THE BIOLOGY OF THE SHORTHORN SCULPIN
MYOXOCEPHALUS SCORPIUS (L.)
IN NEWFOUNDLAND WATERS

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The biology of the shorthorn sculpin
Myoxocephalus scorpius (L.) in Newfoundland waters

by

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Abstract

The shorthorn sculpin *Myoxocephalus scorpius* is not fished commercially in Newfoundland. Its biology, based primarily on year-round monthly samples from Bay Bulls and on direct observations in its natural environment while scuba diving, is presented.

The nomenclature of the species is reviewed briefly.

The length frequencies of males were normally distributed but those of the females were more evenly distributed throughout their range of lengths. Females attain larger sizes and, on the average, are larger than the males.

Various length-weight relationships, including whole, gutted and fillet weights, for each sex are given as well as seasonal changes in the coefficient of condition.

Average length-at-age data were fitted to the von Bertalanffy equation. Below age 4 the growth rates of males and females were little different but above age 4 the females grew much faster than the males. The difference between average length-at-age for males and females became progressively larger with age. Analysis of the age composition of the populations sampled showed definite year-class dominance.

Males were found to mature at a younger age and at a smaller size than females. In any age group where there were mature and immature specimens the mature ones, on the average, were larger.

Ripening ovaries were found to contain 3 generations of ova which were evenly distributed throughout the ovary. Oogenesis takes about 2½ years. Spawning starts in late November to early December and

lasts for about one month. The eggs are deposited in clumps in crevices usually in about 20-35 ft of water and after spawning the females move away from the spawning area into deeper water. The mature males remain behind and guard the eggs until they hatch. At temperatures near 0.0°C embryonic development takes over 3 months. Hatching starts about mid-March, reaches a peak towards the end of March and is completed early in April. Newly-hatched larvae were observed to occupy all layers of the water column where the water was about 25-30 ft deep but were concentrated about 2 ft off the bottom. They were observed to swim upwards and to sink downwards in the water column. Mature females produced between 4000 and 61,000 eggs depending on size.

Shorthorn sculpins are omnivorous carnivores and scavengers. The bulk of their food is benthic invertebrates, mainly crabs, but small, bottom-living fishes form a fairly large part of their diet. Feeding activity changes throughout the year and is considerably reduced before and during the spawning period.

They have a rich parasitic fauna, including a variety of trematodes and nematodes internally and amphipods and hirudineans externally.

Introduction

This thesis presents an account of the biology of the shorthorn sculpin *Myoxocephalus scorpius* (L.) in Newfoundland waters. The shorthorn is included in practically every checklist of North American marine fishes such as Jordan and Evermann (1896-1900), Bigelow and Schroeder (1953) and Leim and Scott (1966). This is practically the only kind of scientific treatment the species has received in the northwest Atlantic and consequently only little is known of its biology and life history in this area. In the northeast Atlantic the species has received more attention and its biology is better known there.

Geographically the shorthorn is widespread. It is found on both sides of the north Atlantic and in the Arctic where it is found from Alaska through to Hudson Bay and Baffin Island and south to New York. It is found at Greenland, Iceland, Spitzbergen, Novaya Zemlya, Siberia and northern Europe south to the Bay of Biscay (Leim and Scott, 1966).

The shorthorn is a demersal species and is generally found close to shore in less than 10 fathoms with very few taken below 15-20 fathoms (Bigelow and Schroeder, 1953). The deepest records in American waters are from 50 fathoms near Campobello Island, at the mouth of the Bay of Fundy (Huntsman, 1922) and 57 fathoms in the northern part of the Gulf of St. Lawrence, just within the Strait of Belle Isle (Anon., 1932).

Shorthorn sculpins have a negative commercial value. They eat many baits on line trawls and handlines and many are caught in gillnets and in the leaders and bottoms of codtraps. They are difficult to remove from netting and often meshes have to be broken. Large numbers of young cod and probably also young lobsters are eaten by sculpins.

Nomenclature

The shorthorn sculpin is widespread geographically. It prefers to stay in the same habitat and tends to break up into local races (Hass, 1937) and this has undoubtedly led to considerable variation within the species. Literature references on sculpins, dealing mainly with taxonomy and distribution, are numerous. The result has been an abundant and confusing nomenclature for the group. This confusion has been reviewed by Morrow (1951) for the sculpin group in general and particularly for the longhorn sculpin *Myoxocephalus octodecemspinosus*.

The shorthorn sculpin *Myoxocephalus scorpius* was originally described by Linnaeus in 1758 and he called it *Cottus scorpius*. Cuvier and Valenciennes (1829) changed the name to *C. groenlandicus* and Richardson (1836) retained *C. groenlandicus* for the Greenland form but considered it synonymous with *C. scorpius*. The genus name was changed to *Acanthocottus* by Girard (1851). A Russian, Tilesius, had proposed the genus name *Myoxocephalus* in 1811 but his work was not known in the United States until about 70 years later. Fabricius (1870) retained *C. scorpius*. Malmgren (1864), Lütken (1876) and Dresel (1884) all considered the Greenland form *groenlandicus* a subspecies of *C. scorpius*. Jordan and Gilbert (1882) rejected Tilesius' *Myoxocephalus* and considered *Acanthocottus* synonymous with *Cottus*. Jordan and Evermann (1896) accepted Girard's *Acanthocottus* as valid for the marine coastal sculpins of both the Atlantic and Pacific coasts of North America. In 1898 however, they recognized Tilesius' *Myoxocephalus* as the valid name of the genus and divided it into two subgenera, *Acanthocottus* for Atlantic forms and *Myoxocephalus* for Pacific forms. The European form they called *M. scorpius* and the North American and Greenland forms *M. groenlandicus*. In 1930, however, Jordan, Evermann and Clark gave full generic rank to the two subgenera of Jordan and Evermann (1898) and the European form became *Acanthocottus scorpius* while the North American and Greenland forms became *Acanthocottus groenlandicus*. Jensen (1910) considered the Greenland and European forms a single species *C. scorpius*. Huntsman (1922) also considered both forms the same species but called them *Myoxocephalus scorpius*. Recent workers (Bigelow and Schroeder, 1953; Leim and Scott, 1966) also use *M. scorpius* for both forms. In recent European papers (Hass, 1937; Kühl, 1961; Lamp, 1966) the European form is also called *Myoxocephalus scorpius* and *Cottus scorpius* is considered synonymous.

Bigelow and Schroeder (1953) and Leim and Scott (1966) give good descriptions of the shorthorn sculpin and closely related species in North American waters.

Materials and methods

Over 1000 shorthorn sculpins were examined from various places in Newfoundland coastal waters from 1965 to 1967. Samples were collected on the west coast at Piccadilly, Port au Port Bay (May-August 1965); Lark Harbour, Bay of Islands (June-August 1965); Cow Head (May-June 1966); St. John Island, St. John Bay (July-August 1966) and on the east coast at Bay Bulls (October 1965-April 1966 and September 1966-August 1967); Tors Cove (October 1965-February 1966); Freshwater Bay (September-November 1966 and November 1967) and from cod fishing grounds near St. John's (less than one mile from shore in 30-40 fathoms) (September-October 1965). Most came from Bay Bulls, where sampling was done on a year-round basis, and Freshwater Bay, where an attempt was made to obtain large samples over a relatively short period for growth studies (Fig. 1).

A variety of methods was used in collecting the samples. All the east coast samples were collected while scuba diving using a spear except those from the fishing grounds near St. John's which were taken on longline trawls. Most of the west coast samples were jigged from wharves using hook and line, but some were also collected while diving.

The fish were sampled soon after being caught while still fresh and usually still alive. Total lengths were measured to the nearest millimetre on a wooden measuring board and weights were measured to the nearest ¼ oz on a Toledo balance and later converted to grams.

The fish were gutted by cutting across the throat and through the esophagus with a sharp knife and cutting the abdomen medio-ventrally to the vent. The viscera were removed but the gills were left intact.

Fillets were removed from gutted fish by cutting obliquely from a point medio-dorsally above the operculum to a point medio-ventrally just posterior to the pectoral fin and by cutting along the side of the vertebral column to the tail and leaving all fins intact. The skin was left on the fillet.

An analysis of stomach contents was done and sex and maturity were recorded while sampling.

Most of the ovaries were examined while still fresh under a dissecting microscope and ova diameters were measured on a 1 mm Turtox grid. Volumes of ovaries were measured in a 100 ml graduated cylinder (ovaries larger than 100 ml were measured in sections). Ovaries used for histological sectioning were fixed in Bouin's solution for 1-2 days and kept in about 80% alcohol. Only ripe ovaries were used for fecundity estimates. The ripe ova were separated by hand and washed through a series of screens to remove ovarian connective tissue and second and third generation ova. They were counted with an electronic "egg" counter. In more than 18,000 ova counted by the counter and recounted by the observer the error was 0.0657%.

The sacculus otoliths were used for age determination but before they could be read the edges of the sulcus (Fig. 6A) on the convex side had to be ground down. They were ground on the fine side of a Carborundum 111 sharpening stone by holding them against the stone and making circular movements with the tip of the index finger. When the annuli could be clearly seen from the centre of the otolith to the edge, the otolith was immersed in 95% ethyl alcohol in a black petri dish and read with reflected light under a microscope.

