, and n = slope.

Length-weight regressions were calculated from spring and fall catches of eels and are respectively, $\log W = -7.81 + 3.733 \log l$ and $\log W = -6.123 + 3.131 \log l$. Combination of the data resulted in an overall regression of $\log W = -7.30 + 3.55 \log l$. Few eels under 400 mm or over 750 mm appear in the samples (Table A-7).

Figure 15 : Histogram of length-classes of eels (<u>Anguilla rostrata</u>), caught in baited pots and fyke nets.



The above regressions are therefore representative of eels in the 400-750 mm range only. The growth (length/weight) of eels in Flat Bay between 400-750 mm is allometric since the slope is greater than three.

By comparison, the slope of the length-weight regression for eels from Lake Ontario between 483 and 792 mm was 3.77 (Hurley,1972). The difference in the slope of the regressions for Flat Bay eels (3.55) and Lake Ontario (3.77) indicates the eels from Flat Bay weigh less per given length than do the Lake Ontario eels.

Gray and Andrews (1971) reported the length-weight regression for eels between 159 and 840 mm in Burnt Berry Brook, Newfoundland, to be $\log W = -3.1797 + 3.2706 \log l$. In the Salmon River they reported that the eels were between 291 and 571 mm, and the length-weight regression was $\log W = -2.8955 + 3.0812 \log l$. These regressions show that eels from Flat Bay are heavier per given length than eels from the two Rivers. Fletcher and Anderson (1972), comparing the length-weight regression for Flat Bay eels with regressions for eels in the Terra Nova, Gambo, Gander and Exploits Rivers of Newfoundland, similarly reported the Flat Bay eels were heavier per length.

The greater productivity of Flat Bay water compared with rivers in Newfoundland is no doubt one of the factors responsible for the greater weight-for-length increment observed in Flat Bay eels.

Comparing the catch data of the two fishing methods, it was observed that over 65% of the eels caught in baited pots were in the 400 - 499 mm length range. ( Table A - 2 )

The fyke nets caught a greater number of large eels with 80% of the catch measuring between 500 - 699 mm ( Table A-3 ). These figures are significant to the eel fishery because eels under 500 mm are usually too small for sale.

## FAT CONTENT

### Introduction

The fat content of eels is extremely important to the eel fishery because it represents one of the few definitive and measurable evaluations of quality. Vieweger (1928) supposed that the eel accumulated its fat for the most part in its muscular tissue. McCance (1944) verified this with findings of 11% and 26-30% fat (in the muscle) of European yellow and silver eels (A. anguilla), respectively. The skin was found to contain 5-6% fat for both immature and mature eels. No detailed reference to fat content in Anguilla rostrata was found in the literature nor could quantitative values be obtained from other eel processors.

Information on the fat content of immature and mature eels was needed to evaluate their relative market quality. The colour phases found in half-grown and adult specimens of eels are the most reliable indicators of their stage of maturity. Morphometric characters ( length and weight ) of eels are poor indicators because great variability exists in growth rates between populations, between sexes, and even among individuals in the same environment (Hurley, 1972, Fletcher and Anderson, 1972).

Analysis I

Eels often display a combination of colour phases, as the transition from one to another is occurring ( See Historical Introduction, p. 13 ).

The majority of the eels I examined from Flat Bay could be placed in one of the following categories: yellow, yellow-green, bronze-yellow, silver and bronze.

A description of the yellow, silver and bronze eels appears in the Historical Introduction,(p.13). The yellow-green and bronze-yellow phases display a mixture of colours, neither being dominant. Broad-nosed eels were not included in the analysis because they were observed only in the yellow phase, and their characteristic low fat content (see below) would have biased the data.

Analysis II

Several European buyers had requested information on the percentage of broad-nosed eels in the catch and remarked on their "poor" quality. Assuming this referred to low fat content, I undertook a comparison between broad and sharp-nosed eels. For a description of these two types see Historical Introduction ( p. 14 ).

Methods and Material

Samples of sharp-nosed eels were collected that displayed each of the above colour phases. Different sized broad-nosed and sharp-nosed eels were collected. Individual descriptions were recorded and eels numbered. The specimens were gutted and skinned carefully, leaving any subcutaneous fat deposits on the flesh. Segments of flesh for analysis were taken from the dorso-anterior part of the abdominal region. Two determinations were made for each fish and the results averaged. The procedure for fat analysis was as follows:

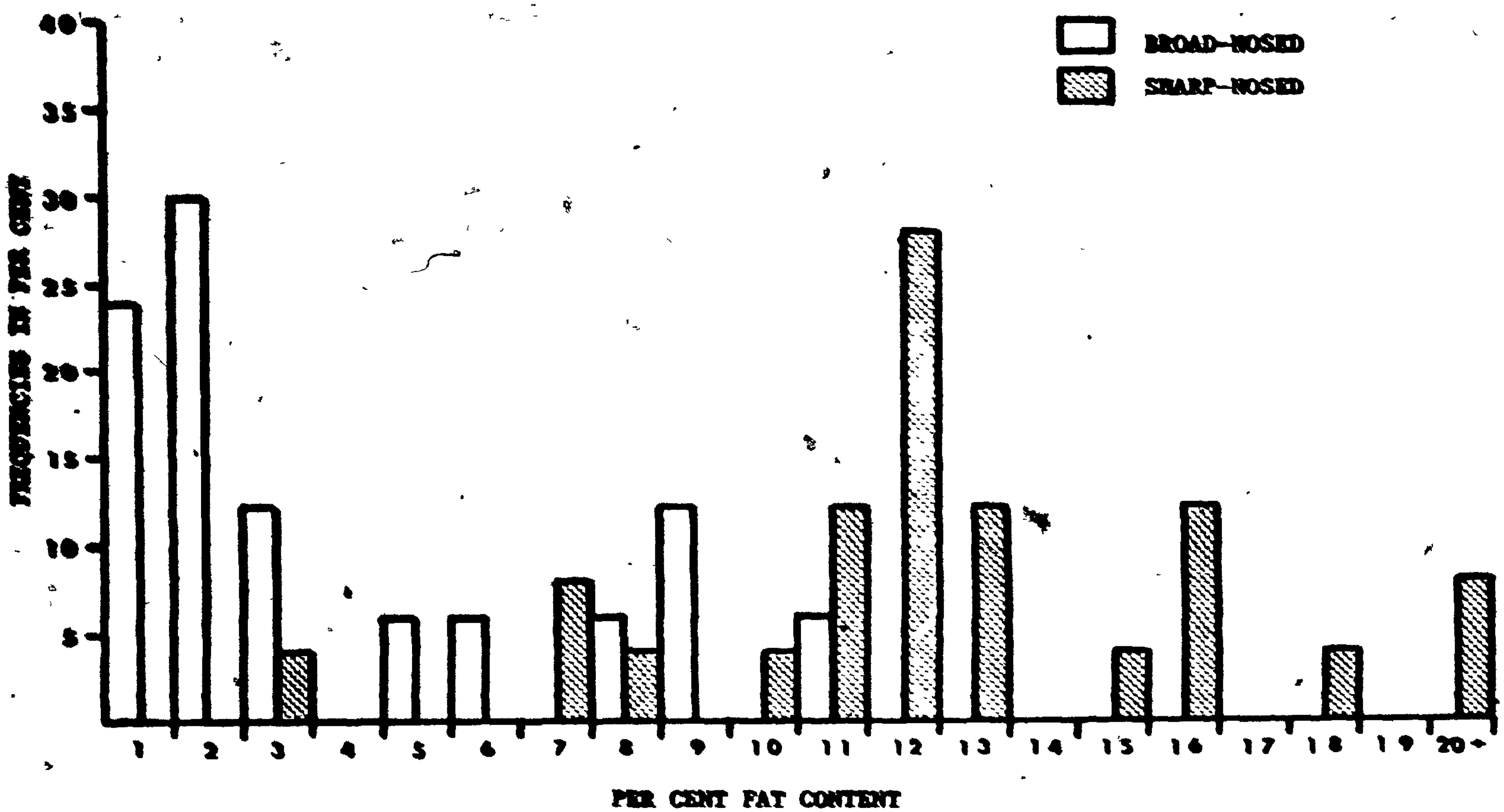
1. weigh 9 gms of ground flesh on a triple beam balance
2. place sample into a Paley type Babcock cheese bottle (Kimble Glass No. 508, 20% size)
3. add 25-30 ml of fresh reagent ( 1 part glacial acetic acid and 1 part 70-72% perchloric acid )
4. stopper bottle and place in boiling water bath for 20-30 minutes until digestion is complete. Swirl bottle every 3-4 minutes while in the water bath
5. remove bottle from the water bath and add enough reagent to have the fat level near the top of the scale ( on bottle neck )
6. Centrifuge for 5 minutes and record the % fat on the scale

Results and Discussion - Comparison of the fat content of broad and sharp-nosed eels

The sample of broad-nosed eels consisted of yellow phase eels while the sample of sharp-nosed eels included all the colour phases. The samples of broad-nosed eels and sharp-nosed eels contained specimens that ranged in size from 400-870 mm and 300-756 mm, respectively.

