A CONTRIBUTION TO THE BIOLOGY OF THE AMERICAN EEL (ANGUILLA ROSTRATA (LESUEUR)) IN CERTAIN AREAS OF NEWFOUNDLAND

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A CONTRIBUTION TO THE BIOLOGY OF THE AMERICAN EEL (*ANGUILLA ROSTRATA* (LESUEUR)) IN CERTAIN AREAS OF NEWFOUNDLAND

by

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ABSTRACT

Some aspects of the growth, relative growth, sex differentiation and distribution and stomach contents were investigated in the American eel in brackish water and freshwater environments from four different areas in Newfoundland. Some aspects of the silver or migrating stage of the American eel were also studied.

The growth of young eels was slow, especially in brackish water habitats. However, as the eels became older, their growth rate improved. The fastest growth was observed in eels from Burnt Berry Brook, followed by those from Indian Pond, Topsail Barachois and Main Brook.

The data on relative growth indicate that differences occur in the growth of certain body parts between brackish and freshwater populations of eels. Bertin's hypothesis on broad-nosed and sharp-nosed eels, however, does not appear to apply to the eels studied in the present investigation.

An abnormal sex ratio was present in eel populations studied in Newfoundland. Females were universal in their distribution throughout the sampling areas, however, only one male was observed.

The food taken by eels in the present investigation varied considerably between brackish water and freshwater habitats. Clams, shrimp, gammarids, brittle stars, adult dragonflies, fish eggs,

sticklebacks, and eels were present in the stomachs of eels in brackish water. Adult dragonflies, dragonfly nymphs, adult mayflies, adult hemipterans, beetle pupae, adult beetles, dipteran larvae, adult dipterans, stonefly nymphs, freshwater snails, freshwater clams, salmonid eggs, salmonids, and eels were present in the stomachs of eels in fresh water.

The migrating eels examined in this study exhibited characteristics typical of the silver eel described by European authors. Data on color, body measurements, internal changes and state of maturity as determined by ova diameters would seem to indicate that they approach the condition observed in the European eel prior to its migration to sea.

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I. INTRODUCTION

Aspects of the biology of the American eel, *Anguilla rostrata* (LeSueur), has depended in many cases on assumed similarities to its close relative, the European eel, *Anguilla anguilla* (L.). Despite its abundance along the eastern coast of the United States and Canada, details of its biology have been very little studied. This is particularly true in Newfoundland and the object of this thesis is to make a contribution to certain aspects of its biology.

A. Growth Studies

The American eel is not exploited commercially to any significant degree in Newfoundland; thus the eels in this study represent populations under natural conditions and growth patterns are not complicated by fishing pressure. Studies of growth in the American eel are rare; the only detailed study which appears in the literature is that by Smith and Saunders (1955). In contrast, the European eel has been studied extensively by Gemzoe (1908), Schneider (1909), Bellini (1907, 1910), Ehrenbaum and Marukawa (1913), Wundsch (1916), Marcus (1919), Hornyold (1922), Jespersen (1926), Tesch (1928), Frost (1945), Bertin (1956), Deelder (1957) and Sinha (1967b).

Food items are ingested by an organism and are utilized to build up new organic material. If catabolism is not as great as anabolism, the organism must get larger and this is referred to as growth i.e. an increase in size over a period of time. Such a definition requires a method for age determination so that the time taken to reach a certain size will be known.

Several methods of age determination have been used in fish: length-frequency or Petersen's method; tagging and recovery; interpretation of layers laid down in the hard parts of fish such as vertebrae, otoliths, spines, rays and opercular bones, and the scale method. Details of these methods are found in Bertalanffy (1949); Lagler (1952), and May (1965).

Of these methods of age determination, only the scale method, and the otoliths have been used for aging purposes in the eel. Gemzoe (1908) was the first to use the scale method for age determination in the study of growth in eels. He showed that the concentric zones or rings in the scales are laid down annually, however, he erred in assuming that the scale appeared in the third year of freshwater life in all eels. Ehrenbaum and Marukawa (1913) and Marcus (1919) showed that the time of formation of the scales depended on the length of an individual and not on age. The length at which the scales appeared was termed 'scale size' by Tesch (1928).

Smith and Saunders (1955) found a similar condition in the American eel. In order to determine 'scale size' they took skin specimens containing embedded scales from an area above the lateral line at mid-length on the eel. Ten scales were loosened from this specimen and were either mounted in glycerin jelly or moistened with aerosol and read immediately. The majority of eels in their study attained 'scale size' during their third or fourth year of life. Thus in order to determine the true age of the fish, three was added to the maximum number of rings which appeared on the scales. Age readings by Smith and Saunders (1955) include the sea life of the leptocephalus, and glass eel as well as its life in freshwater.

Several difficulties arise when using the scale method for age determination in eels:

1. Scales from a specific area on an individual do not always exhibit the same number of annual rings (Frost, 1945; Smith and Saunders, 1955). Scales are laid down over a number of years and the variation in the number of annual rings in old fish is sometimes high (Smith and Saunders, 1955). Even if the maximum number of annual rings is used, there is still the possibility that none of the scales read showed the true maximum.

2. Scales taken from different areas on the same fish show different numbers of annual zones even when the maximum number of rings is used (Smith and Saunders, 1955).

3. In some years, zones or platelets are not laid down on the scales of slow-growing individuals (Marcus, 1919).

4. The time of appearance of the scales varies with locality and growth rate.

Thus, the scale method for age determination is complicated and it is doubtful if it can be accepted as an accurate indicator of age.

In the present investigation, otoliths were used for age determination. This method has been used in most studies on growth in the European eel (Ehrenbaum and Marukawa, 1913; Wundsch, 1916; Marcus, 1919; Hornyold, 1922; Jespersen, 1926; Tesch, 1928; Frost, 1945; Deelder, 1957; and Sinha, 1967b). Otoliths have not previously been used for age determination in the American eel. Concentric zones are laid down in the otolith of the American eel as in the European eel. During the summer (June to October) an opaque or white ring is laid down, and during the succeeding winter period, a transparent or black ring is formed. The technique used in otolith age readings is described in detail in section II of this dissertation. In this investigation comparisons of growth between eels in brackish water and freshwater were made.

B. <u>Relative Growth Studies</u>

The comparison of different populations using regression analysis of original data is a useful tool in studying relative growth (Marr, 1955). If analysis of variance techniques are applied to these regressions, statistical comparisons of the differences between populations can be made. This approach has been utilized by several authors, namely, Mottley (1941), Martin (1949), Svärdson (1950), Marr (1955), McCart (1965), and others.

It has been reported that in both the European and American eel, two types are present in adult populations (Vladykov, 1955; Bertin, 1956).

One type is known as the sharp-nosed eel and has a narrow head; the other is called the broad-nosed eel and has a wider head. The broad-nosed type has been described as having a short blunt muzzle, more or less depressed, with eyes and nostrils placed farther apart, and with a more pronounced lower lip than the sharp-nosed type (Bertin, 1956). These two types have created problems in classification, however, they are considered to be the same species. Bertin (1956) suggested that the differences observed between these individuals were due to environmental effects. The present work was undertaken to determine whether any differences did occur with regard to the shape of the head and several other body parts between populations in brackish water and freshwater.

C. Sex Differentiation and Distribution

Sex distribution in the American eel has been studied by Huver (1966) and Vladykov (1966). Their studies have shown that the geographical distribution of eels is not based on sex as suggested for the European eel by Bertin (1956) and others. This hypothesis states that males occur in salt water and estuarine locations; as one moves away from the sea the percentage of females increases. Exceptions to this hypothesis for the European eel do appear in the literature, noteably, Hornyold (1932), Tesch (1928), Sinha (1966) and others.

With regard to the American eel, this hypothesis as stated previously does not appear to apply. Bigelow and Schroeder (1953) suggested that because large eels were found in salt marshes, females were probably present in such environments. Huver (1966) found that although the organ of Syrski appeared as an immature testis histologically, it later develops into an ovary with an increase in size in the animal. He found that of 124 brackish water eels examined, all were female. Histological examination of 259 freshwater eels showed that 230 were female and 29 possessed the organ of Syrski. Huver (1966) concluded that the law of geographical distribution of eel sex as generally stated does not apply to the American eel. Vladykov (1966) studied the sex distribution of 1500 adult American eels from 31 different areas from Trinidad to Newfoundland. His data indicated that 6-10% of the eel population from Newfoundland to Massachusetts were male; in New York, 33% of the population were males and still a higher percentage of the population farther south was male. Vladykov (1966) reported that males, where present, were found almost exclusively in salt or brackish water while females were found principally in freshwater but were also present in brackish and salt water. The only exception to this pattern was at Crecy Lake, New Brunswick, where 26 of 31 specimens taken were males.

The unusual distribution of sexes as reported by Vladykov (1966) and Huver (1966) indicates that an abnormal sex ratio exists in certain areas. Vladykov (1966) suggested that males predominate in the southern part of the range. He suggested that this distribution was closely correlated with the size distribution of elvers which enter streams in these areas. While this explanation may apply, the reasons for the sex distribution reported by Huver (1966) and Vladykov (1966) remain unproven.

Sex determination in eels has been suggested to be either (a) syngamic, i.e. male and female elvers move up from the estuary and choose a habitat suitable to their sex, or
(b) metagamic, i.e. all elvers on arrival in the river are asexual and disperse in a random manner, sex being determimed by the environment in which the eels live. Syngamic distribution would imply that elvers, male and female, choose a habitat suitable to their sex and consequently move either upstream or remain in brackish or salt water. This view is taken by D'Ancona (1959) who suggested that the presence of a large proportion of males in some places and females in another was possibly due to differences in the migratory habits of the two sexes in the elver stage, but also due in part to the influence of the environment. He concluded that sex determination in the eel was genetic, but varied from a more marked feminity to a more marked masculinity which could be influenced by the environment. Sinha (1966) suggested that the sex of the elver was predetermined as they reached littoral areas and that its subsequent distribution was random as the eels grow. He further suggested that since females are larger, they have grown faster and have tended to move upstream out of crowded waters whereas most males have been content to remain near the river mouths or the sea.

Bertin (1956) suggested "that metagamic distribution of sex is very nearly the general rule, however, a certain number are determined syngamically". He attributed the metagamic determination of eels to the presence of an unstable sex chromosome in a certain percentage of eels. A sex change due to environmental conditions has been reported by several European authors. Tesch (1928) transplanted 80 young eels (20-25 cms.) from the Zuiderzee (salt water - where females were reported to be rare) to a concrete tank filled with running freshwater. After one year, 21 were examined and had the typical organ of Syrski or testis. After two years, the 14 eels which were left were examined and found to have ovaries. A similar sex change after transplantation was reported by Hornyold (1932). In both of these experiments no histological controls were used and migrations within the population were not considered. Thus, the results of these experiments were not conclusive (Sinha, 1966). Overcrowding in certain habitats was also reported to bring about a change in sex. Fidora reported that females were less common than males in areas of crowding, the opposite being the case in sparsely populated areas (Sinha, 1966).

The present investigation was initiated in order to test the hypothesis outlined by Bertin (1956) for the European eel. Since very little attention has been focused on this aspect of the life history of the American eel this study was intended to add information to the available data.

D. Studies on Stomach Analysis

Although several authors have reported that the presence of the American eel in our waters represents a considerable loss of organic matter to the environment (Smith and Saunders, 1955; Smith, 1966; A Murray, pers comm), few attempts have been made to study in detail the food items actually taken from the environment by eels. No comparison of their diet with that of other fish in their environment or correlation of their diet with a quantitative survey of available food in the environment appears in the literature.

Studies on the food of the American eel have usually been correlated with their predatory relationship on the eggs, fry and parr stages of salmonids (Smith, 1948, 1952a, 1956; Elson, 1940, 1941; Godfrey, 1957). Godfrey (1957) found that eels were capable of causing important losses of salmonids during the spring and summer, however, he suggested that other factors in the environment affected the survival rate of salmonids as much as the American eel. Other studies on the food of the American eel were done by Brinley and Bowen (1935), and Perlmutter (1951).

The food of the European eel has been studied in detail by several authors (Hartley, 1940, 1948; Frost, 1946; Bertin, 1956; Thomas, 1962; Sinha, 1967a and others). Studies on the predatory relationship of the European eel on salmonids has been studied by Malloch (1910), Beddington (1951), Frost (1952), Vibert (1956), Piggins (1958), Gibson (1959), Dawson (1960), Jones and Evans (1960, 1962), Allen (1961) and Sinha (1965).

Although several studies have been carried out on the food of the American eel, none have dealt specifically with food items taken by eels in brackish water. Thus, in the present investigation an attempt was made to study the food items taken by eels in Newfoundland in brackish water and freshwater habitats.

E. Studies on the Silver Eel

Very little attention has been devoted to this stage in the life history of the American eel. It has been mentioned in the literature by Meek (1916), Bigelow and Welsh (1925), Bigelow and Schroeder (1953), Smith and Saunders (1955) and Vladykov (1955). The corresponding stage of maturity (also called the silver eel) in the European eel has been described in detail by Frost (1945), Svärdson (1949a), Rasmussen (1952), Bertin (1956) and others. Thus, as in many other aspects of the biology of the American eel, relatively little information is available in the literature.

Vladykov (1955) termed this stage in the development of the American eel, the bronze eel. He described it as a mature eel "with a sombre livery but having metallic reflections of bronze or purple", and "in addition to the colour, this difference that the eyes of the silver eel (European eel) are already much larger whereas they are still small in the bronze eel" (Vladykov, 1955, p. 4). Smith and Saunders (1955) noted several gradations of coloration in the fall migration of eels from Gibson Lake. They found no enlargement of the eyes or change in the head configuration that have been noted to characterize maturity in the European eel and they concluded, "Apparently the changes peculiar to maturity were only beginning to be manifest among the eels leaving Gibson Lake" (Smith and Saunders, 1955, p. 264).

In contrast to these observations are those of Bigelow and Welsh (1925) who stated that the transformation of the American eel into a silver eel was similar to that of the European eel as described by Frost (1945), "The dorsal surface of the fish is now a bronzy-black or dark brown and the belly milky white or silver. The head of the silver eel looks narrower and the snout, more pointed than in the yellow eel and the eyes are definitely larger." Because of the scanty material available on the silver stage of the American eel and the above conflicting views on its migratory dress, this study was undertaken, with the purpose of documenting some of the changes which occur in the appearance of the eel in Newfoundland prior to its seaward migration.

F. Description of the Sampling Areas

The sampling areas chosen for this investigation were Indian Pond, Topsail Barachois, Topsail Pond, Burnt Berry Brook and Main Brook; their geographical position is shown in Figure 1. These areas were selected on the basis of their geographical location and their suitability for studies on brackish water and freshwater populations of the American eel.

Indian Pond and Topsail Barachois were selected because they represented two brackish water areas having a resident population of eels. Indian Pond is a large, deep pond whereas Topsail Barachois is much smaller and shallower; both are connected to the sea by a small stream. Details of these areas are shown in Table 1.

Figure 1. Geographical position of each study area.

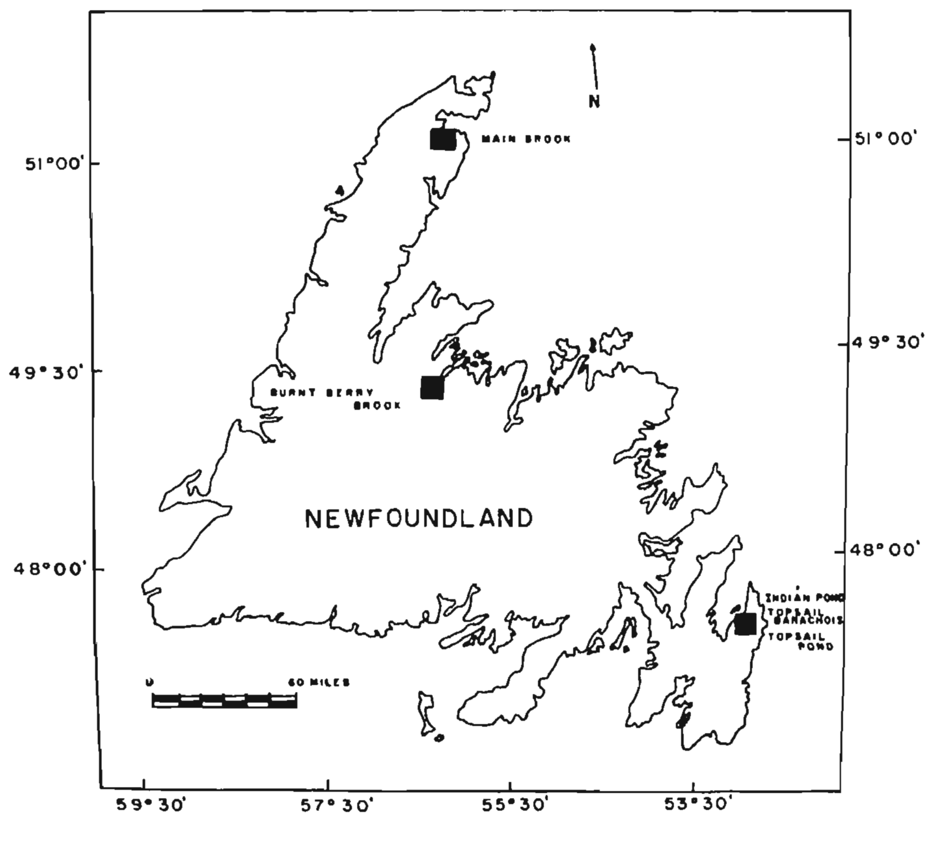

N
MAIN BROOK
51°00'
51°00'
49°30'
49°30'
BURNT BERRY BROOK
NEWFOUNDLAND
48°00'
48°00'
INDIAN POND
TOPSAIL BARACHOIS
TOPSAIL POND
0
60 MILES
59°30'
57°30'
55°30'
53°30'

Table 1. Details of the five areas sampled in this study.

Date	Location	Method of Capture	Mean Water Temperature °C	Mean pH	Mean Salinity ‰	Mean Dissolved Oxygen(ppm)	Number of specimens
June 12 - 16, 1967	Indian Pond	Eel pots	14.4	6.9	2.1	8.7	75
July 14- 16, 1967	Topsail Barachois	Eel pots	19.2	6.3	4.2	8.1	135
August 14 - 19, 1967	Topsail Pond	Fyke net	22.5	6.4	.03	10.4	92
July - August 1967	Burnt Berry Brook	Electrofishing					66
May 25, 1968	Main Brook	Smolt trap	10.0				38

Topsail Pond is a deep, freshwater pond about 13 miles from St. John's. It is part of the Topsail River system which drains several small ponds in the area and enters Topsail Barachois. The outlet to Topsail Pond is situated in the northeast corner and consists of a man-made channel about 8 feet wide leading to a dam and pump house. This sampling area was selected because of the suitability of this channel in capturing silver eels. Further details of this site are found in Table 1.

Burnt Berry Brook is a small freshwater stream located centrally in Newfoundland. Its geographical location was important, particularly, in studies on growth. Main Brook is the most northerly station and is located in Hare Bay on the Great Northern Peninsula. It is a rapid freshwater stream on which the Federal Department of Fisheries maintains a smolt trap. Some details of these areas appear in Table 1.

II. MATERIALS AND METHODS

A. Sampling Methods

a. Eel Pots

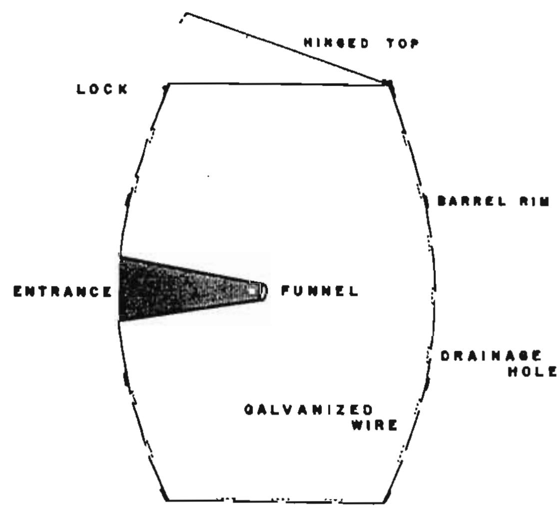
Although attempts have been made to produce eel pots on a commercial scale (Mohr, 1962), for the most part they are varied in design and remain a task for the imagination of the fisherman. The type of eel pot used in this study was constructed from a fifteen gallon wooden barrel and is shown in Figure 2. Twenty eel pots of this type were used during the sampling period. When in use the pots were ballasted with stones, baited, and allowed to sink to the bottom. Once they were sitting in an upright position on the bottom, a float was attached to mark its position.

b. Modified Fyke Net

The modified fyke net was constructed to fit the narrow channel leading from Topsail Pond. From each bank of the channel a lead net of 3/8" mesh was sewn to the fyke net proper. This net was approximately eight feet long on each side and six feet deep. Rocks were placed along the bottom of the lead net to keep it from floating upward which would create openings.

The mouth of the fyke net was situated in the center of the channel; the diameter of its opening was six feet. The fyke net was twenty feet long and tapered to three inches at the 'cod' end. About four feet from the 'cod' end, a second and very much smaller fyke net was knitted to

Figure 2. An eel pot of the type used at Topsail Barachois and Indian Pond.