A set of 10 pairs of otoliths was read by 5 experienced otolith readers - in no case was there 100% agreement. The usual disagreement was one year but in one case it was 5 years. My readings compared very well with theirs.

Three sets of viscera containing endoparasites and several specimens of each of the ectoparasites were sent to Dr Z. Kabata at the Marine Laboratory, Aberdeen, Scotland for identification.

Observations on behaviour and activity of the shorthorn sculpin in its natural environment were made while scuba diving.

Results

Length frequency distributions and relative sizes of males and females

The length frequency distributions of males and females from Bay Bulls are shown in Fig. 2. The females are more evenly distributed over the greater part of their range of lengths than the males and have just as many at the larger sizes as at the intermediate sizes; the males, however, are more or less normally distributed and have a definite modal group. The smaller number of females and the fact that they were taken mainly in the summer and fall whereas the males were taken throughout the year may account somewhat for the difference. Probably the main reason for the difference is that females grow faster and attain larger sizes than males (page 17).

The length frequency distributions of males and females from Freshwater Bay were both similar to that of the females from Bay Bulls, but the number of males from Freshwater Bay was about half the number from Bay Bulls and also the females outnumber the males in the Freshwater Bay samples.

The smallest specimens obtained while scuba diving were 11 and 12 cm in length but below 22 cm relatively few specimens were obtained. The males ranged up to 43 cm in length and the females up to 51 cm.

The average lengths of males and females from the different sampling areas are given in Table 1. In each area the females averaged larger sizes than the males. The difference between the average lengths of males and females ranged from 2.6 cm at Piccadilly, Port au Port Bay, to 6.5 cm at Lark Harbour, Bay of Islands. The samples at these extremes were small and are probably not representative of the natural condition. More representative samples are those from Bay Bulls and Freshwater Bay. The difference between the average lengths of

143 females (average length 36.4 cm) and 258 males (average length 33.4 cm) from Bay Bulls was 3 cm; the difference was 2.9 cm for 168 females (average length 35.2 cm) and 119 males (average length 32.3 cm) from Freshwater Bay. Samples were taken from Bay Bulls throughout the year but from Freshwater Bay only during the fall - this may account for the small differences between the average lengths of males and between the average lengths of females from these two areas because those from Freshwater Bay were taken during the period when growth would be relatively slow whereas those from Bay Bulls were taken from the fast-growing period as well.

Length-weight relationships

Length-weight relationships of fishes do not remain constant throughout the year and are affected by factors such as the availability of food, rate of feeding, gonad development, spawning, etc. Length-weight relationships of a fish species in different areas can be compared from sampling at the same time of the year and changes in length-weight relationships from year to year in an area can be determined from sampling at the same time each year. To get a complete picture of length-weight relationships however year-round sampling is needed.

In the present study year-round monthly sampling was done at Bay Bulls but the monthly samples were small, so the samples from Freshwater Bay and Tors Cove were added. The length-weight relationships are therefore biased towards the fall condition particularly in the females because so few were present in the samples after the spawning period and throughout the winter and spring.

Length-weight (whole weight) relationships. The length-weight (whole weight) relationship in males is different from in females. The relationships for the present data are

$$W = 0.06165\ L^{3.2662}$$

or $\text{Log } W = 3.2662 \text{ Log } L - 2.2101$ for males

and $W = 0.03233\ L^{3.4508}$

or $\text{Log } W = 3.4508 \text{ Log } L - 2.4903$ for females.

These relationships are shown in exponential form in Fig. 3 and in regression form in Fig. 4. It is readily seen that the females are lighter at the smaller sizes but heavier at the larger sizes than the males. The point of intersection of the two curves is at L = 33 cm, which corresponds to an age of about 6 years for females and about 7 years for males. This relationship may not be real because most of the females were taken during the summer and fall when they are heavier, because of increased feeding and gonad development, than in the winter and spring. If adequate sampling of females had been possible during the winter and spring the curves might not even intersect.

Length-weight (gutted weight) relationships. Gutted weight is much less variable than whole weight, particularly in male shorthorn sculpins, because the great fluctuations in weight of the stomach are eliminated. It is more variable for the females because gonad development is, to a large extent, dependent on body tissue. To compare length-weight relationships of shorthorns from different areas and to detect changes from year to year in an area, gutted weight is apparently a more reliable measurement.

The length-weight (gutted weight) relationships for the present data are

$$\text{Log GW} = 3.1057 \text{ Log L} - 2.0371 \quad \text{for males}$$

$$\text{and} \quad \text{Log GW} = 3.1271 \text{ Log L} - 2.0864 \quad \text{for females.}$$

These are shown in regression form in Fig. 4. In this instance the males are heavier than the females and the lines do not intersect indicating that the intersection of the length-weight (whole weight) lines possibly has something to do with maturity and gonad development.

The females show greater seasonal fluctuation in average gutted weight than the males. The highest average gutted weight in females occurs sometime in mid-summer before gonad development starts and the lowest average gutted weight occurs immediately preceding and during the spawning period because in gonad development the females utilize body tissue to a very large extent. Since these samples, particularly for the females, are biased towards the fall condition, the relationship shown in Fig. 4 is probably not a true one. The average gutted weight for the females should be higher and this would tend to bring the lines very close together.

Length-weight (fillet weight) relationships. The fillet is the main part of the body tissue or flesh of a fish and, as with gutted weight, fillet weight is more variable for females than males. Fillet weight in the female shorthorn is greatly affected by gonad development because it is largely at the expense of the fillet that the gonad develops.

The length-weight (fillet weight) relationships for the present data are

$$\text{Log FW} = 2.7818 \text{ Log L} - 2.0215 \quad \text{for males}$$

$$\text{and} \quad \text{Log FW} = 2.7314 \text{ Log L} - 1.9355 \quad \text{for females.}$$

These relationships are shown in regression form in Fig. 4. The females have slightly heavier fillets than the males but the difference gets less as size increases. These length-weight (fillet weight) relationships are not biased towards the fall condition as in the previous length-weight relationships because in the Freshwater Bay samples weight of fillets was not done. At least for the males it can be considered an average relationship but for the females the fillet weights are probably higher than the true average and biased towards the late summer-early fall condition because relatively few were taken immediately preceding and during the spawning period and during the winter when the average weight of fillets is lowest. The true average relationship for females would probably be very close to that for the males.

Coefficient of condition[1]

The coefficient of condition used in the present study is K where

$$K = \frac{\text{Weight (gm)} \times 10^5}{\text{Length}^3 \text{ (mm)}}$$

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[1] For a detailed historical account of the coefficient of condition see Hile (1936).

The average coefficient of condition (K) throughout the year for male and female shorthorn sculpins from Bay Bulls is shown in Fig. 5. This coefficient is high for females through the fall and increases to a peak just before the spawning period, after which it decreases to a low level where it remains throughout the winter and spring until summer when it rises to a peak again. Males show much less fluctuation in condition than females and during the fall are at a lower level. There is only a very slight decrease in the coefficient for males after the spawning period. In the summer there is a rapid increase but this drops off again in early fall. The sharp rise in condition for both sexes during the summer is due to increased feeding activity.

The gradual increase in condition of females throughout the fall is due primarily to gonad development and indicates that gonad development is not entirely at the expense of body tissue for if it were, condition would remain at a more or less uniform level until spawning time. Apparently gonad development during the late part of summer and early fall is by the production of new tissue but during the late fall, when feeding activity decreases and metabolism is slower, gonad development is mainly at the expense of the body tissues.

The sharp drop in the average coefficient of condition of males in September is probably due largely to a rapid increase in length at this time as well as to decreased feeding activity. The females do not show this sharp decline in the average coefficient of condition in the early fall (September) (Fig. 5) because gonad development, which started in mid-summer (July-August), increases sharply at this time (Fig. 10) and the probable rapid increase in length is offset by a correspondingly rapid increase in weight. I have not been able to determine periods of rapid and slow growth in length from otolith examination and I cannot verify that the early fall is in fact the period of rapid growth in length for either or both sexes.

Age and growth

Age determination. Embryonic development of the shorthorn sculpin goes on during the winter period and the nucleus or kernel point of the otolith is of typical winter growth, i.e. it appears dark with reflected light (Fig. 6B). Next to the nucleus is deposited a wide ring of summer growth which appears white with reflected light. Usually the first 5 summer growth rings are fairly wide but later ones are much narrower. Along the ventral margin of the otolith the growth zones are usually much narrower, particularly after the first 2 or 3 years, and often incomplete, the result being that the kernel point of the otolith gets relatively closer to the ventral margin of the otolith as the fish gets older. Lamp (1966) found this in European populations of shorthorn sculpins as well. The summer growth rings were counted and the age group was one less than this number, e.g. if 7 summer growth rings were counted the fish belonged to the 6+ age group.

Interpretation of the otolith edge. From interpretation of the otolith edge it is possible to determine the approximate limits of the fast and slow growing periods during the year for a species. Two growth zones are formed each year - the white or opaque zone, which is usually the widest is associated with the period of fastest growth, and the dark or translucent zone is associated with the period of very slow or negligible growth.