The mean percent fat contents for the broad and sharp-nosed

Figure 16: Histogram of fat content in Broad-nosed and Sharp-nosed eels from St. Georges Bay, Newfoundland.



eels were 3.88 and 12.3 respectively ( Table B-1 ). A student "T" test verified the highly significant difference in fat content between the two types. The obvious question arising from these results is whether these physical and physiological differences are due to environmental influences ( habitat and diet ) or are these two types conspecific morphs and the differences genetically controlled.

It is well known that the composition of fishes is affected by their environment. This is particularly true for fat content and fat composition and has been discussed by Ackman (1967). Dugal (1962) and Karrick et al (1956) reported relatively large differences in fat content of samples of one species collected from two different locations. Thurston (1962) found the fat content to be extremely variable in two sub-species of the lake trout ( *Salvelinus namaycush* Walbaum). These two varieties, a lean one and a fat one, are accepted by biologists as representing two distinct sub-species: *Cristivomer* ( or *Salvelinus* ) *namaycush namaycush* and *Cristivomer namaycush siscowet*, respectively ( Thurston, 1962 ).

From Bertin's (1956) discussion of broad-nosed and sharp-nosed individuals of *A. anguilla* , it seems that both types are found in similar habitats throughout the range of that species. Thurow (1958) concluded: "That eels (*A. anguilla*) with either pointed or broad heads are varieties of a uniform stock, showing a great plasticity of the characteristic. The occurrence of one or the other form depends on environmental factors." He states that in the case of abundant food, eels mainly feed on worms and little crayfish and develop pointed heads.

In the case of limited food, eels are compelled to feed on crustaceans and fish but they can only consume that food once they have attained a certain size then the cranial parts begin to transform their shape resulting in broad head specimens.

Thurow's conclusions do not negate the possibility of several such changes in head form occurring during the trophic stage if the yearly abundance of food varied significantly. This implies an extreme plasticity in a group of eels in a short period of time and is unlikely even if one believes in Lamarckian evolution.

Thurow (1958) found broad-nosed forms to have a lower fat content and mature at a later date ( and attain a greater size )than eels with pointed heads. Thurow (1958) and Bertin (1956) both conclude that the differences displayed by these two types are environmentally controlled. But the evidence is not conclusive and genetic differences may exist.

If the broad-nosed variety is a morph then presumably it seems: 1) only a constant percentage of the eels would be broad-nosed and 2) that this morph exists because the morphism has some selective advantage(s). The longer premigrant existence, greater size and possible different diet of the broad-nosed form may have a stabilizing effect on the ecosystem, thus having evolutionary advantages. Huxley (1955) concluded that morphism frequently serves as an adaptation to the extremes of environmental variation. The differences in diet reported by Thurow (1958) as the cause of the differences between the two forms may be the adaptive value of the morphism, increasing the range of habitats that can be profitably occupied.

It would be interesting to carry out feeding experiments designed, through diet variations, to see whether it is possible to cause sharp-nosed eels to change to the broad-nosed form or vice versa. If this change cannot be induced, then genetic differences would seem to be influencing this characteristic more than environmental factors.

One of the changes involved in the metamorphosis from the yellow to silver stage in the European eel (A. anguilla) is the narrowing and increased pointedness of the eel's snout (D'Ancona, 1960). I have observed the above change in silver and bronze American eels (A. rostrata). No broad-nosed migrants have been reported for either A. anguilla or A. rostrata. It is probable that broad-nosed eels undergo a narrowing and increased pointedness of the snout in the metamorphosis from the immature (yellow) to the mature (bronze or silver) stage.

Although little reference to broad and sharp-nosed members of A. rostrata appears in the literature, they seem to exist throughout the species' range. For example, Vladykov (1973), discussing macrophthalmia, pictures an immature (A. rostrata) female from Shark River, Trinidad, that is clearly a broad-nosed type (Vladykov, Figure 2 right). Both types were caught in estuarine areas in Newfoundland, approximately 90% of the catch being sharp-nosed eels. It is not known whether this figure represents the relative numbers of the two types or whether it is an indication that the fishing areas were not the primary habitat of the broad-nosed eels. The fishermen suggest that the broad-nosed eels spend considerable time feeding in salt water areas, but this could not be verified. Beyond these general statements, no definite statement of habitat and diet differences can be offered. A tagging programme, as described by Vladykov (1970 P.R. no. 5) or an ultrasonic tracking programme as described by Stasko and Rommel (1974) may shed some light on the behaviour and possible habitat preferences of the two types.

Whatever the cause for these differences, the significant difference in fat content is extremely important commercially, because although the broad-nosed eels sampled visually appeared to be robust and of good quality, their low fat content made them totally unsuitable for smoking purposes and therefore of little commercial value.

*Comparison of the fat content of five colour types*

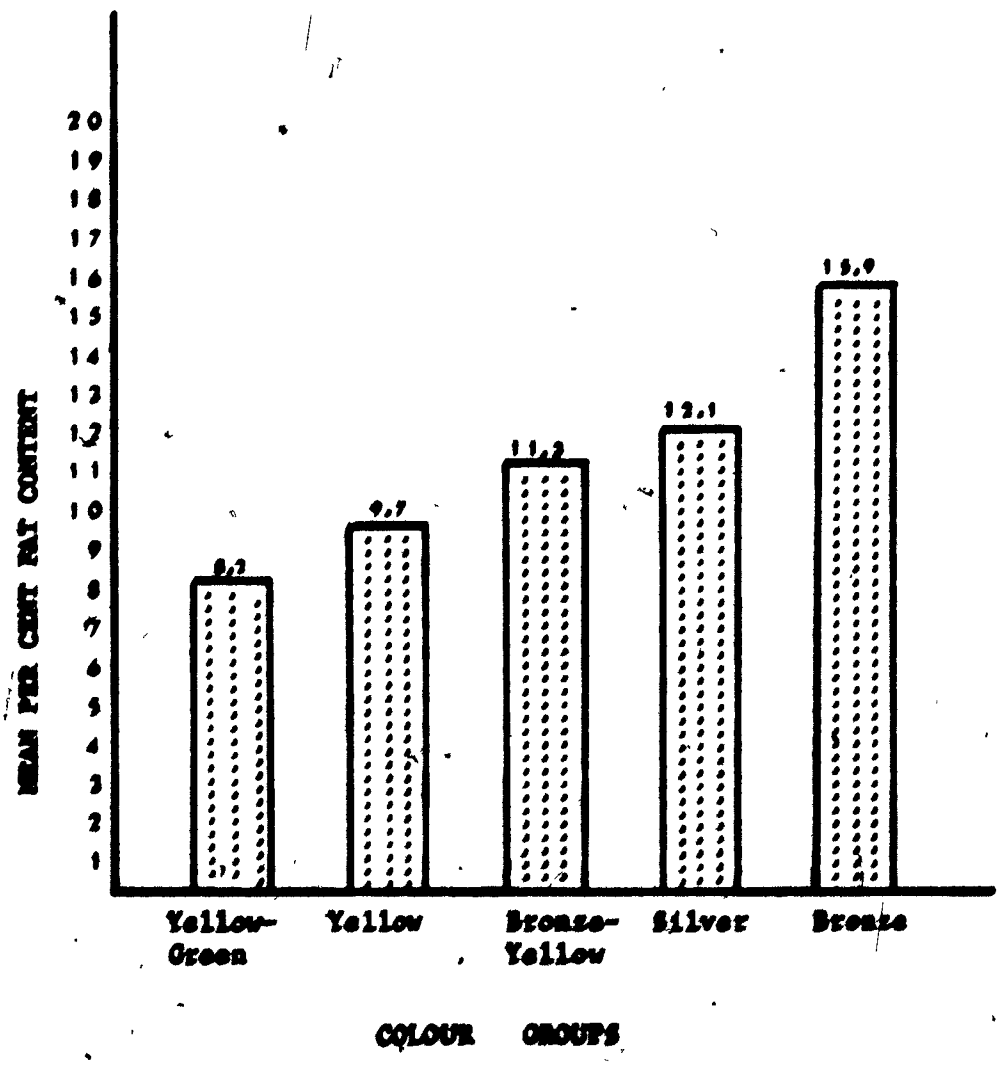
The compiled data for the five colour phases appears in Appendix C. Analysis of variance resulted in a significant F value.

Duncan's multiple range test was carried out to compare the mean fat content of each colour type with that of every other colour type (Table C-13). The results of this test are summarized as follows:

| | Yellow Green | Yellow | Bronze Yellow | Silver | Bronze |
|---|---|---|---|---|---|
| $\bar{x}$ % | 8.2 | 9.7 | 11.3 | 12.1 | 15.9 |

Any two means underscored by the same line are not significantly different. Any two means not underscored by the same line are significantly different.

Figure 17: Histogram of the mean fat contents of five colour groups of sharp-nosed eels (Anguilla rostrata), from the Flat Bay area of Newfoundland.



The mean fat content of the bronze eels was the only mean value significantly different from all other means. Relating fat content to commercial quality, the bronze eels are thus considered the highest quality.