HINGED TOP
LOCK
BARREL RIM
ENTRANCE
FUNNEL
DRAINAGE
HOLE
GALVANIZED
WIRE

the outside of the 'cod' end. The stainless steel rim of the second net was twelve inches in diameter and kept the 'cod' end of the first net open so that eels could pass through the three inch opening into the second part of the fyke net. The second net or bag net extended about five feet beyond the 'cod' end of the first net. The end of this bag net was tied securely and an anchor was attached; a shore line led from the end of the bag net to a tree on shore. This method was used to catch migrating or silver eels leaving Topsail Pond in the fall (Figure 3).

c. Electrofishing

Electrofishing was carried out using 350 volts of pulsed D.C. at 0.5 amperes. This method was used by the Federal Department of Fisheries at Burnt Berry Brook, Halls Bay.

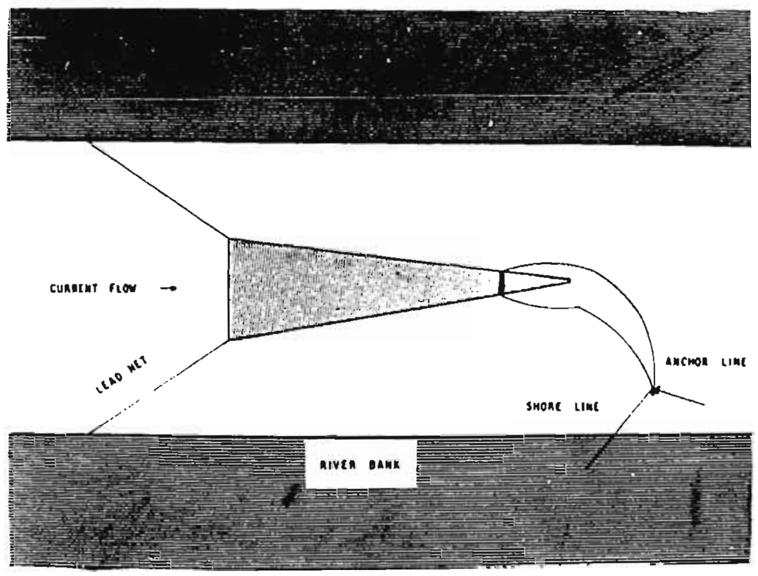
B. Measurements

All specimens collected in this investigation were examined for length and weight immediately on return from the field. The specimens were then deep frozen and body measurements were taken later, usually within one month of capture. Specimens from Burnt Berry Brook and Main Brook were preserved initially in 5% formalin but changed to 70% alcohol after not more than two weeks. Correction factors were not applied to any of these measurements.

(i) Total length was measured from the tip of the lower jaw to the end of the caudal fin.

(ii) Weight was measured to the nearest gram on a Fisher Scientific balance.

Figure 3. The modified fyke net used at Topsail Pond.



CURRENT FLOW
LEAD NET
ANCHOR LINE
SHORE LINE
RIVER BANK

(iii) Predorsal length was measured from the tip of the snout to the origin of the dorsal fin.

(iv) Preanal length (X') was measured from the tip of the snout to the anterior margin of the anus.

(v) Preanal length (X) was measured from the tip of the lower jaw to the anterior margin of the anus.

(vi) Preanal length without the head was measured from the dorsal margin of the opercular opening to the anterior margin of the anus.

(vii) The width of the snout anterior to the eye was measured as the greatest fleshy width at the anterior border of the eyes.

(viii) Head length was measured from the tip of the snout to the dorsal margin of the opercular opening.

(ix) Post-orbital head length was measured from the posterior border of the orbit to the dorsal margin of the opercular opening.

(x) Width of the snout at the level of the nares was measured as the greatest horizontal distance across the snout in this region.

(xi) Snout length was measured from the tip of the snout to the anterior border of the orbit.

(xii) Orbital length was measured as the distance between the anterior and posterior borders of the orbit.

(xiii) Interorbital width was measured as the least fleshy width taken from the most dorsal border of the orbit to a corresponding point on the opposite side.

(xiv) Pectoral length was measured from the anterior margin of the pectoral fin to the tip of the longest pectoral ray.

(xv) Body width was measured as the greatest horizontal distance between each side of the body at the level of the origin of the dorsal fin.

(xvi) Body depth was measured as the greatest vertical distance through the body at the level of the origin of the dorsal fin.

(xvii) Height of dorsal fin was measured from the dorsal part of the body to the tip of the dorsal fin rays, one inch posterior to the origin of the dorsal fin.

(xviii) Height of anal fin was measured as the distance from the ventral body surface to the tip of the outstretched anal rays, one inch posterior to the origin of the anal fin.

(xix) Head depth was measured as the greatest vertical depth through the head at the level of the opercular openings.

(xx) Head width was measured as the greatest horizontal distance across the head at the level of the opercular openings.

(xxi) Sub-orbital width was measured as the vertical distance from the ventral border of the orbit to the ventral border of the maxilla.

(xxii) Body girth was measured as the distance around the circumference of the body at the origin of the dorsal fin. All body measurements except body girth were taken by means of either 9" or 30" adjustable dividers. These distances were determined to the nearest millimeter.

C. Age Determination

Ehrenbaum and Marukawa (1913) were the first to recommend the use of the otolith (sagitta) for the determination of age in the European eel. Since they are more accurate indicators of age than scales, this method has been adopted for the determination of age in the present investigation.

The otoliths appear as small whitish bodies, convex, with a deep groove on one face and concave on the other. They were dissected from each fish by first removing the skin, muscle and bone from the dorsal region of the head immediately posterior to the eyes. The brain was removed exposing the otoliths in each otic capsule. These were removed, cleaned in alcohol and placed in labelled envelopes.

The technique of grinding eel otoliths for age determination as described by Sinha (1967b) was not utilized in this study because of the difficulty in adjusting the dilution of hydrochloric acid. It was found that the rings became clear faster with this method, however, often the acid attacked the edges of the otolith making them unreadable. Instead, only water was used on the otolith;

the technique is described in detail below.

The otoliths were placed in distilled water for about one minute. The convex side was then ground slowly by hand on a wet, fine carborundum stone. The otolith was checked frequently using reflected light on a black background under the binocular microscope to observe the appearance of the rings. The reflected light was adjusted so that the angle and intensity showed the ring pattern best. When the rings showed up clearly, the age was determined and tabulated on the envelope. Both otoliths were treated in the same way for age determination. Only reflected light was used in determining the annual rings on the otolith.

D. Interpretation of the Otoliths and Time of Ring Formation

a. Elver Otoliths

Elver otoliths were removed from pigmented elvers captured at Topsail Hydro Station, 50 yards upstream in freshwater. They were examined using reflected light on a black background at a magnification of 50 x.

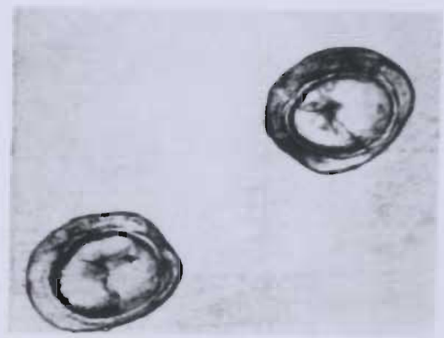
The focus of the sagitta appears as a white dot and is surrounded by a wide black ring. Although the small white dot is sometimes present in the otolith of the elvers of the European eel, Sinha (1967b) refers to this whole area as a black center. A distinct, thin white ring completely surrounds this central area. Following this is a black ring of varying widths which may be incomplete in certain areas. A thick white ring appears outside this, around the whole circumference of the otolith. Around the periphery on about 1/3 of the circumference of the otolith is a black ring; this is difficult to detect because it is thin and refraction of light along the edge makes it appear white in some areas where the transparent or black ring is thin. During the succeeding June to October or November a white or opaque ring appears outside the elver center; this, together with the transparent or black ring which is laid down during the winter make up the first year in freshwater. In determining age in this study, only the life in freshwater is considered and the elver center is ignored for aging purposes (Figure 4).

b. Adult Otoliths

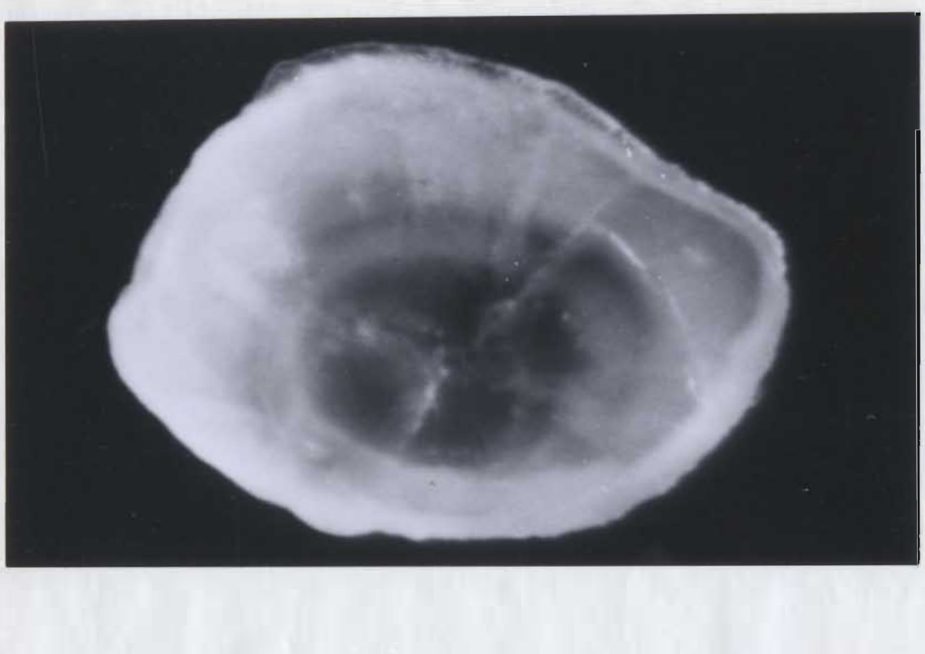
The white or opaque ring first appears in late June at Topsail Barachois and is wider in mid-July. The otoliths from Indian Pond showed the beginnings of the opaque ring in mid-June. Only slight evidence of the beginning of formation of the opaque ring appears on the otoliths taken from Main Brook in June. The otoliths from the Burnt Berry Brook sample all had well established white rings along the edge of the otolith. Although it is difficult to establish the exact time of formation of the white ring on the otolith, it appears that it is formed in early June when the water temperature reaches 10-12 degrees centigrade and eels become active. It is not known when the transparent or black ring

Figure 4. Elver otoliths under different illumination. (a)Taken from Sinha (1967b); under reflected light. (b) Taken from Sinha (1967b); under transmitted light. (c) Taken from elvers moving upstream at Topsail Hydro Station (x50), under reflected light.

(a)



(b)



(c)

appears on the otolith in any of the sampling areas. The last sampling date was in late August and the otoliths of these eels showed no evidence of this black ring. Sinha (1967b) indicated that the formation of the transparent or black ring in the European species started in December. Temperatures drop sharply in late October in Newfoundland and it is possible that growth ceases thereafter. Thus, the black ring may be formed in late October or November in eels in Newfoundland. Figure 5 shows the interpretation of age in some otoliths studied.

c. Multiple Bands

Interpretation of otoliths, especially in the older age groups, is sometimes difficult. This is complicated by the presence of multiple bands or rings. However, the otoliths of eels from one locality usually have a similar ring pattern and if an otolith showed multiple bands it was compared with others from the same area and quite accurate estimates of age could be made.

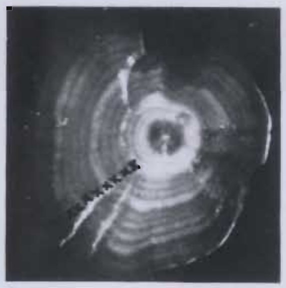
d. Definition of Age Groups

Elvers begin to move upstream at Topsail Barachois by mid-July, while at Seal Cove near Indian Pond, the run begins in early July. However, rather than use an arbitrary date of arrival of the elvers in freshwater in defining age groups, one year in freshwater is defined as one summer's growth period plus

Figure 5. Adult otoliths showing: (a) one summer ring (x32), (b) six summer rings (x32), (c) nine summer rings (x32), (d) seventeen summer rings (x24); taken from Sinha (1967b). Adult otoliths taken from Topsail Barachois showing: (e) eleven summer rings, (f) twelve summer rings.

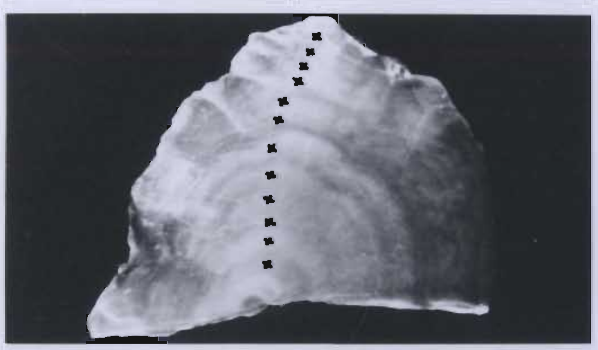
(a)

(b)

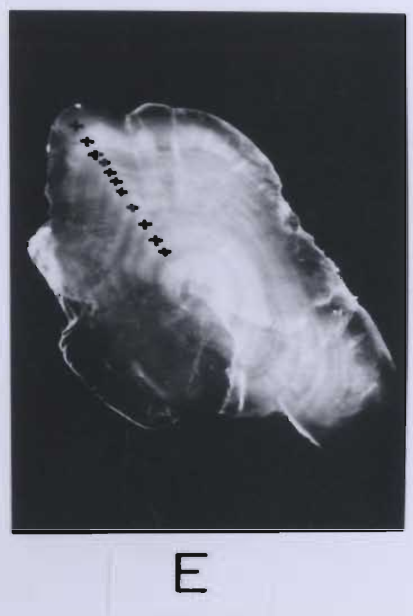


(c)

(d)



F



E

one winter's growth period. Since most of the otoliths showed the formation of the opaque ring around the periphery, this indicated that the previous winter's growth ring was complete. Thus, in establishing age groups in the five areas studied it was only necessary to count the opaque or summer rings starting at the first summer in freshwater; the peripheral opaque ring was not counted since it had not completed (i.e. not even started) its succeeding winter's growth. This method of aging is similar to the method used by Sinha (1967b) however, the opaque ring is laid down in June instead of July as for the European eel studied by Sinha (1967b). This is important since fish caught in June will be one year older according to the present results as compared to Sinha (1967b). To illustrate this, an elver which arrived in May 1964 would be placed by Sinha (1967b) in age-group III if caught in June 1968 but in age-group IV if caught in July 1968. In the present results it would be placed in age-group IV in both cases since the summer ring appears in June. Table 2 is taken from Sinha (1967b, p. 105, Table III) in order to compare different methods of age grouping.

E. Statistical Methods

The details of the computer programs used in this study are found in the appendix of this dissertation.

Table 2. Comparison of age groups used by different authors.

Age Group	0	I	II	III	IV
Ehrenbaum and Marukawa, 1913	I	II	III	IV	V
Frost, 1945	I	II	III	IV	V
June, 1968	W + S + W + S + W + S + W + S + W				
Marcus, 1919	I	II	III		IV
Wundsch, 1916	I	II	III		IV
Tesch, 1928	I	II	III		IV
Sinha, 1967	0	I	II		III
Present Study	0	I	II		III

a. Growth Studies

The original data on age and length have been fitted to the straight line regression, $Y = A + BX$, where A and B are constants and X = age, by the method of least squares. The values for slope (B), intercept (A), correlation coefficient (R) and standard error (SE) have been calculated for the age-length relationship. The age-weight and length-weight relationships were calculated using the equation $Y = AX^{b}$.

b. Relative Growth Studies

All body measurements used in this study were plotted against total length using the straight line regression $Y = A + BX$. The values for slope (B), intercept (A), correlation coefficient (R) and standard error (SE) have been calculated.

c. Analysis of Variance

The slopes of the regression lines used in growth and relative growth studies have been compared using an F test at the 99% and 95% level of significance.

F. Histological Techniques

a. Gonad tissue was removed from each specimen by making a longitudinal incision along the body wall at the point of attachment of the gonad to the body wall. After the tissue was embedded, 10μ sections of the tissue were placed on slides and stained by (a) haemotoxylin-eosin, and (b) the Mallory triple stain (Pantin, 1964).

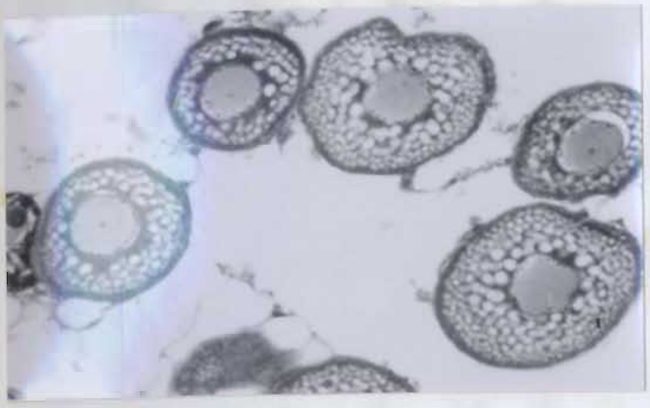
b. Identification of the Sexes

The female gonad was described by Mondini in 1777, and in 1874, Syrski described the male gonad (Bertin, 1956). The descriptions of these gonads as given by Bertin (1956) indicate that macroscopically the ovary is a wide, frilled, ribbon-like structure, while the testis is a narrow, lobed or deeply scalloped organ running the length of the body cavity ventral to the kidney. Although many investigators have used the macroscopic aspect of the gonad in differentiating sexes, Sinha (1966) reported that this method was not always reliable. In fact, Sinha (1966) found that 7% of the 200 lobed organs he examined histologically contained oocytes. It is doubtful, that macroscopic observation of the gonad is accurate enough to be used for sexing and it was not employed in this study.

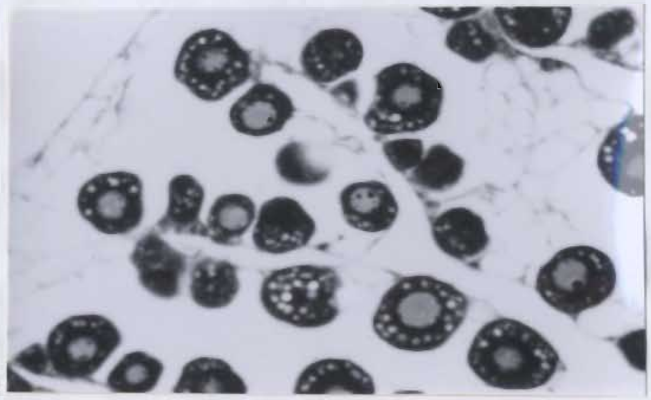
Females were identified by the presence of oocytes in the gonad as shown in Figure 6 and by the large amount of fat present in the ovary. Generally, females were not difficult to identify, however, a few specimens were immature and presented problems in identification. These were classified as immature females since a considerable amount of fat was present and the dark staining cells resembled oocytes both in size and position around the periphery of the gonad.

None of the specimens exhibited the lobulate organ described by Bertin (1956) and Sinha (1966) on macroscopic observation.

Figure 6. Cross-section of eel ovaries stained in hematoxylin and eosin. (a) Mature female, x1000; (b) Female, x510; (c) Female, x120; (d) Immature female, x510; (e) Immature female, x510.

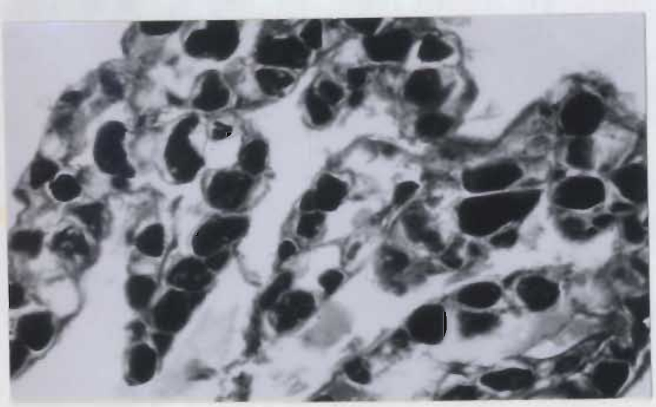


(a)

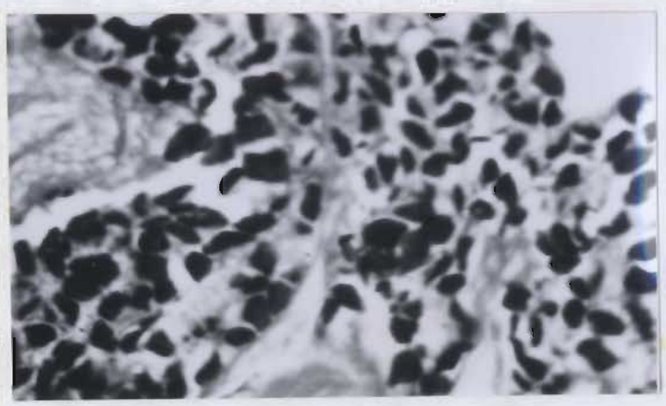


(b)

(c)



(d)



(e)

On histological examination only one specimen resembled a male. (Figure 7). Eels smaller than 22 cms could not be sexed, however, in some cases eels up to 34 cms in length could not be sexed.