Although both winter and summer growth rings are clearly distinguishable in shorthorn sculpin otoliths, I found it very difficult to interpret the otolith edge. Even otoliths collected during the winter period appeared to have summer growth material at the edge, although in these cases it was usually very narrow. I could not detect periods of transition between summer and winter growth at the otolith edge and consequently was unable to define the limits of the slow and fast growing periods of the year for the shorthorn sculpin.

Lamp (1966) has shown that in European waters the time of deposition of new layers depends greatly on the age of the fish. If this is true in our waters it probably explains some of the difficulties experienced during the present study.

Growth curves. The mathematical expression that has been most widely accepted in recent years to describe fish growth is that of von Bertalanffy (1938):

$$L_t = L_\infty \left[1-e^{-K(t-t_o)} \right]$$

where L_t is the length at age t (in years), L_∞ is the theoretical maximum length, K is a constant expressing the rate of change in the length increments with respect to t, and t_o is the hypothetical age at zero length.

The average length-at-age curves for males and females from the fall (Sept.-Nov.) samples from Freshwater Bay were compared with those of the year-round sampling at Bay Bulls and there was so little difference that all the samples were combined and the data fitted to the von Bertalanffy equation. The resulting curves are shown in Fig. 7. No significance can be attributed to the fact that the growth curves intersect at about age 4 because both curves were calculated primarily from data above age 4 and although there were some data below age 4, there was no suggestion that this relationship was real. Above age 4 the relationship is clear - the females grow faster and to larger sizes than the males. The difference between length-at-age gets progressively larger between males and females as age increases.

Although caution must be used in interpreting L_∞ derived from the von Bertalanffy equation (Knight, 1968), the calculated L_∞'s for the present data - 52.6 cm for females and 42.8 cm for males - are fairly close to the observed maxima of 50.6 cm for the females and 42.2 cm for the males. The oldest observed ages were 15 years for the females and 14 years for the males.

Age composition of the populations. Year-class dominance was evident in the shorthorn sculpin populations from Freshwater Bay and Bay Bulls (Fig. 8). The 1960 year-class (5+ age group) was the dominant one in the samples from both areas with the 1955 year-class (10+ age group) second. These two year-classes made up 28.5% and 13.2% respectively of the samples from Freshwater Bay and 19.6% and 16.4% of the samples from Bay Bulls. In both areas there were relatively few younger than age group 5+ and few older than age group 11+.

Reproduction

Age and length at sexual maturity. Maturity was determined by macroscopic examination of the gonads for the year-round samples at Bay Bulls and for some of the fall samples at Freshwater Bay. It was a simple matter to separate mature and immature specimens of both sexes at all times during the year. Age, length and maturity data are given in Table 2. The youngest mature specimens of both sexes appeared at age 3+ towards the end of their fourth summer. There was 1 mature out of 5 for the males and 1 mature out of 4 for the females at this age. However, at age 4+, out of a total of 14 specimens, there were none mature, either male or female. No doubt this was the result of inadequate sampling. At age 5+, 50% of the males were mature but only 13.5% of the females. No immature males were found beyond age 5+. At age 6+, 60% of the females were mature and at age 7+, 80% (4 out of 5 specimens) were mature. No immature females were found beyond age 7+.

The smallest mature specimen was a female 20.1 cm in length and the largest immature specimen was also a female 36.1 cm in length. Most of the males mature at a length of about 30 cm and most of the females at about 34-35 cm.

In general, males mature at a younger age and at a smaller size than females. Another interesting point shown in Table 2 is that in any age group where there are mature and immature specimens, the mature ones are larger than the immature. This is best illustrated by the 5-year-old males where the difference is significant ($P < .01$). The relationship is consistent throughout the data and is not due to sampling the mature and immature specimens at different times of the year. Apparently the faster-growing individuals of the population attain sexual maturity sooner than the slower-growing individuals.

Oogenesis. Sections of ovaries are shown in Fig. 9. In a ripening or ripe ovary there were 3 distinct sizes of ova (Fig. 9A). The largest ova range in size from 0.5-0.6 mm in diameter in early summer just before gonad development starts to about 2 mm in diameter just before spawning (Fig. 10). The range in size of these largest, maturing ova is greatest shortly after maturation starts but near the spawning period they are almost uniform in size. Lamp (1966) noted this in his European studies as well. These ova are yolk laden and opaque. They range in colour from pale pink to bright reddish pink and purplish pink. As the spawning period approaches the colour usually gets more intense, although even some ripe gonads are pale pink in colour. The medium size ova range from about 0.3 mm in early summer to about 0.5 mm just before the spawning period. They are usually translucent to opaque in the centre and around this dark central area is a transparent ring. The smallest ova appear during the summer shortly after gonad development starts. They are less than 0.1 mm in diameter during the summer but are about 0.2-0.3 mm in diameter just before the spawning period. These are completely transparent. These oocytes will not be mature for another 2 years so that oogenesis takes about 2½ years. The 3 sizes of ova are more or less evenly distributed throughout the ovary but only the ripe or largest ova are deposited at spawning time; the others remain intact in the ovary until subsequent spawnings.

Spawning period. The spawning period of the shorthorn sculpin in this area starts late in November or early in December and lasts for about a month. On November 30, 1965 one spent female was taken in Bay Bulls when the water temperature was 3.2°C - this is the earliest a spent female was taken; on December 12, 1965, 5 out of 5 mature females taken at Bay Bulls when the water temperature was 4.9°C were ripe but one batch of newly-spawned eggs was seen on the same day. Two mature females were taken on December 21, 1966, at Bay Bulls when the water temperature was 2.7°C; one was ripe and the other was spent - this is the latest a ripe female was taken. On December 28, 1966, all of 3 mature females taken at Bay Bulls were spent and about 20 batches of newly-spawned eggs were seen the same day. Apparently the spawning period can change slightly from year to year depending probably on temperature conditions throughout the fall.

Recognition of sexes. Male and female shorthorn sculpins differ in appearance and can be readily distinguished by external observation. The males are more slender, have higher fins and are brightly coloured (Bigelow and Schroeder, 1953). The males have a bright red tinge on the belly and along the sides which is not present in females; the belly and sides of females are pale green to a yellowish creamy colour. Each of the scales along the lateral line bears three or more prickles in males, but only one or two at the most and sometimes none in females and the inner edges of the rays of the pectoral and ventral fins are armed with teeth or prickles on the males but not on the females (Bigelow and Schroeder, 1953). In addition, just before spawning time the bellies of ripe females have an inflated appearance.

These sexual differences are probably important in the recognition of sexes at spawning time and in subsequent spawning behaviour and activity.

Spawning. Observations of actual spawning were not made and it is not known if spawning takes place in daylight or darkness. It is probable that only one male and one female participate in the spawning act because each egg mass is guarded by only one male. Apparently the same male may spawn with two females at separate times for on several occasions I have seen one male guarding two separate egg masses.

Internal fertilization has been reported for this species in European waters (Danmarks Fauna, 1914; Duncker, 1928). Ehrenbaum (1936) argued against this but Nikolski (1957) left the question open. Lamp (1966), after extensive tests, concluded that internal fertilization did not occur.

Spawning site. Shorthorn sculpins lay their eggs in individual clumps on the bottom and many of these have been seen while diving. They are usually found in V-shaped crevices between fairly large boulders and in corners of underwater bed-rock outcroppings and cliff faces (Fig. 11). These crevices probably aid in the mechanics of spawning and also give better protection from underwater currents and surge. Some have been seen shallower than 10 ft but most are between 20-35 ft and very few deeper than 50 ft.

The eggs adhere to each other very firmly and the whole batch adheres very firmly to the bottom. Holt (1893) states that when deposited the eggs adhere to each other and to surrounding objects, presumably by virtue of an oviducal secretion, as there is no attachment process. It is only at the time of extrusion, or shortly afterwards, that this power of adhesion exists, as eggs, which have been deposited for some time, if separated artificially, do not adhere again. The egg masses remain firmly attached even in very shallow water during extremely rough storms.

Post-spawning behaviour. Soon after spawning the females move into deep water away from the spawning area. Sex ratios in the spawning area for each season, for the period preceding the spawning period and for the post-spawning period are shown graphically in Fig. 12. During the fall and summer periods males and females are nearly equal in number but during the winter and spring the males greatly outnumber the females. Before the start of the spawning period 58.8% of the combined samples were females but after the spawning period only 10.2% of the combined samples were females. The immature females apparently move off from shore just before the start of the spawning period for they outnumbered the mature females in samples throughout the fall but the mature females outnumbered them in samples taken during and after the spawning period. Even immature males become scarce after the spawning period (Table 3). Although these samples were usually collected in less than 60 ft of water, many dives were made to depths of 100 ft throughout the winter and very few shorthorn sculpins were seen between 75-100 ft. Most of those that move off apparently go deeper than 100 ft. They move inshore again in April-May after the eggs have hatched.

This behaviour undoubtedly has survival value, for the females are starved for some time before spawning takes place and after spawning they become particularly voracious.