Vladykov (1955) found that 1/3 of the eels he examined from five areas in New Brunswick had some degree of bronzeness. However, eels displaying all the bronze characteristics ( see Historical Introduction, p.13) constituted an average of only 2.6% (0.7 to 6.2%) of the eels examined. Vladykov's (1955) findings and the present fat content data suggest that the metamorphosis from yellow to bronze is gradual, requiring probably 2 to 3 years. Commercially, only those eels displaying all the bronze characteristics should be termed "bronze" since the fat content of bronze-yellow eels was not significantly different than that of yellow eels.

It can be concluded that as sharp-nosed eels grow and develop, they accumulate increasing quantities of fat ( Figure 16 ). As they grow and develop, they also display different colour phases which are thus natural indicators of their relative fat content. As would be expected (Bligh,1971), the absolute values will, however, differ to some extent with environmental differences from one area to another.

It can be assumed that since a cessation of feeding coincides with the onset of the adult eels' catadromous reproductive migration, the accumulated fat is necessary to meet the energy demands of the eels during their extensive migration. Due to the greater distance involved in the European eel's return to its spawning area in the Sargasso Sea, it would be expected that it would require more energy reserves (stored fat) than the American eel. Thurow (1959) and Usui (1974), have cited fat content values of 25 to 30% for the European eel. By contrast, the average fat content of migrating bronze eels ( A. rostrata )from Flat Bay was 16%.

The higher mean fat content found in the European eel (A. anguilla) seems to add support to Bruun's (1963) criticism of Tucker's (1959a) theory and suggests that the European eel is capable of returning to the Sargasso Sea to spawn ( see Historical Introduction p.8 ).

Further sampling and fat analysis is needed from other areas to determine whether migrating American eels (A. rostrata) do, on the whole, have a lower fat content than their European counterparts.

Understanding the importance of fat content in eels is essential for eel processors. The knowledge of fat content enables processors to describe more precisely the quality of their product and more accurately evaluate the product's market value.

## MERCURY ANALYSIS

### Introduction

Mercury pollution in fish was first detected in Minamata Bay, Japan (Irukayama, 1966) and later a similar instance was reported at Niigata. The origin of mercury was traced to chemical plants using mercury catalysts. Berglund (1971) believed the methyl compound to be the principal causative agent in the neurological diseases at Minamata and Niigata. Sweden has also experienced problems with mercury in fresh water fish and has closed many areas to fishing (Johnels,1967). Hannerz (1968) suggests that the chemical nature of organic mercury compounds is easily changed in natural waters. Mercury is available for uptake by biota as a mixture of compounds no matter what chemical form the mercury was initially. Methylation is affected by bacteria using any mercury source available. The rate of uptake of mercury in fish, from both water and food, is fast, while the rate of elimination is slow, giving high concentration factors ( Rucker and Amend, 1969; Hannerz, 1968 ). Hannerz (1968) found that for the different mercuric compounds tested, methyl mercury was taken up most readily by fish. It has been shown in Sweden that most mercury in fish ( on the average 92% in fresh water and 82% in marine fish ) exists as methyl-mercury (Norén and Westöö, 1967; Johansson et al, 1970)

Occurrences of fish containing mercury have been reported in Canada (Wobeser et al, 1970; Bligh NS, 1970; Zitko et al, 1971) and specifically in the American eel ( Freeman and Horne, 1972). Much of the mercury found in *Anguilla rostrata* was in a form other than methyl-mercury and Freeman and Horne (1972) concluded "since these eels contained less than 1.0 ppm total mercury, it is possible that they are fit for human consumption".

The Food and Drug Directorate of the Department of National Health and Welfare states that any fish with total mercury values over 0.5 ppm (mg. mercury per Kg wet wt.) are not allowed to be sold in Canada or to be exported, and must be destroyed. This law is enforced under a section of the Food and Drug Act and Regulations. The mercury content in fish is therefore of great concern to the commercial fisheries.

Methods:

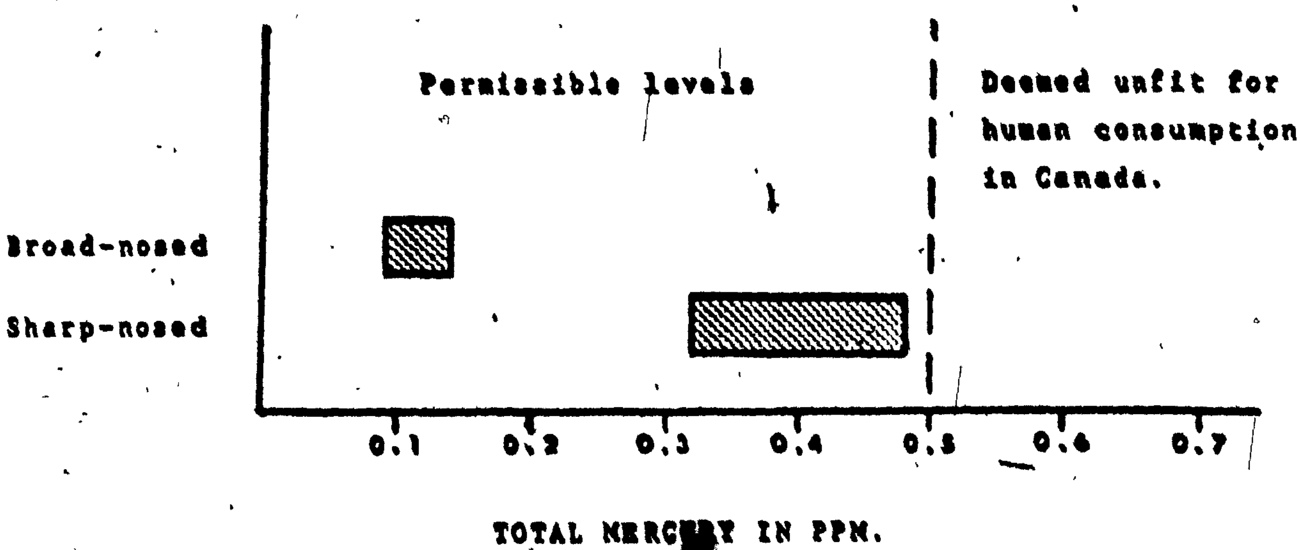
Twenty specimens of broad-nosed eels (437 - 819 mm) and twenty specimens of sharp-nosed eels (410 - 790 mm) were collected from Flat Bay. The eels were pan frozen ( see Freezing Eels, p.51 ) in two groups (broad and sharp-nosed), packaged, labelled and shipped via air express to the Fish Inspection Laboratory in St. John's, Newfoundland, where they were analyzed for total mercury from portions of the flesh only; all internal organs were discarded. This is the standard procedure of the Fish Inspection Laboratory, unfortunately.

Results:

The results from the Fish Inspection Laboratory are:

| Eel Type | Total Mercury (flesh) |
|---|---|
| broad-nosed | 0.09 - 0.13 ppm |
| sharp-nosed | 0.32 - 0.48 ppm |

Figure 18: Concentrations of total mercury found in Broad-nosed and Sharp-nosed eels (*Anguilla rostrata*) from the Flat Bay area of Newfoundland.



Discussion:

The eels used for fat and mercury analysis were caught in the Flat Bay - Muddy Hole area during late September. Both types had been caught in the area throughout the late summer but the sharp-nosed eels constituted approximately 90% of the catch. This fact may indicate either the relative abundance of the two types or, that this area was not the primary habitat of the broad-nosed eel.

All eels analyzed were under the 0.5 ppm permissible level although some of the sharp-nosed eels were very close to this value. ( Figure 18 ).

The source of this mercury may be a pulp mill located in Stephenville, or several pulp mills 72 kilometers distant, or other unknown sources. Since mercury can enter the environment as either water-borne or air-borne mercury (Tejning MS., 1967) a precise location of the source may be difficult. Bligh (1972) states that most Canadian mills had ceased using mercury compounds such as phenylmercuric acetate as slimcides by January 1970. At the time of writing, the author does not know whether these Newfoundland mills have ever used mercury compounds, or if they had, when their use was terminated.

These data show a highly significant difference in the total mercury levels found in the flesh of the two types. The data are adequate for the commercial fishery because the permissible limit of .5 ppm refers to portions of flesh only. Biologically, however, it cannot be stated that the total mercury levels in the total body mass of the two types is different since the internal organs were not analysed. There is sufficient evidence that mercury compounds are found concentrated in the livers and kidneys of fish exposed to a mercury source ( Wobeser et al, 1970, for fish in the Saskatchewan River ) and specifically in eels ( *Anguilla japonica* ) (Hibiya and Oguri, 1961). Rucker and Amend (1969) exposed rainbow trout to a "single dose" of mercury and described the uptake as occurring rapidly in the gills first, then quickly increasing in the blood ( 24 hours ) with a slower increase in the liver and kidneys. Elimination of mercury in the liver and kidneys to normal levels required 20 and 28 weeks, respectively. Many factors are involved in the rate of uptake of mercury compounds by fish but these differences seem to be related to both food habits and habitat (Lockhart, 1972). Hannerz (1968) reported that the uptake of mercury compounds was affected by the concentrations of electrolytes in the water (uptake of methoxythyl mercury was lower in brackish water than in salt water) and that concentration factors differ for different organs, and for the different mercuric compounds tested.