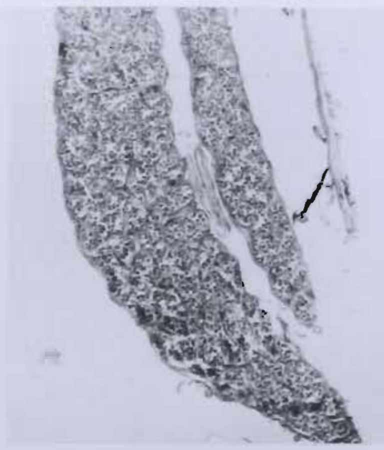
G. Methods used in Stomach Analysis

The sampling methods used in collecting material for stomach analysis have been described in Section II, A. The number of eels taken from each study area together with other sampling data appear in Table 3.

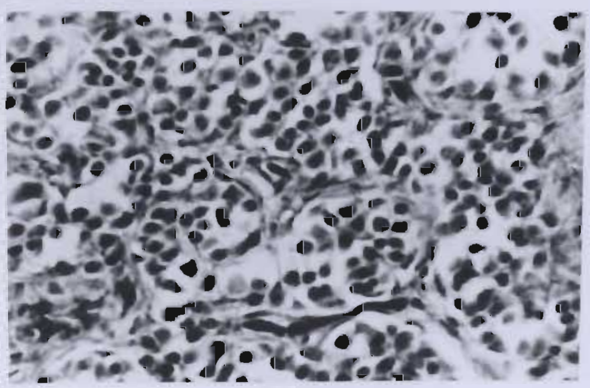
Stomachs were removed from each specimen by cutting through the pylorus at the posterior end of the stomach and through the esophagus dorsal to the heart. Each stomach was placed in a clearly labelled vial and preserved in 5% formalin. The contents of each stomach were analysed by three methods: Number Method, Occurrence Method and Dry Weight Method (Lagler, 1952).

The stomach contents were identified under a low power binocular microscope and classified down to the respective order or family. In cases where fish were present in the stomachs, these were classified to the species level. The food items in each stomach were counted individually (Number Method), and the number of fish containing any one organism was noted (Occurrence Method). After separation, each food item was dried at 40 degrees centigrade for 72 hours and their dry weights were recorded.

Figure 7. Cross-section of testis of *Anguilla rostrata* (LeSueur) from Burnt Berry Brook. (a) x120; (b) x510.



A



B

Table 3. Data on the eels used for stomach analysis in the four study areas.

Location	Number of Stomachs Examined	Empty Stomachs		Number of Stomachs With Only Bait	Number of Stomachs With Indistinguishable Contents	Average Time Between Sampling Periods (hrs)
		No.	%			
Indian Pond	93	14	15.0	29	31	17
Topsail Barachois	121	21	17.3	62	33	15
Burnt Berry Brook	48	16	33.3			
Main Brook	38	21	55.2			

III. RESULTS

A. Growth Studies

1. Frequency Distributions

a. Age Frequency

Age frequencies for the four sampling areas are shown in Table 4 and Figure 8. Eels from Indian Pond range in age from 5 to 12 years; their mean age was 8.7 years. The percentage of eels older than the modal group (10 years) decreased considerably - 9.3% of the sample were 11 years old and 2.7% were 12 years old. Eels from Topsail Barachois ranged in age from 4 to 12 years; their mean age was 8.0 years and their modal group was 9 years. Three percent of this sample were 11 years old and 0.7% were 12 years old. The Burnt Berry Brook sample ranged in age from 2 to 11 years; their mean age was 5.7 years and the modal group was comprised of 6 year old eels. Eleven year old eels made up 1.5% of this sample. At Main Brook, eels ranged in age from 4 to 10 years; their mean age was 6.7 years and their modal group was 8 years old. Ten year old eels made up 2.6% of this sample.

b. Length Frequency

Data collected in the present study on percentage length frequency are shown in Table 5 and Figure 9. The mean length for eels in the Indian Pond sample was 56.1 cms. The eels in this sample ranged in length from 34.5 to 77.0 cms. The modal

Table 4. Percentage age frequency for _Anguilla rostrata_ (LeSueur) in the four sampling areas; number of fish are in parenthesis.

Location	II	III	IV	V	Age Groups VI	VII	VIII	IX	X	XI	XII	Total Fish	Mean Age	Standard Deviation	Standard Error
Indian Pond				2.7 (2)	8 (6)	13.3 (10)	17.3 (13)	20.0 (15)	26.7 (20)	9.3 (7)	2.7 (2)	75	8.7	1.65	.19
Topsail Barachois			1.5 (2)	3.7 (5)	14.1 (19)	14.8 (20)	20.0 (27)	33.3 (45)	8.9 (12)	3.0 (4)	0.7 (1)	135	8.0	1.49	.13
Burnt Berry Brook	3.0 (2)	9.1 (6)	19.7 (13)	19.7 (13)	22.7 (15)	4.5 (3)	9.1 (6)	7.6 (5)	3.0 (2)	1.5 (1)		66	5.7	1.93	.24
Main Brook			7.9 (3)	18.4 (7)	15.8 (6)	23.7 (9)	28.9 (11)	2.6 (1)	2.6 (1)			38	6.7	1.46	.24

Figure 8. Age frequency distribution of *Anguilla rostrata* (LeSueur) in the four study areas.

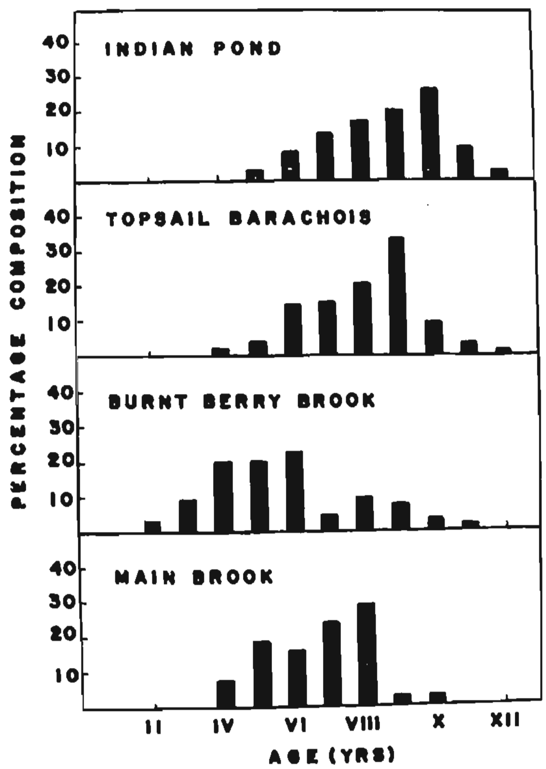
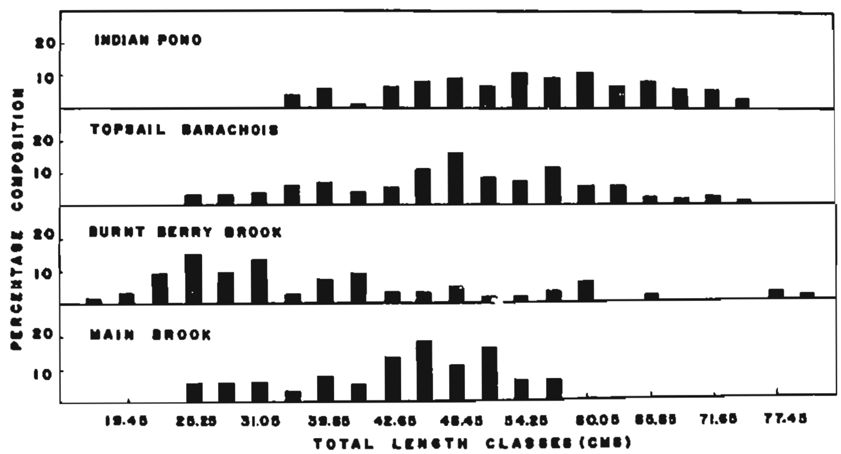

INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
PERCENTAGE COMPOSITION
40
30
20
10
II
IV
VI
VIII
X
XII
AGE (YRS)

Table 5. Percentage length frequency for *Anguilla rostrata* (LeSueur) in the four sampling areas; number of fish

Location	Length Group (cms)													
	15.1-18.0	18.1-21.0	21.1-24.0	24.1-27.0	27.1-30.0	30.1-33.0	33.1-36.0	36.1-39.0	39.1-42.0	42.1-45.0	45.1-48.0	48.1-51.0	51.1-54.0	54.1-57.0
Indian Pond							4.0 (3)	5.3 (4)	1.3 (1)	6.7 (5)	8.0 (6)	9.3 (7)	6.7 (5)	10.7 (8)
Topsail Barachois				3.0 (4)	3.0 (4)	3.7 (5)	5.9 (8)	6.7 (9)	3.7 (5)	5.2 (7)	10.4 (14)	15.6 (21)	8.1 (11)	7.4 (10)
Burnt Berry Brook	1.5 (1)	3.0 (2)	9.1 (6)	15.2 (10)	9.1 (6)	13.6 (9)	3.0 (2)	7.6 (5)	9.1 (6)	3.0 (2)	3.0 (2)	4.5 (3)	1.5 (1)	1.5 (1)
Main Brook				5.3 (2)	5.3 (2)	5.3 (2)	2.6 (1)	7.9 (3)	5.3 (2)	13.2 (5)	18.4 (7)	10.5 (4)	15.8 (6)	5.3 (2)

Figure 9. Length frequency distribution of *Anguilla rostrata* (LeSueur) in the four areas.



INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
PERCENTAGE COMPOSITION
20
10
19.45
25.25
31.05
36.85
42.65
48.45
54.25
60.05
65.85
71.65
77.45
TOTAL LENGTH CLASSES (CMS)

length classes were those having the class marks of 55.55 cms and 61.55 cms. The mean length of eels from Topsail Barachois was 49.2 cms. Eels from Topsail Barachois ranged in length from 24.1 to 76.0 cms. The modal length class was that represented by the class mark of 49.55 cms. The mean length of the Burnt Berry Brook sample was 38.2 cms. Eels ranged in length from 15.9 to 84.0 cms in this sample. The largest number of eels was found in the length class having the class mark of 25.55 cms. The mean length of eels in the Main Brook sample was 44.2 cms. Lengths of eels ranged from 24.1 to 57.3 cms; the modal length class was that with the class mark of 46.55 cms.

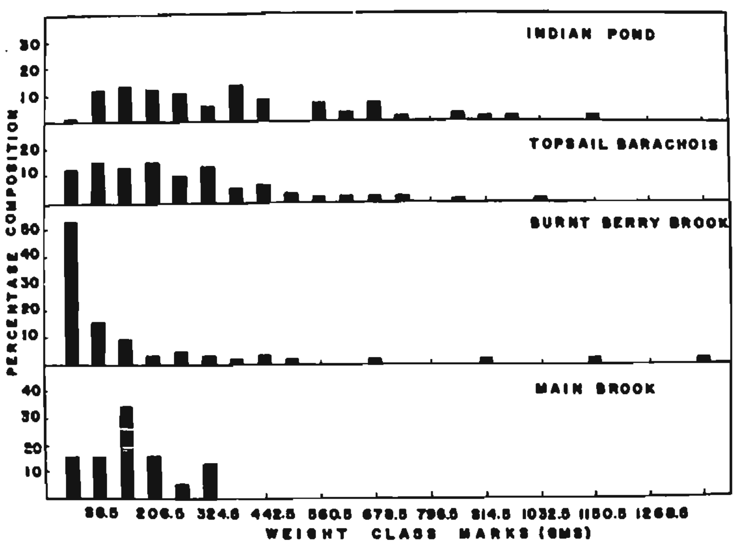
c. Weight Frequency

Data on weight frequency appear in Table 6 and Figure 10. The mean weight of eels in the Indian Pond sample was 368 gms; eels ranged in weight in this sample from 60 to 1173 gms. The modal weight classes were those having the class marks, 150.5 gms and 390.5 gms. Only 7.9% of the sample was heavier than 720 gms. The mean weight of eels in the Topsail Barachois sample was 252 gms; eels ranged in weight from 19 to 1040 gms in this sample. The modal weight class was that with the class mark of 90.5 gms. Eels heavier than 720 gms were scarce, and made up only 2.9% of the sample. The mean weight of eels from Burnt Berry Brook was 165 gms; they ranged in weight from 7 to 1383 gms. The dominant weight class was that with the class mark of 29.5 gms.

Table 6. Percentage weight frequency for <u>Anguilla rostrata</u> (LeSueur) in the four sampling areas; number of fish are in parenthesis.

Location	1-60	61-120	121-180	181-240	241-300	301-360	361-420	421-480	481-540	541-600	601-660	661-720	721-780	781-840	841-900	901-960	961-1020	1021-1080	1081-1140
Indian Pond	1.3 (1)	12.0 (9)	13.3 (10)	12.0 (9)	10.7 (8)	5.3 (4)	13.3 (10)	8.0 (6)		6.7 (5)	2.7 (2)	6.7 (5)	1.3 (1)		2.7 (2)	1.3 (1)	1.3 (1)		
Topsail Barachois	12.6 (17)	15.6 (21)	13.3 (18)	14.8 (20)	9.6 (13)	13.3 (18)	4.4 (6)	5.9 (8)	3.0 (4)	1.5 (2)	1.5 (2)	1.5 (2)	1.5 (2)		.7 (1)			.7 (1)	
Burnt Berry Brook	53.0 (35)	15.2 (10)	9.1 (6)	3.0 (2)	4.5 (3)	3.0 (2)	1.5 (1)	3.0 (2)	1.5 (1)			1.5 (1)				1.5 (1)			
Main Brook	15.8 (6)	15.8 (6)	34.2 (13)	15.8 (6)	5.3 (2)	13.2 (5)													

Figure 10. Weight frequency distribution of _Anguilla rostrata_ (LeSueur) in the four study areas.


INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
PERCENTAGE COMPOSITION
88.5 206.5 324.5 442.5 560.5 678.5 796.5 914.5 1032.5 1150.5 1268.5
WEIGHT CLASS MARKS (GMS)

Very few (4.5%) eels were heavier than 720 gms in this sample. The mean weight of eels in the Main Brook sample was 163 gms, and ranged in weight from 23 to 352 gms. The modal weight class in the Main Brook sample was that having the class mark of 150.5 gms.

2. Age-Length Relationship

Mean total length, range in length, calculated length and annual increments in length appear in Tables 7 and 8 and in Figure 11. The eels from Indian Pond and Topsail Barachois exhibited a very slow growth pattern from ages 4 to 6 years. This was particularly true of eels from Topsail Barachois; they attained a mean length of 34.3 cms compared to 37.0 cms at Indian Pond after 6 years in brackish water. In contrast, the eels from Burnt Berry Brook and Main Brook attained mean lengths of 39.2 cms and 42.2 cms, respectively, after 6 years in freshwater.

The growth rate of eels between ages 7 to 9 years from Indian Pond and Topsail Barachois increased compared to its previous rate up to 6 years of age. After 9 years in brackish water, eels from Indian Pond had a mean langth of 57.2 cms while those from Topsail Barachois had a mean length of 55.3 cms. Between ages 7 to 9 years, eels from freshwater habitats at, Burnt Berry Brook and Main Brook, showed a relatively slower growth rate than their brackish water counterparts. After 9 years eels from Burnt Berry Brook attained a mean length of 62.5 cms while those from Main Brook

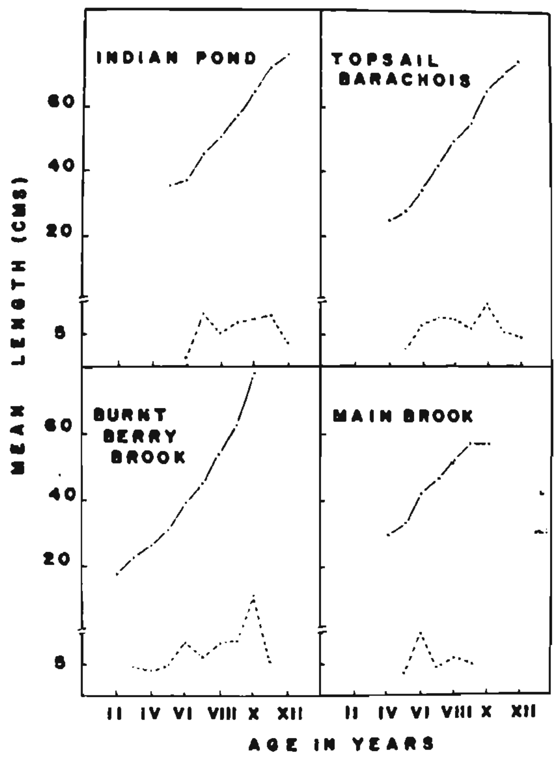
Table 7. Mean length, range in length, calculated length, and annual increments in length for *Anguilla rostrata* (LeSueur) in brackish water.

Age group	IV	V	VI	VII	VIII	IX	X	XI	XII
Indian Pond									
Mean length (cms)		35.6	37.0	45.2	50.3	57.2	64.5	72.4	76.3
Calculated length (cms)		31.4	38.0	44.6	51.2	57.7	64.3	70.9	77.5
Range in length (cms)		35.6	34.5-39.4	42.7-48.6	47.8-53.6	54.8-61.0	60.0-69.9	71.4-73.6	75.5-77.0
Annual increments			1.4	8.2	5.1	6.9	7.3	7.9	3.9
Number of specimens		2	6	10	13	15	20	7	2
Topsail Barachois									
Mean length (cms)	24.9	27.7	34.3	41.8	49.3	55.3	65.2	70.6	74.8
Calculated length (cms)	20.7	27.7	34.8	41.8	48.9	56.0	63.1	70.2	77.3
Range in length (cms)	24.1-25.7	25.8-29.5	29.2-40.6	36.1-47.7	43.9-58.0	49.6-62.9	60.5-73.9	66.2-76.0	74.8
Annual increments		2.8	6.6	7.5	7.5	6.0	9.9	5.4	4.8
Number of specimens	2	5	19	20	27	45	12	4	1

Table 8 . Mean length, range in length, calculated length, and annual increments in length for *Anguilla rostrata* (LeSueur) in freshwater.

Age group	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Burnt Berry Brook											
Mean length (cms)	17.4	22.0	26.0	30.9	39.2	45.6	53.9	62.5	78.3	84.0	
Calculated length (cms)	11.2	18.5	25.8	33.1	40.4	47.7	55.0	62.3	69.7	77.0	84.0
Range in length (cms)	15.9-18.8	21.0-22.7	23.5-28.8	28.2-37.2	32.9-46.2	40.7-48.1	49.5-59.0	60.7-66.4	78.2-78.4	84.0	
Annual increments		4.6	4.0	4.9	8.3	6.4	8.3	8.6	15.8	5.7	
Number of specimens	2	6	13	13	15	3	6	5	2	1	
Main Brook											
Mean length (cms)			29.4	32.9	42.2	46.5	52.2	57.3	57.1		
Calculated length (cms)			29.2	34.8	40.5	46.1	51.8	57.4	63.1	68.5	74.0
Range in length (cms)			29.1-30.0	24.1-39.8	38.5-44.5	44.9-49.6	48.5-55.9	57.3	57.1		
Annual increments				3.5	9.3	4.3	5.7	5.1			
Number of specimens			3	7	6	9	11	1	1		

Figure 11. Age-length relationship for Anguilla rostrata (LeSueur) in the four study areas; annual increments in length are shown by the dotted line (.------.). The mean length (84 cms) at age XI, at Burnt Berry Brook is not shown here.


INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
MEAN LENGTH (CMS)
60
40
20
5
II IV VI VIII X XII
AGE IN YEARS

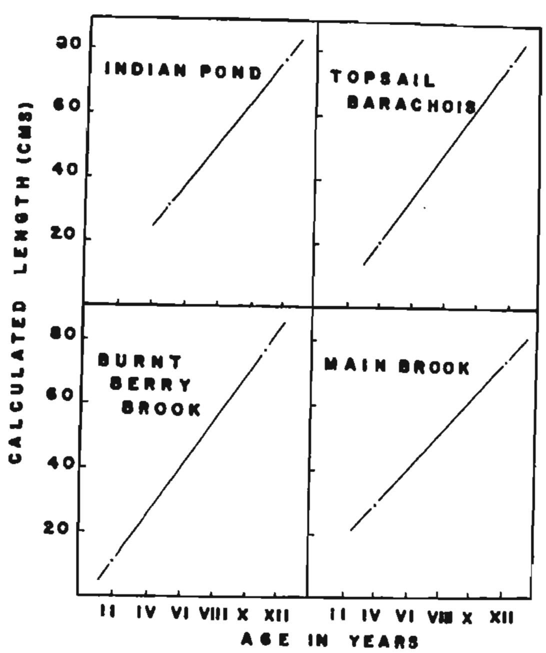
grew somewhat slower having a mean length of 57.3 cms.