The mature males remain on the grounds to guard the egg masses. Usually one male guards one egg mass but occasionally I have seen one male guarding 2 egg masses simultaneously. The male is usually seen "resting" on the eggs like a hen on a nest (Fig. 11A and B). I have never seen them fan the eggs to clean or aerate them and apparently their main purpose is to protect the eggs from predators, for unprotected clumps of eggs fall easy prey to sea urchins *Strongylocentrotus drobachiensis*, sea stars *Asterias vulgaris* (Fig. 11D) and spider crabs *Hyas araneus*. These sculpins remain with the eggs even during heavy swells when a diver has to hold on to remain stationary on the bottom. Male sculpins guarding eggs are very aggressive - much more so than those not guarding eggs. When approached slowly, sculpins guarding eggs raise the dorsal fins until they are nearly completely spread out - the pectoral fins are similarly spread, and if touched the sculpin becomes very rigid and the fins are fully spread. If a diver remains near and particularly if he touches the eggs they start biting at his fingers and hands and sometimes will hold on tenaciously when he pulls away or tries to shake them off. Once while I was photographing one it started biting at the camera flash attachment and flash bulb. Once I found a sculpin guarding two egg masses that were about 10-15 ft apart and it was "resting" on one of the egg masses. When I started taking some eggs from the other egg mass he swam over very quickly and became very aggressive. When I swam over to the other egg mass he swam back and became aggressive again. When prodded with a knife or spear, sculpins not guarding eggs swim away very quickly and usually out of sight, but only with continuous, violent prodding will sculpins guarding eggs swim away - even then only a short distance, but they return again usually immediately or after only 2 or 3 minutes. On another occasion when I saw a sculpin guarding 2 egg masses that were about 3 ft apart I took the complete egg mass that the sculpin was closest to and on a dive 2 weeks later the sculpin was "resting" on the other egg mass. Occasionally egg masses were seen unguarded. One egg mass that was checked several times during the winter was unguarded on one occasion. It was guarded on previous dives and again on later dives. Apparently the males leave the eggs for short periods from time to time, probably to feed, but, except for these short periods, the eggs appear to be guarded continuously until they hatch.

Post-spawning behaviour in the shorthorn sculpin is geared to protecting the newly-laid eggs. The females move off the spawning grounds probably to feed and the males remain on the grounds to guard the eggs from predation.

Embryogenesis. An egg mass which was probably laid early in December was marked on December 21, 1965 at Bay Bulls in about 20 ft of water. A total of 12 small samples of about 200-300 eggs each was taken from this batch at 1-2 week intervals throughout the winter and early spring to check on embryonic development. The egg samples were preserved in 10% formalin for later examination. The observations are given in Table 4. On December 21, after about 2-3 weeks development, the embryos were just forming on the outside of the yolk sacs. The embryos were well formed and about half the size of the yolk on January 25 and on February 5 the dark coloured eyes were faintly visible through the egg shell. On February 13 the embryos and yolk sacs were about the same size and chromatophores were present as tiny spots on the head and along the sides of the embryos above the stomachs. By March 1 the yolk sacs were about half the size of the embryos and were about one-third their size on March 12 when the yolk sacs were almost completely inside the embryos. By March 26 the yolk sacs were completely inside the embryos, the chromatophores were fully formed and the embryos appeared to be ready to hatch. Embryonic development took over 3 months to complete.

Temperatures near the marked egg mass were near 0°C during most of the period of embryonic development. At the start of the spawning period in late November to early December temperatures were around 3°C (3.2°C recorded on November 28, 1965), but by early January temperatures were usually less than 1°C (0.0°C and 0.5°C recorded on December 31, 1965 and January 16, 1966 respectively). By late February temperatures had dropped to about 0°C (0.0°C recorded February 20, 1966) and for the remainder of the period temperatures were usually slightly less than 0°C (-0.2°C, -0.2°C, 0.0°C and -0.3°C recorded on March 1, 12, 19 and 26, 1966 respectively). Temperatures were somewhat lower during February and March of 1967 than in 1966. Temperatures of -1.1°C and -1.0°C were recorded on February 18 and 25, 1967 respectively and on March 18, 1967 a temperature of -1.5°C was recorded.

About mid-February many batches of eggs had a coating of dark brown filamentous algae.

Hatching period. Several egg masses were examined on March 19, 1966 while diving at Bay Bulls and some of them had empty egg shells, indicating that some hatching had taken place; other egg masses had few or no empty egg shells. No larvae were seen while diving but many larvae, from egg samples taken on the same dive, hatched later in the day in a plastic bag partly filled with sea water. On March 26 numerous newly-hatched larvae were seen while diving but the egg masses examined were still made up mostly of unhatched eggs. Egg masses examined on April 2 still had some unhatched eggs but most were empty egg shells. On April 9 there was no trace of the egg mass that had been marked and the sculpin that had been guarding it was gone. Only a very small portion of a mass of empty egg shells was seen on this dive.

The hatching period started around mid-March, there was a peak in the frequency of numbers hatching towards the end of March, and early in April hatching was completed. There is probably some variation from year to year depending on the severity of the winter and the resulting water temperatures during the period of embryonic development. Temperatures during the hatching period were less than 0°C. On March 19 and 29, 1966 temperatures near the spawning sites were 0.0°C and -0.3°C respectively and on March 18, 1967 it was -1.5°C.

Smaller planktonic organisms become particularly abundant just before the hatching period and these probably provide food for newly-hatched larvae after the yolk has been completely used up.

Larval behaviour. Newly-hatched larvae have been observed in buckets and also in nature. Those observed in buckets hatched from eggs collected while diving. Upon hatching from the eggs the larvae started swimming vigorously towards the surface and after a series of omnidirectional movements ceased swimming and gradually sank to the bottom of the bucket where they usually remained motionless for a short time and suddenly started swimming vigorously towards the surface again. Sometimes they sank only part of the way to the bottom before starting to swim again and sometimes only swam part of the way to the surface before ceasing to swim. Although vertical movements were more common they did move horizontally at all levels in the water column. In nature they were observed in all layers of the water column. Although individuals could not be followed from bottom to surface and vice versa they were seen swimming upwards and sinking downwards. The main concentrations were about 2 ft off the bottom. Most of the larvae were seen in areas where the water was 25-30 ft deep but some were seen near the bottom in about 50 ft of water. On one occasion many larvae were seen throughout the water column, where the water was about 20 ft deep, close to shore on a particularly rough day. No larvae were seen to be carried shore-ward into the surge by the current. Their vertical movements probably keep them from being carried ashore by onshore currents because if they get too close to shore they can swim into the counter current and be carried away from shore. This behaviour has been suggested for lobster larvae by Squires (MS, 1968). Ehrenbaum (1905) reports that planktonic larval forms of the shorthorn sculpin are found as far as 40 nautical miles from shore in European waters.

Larval growth. When they hatch from the eggs late in March the larvae are about 10 mm in length. The head is large and covered with dark chromatophores, the mouth is large and well formed and the gut is swollen with the remaining embryonic yolk. The tail is long and transparent, the vertebrae are barely visible, and the dorsal fin is continuous around the tail up to the vent. Holt (1893) gives excellent drawings showing in great detail the anatomy of newly-hatched shorthorn sculpin larvae. The latest these larvae were seen was about mid-May. None were seen on numerous dives in several different areas during the summer. It is probable that by late June most of the larvae have settled to the bottom. Ehrenbaum (1905), referring to shorthorn sculpins in European waters, states that towards the end of April the planktonic young have reached a body length of 17-21 mm and soon afterwards they receive the adult shape and colour. After the end of May they are not encountered with the plankton any more, but rather on the bottom in shallow water. The smallest such fish are about 22 mm long.

The smallest sculpin in the samples was a female 11.4 cm in length and 1+ in age taken October 8, 1966, in Freshwater Bay. Several others about this size were seen at different times. No young-of-the-year (0+ age group) were seen while diving. These probably live down among the rocks where they would find better protection from predation. By the end of their first summer these young sculpins are probably around 5 cm in length.

Fecundity. A total of 36 ripe ovaries was used in fecundity estimates. These were taken from samples collected in Freshwater Bay during November 1966 and 1967. The length-fecundity relationship for the data is

$$\text{Log } F = 2.9243 \text{ Log } L - .2505$$

This relationship is shown in exponential form in Fig. 13. The fish ranged in length from 20.1 cm to 50.5 cm and fecundity ranged from 4205 to 60,976. Considerable variation was found in fecundity at the same length in several cases. Two fish 34.3 cm in length had fecundities of 12,247 and 17,196; two others at 37.2 cm had fecundities of 20,241 and 26,700 and two others at 41.2 cm had fecundities of 23,152 and 39,300. Variations in fecundity at the same length were greater at the larger sizes.

Different age groups at the same length would probably also help to account for variations in fecundity within the same length group with the older fish generally being more productive. However, fecundity also varies considerably within the same age group (Table 8).

Food and feeding

The shorthorn sculpin is among the most voracious fishes (Bigelow and Schroeder, 1953) and is an omnivorous carnivore. Benthic invertebrates and a variety of bottom-living fishes make up its food. It is also a scavenger and is found in great numbers around fishing stages and lobster cars feeding on the offal.

Stomach contents. A total of 237 stomachs was examined during the year-round sampling at Bay Bulls, 42 during the sampling at Cow Head and 24 at St. John Island. Since the sculpin is such a variable feeder a detailed quantitative analysis of stomach contents was not done - the stomach contents were examined macroscopically and the percent occurrence of the major food items in the samples from Bay Bulls is given in Table 5.