Another possible variable in this mercury issue can be suggested from my present findings. The relative proportions of fat and total mercury (portions of flesh) for the two types of eels are very similar. The total mercury ranges were .9 - .13 ppm for the broad-nosed and .32 - .48 for the sharp-nosed eels; the corresponding fat contents were 3.88 and 12.3% respectively. It is probable that a relationship exists between fat content and mercury concentration.

Hinton et al (1973) state that the liver is the primary organ of detoxification. Generally, the liver is also the most important organ for controlling fat utilization by the body. When an excess of glucose occurs, extra glucose passes into the liver and is converted to fat, the fat then leaves the liver to be stored in fat deposits throughout the body. If this occurs in an eel with high liver concentration of mercury compounds, an association of these mercury compounds with the fat molecules may occur. The functions of the liver may thus provide a pathway for mercury compounds to enter the flesh of the fish.

It is not clear, as previously discussed (see Fat Content, p.77) whether the observed difference in the fat content of broad and sharp-nosed eels is genetically controlled or is due to environmental influences. This difference in fat content between the two types is consistent throughout the range of the European eel (A. anguilla) (Bertin,1956; D'Ancona, 1960). This also seems to be the case with the American eel (A. rostrata). Further research is needed to determine whether mercury compounds can be associated with fat molecules in the liver and can subsequently be distributed to fat deposits in the body.

Uthe et al (1973) reported that the rate of mobilization of mercury from the bottom mud was so low during the winter that fish readily excreted all mercury taken in. He suggested that cold depression of metabolism within the fish lowered uptake more than it did excretion. It may thus be possible that eels overwintering in the mud have a net loss of mercury compounds.

Freeman and Horne (1972) found that the methyl-mercury compounds ( the principal cause of Minimata disease ) constituted less than 50 percent of the total mercury in eels ( Anguilla rostrata ). It has been reported by many researchers that the methyl-mercury compounds are the most readily taken up mercuric compounds in fish (Hannerz, 1968 ; Noren and Westöö, 1967; Johansson et al, 1970; Westöö, 1966; Uthe et al, 1973). The eel thus seems to be an exception. Uthe et al (1972)suggested that fish do not methylate mercury after intake so that accumulated methyl-mercury was from direct uptake from the environment.

Eels, due to a lack of large protective scales, carry out up to 60% of the respiratory process through the skin (Usui, 1974). Thus the total respiratory process in eels, unlike most other fresh water fish, does not take place exclusively at the gills. It is suggested that methyl-mercury derivatives, although rapidly absorbed by the gills, may not be readily taken up at the surface of the skin, and that this may account for their lower methyl-mercury content.

The above findings are significant to the commercial fishery. If the proportion of methyl-mercury compounds is in fact lower in eels than in other freshwater fish, then perhaps the methyl-mercury content should replace "total" mercury as the legal definition of mercury contamination in eels.

## Conclusion

The flesh of the bronze and silver eels in the sharp-nosed sample had consistently the highest total mercury levels as well as correspondingly higher fat contents. The migrating bronze and silver eels command the greatest market price representing the processor's greatest profit potential. They also represent his greatest possible loss if they are condemmed because of high mercury levels.

## VI. GENERAL SUMMARY

1) The largest concentrations of eels were found actively feeding throughout the summer months in brackish water areas.

2) The fall migration of yellow (immature) eels to muddy areas to overwinter in the mud is described and appears to be co-incident with the first frosts.

3) Eel activity in the spring began when water temperatures reached 10 - 12ºC.

4) Hoop nets were found to catch a higher percentage of "commercial size" eels than baited pots. Hoop nets also caught more eels per unit fishing effort.

5) The future prospects of a viable eel fishery along the south-west coast of Newfoundland are considered poor. Previous fishing of yellow eels during 1970-72, has severely depleted the eel stocks of "commercial size" fish. A recovery period of 6 to 7 years is predicted.

6) It is recommended, for biological and socio-economic reasons, that the fishing for immature yellow eels be discouraged; the slow growth rate of eels and behavioural characteristics make over-fishing an almost certain result.

7) It is recommended that the fishing for migrating mature eels be encouraged. The commercial quality of these mature eels is far superior to that of immature eels and their total capture represents no unnatural depletion of our eel populations. The fishing for migrating mature eels is also more efficient and controllable.

8) A highly significant difference in fat content was found between broad-nosed and sharp-nosed eels, with mean values of 3.88 and 12.3% respectively. Whether these differences are environmentally induced or genetically controlled is not clear.

9) Bronze eels were found to contain a significantly higher fat content than all other colour types. Commercially, bronze eels are the highest quality.

10) A significant difference in total mercury content (portions of flesh) was found between broad and sharp-nosed eels; the former 0.09 - 0.15 ppm and the latter 0.32 - 0.48 ppm. The relative proportions of total mercury and fat were very similar, suggesting the possible association of mercury compounds and fat in the liver.

11) A procedure was developed for stunning, sorting, packing, freezing and storing frozen eels, to achieve and maintain a high quality product.

12) A smoking procedure was developed that resulted in a smoked eel product acceptable to most European tastes. Broad-nosed eels could not be processed into an acceptable product due to their low fat content.

13) The possibilities for, and advantage of, exporting Canadian smoked eels to Europe is discussed.

## VII. FISHERIES RECOMMENDATIONS

It is biologically sound and economically beneficial to both the fishermen and the processor to have a fishery that concentrates on the capture of silver or bronze migrating eels. The advantages of a silver-bronze eel fishery are summarized below:

1) Biologically, migrating silver-bronze eels represent an unavoidable loss of biomass to an area, their total capture therefore represents no natural standing crop depletion and should be encouraged. It is probable that as elvers display a non-homing, random type migration (see Historical Introduction, p.2 ) annual elver recruitment to any river system should be unaffected. Since there are vast areas in Eastern Canada and the United States where eels are not fished, a lowering of the species' breeding potential is definitely not expected.

2) The silver-bronze eel is preferred for export because of its size and fat content. The price obtained is also considered higher than that for yellow eels.

3) The fishing season extends for only a few months in the fall and comes at a time when the small independent Newfoundland fisherman has little else to fish. Through the income earned, his U.I.C. benefits can be extended to the next spring when he can start fishing again.

4) River weirs are the most efficient means of catching silver eels. Although construction time is greater, once set up, the fishing effort is much reduced. Example: The river weir

in the Richelieu River, Quebec, catches approximately 45 300 kilograms annually and is operated by 3 - 4 men.

5) Provincial governments should be urged to discourage yellow eel fisheries and to implement legislation allowing river weirs. This would encourage silver eel fishing. Exponents of the theory that weirs would greatly interfere with the downstream movement of salmon smolt should bear in mind that this movement occurs primarily in the spring, also that smolts prefer the deeper part of the river while eels prefer the shallow parts. Properly implemented, experimental weirs should be constructed and the potential problems assessed.

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APPENDIX A

TABLE A-1

| EELS CAUGHT IN FYKE NETS | | | | EELS CAUGHT IN BAITED POTS | |
|---|---|---|---|---|---|
| Length mm | Weight gms | Length mm | Weight gms | Length mm | Weight gms |
| 670 | 572 | 550 | 267 | 495 | 199 |
| 620 | 400 | 600 | 489 | 457 | 142 |
| 660 | 470 | [illegible]0 | 292 | 419 | 85 |
| 520 | 216 | 590 | 368 | 483 | 142 |
| 550 | 241 | 500 | 191 | 432 | 85 |
| 460 | 133 | 600 | 356 | 483 | 143 |
| 700 | 635 | 580 | 305 | 407 | 85 |
| 670 | 527 | 560 | 317 | 470 | 114 |
| 630 | 432 | 520 | 241 | 394 | 85 |
| 670 | 559 | 570 | 298 | 483 | 170 |
| 630 | 476 | 530 | 267 | 432 | 113 |
| 640 | 438 | 540 | 267 | 559 | 284 |
| 720 | 673 | 520 | 229 | 572 | 312 |
| 720 | 622 | 480 | 197 | 584 | 340 |
| 655 | 508 | 700 | 673 | 635 | 397 |
| 570 | 324 | 690 | 508 | 406 | 113 |
| 540 | 229 | 700 | 654 | 445 | 114 |
| 570 | 298 | 680 | 482 | 394 | 85 |
| 530 | 260 | 660 | 514 | 445 | 113 |
| 500 | 210 | 610 | 444 | 686 | 624 |
| 780 | 1041 | 530 | 330 | 483 | 170 |
| 690 | 698 | 670 | 482 | 572 | 340 |
| 580 | 362 | 710 | 730 | 445 | 114 |
| 690 | 584 | 650 | 432 | 457 | 142 |
| 710 | 628 | 690 | 508 | 458 | 114 |
| 640 | 495 | | | 559 | 312 |

TABLE A-2

NUMBER OF EELS OF DIFFERENT LENGTH CLASSES (MM) CAUGHT IN BAITED POTS

| Length-Range (mm) | Number | Mean (mm) | Percentage |
|---|---|---|---|
| 200- 99 | | | |
| 300-399 | 2 | 394 | 6.7 |
| 400-499 | 17 | 453.9 | 65.4 |
| 500-599 | 5 | 569.2 | 19.2 |
| 600-699 | 2 | 660.5 | 7.7 |
| 700-799 | | | |
| 800-899 | | | |