Since very few eels were represented in the age range 10 to 12 years in samples obtained from Burnt Berry Brook and Main Brook, calculated lengths have been used instead of mean lengths; mean lengths, however, are shown in parenthesis wherever possible. The eels from Indian Pond and Topsail Barachois continued to grow fast and attained calculated lengths of 77.5 cms (76.3) and 77.3 cms (74.8), respectively, after 12 years. The calculated lengths for eels at Burnt Berry Brook and Main Brook after 12 years were 84.0 cms and 74.0 cms, respectively.

Annual growth increments for each sampling area are shown in Tables 7 and 8 and Figure 11. The annual increments between ages 5 and 6 showed that growth in freshwater was faster than growth in brackish water. Annual increments at Indian Pond, Topsail Barachois, Burnt Berry Brook and Main Brook were 1.4 cms, 6.6 cms, 8.3 cms and 9.3 cms, respectively. Between ages 8 and 9 years, annual increments in length were 6.9 cms, 6.0 cms, 8.6 cms and 5.1 cms, respectively; the slow growth in the Main Brook sample was especially evident. Since no 12-year-old eels were represented in the freshwater samples, the appropriate comparisons could not be made.

Calculated growth in length for each age group is shown in Tables 7 and 8 and Figure 12. The slope (B), intercept (A),

Figure 12. Calculated growth in length for *Anguilla rostrata* (LeSueur) in the four study areas.


INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
CALCULATED LENGTH (CMS)
80
60
40
20
II IV VI VIII X XII
AGE IN YEARS

correlation coefficient (R) and standard error (SE) for each area appear in Table 9. The correlation between growth in length and age was very high, and the standard error for each sample would appear to indicate that the age-length relationship could be approximated by the following equations.

Indian Pond -

$$Y = -1.5230 + 6.5841\ X$$

Topsail Barachois -

$$Y = -7.6418 + 7.0747\ X$$

Burnt Berry Brook -

$$Y = -3.4009 + 7.3052\ X$$

Main Brook -

$$Y = 6.5446 + 5.6533\ X$$

The Burnt Berry Brook sample showed the fastest growth pattern, followed by Topsail Barachois, Indian Pond and Main Brook, in that order. Calculated lengths at age 6 years at Indian Pond, Topsail Barachois, Burnt Berry Brook and Main Brook were 38.0 cms, 34.8 cms, 40.4 cms and 40.5 cms, respectively. After 9 years calculated lengths at Indian Pond, Topsail Barachois, Burnt Berry Brook and Main Brook were 57.7 cms, 56.0 cms, 62.3 cms and 57.4 cms, respectively. Calculated lengths after 12 years at these sampling areas, as previously shown, were 77.5 cms, 77.3 cms, 84.0 cms and 74.0 cms, respectively.

Table 9. Calculated growth in length for *Anguilla rostrata* (LeSueur) in the four study areas.

Location	Indian Pond	Topsail Barachois	Burnt Berry Brook	Main Brook
Slope = B =	6.58	7.07	7.31	5.65
Intercept = A =	- 1.52	- 7.64	- 3.40	6.54
Correlation Coefficient = R =	.98	.95	.97	.93
Standard Error = SE =	2.38	3.63	3.73	3.33

3. <u>Age-Weight Relationship</u>

Data on mean weight, calculated weight, range in weight and annual increments in weight appear in Tables 10 and 11, and in Figures 13 and 14. Growth in weight was slow in both brackish water habitats during the first 6 years. The mean weight of eels from Indian Pond was 86 gms, while the mean weight of eels from Topsail Barachois was 59 gms after 6 years. The eels obtained from freshwater attained mean weights of 106 gms at Burnt Berry Brook and 131 gms at Main Brook after 6 years. The faster growth in weight of young eels from age 2 to 6 years in freshwater was also clearly indicated by their annual increments in weight as shown in Table 11. Eels from Indian Pond and Topsail Barachois had increments of 20 gms and 29 gms, respectively, between ages 5 and 6 compared to 57 gms and 65 gms for Burnt Berry Brook and Main Brook, respectively.

After 9 years eels in brackish water weighed 327 gms and 318 gms at Indian Pond and Topsail Barachois, respectively. At Burnt Berry Brook and Main Brook, eels weighed 494 gms and 324 gms, respectively, after 9 years in freshwater. The annual increments for growth in weight between ages 7 to 9 showed clearly that growth in all areas was very rapid during this period. Between ages 8 and 9 years the annual increments for Indian Pond and Topsail Barachois were 118 gms and 107 gms, respectively; at Burnt Berry Brook and Main Brook, the annual increments in weight were 209 gms and 80 gms,

Table 10. Mean weight, range in weight, calculated weight, and annual increments in weight for <u>Anguilla rostrata</u> (LeSueur) in brackish water

Age group	IV	V	VI	VII	VIII	IX	X	XI	XII
Indian Pond									
Mean weight (gms)		66	86	147	209	327	514	807	971
Calculated weight (gms)		53	96	159	245	360	508	693	920
Range in weight (gms)		60-71	69-109	109-207	168-311	275-398	366-708	641-1173	956-986
Annual increments			20	61	62	118	187	293	164
Number of specimens		2	6	10	13	15	20	7	2
Topsail Barachois									
Mean weight (gms)	20	30	59	120	211	318	530	786	853
Calculated weight (gms)	31	56	91	137	195	266	351	453	571
Range in weight (gms)	19-20	24-34	36-91	69-178	113-480	197-551	415-726	682-1040	853
Annual increments		10	29	61	91	107	212	256	67
Number of specimens	2	5	19	20	27	45	12	4	1

Table 11. Mean weight, range in weight, calculated weight, and annual increments in weight for <u>Anguilla rostrata</u> (LeSueur) in freshwater.

Age group	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Burnt Berry Brook											
Mean weight (gms)	8	16	28	49	106	170	285	494	1060	1383	
Calculated weight (gms)	5	16	39	78	137	222	336	484	671	903	
Range in weight (gms)	7-9	9-20	12-44	29-90	48-165	130-207	202-350	389-680	933-1186	1383	
Annual increments		8	12	21	57	64	115	209	566	323	
Number of specimens	2	6	13	13	15	3	6	5	2	1	
Main Brook											
Mean weight (gms)			40	66	131	164	244	324	352		
Calculated weight (gms)			41	72	113	165	230	308	400		
Range in weight (gms)			36-44	23-106	97-159	134-196	159-347	324	352		
Annual increments				26	65	33	80	80	28		
Number of specimens			3	7	6	9	11	1	1		

Figure 13. Age-weight relationship in *Anguilla rostrata* (LeSueur) in the four study areas.

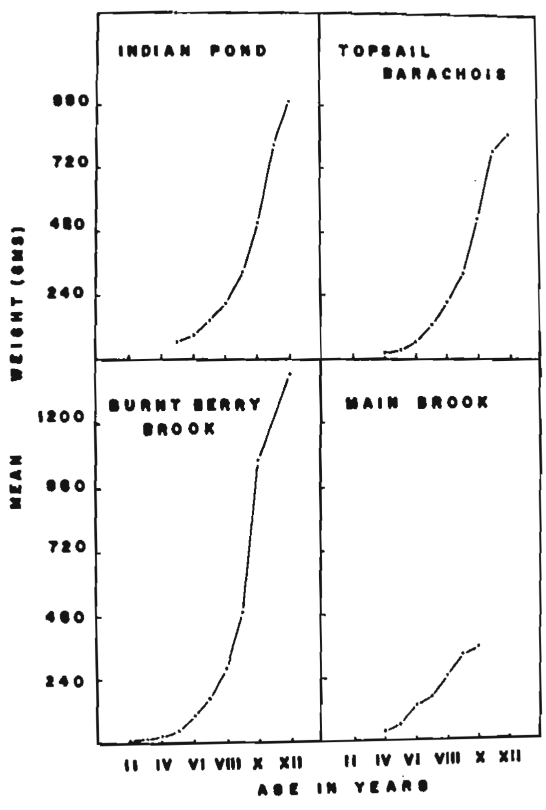
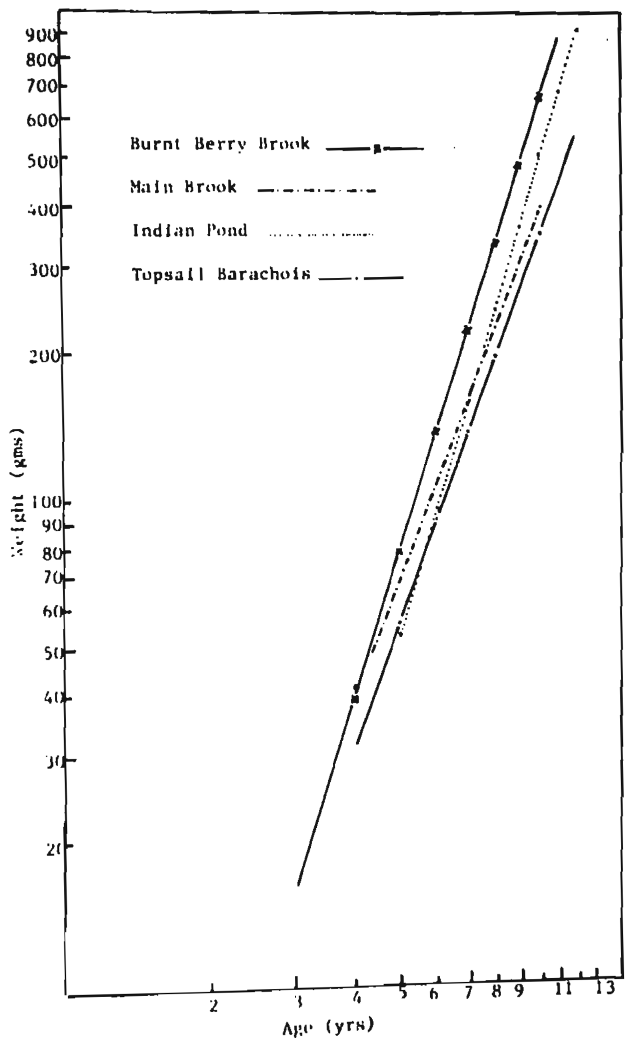

INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
MEAN WEIGHT (GMS)
960
720
480
240
1200
960
720
480
240
II IV VI VIII X XII
II IV VI VIII X XII
AGE IN YEARS

Figure 14. Calculated growth in weight for *Anguilla rostrata* (LeSueur) in the four study areas.



Burnt Berry Brook
Main Brook
Indian Pond
Topsail Barachois
Weight (gms)
Age (yrs)

respectively.

The mean weight at age 12 for eels at Indian Pond was 971 gms while at Topsail Barachois it was 853 gms. These age groups were not represented in the Burnt Berry Brook and Main Brook samples. Annual increments in weight between ages 11 and 12 years clearly show that growth has slowed down considerably; at Indian Pond the annual increment in weight was 164 gms, while at Topsail Barachois it was 67 gms.

Calculated growth in weight for each age group in the four study areas appear in Tables 10 and 11 and Figure 14. Growth in weight was calculated from the equation, Log W = Log a + n Log A, where W = weight, a = constant, n = exponent and A = age. The equations expressing growth in the four study areas were as follows:

Indian Pond

$$\text{Log } W = 3.2616 \text{ Log } A - 0.5561$$

Topsail Barachois

$$\text{Log } W = 2.6517 \text{ Log } A - 0.1054$$

Burnt Berry Brook

$$\text{Log } W = 3.1074 \text{ Log } A - 0.2805$$

Main Brook

$$\text{Log } W = 2.4752 \text{ Log } A + .1268$$

The age-weight relationships in the four study areas indicate that the fastest growth in weight occurred at Burnt Berry Brook, followed by that at Indian Pond, Main Brook and Topsail Barachois. Calculated weight at age 6 years at Indian Pond, Topsail Barachois, Burnt Berry Brook and Main Brook were 96, 91, 137 and 113 gms, respectively. After 9 years calculated weights at Indian Pond, Topsail Barachois, Burnt Berry Brook and Main Brook were 360, 266, 484 and 308 gms, respectively.

4. <u>Length-Weight Relationship</u>

The relationship between length and weight is shown in Table 12 and Figures 15 and 16 . The length-weight relationship was calculated from the logarithm form of the equation, $Y = AX^b$, where Y = weight, A = constant, b = exponent and X = length. The equations for this relationship in the four study areas were:

Indian Pond

$$\text{Log } Y = 3.4409 \text{ Log } X - 3.5092$$

Topsail Barachois

$$\text{Log } Y = 3.4395 \text{ Log } X - 3.4973$$

Burnt Berry Brook

$$\text{Log } Y = 3.2706 \text{ Log } X - 3.1797$$

Main Brook

$$\text{Log } Y = 1.9847 \text{ Log } X - 1.0925$$

The fastest growth pattern as expressed by this relationship occurred at Burnt Berry Brook, followed by that at Indian Pond,

Table 12. Calculated values for 'A' and 'b' in the age-weight and length-weight relationships for eels from the four study areas.

Location	Log A	A	b
*			
Indian Pond	- 0.5561	.2779	3.2616
Topsail Barachois	- 0.1054	.7845	2.6517
Burnt Berry Brook	- 0.2805	.5242	3.1074
Main Brook	0.1268	1.339	2.4752
**			
Indian Pond	- 3.5092	.0003096	3.4409
Topsail Barachois	- 3.4973	.0003182	3.4395
Burnt Berry Brook	- 3.1797	.0006612	3.2706
Main Brook	- 1.0925	.08081	1.9847

* Age-weight relationship

** Length-weight relationship

Figure 15. Length-weight relationship in *Anguilla rostrata* (LeSueur) in the four study areas.

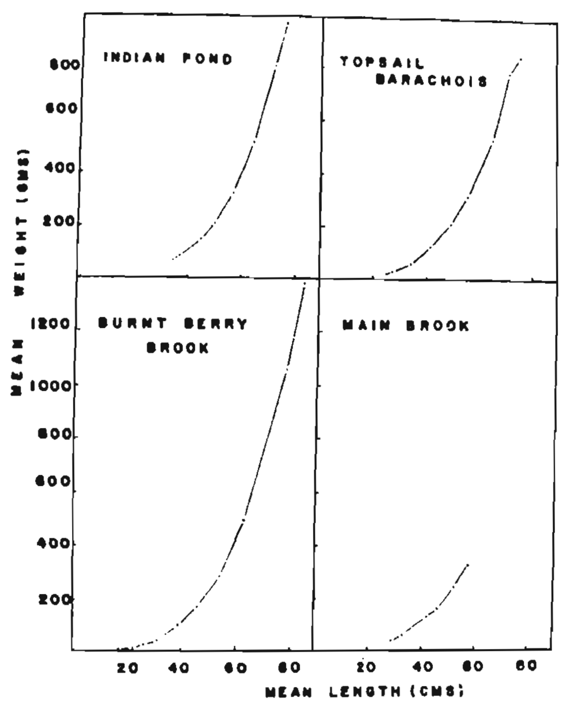
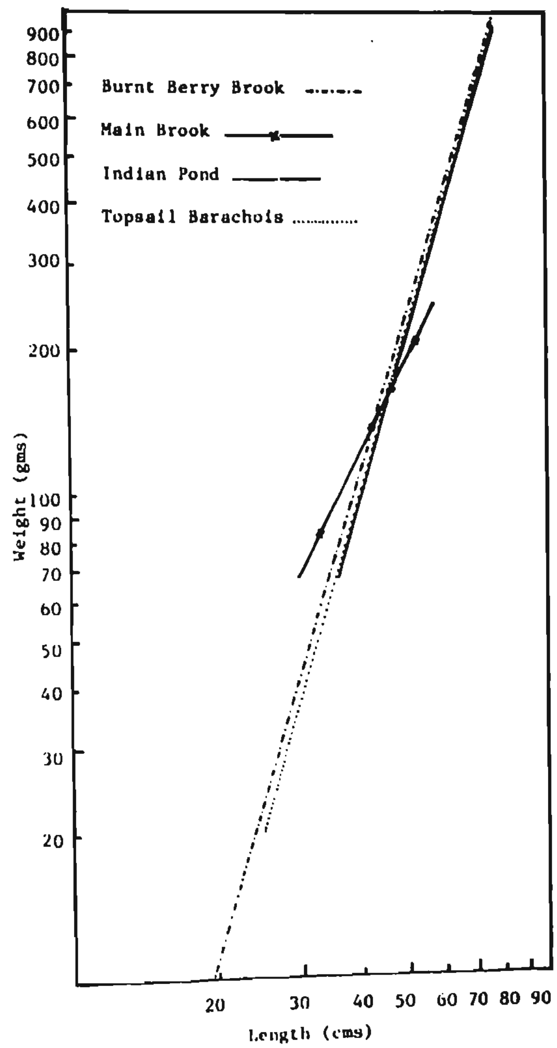

INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
MEAN WEIGHT (GMS)
MEAN LENGTH (CMS)
1200
1000
800
600
400
200
20
40
60
80

Figure 16. Calculated length-weight relationship for *Anguilla rostrata* (LeSueur) in the four study areas.


Burnt Berry Brook
Main Brook
Indian Pond
Topsail Barachois
Weight (gms)
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
Length (cms)
20
30
40
50
60
70
80
90

Topsail Barachois and Main Brook. The calculated growth at Topsail Barachois and Indian Pond as shown in Table 12 and Figure 16 were almost identical. Growth at Main Brook appeared to be slower than that observed in the other three areas.

B. Relative Growth

Each of 20 body measurements was used in a linear regression of size of body part against total length. The data on slope (B), intercept (A), correlation coefficient (R), standard error (SE) and computed "F" are shown in Tables 13 to 16.

Significant differences occurred between brackish and freshwater populations with regard to preanal length measured from the upper jaw (F = 14.99), preanal length measured from the operculum (F = 16.46), preanal length measured from the lower jaw (F = 9.12), width of snout anterior to the eye (F = 5.61), orbital length (F = 4.24), and greatest body width (F = 5.26). None of the other body measurements showed significant differences between the two habitats.

Figures 17 to 20 illustrate the relationship of these 20 body measurements to total length. Of particular interest were those related to: width of snout anterior to eye, interorbital width, greatest head width, and greatest head depth. The results of the present study show that the width of the snout anterior to the eye was significantly greater for eels in freshwater compared

Table 13. Analysis of the relative growth of various body parts of *Anguilla rostrata* (LeSueur) from two areas in Newfoundland.

Body Measurement		Predorsal Length (Lower Jaw)	Preanal Length (Upper Jaw)	Preanal Length (Operculum)	Preanal Length (Lower Jaw)	Greatest Body Depth
Brackish Water	Slope=B=	.36	.46	.32	.48	.08
	Intercept=A=	- .57	-1.33	- .92	-2.45	- .38
	Correlation Coefficient=R=	.99	1.00	.99	.96	.91
	Standard Error=SE=	.72	.56	.60	1.66	.43
Freshwater	Slope=B=	.35	.43	.30	.44	.07
	Intercept=A=	- .32	- .62	- .21	- .65	- .45
	Correlation Coefficient=R=	.99	1.00	1.00	1.00	.98
	Standard Error=SE=	.86	.55	.47	.56	.23
Computed F		1.28	14.99	16.46	9.12	1.31

Table 14. Analysis of the relative growth of various body parts of <u>Anguilla rostrata</u> (LeSueur) from two areas in Newfoundland.

Body Measurement		Width of Snout Anterior to Eye	Width of Snout at Nares	Snout Length	Interorbital Width	Greatest Body Width
Brackish Water	Slope =B=	.03	.01	.02	.02	.06
	Intercept =A=	- .12	- .06	.01	- .25	- .15
	Correlation Coefficient=R=	.94	.91	.94	.97	.92
	Standard Error=SE=	.14	.08	.10	.07	.29
Freshwater	Slope =B=	.04	.02	.02	.03	.06
	Intercept=A=	- .21	- .03	- .02	- .18	- .03
	Correlation Coefficient=R=	.95	.94	.97	.98	.81
	Standard Error=SE=	.17	.09	.10	.08	.29
Computed F		5.61	2.62	2.63	2.82	5.26

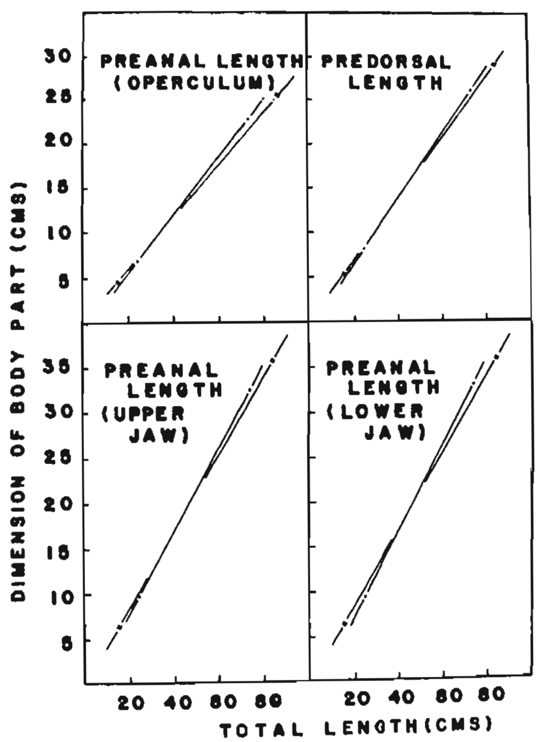
Table 15. Analysis of the relative growth of various body parts of _Anguilla rostrata_ (LeSueur) from two areas in Newfoundland.