Crustaceans, chiefly the spider crab *Hyas araneus*, made up the bulk of the food - they were present in 58.3% of the stomachs that contained food and very often nothing else was present. Polychaetes were present in 27.8% of the stomachs. Small, bottom-living fishes, chiefly rock eels *Pholis gunnellus* (9.3%), sea snails *Liparis atlanticus* (4.6%), and young cod *Gadus morhua* (3.3%) made up a fairly large portion of the food. Unidentifiable fish remains were present in 12.6% of the stomachs. Small sculpins were found in two stomachs and small clumps of sculpin eggs were found in 8 stomachs. Morrow (1951) found small specimens and eggs of *M. octodecemspinosus* in stomachs of adults of that species. A note by George Brown, Captain of the C.G.S. *Parr*, states that he saw small lobsters taken from stomachs of sculpins in North Arm, Bay of Islands, in 1965.

There was some slight seasonal variation in the stomach contents depending primarily on the seasonal availability of some of the food items. Most of the amphipods and polychaetes were taken in the May samples. There were also marked differences in the stomach contents of sculpins taken in different areas and on different types of bottom. By far the bulk of the food in 33 stomachs collected at Cow Head was a polychaete - these were taken on muddy-sandy bottom. In 17 out of 19 stomachs that contained food collected at St. John Island the rock crab *Cancer irroratus* was present and was the only food in 13 of these stomachs - these samples were taken on rocky bottom.

The food of the shorthorn sculpin depends primarily on the availability of the different food items and the relative ease of capture of each. There is an exception however. One of the food items, the sea urchin, is by far the most readily available and easiest to capture but it was found in only 12 stomachs from Bay Bulls. Many of those taken may be accidentally ingested with other food.

Feeding activity. Feeding activity changes throughout the year (Table 6). The percentage of stomachs containing food is fairly high in early spring (over 80%) and presumably remains high throughout the summer (no stomachs were examined during summer sampling at Bay Bulls), there is a sharp drop in the fall, particularly just before the spawning period, and a rise following the spawning period. Cessation of feeding is particularly evident in the mature females for some time before they spawn (Table 7). None of the stomachs of 8 ripe females contained food but 3 out of 4 stomachs of spent females, taken shortly after they spawned, contained food. The very large ovary in ripe females makes feeding almost impossible.

Feeding activity is probably influenced to some extent by changes in temperature conditions but most noticeably by maturation and spawning activity.

Parasites

Shorthorn sculpins have a rich parasitic fauna. They are parasitized internally by trematodes and nematodes and externally by amphipods and hirudineans. Some of Dr Kabata's observations on the material I sent him are given in Table 9. The trematodes belonged to the genera *Hemiurus*, *Prosorhynchus* and *Derogenes* and the nematodes to the genera *Anisakis* or *Porrocaecum* and *Contracaecum*. The ectoparasite was an amphipod *Laphysis sturionis*; at least according to Dr Kabata my specimens were very similar to that species and any differences, if any, were very small. The hirudineans were not positively identified but, according to Dr Kabata, they possibly belonged to one of the three genera *Oceanobdella*, *Ottoniobdella* or *Platybdella*. All three genera are known to occur on the cottids.

Discussion

Length distributions

In Newfoundland waters the maximum size attained by the shorthorn sculpin is over 50 cm. The largest specimen obtained was a female 50.6 cm in total length. The maximum length attained by the males is about 44 cm. Although specimens as small as 11 cm have been taken in regular samples, the minimum size that was taken regularly in the samples was about 22 cm.

European populations of the shorthorn are made up of much smaller individuals. Möbius and Heincke (1883) give 30 cm as the maximum length in a sample of 274 specimens from the Western Baltic Sea and for the Kiel Fjord (Baltic Sea area) in a sample of 1183 specimens the maximum length was less than 27 cm - the males ranged from 8.5 to 22.7 cm and the females from 9.6 to 26.8 cm (Lamp, 1966). Saemundsson (1927) reports 35-40 cm as the maximum length in Iceland waters.

Length-weight relationships

In the present study female shorthorn sculpins were found to be lighter at smaller sizes but heavier at larger sizes than the males. Morrow (1951) found the same relationship for the longhorn sculpin *M. octodecemspinosus* but found that the point of intersection of the curves changed from year to year and he was unable to interpret the significance of this relationship. Olsen and Merriman (1946) working on the biology of the ocean pout, *Macrozoarces americanus*, found the converse relationship, i.e. males were lighter at smaller sizes but heavier at larger sizes than females, and suggested that the point of intersection of the two length-weight curves represented the size at which sexual maturity was attained. They found that the mature males of the ocean pout were heavier than the females and reasoned that proportionately more food was converted into ovarian tissue and yolk material by the female, due to the very large size of the gonad, than was converted into testicular tissue by the male; since this material is lost at spawning, the average weight of the females over a full year is less than that of the corresponding males.

Morrow (1951) states "this reasoning cannot be followed with respect to the sculpin because here the mature females are heavier than the males. If the point of intersection of the two length-weight curves represents the size at sexual maturity, then it becomes necessary to assume either that the females eat more than the males or that they become more efficient in converting food into flesh. Until one or the other of these is shown to be true, it does not seem justifiable to consider the point of intersection of the two length-weight curves as indicating the size at sexual maturity".

In the present study the point of intersection of the two curves was at L = 33 cm. Although most of the males are already mature before they reach this size, many females are just maturing for the first time. In addition the curves of length-weight (gutted weight) for males and females did not intersect. It seems quite possible then that the intersection of the length-weight (whole weight) curves does have something to do with the attainment of sexual maturity in females and subsequent gonad development.

Coefficient of condition. Morrow (1951) found seasonal fluctuations in K in the longhorn sculpin similar to those found in the shorthorn in the present study. He also attributed these fluctuations to changes in weight due to increased feeding, gonad development, spawning and to spurts of rapid growth in length without corresponding growth in weight. He determined that growth in length and in weight were not synchronous and that the approximate periods of the annual growth cycle were not sharply defined and varied somewhat from year to year. However, the same pattern appeared to be repeated with a fair degree of regularity. He concluded that the variations in K indicated actual changes in the manner of growth.

Both male and female shorthorn sculpins reached a peak of condition in July due probably to increased feeding and production of new body tissue. Males showed a sharp drop in K in September and this was probably the result of a period of rapid growth in length at that time. The females did not show this sharp drop in K in September but K remained at a high level throughout the fall and showed a slight increase just before spawning time. It is likely that females also have a period of rapid growth in length early in the fall. The rapid increase in length, however, is apparently offset by a correspondingly rapid increase in weight caused by a period of rapid gonad development which also occurs at this time, hence the value of K does not change appreciably. The only period during the year that females showed a sharp drop in K was just after the spawning period and this was the result of a loss of weight due to loss of ripe ova. Although only a few immature females were taken in the summer samples, their K values were appreciably higher than those taken in the September samples and also in samples taken in October and November. This indicates a period of rapid growth in length for immature females during the early fall and probably also for mature females. Morrow (1951) apparently found a difference in K values with different sized fish for he stated that trends in condition may be obscured, or false trends appear if the lengths covered by each sample are not the same. Hile (1936) also found differences in K values with increasing size in cisco, *Leucichthys artedi*, populations. In some populations K increased with size but in others it decreased as size increased. In the present study a difference was found in K values between mature and immature specimens of both sexes during the fall with the mature specimens generally having higher K values. At no other period of the year was this relationship apparent and there was no indication of a trend for K to increase or decrease with an increase in size.

Age and growth

In Newfoundland waters female shorthorn sculpins grow faster and to larger sizes than males and the difference between length-at-age gets progressively larger as age increases. Also the shorthorn is relatively long-lived in Newfoundland waters with females commonly living to age 15 and males to age 14. Lamp (1966) reported similar differences in the growth rates of males and females in an European sculpin population but he found that mortality increased rapidly after the second year and only a few fish got as old as 4-5 years. Hass (1937) also stated that in European waters the shorthorn rarely lives longer than 6 years. Saemundsson (1927) reported 20-30 cm fish to be 4-6 years old in Iceland waters. These lengths-at-ages correspond closely to those found in Newfoundland specimens.

Longevity and maximum size attained is associated with size and age at maturity. Alm (1959) reviewed the work of many investigators on the connection between maturity, size and age in fishes. He stated that the small-sized forms of a species are said to become mature rather early and have a rather short length of life, while the larger-sized forms reach maturity at a higher age and grow rather old.

Reproduction

Age and length at sexual maturity. Male shorthorn sculpins mature at a younger age and at a smaller size than females in Newfoundland waters. Although mature specimens of both sexes as small as 20-22 cm and age 3+ were found, these were rare and most of the males matured at an age of 5-6 years at a length of about 30 cm and most of the females at an age of 5-7 years at a length of 34-35 cm. Lamp (1966), however, has shown that in the shorthorn in European waters both sexes become sexually mature towards the end of their second year at an average length of about 15 cm. Jenkins (1946) stated that British Isles specimens of a little more than 10 cm already reproduce. In Iceland waters male shorthorns mature at a length of 15 cm and females at 20 cm and 3-4 years of age (Saemundsson, 1927).