TABLE A-3

NUMBER OF EELS OF DIFFERENT LENGTH CLASSES (MM) CAUGHT IN FYKE NETS

| Length-Range (mm) | Number | Mean (mm) | Percentage |
|---|---|---|---|
| 200-299 | | | |
| 300-399 | | | |
| 400-499 | 2 | 470 | 3.9 |
| 500-599 | 20 | 544.5 | 39.2 |
| 600-699 | 21 | 653.9 | 41.2 |
| 700-799 | 8 | 717.5 | 15.7 |
| 800-899 | | | |

TABLE A-4

COMBINED SAMPLES OF EELS OF DIFFERENT LENGTHCLASSES (MM) CAUGHT IN BOTH FYKE NETS AND BAITED POTS

| Length-Range (mm) | Number | Mean (mm) | Percentage |
|---|---|---|---|
| 200-299 | | | |
| 300-399 | 2 | 394.0 | 2.6 |
| 400-499 | 19 | 454.6 | 24.7 |
| 500-599 | 25 | 549.4 | 32.5 |
| 600-699 | 23 | 653.5 | 29.8 |
| 700-799 | 8 | 717.5 | 10.4 |
| 800-899 | | | |

TABLE A-5

PERCENT UTILIZATION OF TOTAL CATCH

| | Weight (lbs) | Percent |
|---|---|---|
| Weight of eels purchased | 25,079 | 100 |
| Weight of eels processed | 21,779 | 86.84 |
| Weight lost (death or damage) | 3,300 | 13.16 |

TABLE A-6

WEIGHT CLASSES OF PROCESSED EELS

| Weight Classes (gms) | Total Weight (lbs) | Total Weight (kg) | Percent |
|---|---|---|---|
| 200-250 | 8,613 | 3,907 | 39.6 |
| 250-500 | 9,744 | 4,420 | 44.8 |
| 500 up | 3,422 | 1,552 | 15.6 |
| TOTALS | 21,779 | 9,879 | 100 |

Table A-7: Raw data for length-weight equations

| Length mm | log L | Weight gm | log W | log L x log W | $(\log L)^2$ |
|---|---|---|---|---|---|
| 670 | 2.82607 | 572 | 2.75740 | 7.792605 | 7.986671 |
| 620 | 2.79239 | 400 | 2.60206 | 7.265966 | 7.797441 |
| 660 | 2.81954 | 470 | 2.67210 | 7.534092 | 7.949805 |
| 520 | 2.71600 | 216 | 2.33445 | 6.340366 | 7.376656 |
| 550 | 2.74036 | 241 | 2.38202 | 6.527592 | 7.509572 |
| 460 | 2.66276 | 133 | 2.12385 | 5.655302 | 7.090290 |
| 700 | 2.84510 | 635 | 2.80277 | 7.974160 | 8.094594 |
| 670 | 2.82607 | 527 | 2.72181 | 7.692025 | 7.986671 |
| 630 | 2.79934 | 432 | 2.63548 | 7.377604 | 7.836304 |
| 670 | 2.82607 | 559 | 2.74741 | 7.764372 | 7.986671 |
| 630 | 2.79934 | 476 | 2.67761 | 7.495540 | 7.836304 |
| 640 | 2.80618 | 438 | 2.64147 | 7.412440 | 7.874646 |
| 720 | 2.85733 | 673 | 2.82802 | 8.080586 | 8.164334 |
| 720 | 2.85733 | 622 | 2.79379 | 7.982779 | 8.164334 |
| 650 | 2.81291 | 508 | 2.70586 | 7.611340 | 7.912462 |
| 570 | 2.75587 | 324 | 2.51055 | 6.918749 | 7.594819 |
| 540 | 2.73239 | 229 | 2.35984 | 6.448003 | 7.465955 |
| 570 | 2.75587 | 298 | 2.47422 | 6.818628 | 7.603087 |
| 530 | 2.72428 | 260 | 2.41497 | 6.579054 | 7.421701 |
| 500 | 2.69897 | 210 | 2.32220 | 6.267548 | 7.284439 |
| 780 | 2.89209 | 1041 | 3.03330 | 8.772576 | 8.364184 |
| 690 | 2.83886 | 698 | 2.84386 | 8.073320 | 8.059126 |
| 580 | 2.76343 | 362 | 2.55871 | 7.070815 | 7.636545 |
| 690 | 2.83886 | 584 | 2.76641 | 7.853450 | 8.059126 |
| 710 | 2.85126 | 628 | 2.79796 | 7.977711 | 8.129683 |
| 640 | 2.80618 | 495 | 2.69461 | 7.561560 | 7.874646 |
| 550 | 2.74036 | 267 | 2.42651 | 6.649510 | 7.509572 |
| 600 | 2.77815 | 489 | 2.68931 | 7.471306 | 7.718117 |
| 540 | 2.73239 | 292 | 2.46538 | 6.736379 | 7.465960 |
| 590 | 2.77085 | 368 | 2.56586 | 7.109613 | 7.677609 |
| 500 | 2.69897 | 190 | 2.27875 | 6.150277 | 7.284439 |
| 600 | 2.77815 | 356 | 2.55146 | 7.088338 | 7.718117 |
| 580 | 2.76343 | 305 | 2.48430 | 6.865189 | 7.636450 |
| 560 | 2.74819 | 318 | 2.50243 | 6.877153 | 7.552548 |
| 520 | 2.71600 | 241 | 2.38202 | 6.469566 | 7.376656 |
| 570 | 2.75587 | 298 | 2.47422 | 6.818628 | 7.594819 |
| 530 | 2.72428 | 267 | 2.42651 | 6.610492 | 7.421701 |
| 540 | 2.73239 | 267 | 2.42651 | 6.630171 | 7.465955 |
| 520 | 2.71600 | 229 | 2.35984 | 6.409325 | 7.376656 |
| 480 | 2.68124 | 197 | 2.29447 | 6.152024 | 7.189047 |
| 700 | 2.84510 | 673 | 2.82802 | 8.045999 | 8.094594 |
| 690 | 2.83886 | 508 | 2.70586 | 7.681557 | 8.059126 |
| 700 | 2.84510 | 654 | 2.81558 | 8.010606 | 8.094594 |
| 680 | 2.83569 | 483 | 2.68396 | 7.610878 | 8.041137 |
| 660 | 2.81954 | 514 | 2.71096 | 7.643660 | 7.949805 |
| 610 | 2.78533 | 444 | 2.64738 | 7.373826 | 7.758063 |

Table A-7 Continued

| Length mm | log L | Weight gm | log W | log L x log W | $(\log L)^2$ |
|---|---|---|---|---|---|
| 530 | 2.72428 | 330 | 2.51851 | 6.861126 | 7.421701 |
| 670 | 2.82607 | 482 | 2.68306 | 7.582515 | 7.986671 |
| 710 | 2.85126 | 730 | 2.86332 | 8.164069 | 8.129683 |
| 650 | 2.81291 | 432 | 2.63548 | 7.413368 | 7.912462 |
| 690 | 2.83886 | 508 | 2.70586 | 7.681557 | 8.059126 |
| 495 | 2.69461 | 199 | 2.29885 | 6.194504 | 7.260923 |
| 457 | 2.65992 | 142 | 2.15229 | 5.724919 | 7.075174 |
| 419 | 2.62221 | 85 | 1.92942 | 5.059344 | 6.875985 |
| 483 | 2.68396 | 142 | 2.15229 | 5.776660 | 7.203641 |
| 432 | 2.63548 | 85 | 1.92942 | 5.084947 | 6.945754 |
| 483 | 2.68395 | 142 | 2.15229 | 5.776638 | 7.203587 |
| 406 | 2.60853 | 85 | 1.92942 | 5.032949 | 6.804428 |
| 470 | 2.67210 | 114 | 2.05690 | 5.496242 | 7.140118 |
| 394 | 2.59560 | 85 | 1.92942 | 5.008002 | 6.737139 |
| 483 | 2.68396 | 170 | 2.23046 | 5.986465 | 7.203641 |
| 432 | 2.63548 | 114 | 2.05690 | 5.420918 | 6.945754 |
| 559 | 2.74741 | 284 | 2.45332 | 6.740275 | 7.548261 |
| 572 | 2.75740 | 312 | 2.49415 | 6.877369 | 7.603254 |
| 584 | 2.76641 | 340 | 2.53148 | 7.003111 | 7.653024 |
| 635 | 2.80277 | 397 | 2.59879 | 7.283810 | 7.855519 |
| 406 | 2.60853 | 114 | 2.05690 | 5.365485 | 6.804428 |
| 445 | 2.64836 | 113 | 2.05308 | 5.437294 | 7.013810 |
| 394 | 2.59560 | 85 | 1.92942 | 5.008002 | 6.737139 |
| 445 | 2.64836 | 113 | 2.05308 | 5.437294 | 7.013810 |
| 686 | 2.83632 | 624 | 2.79518 | 7.928024 | 8.044711 |
| 483 | 2.68396 | 170 | 2.23046 | 5.986465 | 7.203641 |
| 572 | 2.75740 | 340 | 2.53148 | 6.980302 | 7.603254 |
| 445 | 2.64836 | 114 | 2.05690 | 5.447411 | 7.013810 |
| 457 | 2.65992 | 142 | 2.15229 | 5.724919 | 7.075174 |
| 457 | 2.65992 | 114 | 2.05690 | 5.471189 | 7.075174 |
| 559 | 2.74741 | 312 | 2.49415 | 6.852452 | 7.548261 |

Table A-8: Summary of Table A-7

| | log L | log W | log L x log W | $(\log L)^2$ |
|---|---|---|---|---|
| July Data | Σ= 69.74393 | Σ= 57.30524 | Σ= 154.10499 | Σ= 187.189122 |
| Sept. Data | Σ=142.00412 | Σ= 132.32829 | Σ= 368.955315 | Σ= 395.554674 |
| Combined | Σ=211.74805 | Σ= 189.63353 | Σ= 523.060305 | Σ= 582.743796 |

Table A-9:

Length-Weight Equations

I. *July Data $\log W = -7.81 + 3.733 \log L$

II.*Sept. Data $\log W = -6.123 + 3.131 \log L$

III.Combined $\log W = -7.30 + 3.55 \log L$

* July samples caught in baited pots.