Body Measurement		Head Length	Postorbital Head Length	Orbital Length	Pectoral Length	Greatest Head Width
Brackish Water	Slope =B=	.13	.10	.01	.06	.07
	Intercept =A=	- .41	- .41	.14	- .50	- .66
	Correlation Coefficient =R=	.97	.97	.84	.97	.95
	Standard Error =SE=	.46	.34	.08	.17	.26
Freshwater	Slope =B=	.14	.11	.01	.05	.07
	Intercept =A=	- .39	- .46	.06	- .44	- .58
	Correlation Coefficient =R=	.99	.99	.97	.98	.98
	Standard Error =SE=	.34	.22	.05	.19	.19
Computed F		.00	.80	4.24	.51	.29

Table 16. Analysis of the relative growth of various body parts of *Anguilla rostrata* (LeSueur) from two areas in Newfoundland.

Body Measurement		Height of Dorsal Fin	Height of Anal Fin	Greatest Head Depth	Suborbital Width	Body Girth
Brackish Water	Slope =B=	.02	.01	.07	.01	.22
	Intercept =A=	.10	.07	- .52	.01	- 1.66
	Correlation Coefficient =R=	.85	.81	.91	.84	.94
	Standard Error =SE=	.12	.13	.38	.05	1.00
Freshwater	Slope =B=	.02	.01	.06	.01	.21
	Intercept =A=	- .07	.03	- .35	- .05	-1.13
	Correlation Coefficient =R=	.93	.91	.99	.87	.98
	Standard Error =SE=	.10	.10	.16	.06	.61
Computed F		.89	.01	1.31	.04	1.38

Figure 17. Relative growth of different body parts in *Anguilla rostrata* (LeSueur) from two areas in Newfoundland; brackish water specimens (.______.) freshwater specimens (x______x).



PREANAL LENGTH (OPERCULUM)
PREDORSAL LENGTH
PREANAL LENGTH (UPPER JAW)
PREANAL LENGTH (LOWER JAW)
DIMENSION OF BODY PART (CMS)
TOTAL LENGTH (CMS)
5 10 15 20 25 30
5 10 15 20 25 30 35
20 40 60 80

Figure 18. Relative growth of different body parts in <u>Anguilla rostrata</u> (LeSueur) from two areas in Newfoundland; brackish water specimens (.___.), freshwater specimens (x_____x).

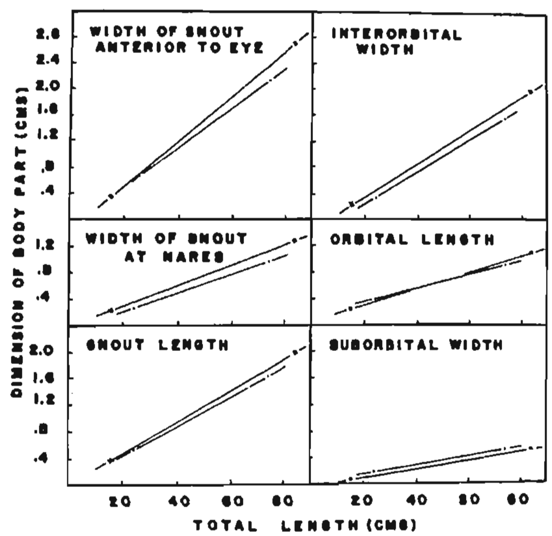

WIDTH OF SNOUT ANTERIOR TO EYE
INTERORBITAL WIDTH
WIDTH OF SNOUT AT NARES
ORBITAL LENGTH
SNOUT LENGTH
SUBORBITAL WIDTH
DIMENSION OF BODY PART (CMS)
TOTAL LENGTH (CMS)

Figure 19. Relative growth of different body parts in *Anguilla rostrata* (LeSueur) from two areas in Newfoundland; brackish water specimens (.____.), freshwater specimens (x____x).

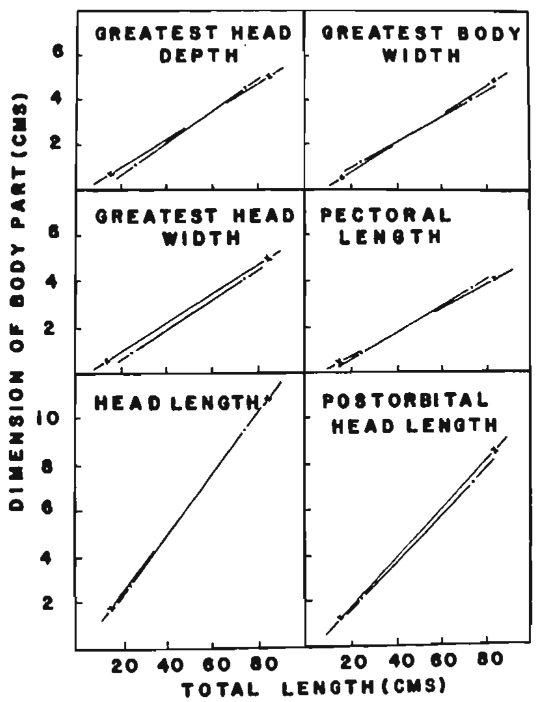
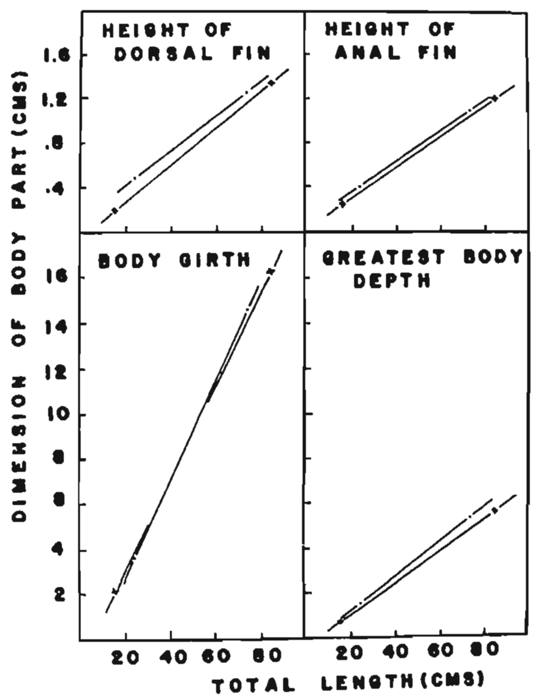

GREATEST HEAD DEPTH
GREATEST BODY WIDTH
GREATEST HEAD WIDTH
PECTORAL LENGTH
HEAD LENGTH
POSTORBITAL HEAD LENGTH
DIMENSION OF BODY PART (CMS)
TOTAL LENGTH (CMS)
2
4
6
8
10
20
40
60
80

Figure 20. Relative growth of different body parts in *Anguilla rostrata* (LeSueur) from two areas in Newfoundland; brackish water specimens (._____.), freshwater specimens (x____x).


HEIGHT OF DORSAL FIN
HEIGHT OF ANAL FIN
BODY GIRTH
GREATEST BODY DEPTH
DIMENSION OF BODY PART (CMS)
TOTAL LENGTH (CMS)
1.6
1.2
.8
.4
16
14
12
10
8
6
4
2
20 40 60 80
20 40 60 80

to those in brackish water. Freshwater eels had wider snouts at the nares than brackish water eels, however, the regression lines representing the two populations were not significantly different (F = 2.62). Eels in freshwater had longer snouts than eels in brackish water, however the differences were not significant (F = 2.63). Interorbital widths of eels in freshwater were greater than those in brackish water eels, however, the differences were not significant (F = 2.82). Figure 19 shows that very little difference (F = .28) occurred between the head width of eels in freshwater and brackish water. The same situation was true for head depth as no significant difference (F = 1.31) was found between the two study areas.

As stated previously, significant differences occurred between the two populations with regard to the measurements of preanal length plotted against total length. In all cases eels (>40 cms) total length in brackish water populations had greater preanal lengths than their freshwater neighbours. Predorsal lengths of brackish water eels were greater than those in freshwater, however, the differences were not significant (F = 1.28). Eels from freshwater were wider than those in brackish water; however, the results of this body measurement are of doubtful value since the condition of the stomach (full or empty) altered the measurement considerably.

C. Sex Differentiation and Distribution

The number of eels studied for sex distribution in each area appears in Table 17. Sex distribution in the four study areas is

Table 17. Analysis of eels obtained for the study of sex distribution.

Location	Number of Eels	Method of Capture	Mean Salinity ‰.	Description	Distance from the Sea
Indian Pond	60	Eel Pot	2.1	Brackish	25 yds.
Topsail Barachois	110	Eel Pot	4.2	Brackish	15 yds.
Burnt Berry Brook	59	Electrofishing		Freshwater	10 miles
Main Brook	33	Smolt Trap		Freshwater	5 miles

shown in Table 18 and Figure 21.

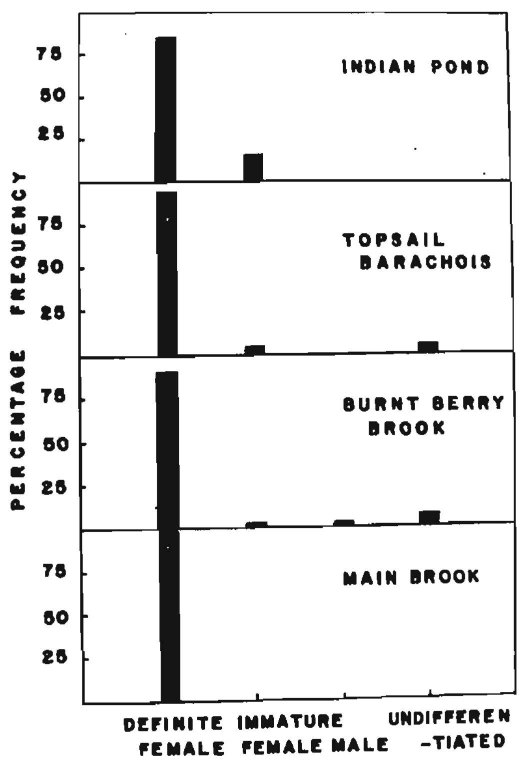
At Indian Pond and Topsail Barachois the majority of the eels, 85.0% and 93.6%, respectively, were definite females, however, a few were classified as immature females. 3.6% of the sample at Topsail Barachois were undifferentiated; no males were represented at either study area. At Burnt Berry Brook 89.8% of the sample were definite females, 1.7% were immature females, 1.7% were males and 6.8% were undifferentiated. Only definite females were represented in the Main Brook sample.

Range in length, average length and average age for each stage of development appear in Table 19. At Indian Pond definite females ranged in length from 35.6 cms to 77.0 cms and were 9.4 years old. Immature females ranged from 34.5 cms to 49.2 cms in length and were 6.4 years old. The smallest specimen taken at Indian Pond was 34.5 cms. Definite females at Topsail Barachois ranged from 28.1 to 76.0 cms in length and averaged 8.4 years old. Only one immature female was represented; it was 33.1 cms in length and was 6.0 years old. Undifferentiated eels ranged in length from 24.1 to 33.6 cms and were 5.5 years old. The smallest eel caught at Topsail Barachois was 24.1 cms. The smallest definite female examined from Burnt Berry Brook was 22.7 cms, while the largest was 84.0 cms. The average age of definite females was 6.0 years. Only one immature female (30.3 cms; 5.0 years old)

Table 18. Sex distribution of *Anguilla rostrata* (LeSueur) in the four study areas.

Location	Number of Eels	Definite Females No.	Definite Females %	Immature Females No.	Immature Females %	Males No.	Males %	Undifferentiated No.	Undifferentiated %
Indian Pond	60	51	85.0	9	15.0				
Topsail Barachois	110	103	93.6	3	2.7			4	3.6
Burnt Berry Brook	59	53	89.8	1	1.7	1	1.7	4	6.8
Main Brook	33	33	100.0						

Figure 21. Sex distribution of *Anguilla rostrata* (LeSueur) in the four study areas.



INDIAN POND
TOPSAIL BARACHOIS
BURNT BERRY BROOK
MAIN BROOK
PERCENTAGE FREQUENCY
75
50
25
DEFINITE FEMALE
IMMATURE FEMALE
MALE
UNDIFFEREN -TIATED

Table 19. Stages of sexual development in Anguilla rostrata (LeSueur) in the four study areas.

Location	Definite Females: Range in Length (cms)	Ave. Length (cms)	Ave. Age (yrs)	Immature Females: Range in Length (cms)	Ave. Length (cms)	Ave. Age (yrs)	Males: Range in Length (cms)	Ave. Length (cms)	Ave. Age (yrs)	Undifferentiated: Range in Length (cms)	Ave. Length (cms)	Ave. Age (yrs)	Smallest Eel (cms)
Indian Pond	35.6-77.0	60.6	9.4	34.5-49.2	41.6	6.4							34.5
Topsail Barachois	28.1-76.0	51.9	8.4	33.1-	33.1	6.0				24.1-33.6	32.4	5.5	24.1
Burnt Berry Brook	22.7-84.0	40.0	6.0	30.3	30.3	5.0	25.2	25.2	4	15.9-26.9	19.6	2.5	15.9
Main Brook	24.1-57.3	44.7	6.6										24.1

and one male (25.2 cms; 4 years old) were represented in the sample. Undifferentiated eels at Burnt Berry Brook ranged in length from 15.9 cms to 26.5 cms and were 2.5 years old. Definite females in the Main Brook sample ranged in length from 24.1 cms to 57.3 cms and were 6.6 years old. The smallest eels caught at Burnt Berry Brook and Main Brook were 15.9 cms and 24.1 cms, respectively.

Of 262 eels examined from the four study areas, 240 eels (91.6%) were definite females, 13 eels (4.9%) were immature females, 8 eels (3.1%) were undifferentiated and 1 eel (.4%) was a male. Thus, the results indicate a high percentage of females in all areas studied in Newfoundland.

D. Stomach Analysis

The percentage of empty stomachs, percentage of stomachs having only bait, percentage of stomachs with indistinguishable contents and the time interval which baited eel pots were left in the water are shown in Table 3. The percentage of empty stomachs at Indian Pond (15.0%), Topsail Barachois (17.3%), Burnt Berry Brook (33.3%) and Main Brook (55.2%) was high. A large number of the stomachs at Indian Pond (29) and Topsail Barachois (62) contained only bait. A large proportion of the stomachs at Indian Pond (31) and Topsail Barachois (33) also had indistinguishable contents.

a. Number Method

The data for stomach analysis in brackish water habitats appear in Table 20 and Figure 22. The food items which formed the major part of the diet of eels at Indian Pond were clams (*Macoma balthica*) and shrimp (Pandalidae). Other food items included gammarids (Malacostraca) and a brittle star (Ophiuroidea).

At Topsail Barachois, dietary items included eels (*Anguilla rostrata*), sticklebacks (*Gasterosteus aculeatus*), adult dragonflies (Odonata), unidentified eggs, unidentified insects and bird feathers.

The food items taken from the stomachs of eels in freshwater habitats are shown in Table 21 and Figure 23. The data show that salmonids (*Salmo salar*), dragonfly nymphs, caddis fly larvae (Trichoptera), freshwater snails (*Lymnaea elodes* and *Lymnaea catascopium*), and salmonid eggs formed the major part of the diet of eels at Burnt Berry Brook. Other dietary items included eels, mayfly nymphs and adults (Ephemeroptera), adult dragonflies, adult hemipterans (Hemiptera), caddis fly cases, beetle pupae and adults (Coleoptera), dipteran larvae and adults (Diptera), and freshwater clams (Pelecypoda).

At Main Brook, salmonids (*Salmo salar* and *Salvelinus fontinalis*), stonefly nymphs (Plecoptera), mayfly nymphs and

Table 20. Food items taken by Anguilla rostrata (LeSueur) in brackish water habitats

Food Item	Indian Pond: Number Method No.	%	Occurrence Method No.	%	Dry Weight Method No.	%	Topsail Barachois: Number Method No.	%	Occurrence Method No.	%	Dry Weight Method No.	%
Anguilla rostrata							1	3.1	1	.8	.1	7.2
Gasterosteus aculeatus							1	3.1	1	.8	.02	1.4
Odonata (adult)							1	3.1	1	.8	.03	2.2
Macoma balthica	28	68.3	7	7.5	3.65	46.7						
Gammarus sp.	1	2.4	1	1.1	.13	1.7						
Pandalidae	11	26.8	9	9.7	3.79	48.5						
Ophiuroidea	1	2.4	1	1.1	.24	3.1						
Unidentified Eggs							15	46.9	1	.8	.12	8.6
Unidentified Insects							8	25.0	1	.8	.89	64.0
Bird Feathers							6	18.8	1	.8	.34	24.4

Figure 22. Stomach contents of <u>Anguilla rostrata</u> (LeSueur) in brackish water habitats.

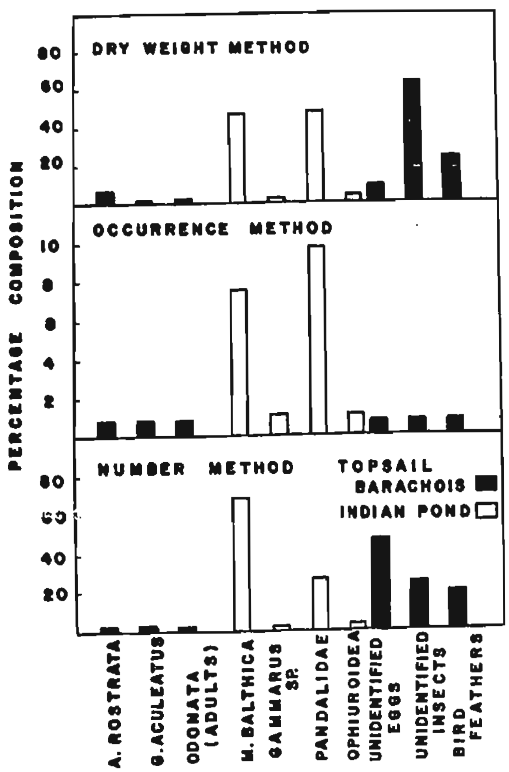
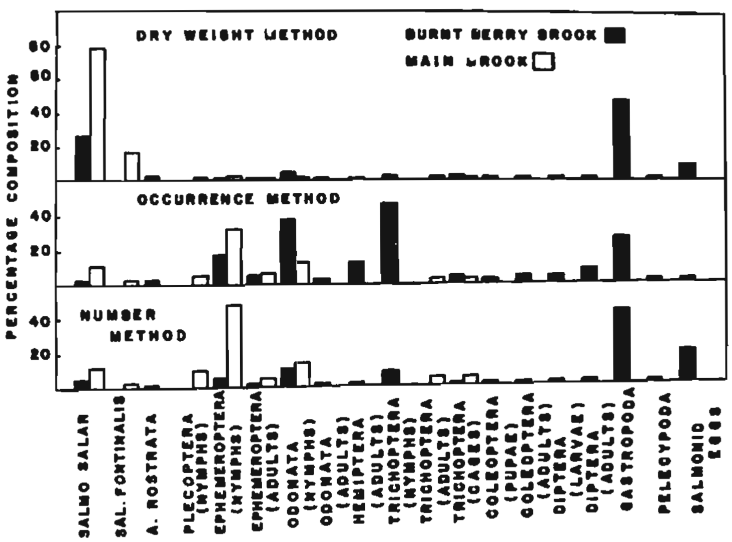

PERCENTAGE COMPOSITION
DRY WEIGHT METHOD
OCCURRENCE METHOD
NUMBER METHOD
TOPSAIL BARACHOIS
INDIAN POND
A. ROSTRATA
G. ACULEATUS
ODONATA (ADULTS)
M. BALTHICA
GAMMARUS SP.
PANDALIDAE
OPHIUROIDEA
UNIDENTIFIED EGGS
UNIDENTIFIED INSECTS
BIRD FEATHERS

Table 21. Food items taken by *Anguilla rostrata* (LeSueur) in freshwater habitats.

Food Item	Burnt Berry Brook						Main Brook					
	Number Method		Occurrence Method		Dry Weight Method		Number Method		Occurrence Method		Dry Weight Method	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Salmo salar	2	5.2	1	2.1	2.30	27.3	5	11.9	4	10.5	5.59	78.2
Salvelinus fontinalis							1	2.4	1	2.6	1.23	17.2
Anguilla rostrata	1	.2	1	2.1	.21	2.4						
Plecoptera (nymphs)							4	9.5	2	5.3	.06	.8
Ephemeroptera												
(nymphs)	19	4.9	8	16.7	.08	.9	20	47.6	12	31.6	.12	1.7
(adults)	2	.5	2	4.2	.01	.1	2	4.8	2	5.3	.01	.1
Odonata												
(nymphs)	40	10.4	18	37.5	.43	5.1	6	14.3	4	10.5	.04	.6
(adults)	2	.5	1	2.1	.02	.2						
Hemiptera (adults)	6	1.5	5	10.4	.03	.4						
Trichoptera												
(larvae)	33	8.6	22	45.8	.19	2.3						
(adults)							2	4.8	1	2.6	.07	.9
(cases)	2	.5	2	4.2	.16	1.9	2	4.8	1	2.6	.03	.4
Coleoptera												
(pupae)	1	.2	1	2.1	.01	.1						
(adults)	2	.5	2	4.2	.02	.2						

Figure 23. Stomachs contents of <u>Anguilla</u> <u>rostrata</u> (LeSueur) in freshwater habitats.