In the shorthorn in Newfoundland waters the faster-growing individuals in a population become mature sooner than the slower-growing individuals. Fleming (1960) found that in cod from the southwest part of the Grand Bank growth in size was much more rapid than for Labrador cod, yet the Grand Bank fish were generally not mature until a larger size and greater age than the Labrador fish. He formed no conclusion, however, about the faster- and slower-growing individuals of the same stock.

Alm (1959) stated that maturity appears at a lower age and at a smaller size in a population with a good growth rate and that, in a population with a poor growth rate, maturity is reached later and at a larger size. This theory explains the differences between size and age at maturity between European and Newfoundland populations of the shorthorn, assuming that European populations have the faster growth rate.

Oogenesis. Ripe ovaries of shorthorn sculpins in Newfoundland waters were found to contain 3 distinct sizes of ova. These were interpreted as representing 3 different generations. Lamp (1966) also found 3 sizes of ova in mature ovaries from shorthorns in European waters but stated that the smallest were newly-formed ova of the second generation. He also found that oogenesis took slightly more than one year; in

Newfoundland, however, oogenesis in the shorthorn was found to take about 2½ years.

Spawning period. The spawning period of the shorthorn in Newfoundland waters starts late in November or early in December and lasts for about a month. It appears that the spawning period can change slightly from year to year depending probably on temperature conditions throughout the fall. In European waters the spawning period of the shorthorn is more prolonged. Lamp (1966) stated that spawning starts at the end of November or the beginning of December and lasts well into February. Ehrenbaum (1905) gave December to February and Duncker and Ladiges (1961) gave October to March as the limits of the spawning period.

Differences in the time of the spawning period and duration of the spawning period in the same species from different areas are well known in many species of fish. Maturation and spawning are greatly influenced and partly controlled by environmental conditions, the most important of which would probably be temperature.

Embryogenesis. In the shorthorn sculpin in Newfoundland waters embryonic development takes over 3 months to complete. It takes place during the winter months and temperatures over most of the period are close to 0°C. In European waters the embryonic development period of the shorthorn has been reported to be much shorter. Ehrenbaum (1905) stated that development took about 5 weeks. He gave no temperature data but this faster rate of embryonic development most likely resulted from higher temperature conditions. Differences in temperature of only a few °C can greatly influence rates of embryonic development in the same species.

Hatching period. In Newfoundland waters it was found that the hatching period of the shorthorn sculpin starts around mid-March, there is a peak in the frequency of numbers hatching towards the end of March, and early in April hatching is completed. There is probably slight variation from year to year in the time and duration of the hatching period depending on the severity of the winter and the resulting water temperatures during the period of embryonic development.

Shorthorn sculpin larvae have been found as early as February in the Bay of Fundy (Huntsman, 1922) where winter temperatures are higher than in Newfoundland (Lauzier and Hull, 1962) and where embryonic development would be faster.

In European waters where embryonic development is much more rapid than in Newfoundland the newly-hatched larvae are taken correspondingly earlier in the year. Kändler (1961) reported that the first larvae are taken in January in the Baltic Sea but hatching reaches a clear maximum in February.

Conclusion

The shorthorn sculpin prefers to stay in the same habitat and tends to break up into local races (Hass, 1937) and because of the widespread geographical distribution this has undoubtedly led to considerable variation within the species. The geographical isolation involved and the presumably great differences in the physical and biological environments can probably account for the great differences observed in the biology of the shorthorn sculpin in Newfoundland and in European waters.

In view of the abundant and confusing nomenclature for the shorthorn and particularly in view of the fact that several relatively recent workers (Kendall, 1909; Johansen, 1926; Vladykov, 1933; Vladykov and McKenzie, 1935; Walters, 1953) have separated the European and North American groups into two species or at least two subspecies, the possibility that the European and North American shorthorns are indeed different species should not be overlooked. This possibility can only be verified by a detailed systematic study.

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Table 1. Average lengths of male and female shorthorn sculpins from the various sampling areas.

	Males		Females		
	No.	Average length (cm)	No.	Average length (cm)	Difference (cm)
Fishing grounds off St. John's	11	36.4	29	41.5	5.1
Bay Bulls	258	33.4	143	36.4	3.0
Tors Cove	35	35.2	18	40.3	5.1
Freshwater Bay	119	32.3	168	35.2	2.9
Piccadilly, Port au Port Bay	21	27.7	61	31.3	2.6
Lark Harbour, Bay of Islands	11	20.7	18	27.2	6.5
Cow Head	38	32.5	39	37.0	4.5
St. John Bay	29	30.1	22	34.9	4.8

Table 2. Age and length of shorthorn sculpins at sexual maturity.

	Males					Females				
Age	No. Imm.	Av. Length	No. Mat.	Av. Length	% Mat.	No. Imm.	Av. Length	No. Mat.	Av. Length	% Mat.
1	-	-	-	-	-	1	11.4	-	-	0
2	1	15.5	-	-	0	3	16.3	-	-	0
3	4	21.0	1	22.2	20	3	17.9	1	20.1	25
4	6	24.2	-	-	0	8	25.4	-	-	0
5	20	26.9	20	29.3	50	32	28.9	5	29.0	13.5
6	-	-	9	32.4	100	4	32.5	6	33.8	60
7	-	-	8	33.2	100	1	36.1	4	37.2	80
8	-	-	-	-	-	-	-	5	39.0	100

Table 3. Number of immature males, immature and mature females in samples throughout the fall, and during and after the spawning period.

Date	Number of immature males	Number of immature females	Number of mature females
September 17, 1966	2	6	5
October 22, 1966	3	8	4
November 19, 1966	2	7	2
December 3, 1966	2	1	5
January 21, 1967	0	0	4
February 18, 1967	1	0	0
March 18, 1967	0	0	1

Table 4. Dates egg samples were taken from the same batch of eggs at Bay Bulls, water temperatures near the eggs, and observations on embryonic development.

Date	Water temp. °C	Embryonic development
Dec. 21, 1965	1.9	Eggs 2.3-2.5 mm in diameter and shells lifted off yolk material inside. Embryos just forming on outside of yolk.
Dec. 26, 1965	1.9	Embryos forming.
Dec. 31, 1965	0.9	Embryos forming.
Jan. 16, 1966	0.5	Embryos partly formed on outside of yolk sacs.
Jan. 25, 1966	0.5	Embryos formed and attached to yolk sacs - about half the size of the yolk.
Feb. 5, 1966	0.5	Eye spots clearly visible.
Feb. 13, 1966	0.5	Eye spots enlarging - embryos and yolk sacs about the same size. Chromatophores appearing as tiny specks on head and along sides above stomach.
Feb. 20, 1966	0.0	Embryos slightly larger than yolk sacs. Chromatophores getting larger.
March 1, 1966	-0.2	Yolk sacs about half the size of embryos.
March 12, 1966	-0.2	Yolk sacs about 1/3 size of embryos and almost inside embryos.
March 19, 1966	0.0	Yolk sacs small and inside embryos.
March 26, 1966	-0.3	Yolk sacs completely inside embryos and chromatophores fully formed.

Table 5. Major food items of the shorthorn sculpin in Bay Bulls and percent occurrence of each in the stomachs examined.

Stomach contents	% occurrence
Crustacea	
Spider crabs (*Hyas araneus*)	58.3
Amphipods (chiefly gammarids but some caprellids)	9.3
Shrimps	6.6
Polychaeta	
Two unidentified species	27.8
Echinodermata	
Sea urchins (*Strongylocentrotus drobachiensis*)	7.9
Brittle stars (*Ophiopholis aculeatus*)	1.3
Sea cucumbers (*Cucumaria frondosa*)	1.9
Gastropods (unidentified)	1.3
Fish	
Rock eels (*Pholis gunnellus*)	9.3
Sea snails (*Liparis atlanticus*)	4.6
Young cod (*Gadus morhua*)	3.3
Young eelpouts (*Macrozoarces americanus*)	1.3
Small sculpins (*Myoxocephalus scorpius* or *M. aeneus*)	1.3
Unidentifiable fish remains	12.6

Cont'd.

Table 5 (Cont'd.)

Stomach contents	% occurrence
Sculpin eggs	5.3
Sea weed	2.6
Unidentifiable partly digested remains	7.9

Table 6. Feeding activity with season (from Bay Bulls samples).

Period	Males			Females		
	Number stomachs examined	Number with food	Percent with food	Number stomachs examined	Number with food	Percent with food
Sept. 17-Oct. 22, 1966 (pre-spawning)	14	9	64.3	24	13	54.2
Nov. 19-Dec. 28, 1966 (spawning)	52	18	34.6	21	10	47.6
Jan. 21-Feb. 18, 1967 (post-spawning)	36	25	69.4	4	4	100
Mar. 1-Apr. 27, 1966 Mar. 18-May 19, 1967 (spring)	61	49	80.3	21	21	100

Table 7. Feeding activity of mature females during the spawning period.

	Number of stomachs examined	Number with food	Percent with food
Ripe females	8	0	0
Spent females	4	3	75

Table 8. Variations in fecundity with age.

Age group	No.	Fecundities	Average fecundity
6	2	(13,014)(17,196)	15,105
7	2	(19,838)(28,613)	24,225
8	2	(26,700)(39,300)	33,000
9	1	(37,280)	37,280
10	3	(43,165)(41,073)(47,414)	43,884
11	2	(43,060)(38,861)	40,960

Table 9. Endoparasites identified by Dr Z. Kabata in 3 sets of shorthorn sculpin viscera.