* September samples caught in fyke nets.

Table A-10: CALCULATED VALUES OF WEIGHT FROM THE JULY SAMPLE OF EELS

$$\log W = -7.81 + 3.733 \log L$$

| Length (mm) | log L | log W | Weight (gms) |
|---|---|---|---|
| 200 | 2.30103 | .779744 | |
| 250 | 2.39794 | 1.141510 | 13.9 |
| 300 | 2.47712 | 1.437088 | 27.3 |
| 350 | 2.54407 | 1.687013 | 48.6 |
| 400 | 2.60206 | 1.903489 | 80.8 |
| 450 | 2.65321 | 2.094432 | 124.3 |
| 500 | 2.69897 | 2.265255 | 184.2 |
| 550 | 2.74036 | 2.419763 | 262.9 |
| 600 | 2.77815 | 2.560833 | 363.8 |
| 650 | 2.81291 | 2.690593 | 490.5 |
| 700 | 2.84510 | 2.810758 | 646.8 |
| 750 | 2.87506 | 2.922598 | 836.8 |
| 800 | 2.90309 | 3.027234 | 1106.5 |
| 850 | 2.92942 | 3.125524 | 1133.5 |
| 900 | 2.95424 | 3.218177 | 1165.3 |

Table A-11: CALCULATED VALUES OF WEIGHT FROM THE SEPTEMBER SAMPLE OF EELS

$$\log W = -6.123 + 3.131 \log L$$

| Length (mm) | log L | log W | Weight (gms) |
|---|---|---|---|
| 200 | 2.30103 | 1.081524 | 12.7 |
| 250 | 2.39794 | 1.384950 | 24.2 |
| 300 | 2.47712 | 1.632862 | 42.9 |
| 350 | 2.54407 | 1.842483 | 69.6 |
| 400 | 2.60206 | 2.024049 | 105.7 |
| 450 | 2.65321 | 2.184200 | 152.8 |
| 500 | 2.69897 | 2.327475 | 212.5 |
| 550 | 2.74036 | 2.457067 | 286.5 |
| 600 | 2.77815 | 2.575387 | 359.3 |
| 650 | 2.81291 | 2.684221 | 483.3 |
| 700 | 2.84510 | 2.785008 | 609.6 |
| 750 | 2.87506 | 2.878812 | 756.5 |
| 800 | 2.90309 | 2.966574 | 925.8 |
| 850 | 2.92942 | 3.049014 | 1112.0 |
| 900 | 2.95424 | 3.126725 | 1113.9 |

Table A-12: CALCULATED VALUES OF WEIGHT FROM THE COMBINED SEPTEMBER AND JULY SAMPLES OF EELS

$$\log W = -7.30 + 3.55 \log L$$

| Length (mm) | log L | log W | Weight (gms) |
|---|---|---|---|
| 200 | 2.30103 | 0.868656 | 0.7 |
| 250 | 2.39794 | 1.212687 | 16.3 |
| 300 | 2.47712 | 1.493776 | 31.0 |
| 350 | 2.54407 | 1.731448 | 53.9 |
| 400 | 2.60206 | 1.937313 | 86.6 |
| 450 | 2.65321 | 2.118895 | 154.5 |
| 500 | 2.69897 | 2.281343 | 191.1 |
| 550 | 2.74036 | 2.428278 | 268.1 |
| 600 | 2.77815 | 2.562432 | 365.1 |
| 650 | 2.81291 | 2.685830 | 485.1 |
| 700 | 2.84510 | 2.800105 | 631.1 |
| 750 | 2.87506 | 2.906463 | 806.2 |
| 800 | 2.90309 | 3.005969 | 1101.3 |
| 850 | 2.92942 | 3.099441 | 1125.6 |
| 900 | 2.95424 | 3.187552 | 1154.0 |

## Table A-13: FALL FISHING CATCH DATA, 1973

| FISHERMAN | DATE OF SALE | FISHING LOCATION | NUMBER OF NIGHTS FISHED | NUMBER OF NETS FISHED | CATCH IN LBS. | LBS/NET/NIGHT |
|---|---|---|---|---|---|---|
| A.H. & M.L. | 8-24-73 | Crabbes | 1 | 4 | 633 | 158.3 |
| A.H. & M.L. | 8-27-73 | Crabbes | 3 | 4 | 587 | 48.9 |
| G.C. & W.B. | 8-28-73 | Grand Conroy | 3 | 14 | 334 | 8.0 |
| A.H. & M.L. | 8-29-73 | Crabbes | 2 | 5 | 375 | 37.5 |
| G.C. & W. B. | 8-30-73 | Grand Condroy | 3 | 18 | 229 | 4.3 |
| A.H. & M.L. | 9-01-73 | Crabbes | 3 | 4 | 529 | 44.1 |
| A.H. & M.L. | 9-04-73 | Crabbes | 3 | 4 | 452 | 37.7 |
| A.H. & M.L. | 9-07-73 | Crabbes | 3 | 8 | 1346 | 56.1 |
| A.H. & M.L. | 9-10-73 | Crabbes | 3 | 8 | 1293 | 53.9 |
| A.H. & M.L. | 9-13-73 | Crabbes | 3 | 8 | 665 | 27.7 |
| E.B. | 9-14-73 | Muddy Hole | 5 | 8 | 225 | 5.6 |
| C.B. | 9-14-73 | Muddy Hole | 5 | 13 | 362 | 5.6 |
| A.H. & M.L. | 9-17-73 | Crabbes | 4 | 8 | 189 | 5.9 |
| E.B. | 9-19-73 | Muddy Hole | 5 | 8 | 401 | 10.0 |
| C.B. | 9-19-73 | Muddy Hole | 5 | 13 | 1038 | 16.0 |
| G.C. & W.B. | 9-20-73 | Grand Codroy | 5 | 19 | 361 | 3.8 |
| E.B. | 9-22-73 | Muddy Hole | 3 | 8 | 391 | 16.3 |
| C.B. | 9-22-73 | Muddy Hole | 3 | 13 | 809 | 20.8 |
| G.C. & W.B. | 9-23-73 | Grand Codroy | 3 | 19 | 869 | 15.3 |
| C.B. | 9-23-73 | Muddy Hole | 2 | 13 | 2019 | 77.7 |
| E.B. | 9-23-73 | Muddy Hole | 2 | 8 | 741 | 46.3 |
| A.H. & M.L. | 9-24-73 | Muddy Hole | 7 | 10 | 1410 | 20.2 |
| G.C. & W.B. | 9-26-73 | Grand Codroy | 3 | 19 | 1837 | 32.2 |
| G.C. & W.B. | 9-29-73 | Grand Codroy | 3 | 19 | 915 | 16.1 |
| A.H. & M.L. | 9-29-73 | Muddy Hole | 5 | 10 | 1015 | 20.3 |
| E.B. | 10-01-73 | Muddy Hole | 7 | 8 | 437 | 7.8 |
| C.B. | 10-01-73 | Muddy Hole | 7 | 14 | 341 | 3.5 |
| G.C. & W.B. | 10-03-73 | Grand Codroy | 3 | 19 | 579 | 10.2 |
| E.B. | 10-04-73 | Muddy Hole | 2 | 8 | 366 | 22.9 |