DRY WEIGHT METHOD
BURNT BERRY BROOK
MAIN BROOK
OCCURRENCE METHOD
NUMBER METHOD
PERCENTAGE COMPOSITION
20
40
60
80
SALMO SALAR
SAL. FONTINALIS
A. ROSTRATA
PLECOPTERA (NYMPHS)
EPHEMEROPTERA (NYMPHS)
EPHEMEROPTERA (ADULTS)
ODONATA (NYMPHS)
ODONATA (ADULTS)
HEMIPTERA (ADULTS)
TRICHOPTERA (NYMPHS)
TRICHOPTERA (ADULTS)
TRICHOPTERA (CASES)
COLEOPTERA (PUPAE)
COLEOPTERA (ADULTS)
DIPTERA (LARVAE)
DIPTERA (ADULTS)
GASTROPODA
PELECYPODA
SALMONID EGGS

dragonfly nymphs, made up the major part of the diet of the eels. Other food items included mayfly adults and caddis fly adults and cases.

b. Occurrence Method

Analysis of stomach contents by this method indicated that the food item taken most frequently at Indian Pond was shrimp. Clams, gammarids and brittle stars were taken in lesser amounts as shown in Table 20 and Figure 22.

The data from Topsail Barachois show that all food items listed in Table 20 and Figure 22 were taken in equal frequencies. These included eels, sticklebacks, adult dragonflies, unidentified eggs, unidentified insects and bird feathers.

The food item taken most often by eels at Burnt Berry Brook was caddis fly larvae. Food items taken less frequently included dragonfly nymphs, freshwater snails, mayfly nymphs, adult hemipterans, adult dipterans, adult mayflies, caddis fly cases, adult beetles, dipteran larvae, salmonids, eels, adult dragonflies, beetle pupae, freshwater clams and salmonid eggs (Table 21, Figure 23).

At Main Brook, the food item taken most frequently was mayfly nymphs (Table 21, Figure 23). Other dietary items, in order of diminishing frequency of being eaten included, salmonids, dragonfly nymphs, stonefly nymphs, adult mayflies, and caddis fly larvae and adults.

c. Dry Weight Method

Stomach analysis by this method indicates that at Indian Pond, the food item taken in greatest quantity was the shrimp. Clams, brittle stars and gammarids were taken in lesser amounts (Table 20, Figure 22).

At Topsail Barachois unidentified insects were taken in greatest quantity (Table 20, Figure 22). Eels, sticklebacks, dragonflies, unidentified eggs and bird feathers were taken in lesser quantities.

The food item taken in greatest quantity at Burnt Berry Brook was freshwater snails (Table 21, Figure 23). Salmonids, eels, mayfly nymphs and adults, dragonfly nymphs and adults, adult hemipterans, caddis fly larvae and cases, beetle pupae and adults, dipteran larvae and adults, freshwater clams, and salmonid eggs were taken in smaller amounts.

Salmonids comprised the largest portion of the diet of eels at Main Brook (Table 21, Figure 23). Other food items taken in lesser quantities included stonefly nymphs, mayfly nymphs and adults, dragonfly nymphs, caddis fly larvae and adults.

E. The Silver Eel

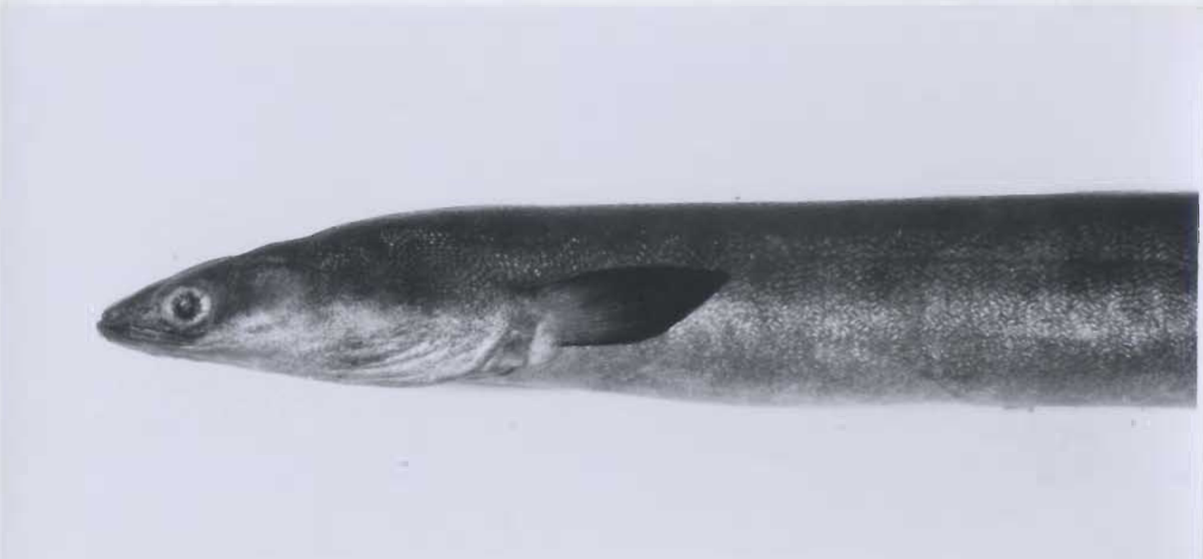
a. Description

The back and sides of the silver eel to just below the lateral line were black. Latero-ventral to this, the coloration merged to black-grey, grey-white and on the belly, milky-white or silver. The lower part of the operculum from the middle of the pectoral fin to the ventral surface of the head was silvery, and sometimes white, ventrally. The dorsal fin and pectoral fins were darkly pigmented and appeared black. The white or silvery-white undersurface extended to the anal fin which was white; in some instances the anal fin was white with a slightly pink tinge.

Coloration was variable in the specimens examined as different gradations of maturity were present. In all cases, however, the silver eels showed the dark back and fins with at least some evidence of a whitish or greyish undersurface (Figure 24). None of the specimens exhibited the bronze or purple coloration described by Vladykov (1955), or the brown or reddish brown on the back and belly typical of the nuptial stage or more advanced stage described in the European eel by Svärdson (1949a).

The pectoral fins ranged in length from 2.2 to 4.7 cms; the average was 3.4 cms in length. The regression line expressing length of pectoral fin with total length indicated a slight

Figure 24. The silver eel, <u>Anguilla rostrata</u> (LeSueur), taken from Topsail Pond on September 20, 1967.



difference between values for freshwater and the silver eel (FS = .99).

The nostrils were prominent in all silver eels examined and the lateral line was more distinct than in the yellow eel stage. The upper and lower lips were thin and the eyes were prominent. Orbital length ranged from 0.70 cms to 1.1 cms; the average orbital length was 0.85 cms. The body of the silver eel was firm and appeared more symmetrical than the yellow eel; this was possibly due to the shrunken state of the stomach and also to the accumulation of fat in the tissues.

Several other body measurements were investigated and regression analysis of these characters was carried out to determine whether significant differences occurred between the freshwater eel and the silver eel (values for brackish water eels and combined values for brackish and freshwater eels were not compared with the silver eel since the silver eels were caught in freshwater and it was desirable not to complicate the analysis with environmental differences by using brackish water eels in these comparisons). The other characters used in this analysis were: orbital length, pectoral length, width of snout anterior to eye, width of snout at nares, snout length, body girth, head length, postorbital head length, greatest head depth, greatest head width, greatest body depth and greatest body width.

Tables 22 and 23 show that significant differences occurred between the freshwater eel and the silver eel with respect to orbital length (12.08) and body girth (6.48). Substantial (although not significant at the 95% level) differences occurred with regard to width of snout anterior to the eye (1.24), snout length (3.51), head length (2.65), greatest body width (2.27) and greatest body depth (2.75). Eels in freshwater had longer snouts, wider snouts at the nares and anterior to the eye, longer heads, greater postorbital head lengths, wider heads and deeper heads (> 71 cms, total length), shorter pectorals, smaller body girths (< 61 cms, total length), shallower bodies (< 77 cms, total length) and narrower bodies (< 77 cms, total length) than the silver eel (Figure 25 and 26) .

The relationship between orbital length and total length as shown in Figure 25 indicates that the silver eel has a smaller eye than the freshwater eel at lengths greater than 60 cms. Since yellow eels would normally have become silver eels by the time they reach 60-70 cms, this part of the regression is misleading. It would appear that a growth inflection occurs at approximately 60 cms in orbital length; enlargement of the orbit possibly occurs as the eel begins its migration. The orbits as mentioned previously, averaged 0.85 cms; the largest was 1.1 cms.

b. Internal Changes

While these external characters serve as a partial index of the physiological state of development of the silver eel, internal

Table 22. Regression analysis of several body parts of the silver eel.

Character	Orbital Diameter	Pectoral Length	Width of Snout Anterior to Eye	Width of Snout at Nares	Snout Length	Body Girth
Slope =B=	.01	.05	.03	.01	.02	.18
Intercept =A=	.25	.01	- .51	- .26	- .03	.43
Correlation Coefficient =R=	.70	.77	.75	.78	.75	.87
Standard Error =S=	.06	.29	.19	.08	.12	.69
Computed F (freshwater eel vs silver eel)	12.09	.99	1.24	.54	3.51	6.48

Table 23. Regression analysis of several body parts of the silver eel.

Character	Head Length	Postorbital Head Length	Greatest Head Depth	Greatest Head Width	Greatest Body Depth	Greatest Body Width
Slope =B=	.12	.11	.06	.07	.06	.06
Intercept =A=	- .58	- 1.55	- .84	- 1.39	.11	- .03
Correlation Coefficient =R=	.88	.90	.85	.82	.84	.81
Standard Error =S=	.46	.37	.28	.33	.29	.29
Computed F (freshwater eels vs silver eels)	2.66	.41	.02	.10	2.75	2.27

Figure 25. Relative growth of different body parts of the silver eel (x____x) and eels from freshwater (.______.).

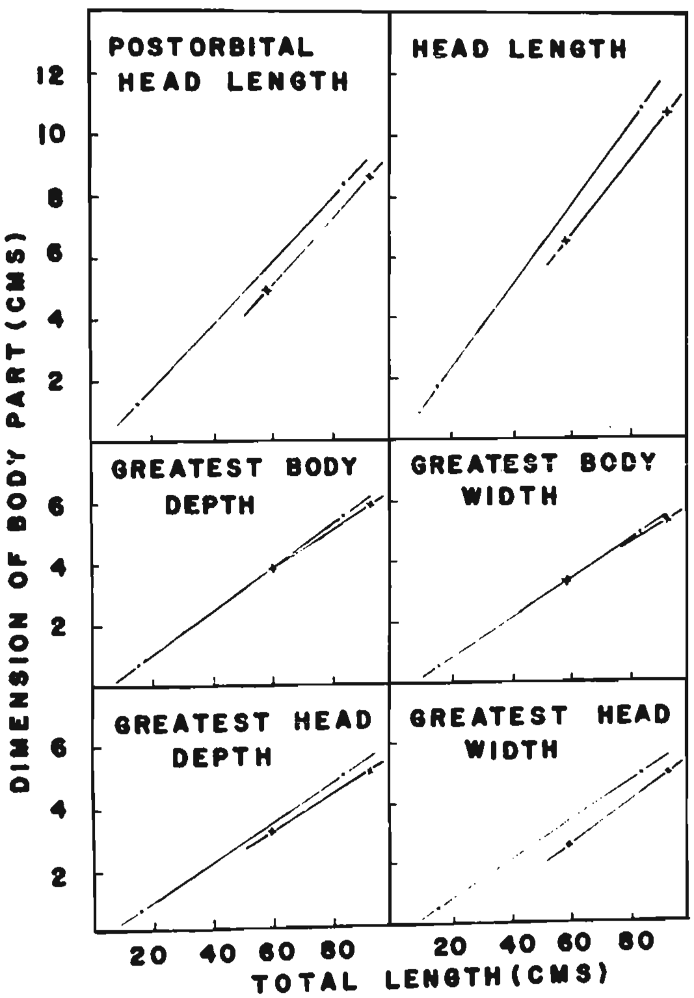
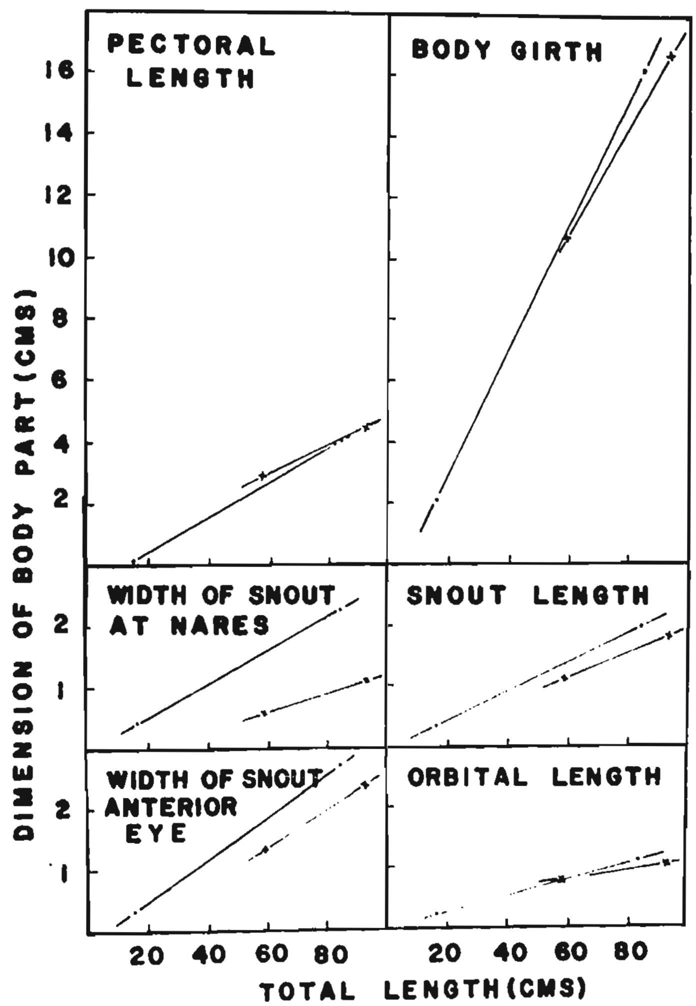

POSTORBITAL HEAD LENGTH
HEAD LENGTH
GREATEST BODY DEPTH
GREATEST BODY WIDTH
GREATEST HEAD DEPTH
GREATEST HEAD WIDTH
DIMENSION OF BODY PART (CMS)
12
10
8
6
4
2
20 40 60 80
TOTAL LENGTH (CMS)

Figure 26. Relative growth of different body parts of the silver eel (x____x), and eels from freshwater (.____.).


PECTORAL LENGTH
BODY GIRTH
WIDTH OF SNOUT AT NARES
SNOUT LENGTH
WIDTH OF SNOUT ANTERIOR EYE
ORBITAL LENGTH
DIMENSION OF BODY PART (CMS)
TOTAL LENGTH (CMS)
16
14
12
10
8
6
4
2
1
20
40
60
80

changes were also observed. Bertin (1956) states that from the beginning of the European eel's sexual maturation until the time it migrates, the European eel does not feed. In the present study, several freshly baited eel pots were kept in the channel leading from Topsail Pond to determine whether the migrating eels would enter them to feed. During the period from August 17, 1967 to September 27, 1967 no silver eels (or yellow eels) were found in the eel pots and the bait was untouched even though many migrating eels were present in the channel.

On gross examination, none of the migrating eels exhibited any degeneration in the stomach or intestine. The stomachs were, however, shrunken (Figure 27) and empty. A large amount of fat was deposited in the tissues, along the gastrointestinal tract and mesenteries.

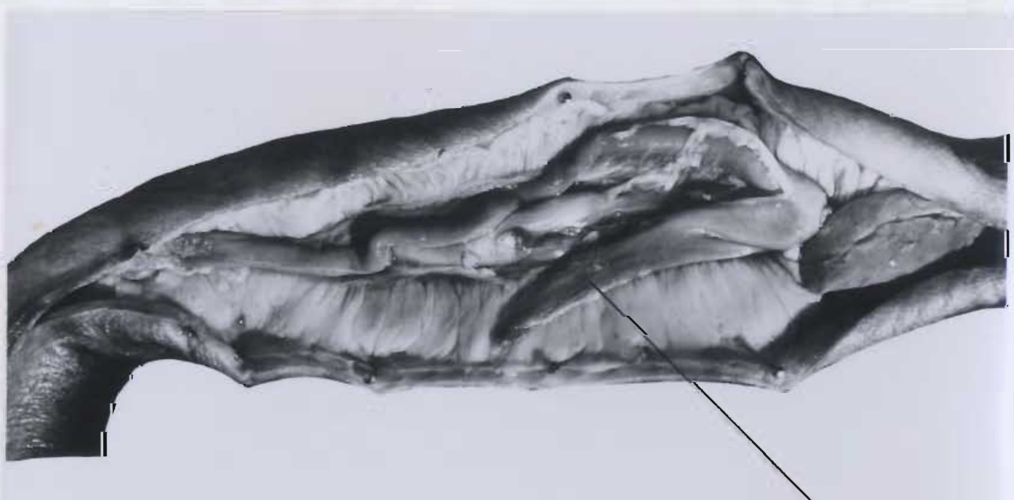
c. <u>Frequency Distributions</u>

i. <u>Age Frequency</u>

The age frequency distribution is shown in Table 24 and Figure 28. Clearly, 12 year old fish made up the dominant age group in migrating American eels (36.95%). Mature eels leaving Topsail Pond ranged in age from 9 to 18 years; the mean age was 12.28 years.

Figure 27. Stomachs taken from, (a) Yellow eel; (b) Silver eel; showing the shrunken state of the latter.

a

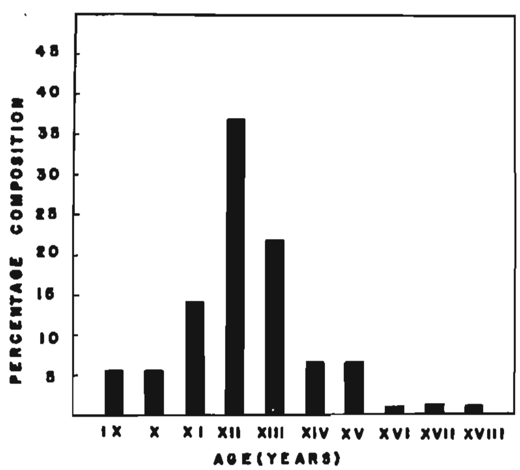


b

Table 24. Percentage age frequency of silver eels leaving Topsail Pond; number of fish are in parenthesis.

Age (Years)	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
Percentage	5.4 (5)	5.4 (5)	14.1 (13)	36.9 (34)	21.7 (20)	6.5 (6)	6.5 (6)	1.1 (1)	1.1 (1)	1.1 (1)

Figure 28. Age-frequency distribution in the silver eel.


PERCENTAGE COMPOSITION
45
40
35
30
25
20
15
10
5
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
AGE (YEARS)

ii. Length Frequency

Length frequency data are shown in Table 25 and Figure 29. Eels migrating from Topsail Pond ranged from 53.5 cms to 93.1 cms in length; the dominant length class was that with the class mark of 69.95 cms. The mean length for the sample was 69.4 cms (Table 26).

iii. Weight Frequency

Weight frequency distribution is shown in Table 27 and Figure 30. Migrating eels ranged from 224 to 1517 gms in weight. The dominant weight class was that having the class mark of 564.5 gms; the mean weight for the sample was 592 gms (Table 28).

d. Maturity

Since all silver eels examined were females, ova diameters were used as an index of the state of maturity of the migrating eels. A random sample of 7 ova was measured on prepared slides of each specimen; the average of the longest diameter of each ovum together with the diameter measured at right angles to the longest diameter was taken as the ovum diameter. Tables 29 and 30 show the total length, age, range in ova diameters, mean ova diameter and standard deviation of these means for silver eels taken from Topsail Pond. Figures 31 to 32 show the distribution of ova diameters by age and length, respectively. The ova sizes are not closely related to either age or length, and the sample is not large enough to elaborate further on these results. Ova ranged from .109 mm to .214 mm; the average ova diameter was .165 mm.

Table 25. Percentage length frequency of silver eels leaving Topsail Pond; number of fish are in parenthesis.

Length Class (cms)	51.1-54.0	54.1-57.0	57.1-60.0	60.1-63.0	63.1-66.0	66.1-69.0	69.1-72.0	72.1-75.0	75.1-78.0	78.1-81.0	81.1-84.0	84.1-87.0	87.1-90.0	90.1-93.0	93.1-96.0
Percentage	1.1 (1)		6.5 (6)	7.6 (7)	9.8 (9)	25.0 (23)	27.2 (25)	8.7 (8)	3.3 (3)	5.4 (5)	1.1 (1)	2.2 (2)		1.1 (1)	1.1 (1)

Figure 29. Length-frequency distribution in the silver eel.