Specimen No.	Area	Parasites present
1	Liver (surface)	encapsulated nematodes, 1 *Anisakis* or *Porrocaecum* sp., 1 larval *Contracaecum* sp.
	Stomach (surface)	4 to 6 mummified nematodes (unidentifiable)
	(lumen)	2 *Derogenes varicus*, 1 *Prosorhynchus crucibulum* (Digenea)
	Pyloric caeca (surface)	21 larval *Contracaecum* sp.
	(lumen)	1 *Derogenes varicus*, 34 *Prosorhynchus crucibulum* (Digenea)
	Mesenteries	4 larval *Contracaecum* sp.
	Fore-intestine	8 larval *Contracaecum* sp., 3 *Prosorhynchus crucibulum*
	Mid-intestine	1 *Derogenes varicus*
	Hind-intestine	1 larval *Contracaecum* sp.
2	Stomach (lumen)	4 *Derogenes varicus*, 2 immature hemiurids (possibly *Hemiurus* sp.)
3	Stomach (surface)	2 larval *Contracaecum* sp.
	(lumen)	1 *Derogenes varicus*, 1 *Hemiurus communis*, 1 immature hemiurid (possibly *Hemiurus* sp.)

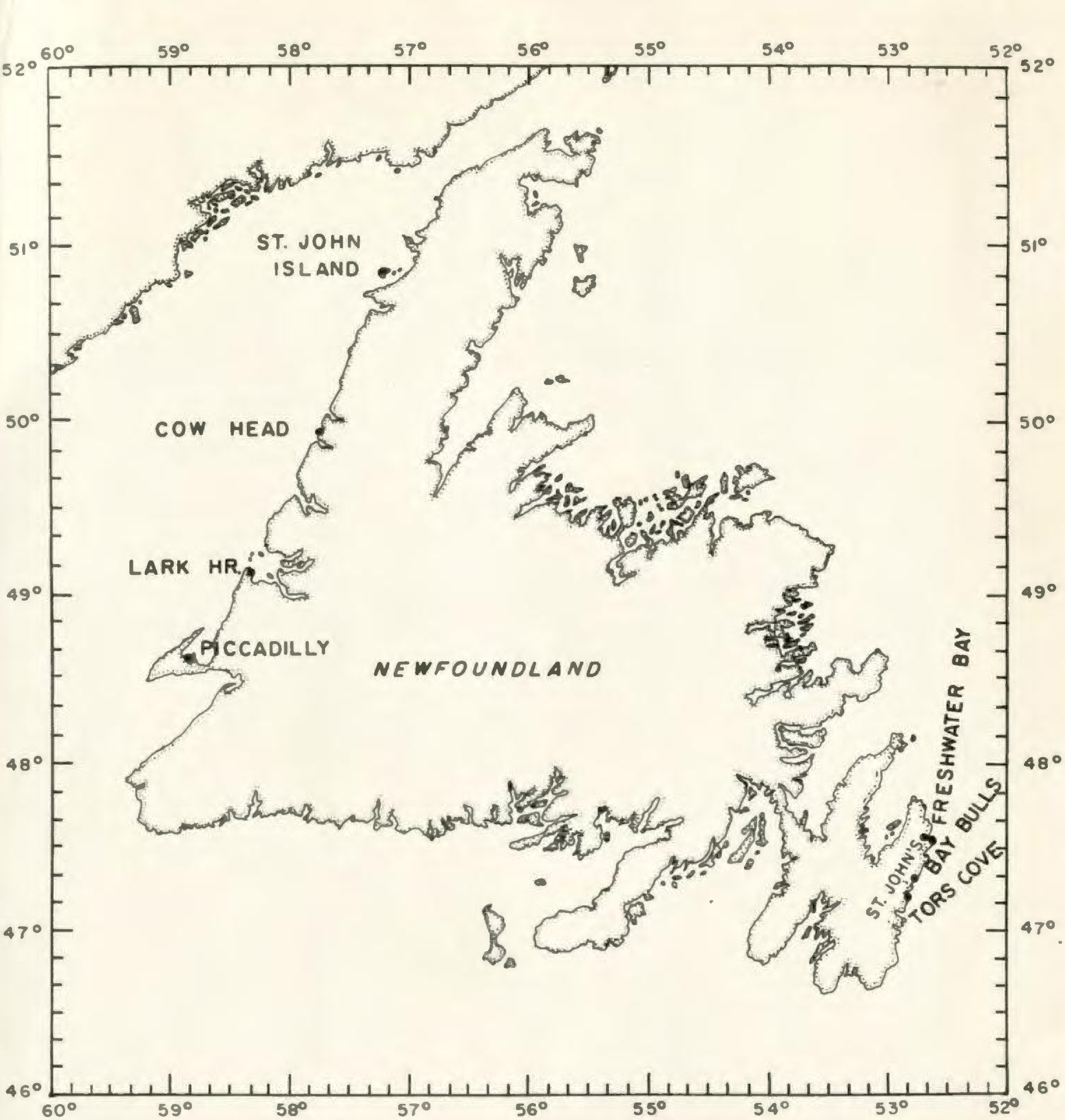

Fig. 1. Map of Newfoundland showing sampling areas.

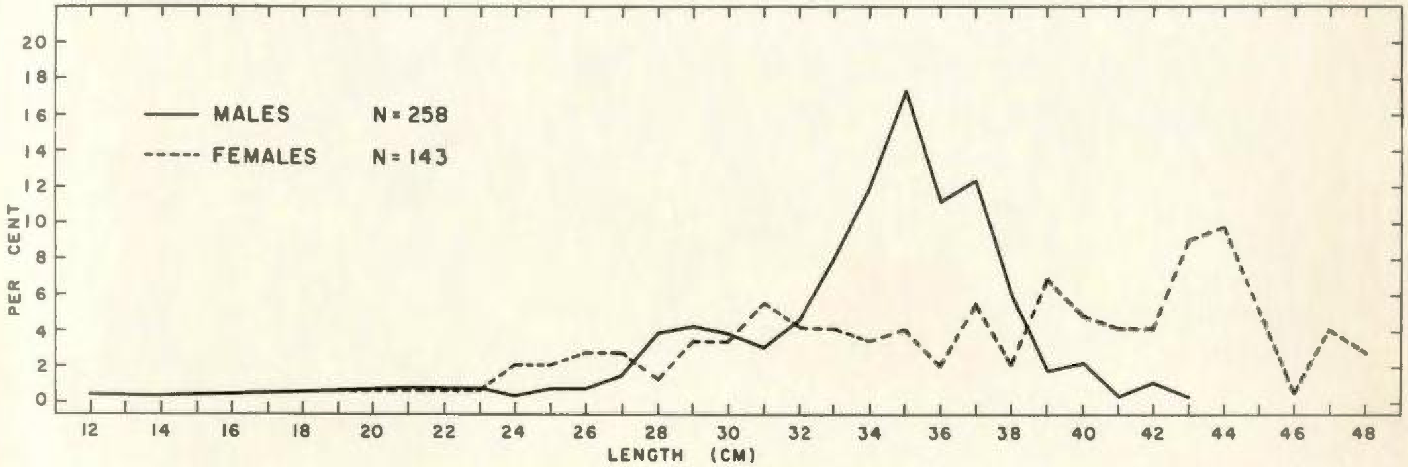

Fig. 2. Length frequency distributions of male and female shorthorn sculpins from Bay Bulls.