CONTINUED

Table A-13 Continued

| FISHERMAN | DATE OF SALE | FISHING LOCATION | NUMBER OF NIGHTS FISHED | NUMBER OF NETS FISHED | CATCH IN LBS. | LBS/NET/NIGHT |
|---|---|---|---|---|---|---|
| C.B. | 10-04-73 | Muddy Hole | 2 | 15 | 617 | 20.6 |
| G.C. & W.B. | 10-09-73 | Grand Codroy | 5 | 19 | 355 | 3.7 |
| A.H. & M.L. | 10-13-73 | Muddy Hole | 8 | 27 | 858 | 3.8 |
| E.B. | 10-14-73 | Muddy Hole | 9 | 8 | 367 | 5.1 |
| C.B. | 10-14-73 | Muddy Hole | 9 | 15 | 526 | 5.5 |
| A.H. & M.L. | 10-19-73 | Muddy Hole | 6 | 29 | 595 | 3.4 |
| G.C. & W.B. | 10-24-73 | Grand Codroy | 14 | 19 | 277 | 1.1 |
| A.H. & M.L. | 10-21-73 | Muddy Hole | 2 | 27 | 225 | 4.2 |
| E.B. | 10-27-73 | Muddy Hole | 12 | 8 | 329 | 3.4 |
| C.B. | 10-27-73 | Muddy Hole | 12 | 13 | 397 | 2.6 |

Table A-14: MEAN VALUES (WEEKLY) OF LBS/NIGHT/NET BY FISHING LOCATION

| FISHING WEEK | FLAT BAY | GRAND CODROY | CRABBES RIVER |
|---|---|---|---|
| August 3 | | | |
| August 4 | | 6.15 | 81.56 |
| Sept. 1 | | | 45.96 |
| Sept. 2 | 5.60 | | 40.80 |
| Sept. 3 | 15.77 | 3.8 | 5.90 |
| Sept. 4 | 41.12 | 21.20 | ceased fishing |
| Oct, 1 | 13.70 | 10.2 | |
| Oct. 2 | 4.80 | 3.7 | |
| Oct. 3 | 3.80 | 1.1 | |
| Oct. 4 | 3.00 | | |

TABLE A-15: Hourly night observations of eels in Two Guts Pond.

| TIME | NUMBER OF EELS SIGHTED | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | DAY I | DAY II | DAY III | DAY IV | DAY V | DAY VI | DAY VII | TOTAL | NUMBER OF OBS. | MEAN |
| 1700 | 6 | * | 7 | 3 | * | 11 | 6 | 33 | 5 | 6.5 |
| 1800 | 4 | 6 | 5 | 0 | * | 10 | 12 | 37 | 6 | 6.2 |
| 1900 | 11 | 13 | 8 | 6 | 16 | 19 | 19 | 92 | 7 | 13.1 |
| 2000 | 12 | 14 | 7 | 9 | 13 | 16 | 17 | 88 | 7 | 12.6 |
| 2100 | 4 | 11 | * | 11 | 9 | 7 | 16 | 58 | 6 | 9.7 |
| 2200 | 16 | 5 | * | 3 | 18 | 16 | ** | 58 | 5 | 11.6 |
| 2300 | 9 | ** | 6 | 6 | 11 | 13 | ** | 45 | 5 | 9.0 |
| 2400 | 6 | 13 | 2 | 7 | 12 | 14 | 16 | 70 | 7 | 10.0 |
| 0100 | 4 | 8 | 0 | 2 | 9 | 7 | 12 | 42 | 7 | 6.0 |
| 0200 | 2 | 3 | 3 | 4 | 4 | 9 | 9 | 34 | 7 | 4.9 |
| 0300 | 3 | 5 | 1 | 6 | 7 | ** | 11 | 33 | 6 | 5.5 |
| 0400 | 3 | 5 | 3 | 0 | 6 | ** | 6 | 23 | 6 | 3.8 |
| 0500 | * | 7 | 2 | 0 | 11 | ** | 4 | 24 | 5 | 4.8 |
| Weather | clear | cloudy | clear | clear | cloudy | cloudy and rain | cloudy and rain | | | |

* water too choppy

** raining

TABLE A-16: Daily eel activity in Two Guts Pond *

| DAY | TOTAL NUMBER OF EELS CAUGHT AT | | |
|---|---|---|---|
| | 2300-2400 hrs | 0500-0600 hrs | 1600-1700 hrs. |
| 1 | 203 | 76 | 36 |
| 2 | 312 | 179 | 19 |
| 3 | 186 | 43 | 23 |
| 4 | 262 | 57 | 14 |
| 5 | 216 | 71 | 19 |
| 6 | 386 | 87 | 32 |
| 7 | 239 | 153 | 29 |
| TOTAL | 1804 | 666 | 172 |
| MEAN | 257.7 | 95.1 | 24.6 |

* Twenty bailed pots were hauled thrice daily for seven consecutive days.

APPENDIX B

TABLE B-1

Fat Content of Eels, Anguilla Rostrata, from the Stephenville area of Newfoundland, in Per Cent*

| | $X_1$ (broad nose) | $X_2$ (sharp nose) |
|---|---|---|
| | 2.0 | 30.0 |
| | 3.5 | 25.0 |
| | 2.0 | 17.0 |
| | 2.0 | 15.0 |
| | 8.0 | 2.5 |
| | 1.5 | 15.5 |
| | 1.0 | 10.5 |
| | 4.0 | 11.0 |
| | 1.5 | 11.5 |
| | 1.5 | 10.0 |
| | 3.5 | 11.0 |
| | 2.0 | 12.0 |
| | 2.5 | 9.5 |
| | 7.0 | 11.0 |
| | 8.0 | 6.0 |
| | 5.5 | 12.0 |
| | 10.5 | 14.5 |
| | | 10.0 |
| | | 15.0 |
| | | 11.0 |
| | | 11.0 |
| | | 12.0 |
| | | 7.0 |
| | | 6.5 |
| | | 11.0 |
| $\Sigma X$ | 66.0 | 307.5 |
| $\Sigma X^2$ | 387.6 | 4,538.75 |
| $\bar{x}$ | 3.88% | 12.3% |

* Per Cent values were not transformed to arcsin values because of extremely large differences in the $x_1$ and $x_2$.

Table B-2: STUDENT T TEST

$$\Sigma x_1^2 = \Sigma X_1^2 - \frac{(\Sigma X_1)^2}{n_1} = 387.6 - \frac{(66)^2}{17} = 131.6$$

$$\Sigma x_2^2 = \Sigma X_2^2 - \frac{(\Sigma X_2)^2}{n_2} = 4,538.75 - \frac{(307.5)^2}{25} = 756.5$$

$$s^2 = \frac{\Sigma x_1^2 + \Sigma x_2^2}{(n_1-1)+(n_2-1)} = \frac{131.6 + 756.5}{(17-1)+(25-1)} = \frac{888.1}{40} = 22.2,$$ an

estimate of the common $\sigma^2$

$$s_{\bar{d}} = \sqrt{s^2 \frac{(n_1+n_2)}{n_1 \; n_2}} = \sqrt{22.2 \; \frac{(17+25)}{(17+25)}} = \sqrt{22.2 \; (0.0988)}$$

$= \sqrt{2.1936} = 1.48\%$, the standard deviation appropriate to the difference between the sample means

$$t = \frac{\bar{d}}{s_{\bar{d}}} = \frac{3.88 - 12.3}{1.48} = \frac{-8.42}{1.48} = -5.689^{**}; \quad \text{df } 40.$$

For the 95% confidence interval for $\mu_2 - \mu_1$, $\bar{x}_2 - \bar{x}_1 \pm t_{.05} \; s_{\bar{x}_1 - \bar{x}_2}$

$$= -8.42 \pm 2.021 \; (1.48)$$

$$= -.842 \pm 2.991$$

$$l_1 = 5.429\%$$

$$l_2 = 11.411\%$$

APPENDIX C

ANALYSIS OF VARIANCE

Table C-1:
PERCENT FAT CONTENT FOR YELLOW GREEN EELS

| PERCENT FAT | ARCSIN | $x_{ij}^2$ |
|---|---|---|
| 11.0 | 19.4 | 376.4 |
| 12.0 | 20.3 | 412.1 |
| 9.8 | 18.2 | 331.2 |
| 6.4 | 14.7 | 216.1 |
| 9.9 | 18.3 | 334.9 |
| 11.4 | 19.7 | 388.1 |
| 7.6 | 16.0 | 256.0 |
| 4.5 | 12.2 | 148.8 |
| 12.4 | 20.6 | 424.4 |
| 6.3 | 14.5 | 210.3 |
| 7.9 | 16.3 | 265.7 |
| 9.4 | 17.9 | 320.4 |
| 5.6 | 13.4 | 179.6 |
| 6.7 | 15.0 | 225.0 |
| 11.2 | 19.6 | 384.2 |
| 10.0 | 18.4 | 338.6 |
| 9.0 | 17.5 | 306.3 |
| 4.3 | 12.0 | 144.0 |
| 2.1 | 8.3 | 68.9 |
| 6.4 | 14.7 | 216.1 |
| $\Sigma X = 163.9$ <br> $\bar{x} = 8.195$ | $\Sigma X_a = 327.0$ <br> $\bar{x}_a = 16.4$ | $\Sigma x_{ij}^2 = 5,547.1$ |