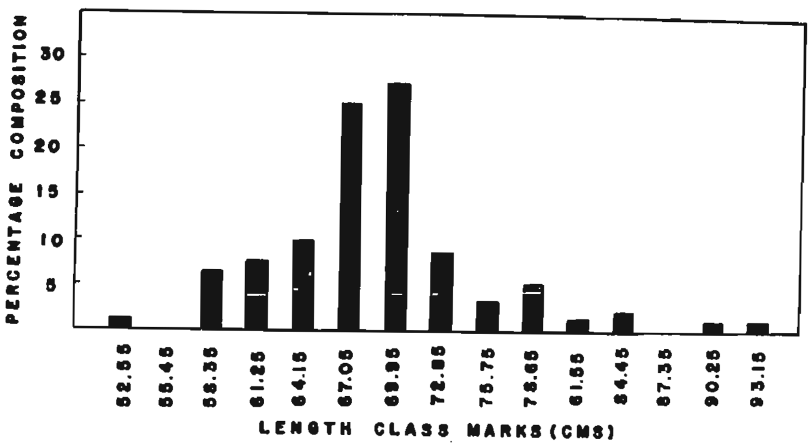

PERCENTAGE COMPOSITION
30
25
20
15
10
5
52.55
55.45
58.35
61.25
64.15
67.05
69.95
72.85
75.75
78.65
81.55
84.45
87.35
90.25
93.15
LENGTH CLASS MARKS (CMS)

Table 26. Mean length and range in length of silver eels leaving Topsail Pond.

Age Group	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
Mean length (cms)	58.7	61.7	64.5	67.6	71.9	74.3	81.5	86.8	92.4	93.1
Range in length (cms)	53.5-61.8	59.6-64.8	58.0-68.3	58.1-71.0	68.0-75.6	71.4-79.5	78.7-85.9	86.8	92.4	93.1
Number of specimens	5	5	13	34	20	6	6	1	1	1

Table 27. Percentage weight frequency of silver eels leaving Topsail Pond; number of eels are in parenthesis

Weight Class (gms)	181-240	241-300	301-360	361-420	421-480	481-540	541-600	601-660	661-720	721-780	781-840	841-900	901-960	961-1020	1021-1080	1081-1140	1141-1200
Percentage	1.1 (1)	2.2 (2)	5.4 (5)	7.6 (7)	8.7 (8)	18.5 (17)	23.9 (22)	11.9 (11)	9.8 (9)		2.2 (2)	1.1 (1)				3.3 (3)	

1201–1260	1261–1320	1321–1380	1381–1440	1441–1550	1501–1560
	2.2 (2)		1.1 (1)		1.1 (1)

Figure 30. Weight-frequency distribution in the silver eel.

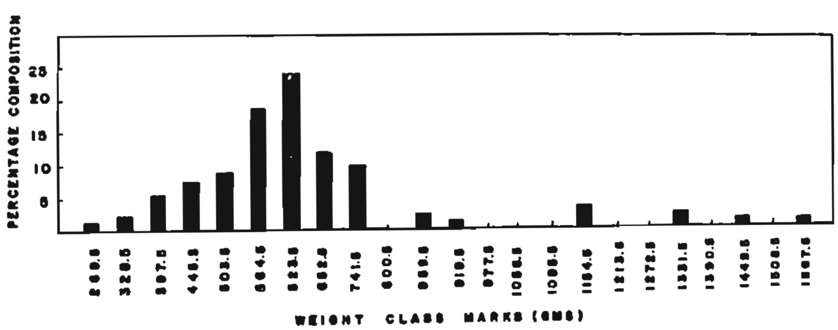

PERCENTAGE COMPOSITION
20
10
WEIGHT CLASS MARKS (GMS)

Table 28. Mean weight and range in weight, of silver eels leaving Topsail Pond.

Age Group	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII
Mean weight (gms)	318	393	467	531	608	752	1014	1103	1517	1413
Range in weight (gms)	224-377	256-448	312-563	257-665	462-828	656-1132	708-1277	1103	1517	1413
Number of specimens	5	5	13	34	20	6	6	1	1	1

Table 29. Correlation of ova diameters with age in silver eels leaving Topsail Pond

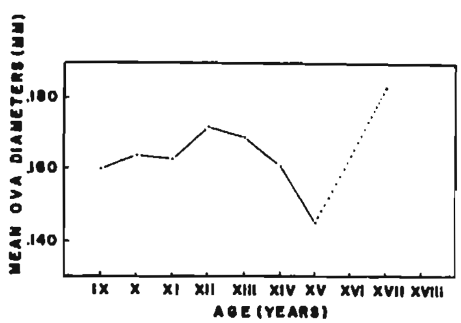
Age (yrs)	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	Sample
Range in ova diameters (mm)	.160	.152-.175	.130-.195	.144-.214	.130-.208	.139-.182	.109-.179		.183	.109-.214
Mean ova diameters (mm)	.160	.164	.163	.172	.169	.161	.145		.183	.165
Standard deviation		.009	.019	.018	.025	.017	.024			.022

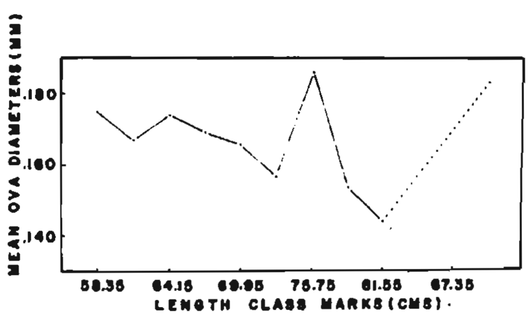
Table 30. Correlation of ova diameters with length in silver eels leaving Topsail Pond

Length Class (cms)	57.1-60.0	60.1-63.0	63.1-66.0	66.1-69.0	69.1-72.0	72.1-75.0	75.1-78.0	78.1-81.0	81.1-84.0	84.1-87.0	87.1-90.0	90.1-93.0
Range in ova diameter (mm)	.175	.152-.197	.153-.187	.130-.214	.144-.206	.130-.206	.163-.208	.109-.182	.144			.183
Mean ova diameter (mm)	.175	.167	.174	.169	.166	.157	.186	.154	.144			.183
Standard deviation		.056	.012	.021	.020	.027	.024	.029				

Figure 31. Correlation of ova diameters with age in the silver eel; the dotted line indicates that several ages are not represented in the sample.

Figure 32. Correlation of ova diameters with total length in the silver eel; the dotted line indicates that several length classes are not represented in the sample.


MEAN OVA DIAMETERS (MM)
.180
.160
.140
IX X XI XII XIII XIV XV XVI XVII XVIII
AGE (YEARS)


MEAN OVA DIAMETERS (MM)
.180
.160
.140
58.35 64.15 69.95 75.75 81.55 87.35
LENGTH CLASS MARKS (CMS).

IV. DISCUSSION

A. Growth Studies

The diversity of habitats sampled in the present study made it difficult to use uniform sampling methods throughout the four study areas. Thus, gear selectivity is a factor which must be considered in discussing the results.

The eel pots used in sampling the brackish water environments at Indian Pond and Topsail Barachois were biased in their catch since small eels ($<$ 15 cms) could escape through the drainage holes in the eel pots even though these were covered with ¼" galvanized wire mesh. Also, when a large eel ($>$ 70 cms) entered the eel pot, frequently it was the only occupant; eels of roughly the same size appeared to enter the same eel pot. This would appear to suggest that behaviour patterns in feeding activity may exist with regard to eels of different sizes.

Electrofishing at Burnt Berry Brook was found to be ineffective in water deeper than 3 feet; thus, the whole stream could not be searched for the presence of eels. Secondly, since a stronger current is required to capture smaller fish (A. Murray, pers comm), it is possible that many of these were not taken at Burnt Berry Brook.

Eels less than approximately 25 cms were able to escape through the smolt trap at Main Brook. Thus, not only was the sample from this stream small in number but it lacked representatives in the younger age groups.

Growth, since it is the result of metabolic activities, is affected by various physical, chemical and biotic environmental factors. Annual, seasonal and geographical variations in growth are common and wide variations in length and weight within a species in a given age group are not rare. In this discussion several factors which may affect growth in the different areas are mentioned, however, the direct effects which these variables have on eel growth have not been studied. They are included only in an attempt to explain the differences in growth observed in the different sampling areas.

Despite the variety of sampling gear used in the different areas, brackish water habitats appeared to accommodate greater numbers of older and larger eels than the freshwater areas studied (Table 4 and 5). The freshwater lakes sampled during the course of this investigation (Adam's Pond, Long Pond and Topsail Pond) and the stream surveys conducted at Burnt Berry Brook (C. Sturge, pers comm) would appear to support this hypothesis.

Eels appear to favor warm, sluggish water over cooler, fast moving streams (Bertin, 1956; Gardiner and King, 1922). Although continuous temperature records were not kept in the sampling areas, it is probable that the shallow, sluggish water in the more southerly brackish environments had higher mean annual temperatures than the more northerly, fast moving streams at Burnt Berry Brook and Main Brook or the freshwater lakes sampled. Consequently, it is possible that the warmer brackish water areas may act as an attractant for eels. Secondly, although the eel is euryhaline, it may prefer a more saline environment over freshwater and thus congregate in the brackish ponds; no mention is made of such a preference in the literature and remains conjecture at this stage.

The eels from Main Brook, the most northerly station, exhibited the slowest growth as expressed by the age-length and length-weight relationship and the second slowest growth rate as expressed by the age-weight relationship. The small sample size is possibly a contributory factor to these results, and mean annual temperatures in this stream are possibly lower than the more southerly study areas. It is well documented in the literature that temperature affects the rate of food intake, rate of digestion, and growth of several species (Hathway, 1927; Baldwin, 1956; Markus, 1932; Kohler, 1964, and May, et al, 1964). The adverse effects of low temperature on the European eel have been studied by Bruun, 1963; Adams and Hankinson, 1928; Gardiner and King, 1922, and

Sinha, 1965; similar effects have been reported on the American eel by Fowler, 1906; Bigelow and Schroeder, 1953; Smith and Saunders, 1955, and Medcof, 1966. If Mean annual temperatures are lower at Main Brook this might suggest a shorter annual growth period and consequently a slower growth pattern than the other study areas.

A second factor which may adversely affect growth at Main Brook is water current. Although no laboratory data are available on the effect which water movements have on fish, it is probable that maintenance requirements are higher (especially in larger fish) for fish living in rapid currents than for fish living in sluggish or still water (Brown, 1957). Female eels in Europe have a faster growth rate in lakes than in fast moving streams (Bertin, 1956; Sinha, 1967b). If such a relationship exists in the American eel it would help explain the slow growth pattern observed in this stream.

The fastest growth pattern as expressed by the age-length, age-weight and length-weight relationships occurred at Burnt Berry Brook. Although continuous temperature records were not kept in this stream, it is possible that mean annual temperatures were slightly higher than those at Main Brook; such a condition may help to explain the better growth rate observed in this stream. No data on current speed is available and comparisons in this respect with Main Brook are not possible.

The data on empty stomachs of eels from Burnt Berry Brook (Table 3) would seem to suggest that more food was available in this stream than at Main Brook. Thus, the fast growth of eels in this stream may be partly attributed to the amount of food available.

The growth rates observed at Indian Pond and Topsail Barachois were not greatly different; Indian Pond appears to have a slightly faster growth rate as expressed by the age-weight and length-weight relationships. The geographical position of these areas would seem to suggest that mean annual temperatures are higher than in the two freshwater habitats studied; this would seem to imply that eels have a longer growth period in these habitats. Still water is present at both Indian Pond and Topsail Barachois and it is possible that maintenance requirements in these areas are lower than those at Burnt Berry Brook and Main Brook. Both of these factors would appear to enhance growth in these brackish water habitats.

Quantitative measurements of eel densities were not made since in a short term investigation this would have necessitated destruction of each population studied and this was not desirable or practical in the areas sampled. However, from observations made during the sampling period between freshwater lakes and brackish water ponds, and the stream surveys carried out at

Burnt Berry it would appear that eel densities may be higher in brackish water habitats than in the freshwater habitats studied. This would suggest that competition for food and space may be higher in brackish water than in freshwater.

The effects of competition for food on other species have been studied by Pierce (1936), Tanaka (1955), Graham (1956), Ivlev (1961) and others. Sinha (1967b) noted that under over-crowded conditions cannabalism in the European eel was common. The data on stomach analysis suggests that a large number of eels in brackish water had either empty stomachs or stomachs with only bait (Indian Pond - 46%; Topsail Barachois - 68%). This might suggest that food was not as plentiful as in the freshwater habitats sampled. Although the data on stomach analysis do not strongly support the hypothesis that cannabalism is common, it is possible that the behaviour patterns previously mentioned may be effective in providing the larger eels with a feeding advantage over smaller eels in the population.

Competition for space in the two brackish water habitats may also affect growth patterns. Competition for space has been studied by Hornyold in the European eel (Bertin, 1956). He found that if eels were kept in small bottles they became dwarfed in spite of the presence of adequate amounts of food. If such a relationship exists in the brackish water areas sampled it is possible that Indian Pond was affected less than Topsail Barachois in this respect since it is a larger pond.

Other factors which may have influenced growth in the four study areas were: day length, physiological stress caused by osmoregulation, and the chemical composition of the water. The effect of light on animal activity and consequently growth has been studied by several authors (Darnell and Meierotto, 1962; Swift, 1955; Brown, 1946; Qasim, 1955, and Ball, 1961). Sinha (1967b) has reported that day length (and thus night length) has an effect on growth in the European eel. While the sampling areas are widely separated (approximately 600 miles), it is probable that each area had roughly the same number of hours of darkness and hence the effects of this factor on growth were equalized.

The effect of physiological stress caused by osmoregulatory mechanisms on growth is not known. Although the eel is euryhaline, a certain amount of energy must be expended in maintaining an equilibrium between its internal body fluids and the external environment. In freshwater, the internal environment of the eel is hypertonic, while in salt water it is hypotonic in relation to the external environment (Duval, 1925). This factor apparently would affect growth rate, however, its relationship was not studied in this investigation and it is impossible to relate its effect explicitly on growth in any of the sampling areas.

It has never been unequivocally shown that fish growth rates are directly affected by the ionic composition of water (Brown, 1957). Most differences in growth rate between marine and freshwater habitats are due more to differences in fauna and availability of food than to the chemical composition of water (Brown, 1957).

Although different food items were taken in brackish water habitats compared to freshwater habitats, it is not possible to relate the effects which these differences have on eel growth. Since a detailed study of the chemical environment was not made the effect which the ionic composition of the water might have on growth is not known.

B. Relative Growth Studies

As stated in the Introduction, several authors attributed changes in the growth of certain body parts to different physical, chemical or biotic factors in the environment. In particular, two different types of eels have been observed in adult populations (Vladykov, 1955); in the European eel Bertin (1956) has suggested that these differences are due to different environmental conditions. In the present study, two completely different habitats were chosen, a freshwater stream (Burnt Berry Brook) and a brackish water barachois (Topsail Barachois), to determine whether the environment had any significant effect in altering the growth of 20 different body parts.

With regard to the broad-nosed and sharp-nosed eel hypothesis, the results of this investigation suggest that eels living in freshwater have wider snouts at the level of the eye and at the nares, longer snouts, greater interorbital widths, slightly wider heads, and shallower heads. Of these measurements only the width of the snout at the level of the eye was statistically significant. From these data it would appear that the resident populations in freshwater do not vary significantly from those in brackish water with regard to the broad-nosed and sharp-nosed eel concept suggested by Bertin (1956).

Several broad-nosed eels as described by Bertin (1956) were noted in the course of this study. They were, however, observed in both habitats and probably represent individual genetic variations or possibly genetic polymorphism. Thus, it would appear that the two types of eels commonly observed are the result of genetic differences rather than environmental factors.

The results of the other body parts show that eels in brackish water had longer preanal lengths measured from the upper jaw, operculum and lower jaw, and greater predorsal lengths than eels in freshwater. Eels in brackish water had slightly longer pectoral fins (> 41 cms, total length) and had higher dorsal fins and slightly larger anal fins than eels in freshwater. Eels in brackish water had larger body girths (> 42 cms, total length), greater suborbital widths and deeper bodies than eels in freshwater. Eels in freshwater had wider bodies (> 50 cms, total length), longer heads and slightly greater postorbital head lengths. Eels (> 48 cms, total length) in freshwater had longer orbits than eels in brackish water.

Several factors appear to affect the relative growth of various body parts in different species. The effects of competition for food and space in the environment on relative growth has been studied by Koelz (1929), Svärdson (1950), Fenderson (1964) and McCart (1965). Their studies have shown that competition for food and space tends to dwarf one of the competing species or forms. Direct measurements of intraspecific and interspecific competition in these habitats were not made, however, it would seem that competition for both food and space is higher in brackish water habitats and this may account for some of the body changes observed in this investigation.

Changes in the physical or chemical environment, or in the diet of a species has been shown to effect changes in body form (Martin, 1949; Marr, 1955). The two habitats studied in this investigation varied greatly with regard to the chemical composition of the water and the changes observed in the different body parts may be related to changes in the chemical environment. Different food items were taken by eels in brackish water and freshwater and these dietary differences may help to explain the changes observed in body growth between the two habitats.

Since it is likely that American eels share a common breeding ground (Schmidt, 1925; Vladykov, 1964) it would not appear that isolation is a factor to be considered in explaining the above results. Therefore, the observed morphological differences would appear to be the result of genetic variation, competition for food and space, differences in the chemical environment, and dietary differences.

C. Sex Differentiation and Distribution

The results of this investigation indicate that females predominate in all the sampling areas. Only one male was observed in 262 eels examined; this specimen was taken from Burnt Berry Brook. Since both brackish water and freshwater habitats were sampled by a variety of methods and females were universal in their distribution it would appear that the geographical distribution of sex as stated by Bertin (1956) and others for the European eel does not apply for the American eel in the areas studied in Newfoundland. This view is supported in other areas of eastern Canada and the United States by the studies of Huver (1966) and Vladykov (1966).

The problem of sex differentiation in eels has been discussed in detail by Bertin (1956). Two hypothesis (Syngamic and metagamic) have been suggested; these are briefly outlined in section I,C.

The results of sex differentiation in this study indicate that the length at which differentiation takes place varied between the four study areas. Most eels became differentiated between 23-26 cms, however, in a few cases differentiation did not occur until eels had reached 34 cms. The data in Table 19 would appear to suggest that eels in freshwater differentiate at slightly younger ages than those in brackish water.

Vladykov (1966) has suggested a type of syngamic determination in the American eel. He suggested that elvers less than 55 mm developed into males while those elvers greater than 75.5 mm became females. While this hypothesis may apply, difficulties in explaining abnormal sex ratios in some areas are foreseen, noteably, Crecy Lake, New Brunswick. If large numbers of males are present in this lake, how can this be explained?

The effects of space, nutrition, temperature, salinity, and other factors on sex determination in the European eel have been studied by Tesch (1928), Hornyold (1932), D'Ancona (1943, 1951, 1959), Svärdson (1949b), Fidora (1951), Bertin (1956) and Sinha (1966). The effects of these environmental factors on sex determination in the American eel have not been studied.

The large number of females in Newfoundland suggests an abnormal sex ratio as stated previously. While the explanation given by Vladykov (1966) may account in part for the high percentage of females in Newfoundland and other areas in eastern Canada and the United States, it is possible that the distribution of sex in the American eel may be correlated with latitude (Vladykov, 1966) and hence temperature. Vladykov (1966) reported a high percentage of males in the south and a gradual increase in the percentage of females with an increase in latitude. Since temperatures are probably lower in the higher latitudes and a large number of females are present in the north, temperature may be an important factor in sex determination in the American eel. While temperatures in the areas studied in Newfoundland were not always low, the average annual temperatures were probably below those farther south (Florida). In most areas of Newfoundland, water temperatures are below 15 degrees centigrade for approximately 8-9 months each year and this may have an effect in producing more females than males.

While females predominate in the northern part of the range, it is possible that males make up a large proportion of resident populations in some areas in the north. Vladykov (1966) reported that in several small shallow lakes in New Brunswick, noteably, Crecy Lake, males were abundant (83.9%). This lake has a mean depth of 2.4 m and water temperatures are probably quite high during the summer. Details of these lakes are given by Smith and Saunders (1955) and Smith (1952b). While temperature appears to be an important factor in explaining the abnormal sex ratios obtained in this study, it is of course speculation and a concrete explanation of sex differentiation and distribution can only be obtained through more detailed laboratory and field experiments.

D. Stomach Analysis

Table 3 shows that the percentage of empty stomachs in freshwater was higher than the percentage of empty stomachs in brackish water. However, the combined values of eels with empty stomachs and those which had only bait indicate that 58.8% of the eels from Indian Pond and Topsail Barachois had empty stomachs before entering the eel pots. In addition, 29.9% of the eels in brackish water had indistinguishable stomach contents. Thus, only 11.3% of the eels in brackish water had stomach contents which could be identified with accuracy; in contrast, 57.0% of the stomachs examined from freshwater had stomach contents which could be identified. Because of the large proportion of stomachs which were empty or had indistinguishable contents it is evident that the eel pot is not a good sampling method for studies on stomach contents. In order to investigate thoroughly the food being taken by eels in brackish water it would be more feasible to use a limited amount of rotenone in a small brackish water barachois where the American eel is the major vertebrate occupant.