Table C-2: PERCENT FAT CONTENT FOR YELLOW EELS

| PERCENT FAT | ARCSIN | $x_{ij}^2$ |
|---|---|---|
| 14.1 | 22.1 | 488.4 |
| 12.0 | 20.3 | 412.1 |
| 9.5 | 18.0 | 324.0 |
| 11.0 | 19.4 | 376.4 |
| 9.6 | 18.0 | 324.0 |
| 8.9 | 17.4 | 302.8 |
| 6.4 | 14.7 | 216.1 |
| 11.2 | 19.6 | 384.2 |
| 7.8 | 16.2 | 262.4 |
| 8.9 | 17.4 | 302.8 |
| 11.4 | 19.7 | 388.1 |
| 9.1 | 17.6 | 309.8 |
| 9.0 | 17.5 | 306.3 |
| 12.5 | 20.7 | 428.5 |
| 7.8 | 16.2 | 262.4 |
| 11.1 | 19.5 | 380.3 |
| 4.35 | 12.1 | 146.4 |
| $\Sigma X = 164.65$ | $\Sigma X = 306.4$ | $\Sigma x_{ij}^2 = 5615$ |
| $x = 9.69$ | $\bar{x} = 18.0$ | |

Table G-3: PERCENT FAT CONTENT

FOR BRONZE YELLOW EELS

| PERCENT FAT | ARCSIN | $X_{ij}^2$ |
|---|---|---|
| 10.5 | 18.9 | 357.2 |
| 12.0 | 20.3 | 412.1 |
| 11.4 | 19.7 | 388.1 |
| 14.3 | 22.2 | 492.8 |
| 9.8 | 18.2 | 331.2 |
| 7.9 | 16.3 | 265.7 |
| 9.7 | 18.1 | 327.6 |
| 15.4 | 23.1 | 533.6 |
| 11.4 | 19.7 | 388.1 |
| 12.6 | 20.8 | 432.6 |
| 13.4 | 21.5 | 462.3 |
| 7.1 | 15.5 | 240.3 |
| $\Sigma X$ = 135.5 | $\Sigma X$ = 234.3 | $\Sigma X_{ij}^2$ = 4,631.6 |
| $\bar{X}$ = 11.29 | $\bar{X}$ = 19.5 | |

Table C-4: PERCENT FAT CONTENT

FOR SILVER EELS

| PERCENT FAT | ARCSIN | $x_{ij}^2$ |
|---|---|---|
| 10.0 | 18.4 | 338.6 |
| 11.0 | 19.4 | 376.4 |
| 17.0 | 24.4 | 590.5 |
| 15.0 | 22.8 | 519.8 |
| 15.5 | 23.2 | 538.2 |
| 14.5 | 22.4 | 501.8 |
| 10.0 | 18.4 | 338.7 |
| 15.0 | 22.8 | 519.8 |
| 11.0 | 19.4 | 376.4 |
| 11.5 | 19.8 | 392.0 |
| 11.0 | 19.4 | 376.4 |
| 7.0 | 15.3 | 234.1 |
| 6.5 | 14.8 | 219.0 |
| 12.1 | 20.4 | 416.2 |
| 14.1 | 22.1 | 488.4 |
| $\Sigma x = 181.2$ <br> $\bar{x} = 12.08$ | $\Sigma x = 303.0$ <br> $\bar{x} = \cdot 20.2$ | $\Sigma x_{ij}^2 = 6,226.3$ |

Table C-5: PERCENT FAT CONTENT FOR BRONZE EELS

| PERCENT FAT | ARCSIN | $x_{ij}^2$ |
|---|---|---|
| 30.0 | 33.2 | 1102.2 |
| 25.0 | 30.0 | 900.0 |
| 6.0 | 14.2 | 201.6 |
| 14.6 | 22.5 | 506.3 |
| 11.9 | 20.2 | 408.0 |
| 13.8 | 21.8 | 475.0 |
| 16.4 | 23.9 | 571.2 |
| 17.1 | 24.4 | 595.4 |
| 9.8 | 18.2 | 331.2 |
| 12.4 | 20.6 | 424.4 |
| 16.8 | 24.2 | 585.6 |
| 15.5 | 23.2 | 538.2 |
| 16.8 | 24.2 | 585.6 |
| $\Sigma x$ = 206.1 | $\Sigma x$ = 300.6 | $\Sigma x_{ij}^2$ = 7,224.7 |
| $\bar{x}$ = 15.85 | $\bar{x}$ = 23.1 | |

Table C-6: ANALYSIS OF VARIANCE

$$C = \frac{X^2}{\Sigma r_i}$$

$$= \frac{(1471.3)^2}{77}$$

$$= 28,113.8$$

$$\text{TOTAL SS} = \sum_{ij} X_{ij}^2 - C$$

$$= 29,244.7 - 28,113.3$$

$$= 1,131.4$$

$$\text{TREATMENT SS} = \sum_i \frac{X_i^2}{r_i} - C$$

$$= 28,515 - 28,113.3$$

$$= 401.7$$

ERROR SS = TOTAL SS - TREATMENT SS

$$= 1,131.4 - 401.7$$

$$= 729.7$$

$$F = \frac{\text{LARGER SS}}{\text{SMALLER SS}}$$

$$= 1.8165$$

Table C-7:

SUMMARY OF FAT CONTENT OF FIVE COLOUR TYPES OF *ANGUILLA ROSTRATA*, FROM THE STEPHENVILLE AREA OF NEWFOUNDLAND

| COLOUR | $r_i$ | $\sum_j x_{ij}$ | $\bar{x}_i$ % | $\bar{x}_i$ Arcsin | $\sum_j x^2_{ij}$ | $x_i^2 / r_i$ | $\sum_j x^2_{ij}$ |
|---|---|---|---|---|---|---|---|
| Yellow-Green | 20 | 327.0 | 8.2 | 16.4 | 5,547.1 | 5,346.5 | 200.6 |
| Yellow | 17 | 306.4 | 9.7 | 18.0 | 5,615.0 | 5,522.4 | 92.6 |
| Bronze-Yellow | 12 | 234.3 | 11.3 | 19.5 | 4,631.6 | 4,574.7 | 56.9 |
| Bronze | 13 | 300.6 | 15.9 | 23.1 | 7,224.7 | 6,950.8 | 273.9 |
| Silver | 15 | 303.0 | 12.1 | 20.2 | 6,226.3 | 6,120.6 | 105.7 |
| TOTALS | 77 | 1,471.3 | $\bar{x}$ = 11.44 | $\bar{x}$ = 19.44 | 29,244.7 | 28,515.0 | 729.7 |

Table C-8:

ANALYSIS OF VARIANCE OF THE DATA SUMMARIZED IN TABLE C-7

| SOURCE OF VARIATION | df. | SS | MS | F |
|---|---|---|---|---|
| Among Colors | 4 | 401.7 | 100.425 | 9.91 |
| Within Colors | 72 | 729.7 | 10.14 | |
| TOTALS | 76 | 1,131.4 | | |

**Tables C-9, 10, 11:** DUNCAN'S MULTIPLE RANGE TEST (UNEQUAL OBSERVATIONS)

STANDARD DEVIATION = 3.18434

| VALUE OF | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Intermediate Significant Ranges | 8.98301 | 9.46066 | 9.77910 | 9.9771 |

MULTIPLIERS

| | Yellow Green | Yellow | Bronze Yellow | Silver | Bronze |
|---|---|---|---|---|---|
| Yellow Green | | 0.23326 | 0.25820 | 0.24152 | 0.25192 |
| Yellow | | | 0.26610 | 0.25049 | 0.26053 |
| Bronze Yellow | | | | 0.27386 | 0.28307 |
| Silver | | | | | 0.26795 |

LEAST SIGNIFICANT RANGES (MULTIPLIERS X INTERMEDIATE SIGN.RANGES)

| | Yellow Green | Yellow | Bronze Yellow | Silver | Bronze |
|---|---|---|---|---|---|
| Yellow Green | | 2.10 | 2.44 | 2.36 | 2.51 |
| Yellow | | | 2.39 | 2.37 | 2.55 |
| Bronze Yellow | | | | 2.46 | 2.68 |
| Silver | | | | | 2.41 |

Table C-12: RANKED MEANS OF PERCENT FAT CONTENT

| Means | Yellow Green | Yellow | Bronze Yellow | Silver | Bronze |
|---|---|---|---|---|---|
| ARCSIN | 16.4 | 18.0 | 19.5 | 20.2 | 23.1 |
| PERCENT | 8.2 | 9.7 | 11.3 | 12.1 | 15.9 |

Table C-13:

TEST OF DIFFERENCES

| | | | | |
|---|---|---|---|---|
| B - YG | = 23.1 - 16.4 | = 6.7 > 2.51 | ; | significant |
| B - Y | = 23.1 - 18.0 | = 5.1 > 2.55 | ; | " |
| B - BY | = 23.1 - 19.5 | = 3.6 > 2.68 | ; | " |
| B - S | = 23.1 - 20.2 | = 2.9 > 2.41 | ; | " |
| S - YG | = 20.2 - 16.4 | = 3.8 > 2.36 | ; | significant |
| S - Y | = 20.2 - 18.0 | = 2.2 < 2.37 | ; | not significant |
| S - BY | = 20.2 - 19.5 | = .7 < 2.46 | ; | " " |
| BY - YG | = 19.5 - 16.4 | = 3.1 > 2.44 | ; | significant |
| BY - Y | = 19.5 - 18.0 | = 1.5 < 2.39 | ; | not significant |
| Y - YG | = 18.0 - 16.4 | = 1.6 < 2.10 | ; | not significant |