As pointed out in the results, the major food items taken by eels in brackish water were clams, shrimp (probably Pandalus) gammarids, brittle stars (probably Ophiocomina), eels, sticklebacks, unidentified eggs, and dragonflies. Although the eel pots were sitting on the bottom, the water was not deeper than five feet in many cases and eels both at the surface as well as on the bottom may be attracted by the bait in the eel pots. The stomach contents of eels in brackish water are not extensive, however, they would appear to suggest that the American eel in brackish water depends to a significant degree on bottom organisms.

The tendency of eels to enter eel pots in search of food and the fact that they took the dead material (capelin, herring, cod and squid) would appear to testify to their reported scavenger habits (Bigelow and Schroeder, 1953). Occasionally fishermen at Indian Pond observed eels take dead fish when these were thrown into the pond.

Although eels took dead material, they also took live fish. This was suggested by the presence of apparent healthy eels, salmonids, and sticklebacks in some of the stomachs examined. Similar observations have been made by Brinley and Bowen (1935), Perlmutter (1951) and Godfrey (1957).

An alternate food supply may be available to brackish water populations of eels in some areas. Fishermen have reported that eels have been seen leaving brackish water ponds and moving out to sea and returning later. Such migrations have been observed when capelin, herring or squid are found in inshore waters; their movements have been correlated to tidal patterns in the area. While such movements have not been reported in the literature, they do provide a possible explanation for the maintenance of eel populations in these small barachois.

The results of stomach analysis in freshwater would seem to indicate that the major food items taken by eels are bottom-dwelling invertebrates. These include several different aquatic larvae and nymphs; dragon fly nymphs, caddis fly larvae, may-fly nymphs, caddis fly cases, beetle pupae, dipteran larvae, and stonefly nymphs. Eels also took freshwater snails, salmonid eggs and freshwater clams which were distributed over the bottom. In addition to these bottom-dwelling organisms, the eel took several types of adult insects, namely, mayflies, dragon flies, hemipterans, beetles, dipterans and caddis flies. The American eel preyed on several fish species, particularly, salmonids and eels. While the data are limited, it would appear that the American eel is mainly a bottom feeder.

The main difference in food items taken by the American eel in brackish water and freshwater was the large proportion of insects taken by eels in freshwater. Fish constituted a larger portion of the diet of eels in freshwater (19.7%) than eels taken from brackish water (5.4%). The data from both habitats suggests that the American eel may actively prey on other fish in its environment and is not strictly a scavenger.

Analysis of the data with regard to the three methods employed in this study showed that usually the food item taken in greatest number (Number Method) was also found in the largest number of stomachs (Occurrence Method). Thus in brackish water, shrimp, clams and fish were found in more stomachs than the other dietary items. In freshwater, caddis fly larvae, dragon fly nymphs, freshwater snails, mayfly nymphs, adult hemipterans, adult dipterans and salmonids were found in the majority of the stomachs examined. The dry weight method shows that the organisms taken in greatest quantity in brackish water were shrimp, clams, and fish. In freshwater salmonids and freshwater snails were taken in greatest quantity. The dry weight method has certain disadvantages since most of the animals represented have hard parts which are of doubtful food value.

The present results agree with those of Godfrey (1957) with regard to predation on salmonids. They were represented in 5.8% of the stomachs examined in freshwater; Godfrey reported that 6 of 390 eels or 1.5% had eaten salmon fry. These data indicate that predation of eels on salmonids represent a substantial loss of salmonids in the stream.

Godfrey (1957) concluded that the food of eels in freshwater was mainly insects that live among the stones on the river bottom. These included mayfly nymphs, stonefly nymphs, fly larvae (mostly midges and blackflies), dragon fly nymphs, beetle larvae and caddis larvae. In addition he reported the presence of black-nosed dace, sticklebacks, sculpins, crayfish, freshwater snails, earthworms, and roundworms in the stomachs of these eels.

Other authors have reported that the American eel preys on menhaden (Brevoortia tyrannus), alewives (Alosa pseudoharengus), ammocoete of sea lamprey (Petromyzon marinus), American brook lamprey (Entosphenus lamottei), shrimp, crabs, lobsters and other small crustaceans (Brinley and Bowen, 1935; Perlmutter, 1951; Bigelow and Schroeder, 1953).

The diet of the American and European eels would appear to be similar, however differences are present due to variation in the bottom fauna. The present data are too limited to correlate dietary changes with size in the American eel; also, all eels were collected during the summer months and no information is available on their feeding habits during the winter. Despite the limitations of sampling procedures the data would appear to suggest that the American eel both in brackish water and freshwater depends to a significant degree on food items found on the bottom. It is not solely a bottom feeder, however, as it takes food from several sources.

E. The Silver Eel

The observations made in the present study on coloration suggest that the American eel goes through the same colour phase as its European relative. Since all migrating eels are not in the same stage of sexual maturity (from ova diameters), different gradations of the coloration described in this thesis will occur. Despite these color differences, the American eel's migratory coloration is basically similar to that described for the European eel and the term silver eel can appropriately be used.

The use of regression analysis in the yellow stage and silver stage of the American eel suggests that growth inflections probably occur with regard to several of the body measurements examined. Since all of the silver eels were taken from freshwater, accurate comparisons of changes in body form should be restricted to freshwater specimens. The most extreme cases of growth inflection were exhibited by the following body parts: orbital diameter, pectoral length, greatest head depth, greatest body width, greatest body depth and body girth.

The rapid growth in the size of the eye with respect to length in the yellow eel does not continue in the silver eel and a growth inflection would seem to occur at approximately 55 cms in the total length; the size of the orbit does not increase as rapidly as in the yellow stage . Despite this growth inflection there is evidence of macropthalmia since the eye is large (average = 0.85 cms) and the head has become shorter, shallower and narrower in comparison to the condition present in the yellow eel.

The silver eel has longer pectoral fins than the yellow eel. A growth inflection with regard to greatest head depth occurs at approximately 71 cms; above this, silver eels have shallower heads than yellow eels. Growth inflections for greatest body width, greatest body depth and body girth occur at approximately 77 cms, 52 cms and 62 cms, respectively. Above these lengths, growth of the corresponding body part is less in silver eels than for yellow eels. Thus, changes in body form do occur in the silver eel and as a result of these changes it has a shorter, narrower, shallower head, longer pectoral fins, smaller body girths

($<$ 62 cms total length), shallower bodies ($>$52 cms total length), narrower bodies ($>$ 77 cms total length), narrower snouts and prominent eyes.

While some of these changes in body form as represented by the regression lines in Figures 25 and 26 are not significant at the 95% level of significance, they do agree with the changes reported in the European eel (Frost, 1945) prior to its migration to sea. It would appear that the silver eels leaving Topsail Pond have begun to acquire changes in body form similar to the silver eel in Europe but these changes do not appear to have progressed to the stage described by European authors.

The internal changes observed in the digestive tract in the silver eels leaving Topsail Pond were not as pronounced as those described in the European silver eel by Bertin (1956). Clearly, however, the silver eel does not feed and the stomachs are consequently shrunken to a fraction of their previous size (Figure 27). The mesenteries, digestive tract, gonads and other tissues have stored large amounts of fat in preparation for their spawning migration.

The ova diameters of eels leaving Topsail Pond ranged from .109 mm to .214 mm; the average was 0.165 mm. The majority (58.7%) of the ova ranged from .131 to .202 mm in diameter. These ova were not as large as those reported in the American eel by

Vladykov (1964). However, the eels (four specimens) examined by this author were large eels (average weight = 1280 gms) and possibly not totally representative; the ova of these eels ranged from 0.20 mm to 0.35 mm in diameter. Svärdson (1949a, p. 128), reported that European silver eels "normally have eggs with a diameter of 0.1 - 0.2 mm but not larger". On this basis, the silver eels observed at Topsail Pond were probably in the same state of sexual maturity as the European silver eel prior to its seaward migration.

The data in the present study are too limited to draw any conclusions regarding ova size and eel length or age. Figures 30 and 31 suggest that neither length nor age are closely correlated with ova diameter, however, more extensive material would be necessary to elaborate on such a relationship.

Although silver eels ranged in age from 9 to 18 years, the majority of eels leaving Topsail Pond were 12 or 13 years of age (58.7%). The average age of American silver eels collected in this study was 12.28 years. These results correspond closely to those reported for the European eel by Frost (1945), and Rasmussen (1952), and for the American eel by Bigelow and Schroeder (1953). Frost (1945) found that migrating eels were on the average 12.27 years old; Rasmussen (1952) reported that migrating European eels were 11.4 years old. Bigelow and Schroeder

(1953) reported that one migrating female silver eel was examined by Dr. Hugh M. Smith and found to be 12 years old. The data presented on age are not extensive. However, the results would appear to corroborate the fact that American eels migrate at the same age as the European silver eel.

Migrating eels ranged from 53.5 to 93.1 cms in length; the mean length of the sample was 69.4 cms. Frost (1945) reported that the mean length of migrating eels was 60.78 cms; Rasmussen (1952) found that migrating eels in Denmark were 56.9 cms. No comparable results for the American eel appear in the literature. From the present data the American silver eel would appear to be larger at the onset of migration than its European neighbour.

The eels leaving Topsail Pond ranged in weight from 224 to 1517 gms; the average weight was 592 gms. Rasmussen (1952) reported that the average weight of silver eels leaving Danish waters was 330.8 gms. Thus, the American silver eel would appear to be heavier than the silver eel in Europe prior to its migration to sea.

V. SUMMARY AND CONCLUSIONS

1. The data on growth indicate a slow growth pattern in the American eel. Growth during the first 6 years is very slow, especially in brackish water habitats. As eels in brackish water become older and consequently larger, they grow proportionately faster than their neighbours in freshwater.

2. Eels from Burnt Berry Brook exhibited the fastest growth in length, followed by those from Topsail Barachois, Indian Pond and Main Brook. The fastest growth in weight occurred in eels from Burnt Berry Brook, followed by eels from Indian Pond, Main Brook, and Topsail Barachois.

3. The data on relative growth indicate that significant differences in the growth of body parts between brackish water and freshwater habitats occurred with regard to preanal length measured from the upper jaw, preanal length measured from the lower jaw, preanal length measured from the operculum, width of snout anterior to the eye, orbital length and greatest body width. Although these variations suggest the existence of separate populations, the broad-nosed and sharp-nosed eel concept reported by Bertin (1956) for European eels does not appear to apply to the populations studied in this investigation.

4. The data on sex distribution indicates that an abnormal sex ratio exists in all areas studied in Newfoundland. Only one male

was identified in the material. Although conclusive evidence has not been compiled to determine the reasons for this abnormality, it is possible that this condition is related to the cooler temperatures present in Newfoundland compared to those in the southern part of the range of the American eel.

5. The principal food items taken by eels in brackish water were clams, shrimp, gammarids, brittle stars, adult dragon flies, fish eggs, sticklebacks and other eels. In contrast, eels in freshwater had a larger insect diet which included adult dragonflies, dragonfly nymphs, caddis fly cases, caddis fly larvae, adult caddis flies, mayfly nymphs, adult mayflies, adult hemipterans, beetle pupae, adult beetles, dipteran larvae, adult dipterans, stonefly nymphs. They also took freshwater snails, freshwater clams, salmonid eggs, salmonids, and other eels. The data on stomach contents would appear to suggest that the American eel in both brackish water and freshwater depends to a significant degree on food items found on the bottom, however, it is not solely a bottom-feeder since it appears to take food from several sources.

6. The data on color, body measurements, internal changes in the gastrointestinal tract and state of maturity suggest that the American eel at the onset of seaward migration can appropriately be called a silver eel. This condition is reached at a mean age

of 12.28 years, a mean length of 69.4 cms and a mean weight of 592 gms. The mean ova diameter of the migrating females was .165 mm. The American eel at the onset of migration is generally larger than its European counterpart, however, its state of sexual maturity appears to be the same as that observed in the silver eel in Europe.

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APPENDIX I

COMPUTER PROGRAM

```
      Growth Analysis of the American Eel
      Dimension X(5,135),Y(5,135),SSXD(5),SSYD(5),CY(135),P(10)
      Dimension SPD(5),RSS(5),XX(10),YY(10),YX(10),RY(10),FR(10)
      N = 0
      DO 40 K = 1,3
      PUNCH 50
      PUNCH 51,K
      DO 6 I = 1,5
      READ 48,M
      IF(K-2)4,4,5
    4 READ 49,(X(I,J),J = 1,M)
      GO TO 6
    5 READ 52,(X(I,J),J = 1,M)
    6 READ 52,(Y(I,J),J = 1,M)
    3 DO 30 I = 1,5
      GO TO (81,82,83,84,85),I
81    M = 135.0
      GO TO 86
82    M = 75.0
      GO TO 86
83    M = 38
      GO TO 86
84    M = 66.0
```

COMPUTER PROGRAM (CONT'D)

```
      GO TO 86
85    M = 92.0
86    F = M
      SX = 0.0
      SY = 0.0
      SP = 0.0
      DO 11 J = 1,M
      SX = SX+X(I,J)
      SY = SY+Y(I,J)
      SSX = SSX+X(I,J)*X(I,J)
      SSY = SSY+Y(I,J)*Y(I,J)
 11   SP = SP+X(I,J)*Y(I,J)
      SSXD(I) = SSX-SX*SX/F
      SSYD(I) = SSY-SY*SY/F
      SPD(I) = SP-SX*SY/F
      RSS(I) = SSYD(I)-SPD(I)*SPD(I)/SSXD(I)
      R = SQRT((SPD(I)*SPD(I))/(SSXD(I)*SSYD(I))
      B = SPD(I)/SSXD(I)
      A = SY/F-B*SX/F
      SE = SQRT((1.0-R*R)*SSYD(I)/F-2.0))
      DO 8 J = 1,M
      CY(J) = A+(B*X(I,J))
      PUNCH 53 , SPD(I),R,B,A,SE
      PUNCH 54
      PUNCH 55,(CY(J),J = 1,M)
```

COMPUTER PROGRAM (CONT'D)

```
PUNCH 56
DO 1 J = 1,4
XX(J) = SSXD(1)+SSXD(J+1)
YY(J) = SSYD(1)+SSYD(J+1)
YX(J) = SPD(1)+SPD(J+1)
RY(J) = RSS(1)+RSS(J+1)
DO 2 J = 5,7
XX(J) =SSXD(2)+SSXD(J-2)
YY(J) = SSYD(2)+SSYD(J-2)
YX(J) = SPD(2)+SPD(J-2)
RY(J) = RSS(2)+RSS(J-2)
DO 44 J = 8,9
XX(J) = SSXD(3)+SSXD(J-4)
YY(J) = SSYD(3)+SSYD(J-4)
YX(J) = SPD(3)+SPD(J-4)
RY(J) = RSS(3)+RSS(J-4)
XX(10) = SSXD(4)+SSXD(5)
YY(10) = SSYD(4)+SSYD(5)
YX(10) = SPD(4)+SPD(5)
RY(10) = RSS(4)+RSS(5)
DO 9 I = 1,10
GO TO (71,72,73,74,75,76,77,78,79,80),I
G = 206.0
GO TO 17
G = 169.0
```

COMPUTER PROGRAM (CONT'D)

```
GO TO 17
G = 197.0
GO TO 17
G = 223.0
GO TO 17
G = 109.0
GO TO 17
G = 137.0
GO TO 17
G = 163.0
GO TO 17
G = 100.0
GO TO 17
G = 126.0
GO TO 17
G = 154.0
P(I) = (YY(I)-YX(I)*YX(I)/XX(I)) -RY(I)
FR(I) = P(I)/(RY(I) / G)
PUNCH 57,(FR(I),I = 1,10)
PUNCH 50
N = N+1
IF(N-K*2)22,40,40
DO 21 I = 1,5
GO TO (91,92,93,94,95),I
```

COMPUTER PROGRAM (CONT'D)

```
M = 135.0
GO TO 27
M = 75.0
GO TO 27
M = 38.0
GO TO 27
M = 66.0
GO TO 27
M = 92.0
DO 21 J = 1,M
X(I,J)=LOG(X(I,J))
Y(I,J)=LOG(Y(I,J))
GO TO 3
CONTINUE
FORMAT(13)
FORMAT(2014)
FORMAT(10HCHARACTER  12)
FORMAT (20F4.1)
FORMAT(2HS = ,F16.1,3X,2HR = ,F6.4,3X,2HB = ,F11.4,3X,2HA =
                    ,F14.4,3X,3HSE1 = ,F9.4
FORMAT(10HCOMPUTED Y)
FORMAT(10F8.3)
FORMAT(10HCOMPUTED F)
FORMAT(5F10.3)
END
```

APPENDIX II.

COMPUTER PROGRAM

```
C     GROWTH ANALYSES OF THE AMERICAN EEL (A)
      DIMENSION X(4,140),Y(4,140),CY(140),SSXD(4),SSYD(4),YX(1)
      DIMENSION SPD(4),RSS(4),XX(4),YY(4)     ,RY(4),P(4),FR(4)
      N=0
      DO 40 K=1,20
      DO 1 I=1,3
 1    READ 52,(X(I,J),J=1,70)
      DO 2 I=1,3
 2    READ 52,(Y(I,J),J=1,70)
      DO 6 J=1,70
      X(4,J)=X(1,J)
      X(4,J+70)=X(2,J)
      Y(4,J)=Y(1,J)
    6 Y(4,J+70)=Y(2,J)
      PUNCH 50
      PUNCH 51,K
    3 DO 30 I=1,4
      SX=0.0
      SY=0.0
      SSX=0.0
      SSY=0.0
      SP=0.0
      IF(I-3)5,5,4
```

```
    4 M=140
      F=140.0
      GO TO 7
    5 M=70
      F=70.0
7     DO 11 J=1,M
      SX=SX+X(I,J)
      SY=SY+Y(I,J)
      SSX=SSX+X(I,J)*X(I,J)
      SSY=SSY+Y(I,J)*Y(I,J)
11    SP=SP+X(I,J)*Y(I,J)
      SSXD(I)=SSX-SX*SX/F
      SSYD(I)=SSY-SY*SY/F
      SPD(I)=SP-SX*SY/F
      RSS(I)=SSYD(I)-SPD(I)*SPD(I)/SSXD(I)
      R=SQRT((SPD(I)*SPD(I))/(SSXD(I)*SSYD(I)))
      B=SPD(I)/SSXD(I)
      A=SY/F-B*SX/F
      SE=SQRT((1.0-R*R)*SSYD(I)/(F-2.0))
      DO 8 J=1,M
    8 CY(J)=A+(B*X(I,J))
      PUNCH 53,SPD(I),R,B,A,SE
      PUNCH 54
   30 PUNCH 55,(CY(J),J=1,M)
      PUNCH 56
```

```
      XX(1)=SSXD(1)+SSXD(2)
      XX(2)=SSXD(1)+SSXD(3)
      XX(3)=SSXD(2)+SSXD(3)
      XX(4)=SSXD(3)+SSXD(4)
      YX(1)=SPD(1)+SPD(2)
      YX(2)=SPD(1)+SPD(3)
      YX(3)=SPD(2)+SPD(3)
      YX(4)=SPD(3)+SPD(4)
      YY(1)=SSYD(1)+SSYD(2)
      YY(2)=SSYD(1)+SSYD(3)
      YY(3)=SSYD(2)+SSYD(3)
      YY(4)=SSYD(3)+SSYD(4)
      RY(1)=RSS(1)+RSS(2)
      RY(2)=RSS(1)+RSS(3)
      RY(3)=RSS(2)+RSS(3)
      RY(4)=RSS(3)+RSS(4)
      DO 9 I=1,4
      IF(I-3)16,16,15
   15 G=206.0
      GO TO 17
   16 G=136.0
17    P(I)=(YY(I)-YX(I)*YX(I)/XX(I))-RY(I)
    9 FR(I)=P(I)/(RY(I)/G)
      PUNCH 57,(FR(I),I=1,4)
      N=N+1
```

```
      IF(N-K*2)22,40,40
   22 DO 21 I=1,4
      IF(I-3)25,25,24
   24 M=140
      GO TO 27
   25 M=70
27    DO 21 J=1,M
      X(I,J)=LOG(X(I,J))
21    Y(I,J)=LOG(Y(I,J))
      GO TO 3
   40 CONTINUE
   50 FORMAT(/)
51    FORMAT(10HCHARACTER 12)
   52 FORMAT(20F4.1)
   53 FORMAT(2HS=,F16.1,3X,2HR=,F6.4,3X,2HB=,F11.4,3X,2HA=,F14.4,3X,3HSE
      1=,F9.4)
   54 FORMAT(10HCOMPUTED Y)
   55 FORMAT(10F8.3)
   56 FORMAT(10HCOMPUTED F)
   57 FORMAT(3HBF=,F9.3,4X,3HBS=,F9.3,4X,3HFS=,F9.3,4X,6H(BF)S=,F9.3)
      END
```