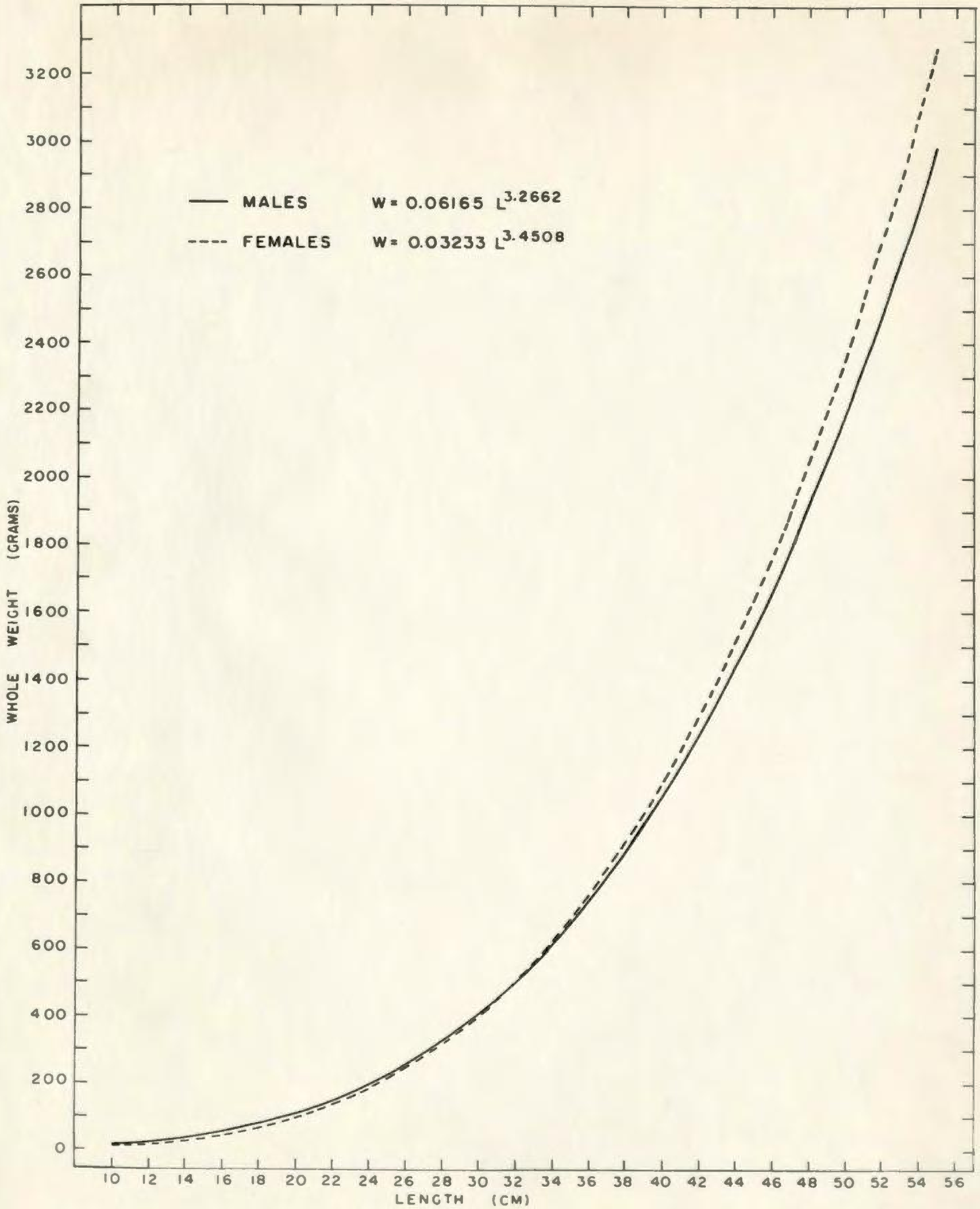

Fig. 3. Length-weight (whole weight) relationships of male and female shorthorn sculpins from Bay Bulls, Tors Cove and Freshwater Bay.

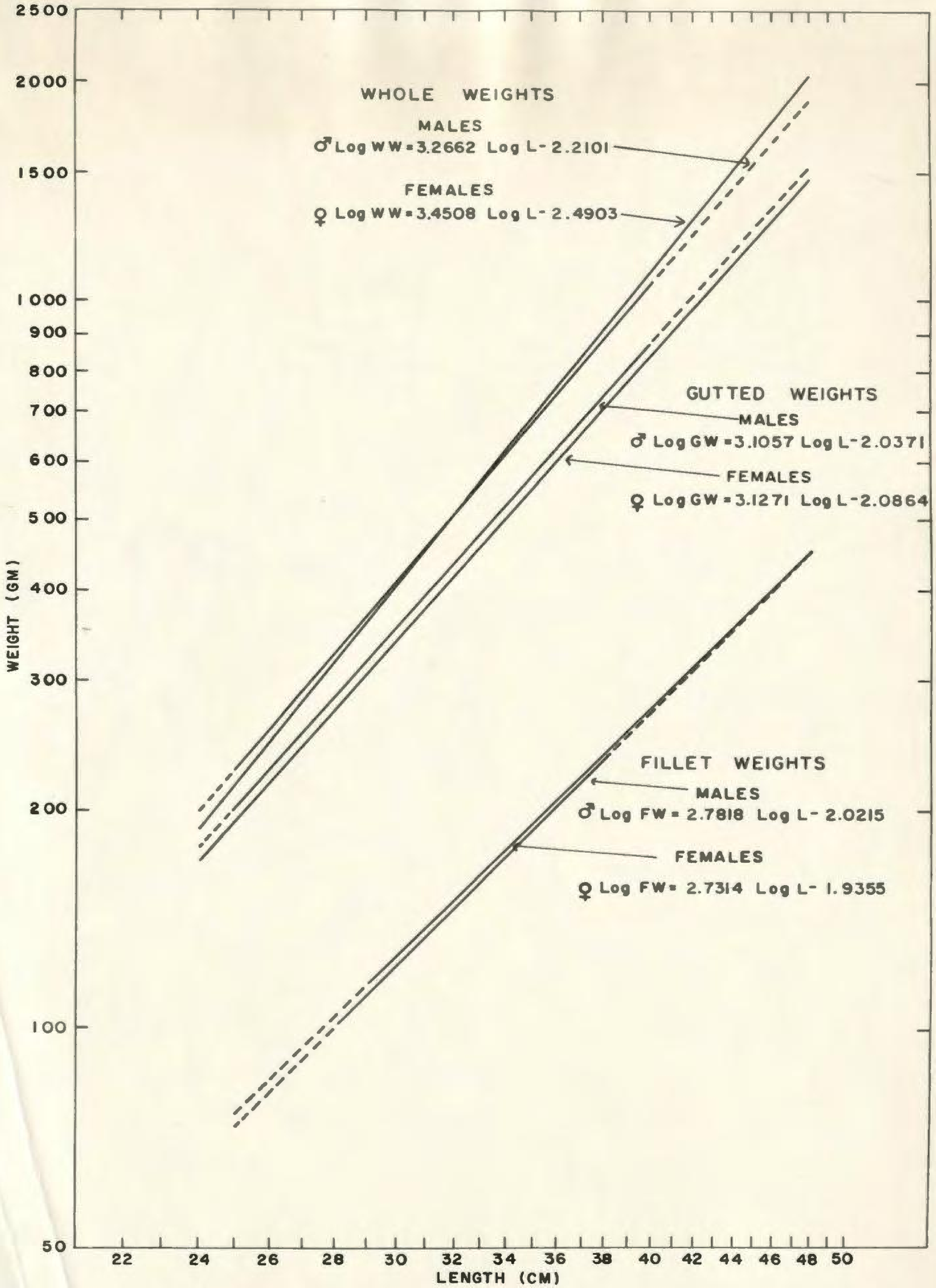

Fig. 4. Regression lines of length-weight relationships of male and female shorthorn sculpins from Bay Bulls, Tors Cove and Freshwater Bay.

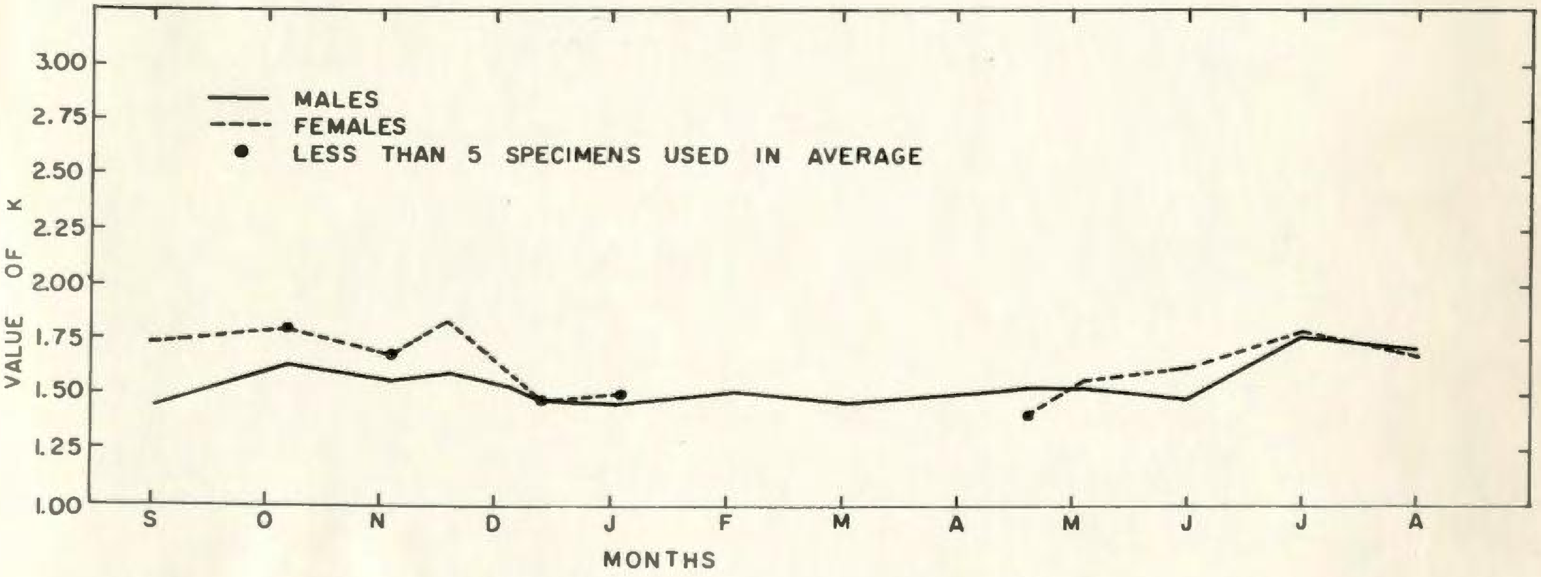

Fig. 5. Average year-round coefficient of condition (K) of male and female shorthorn sculpins from Bay Bulls.

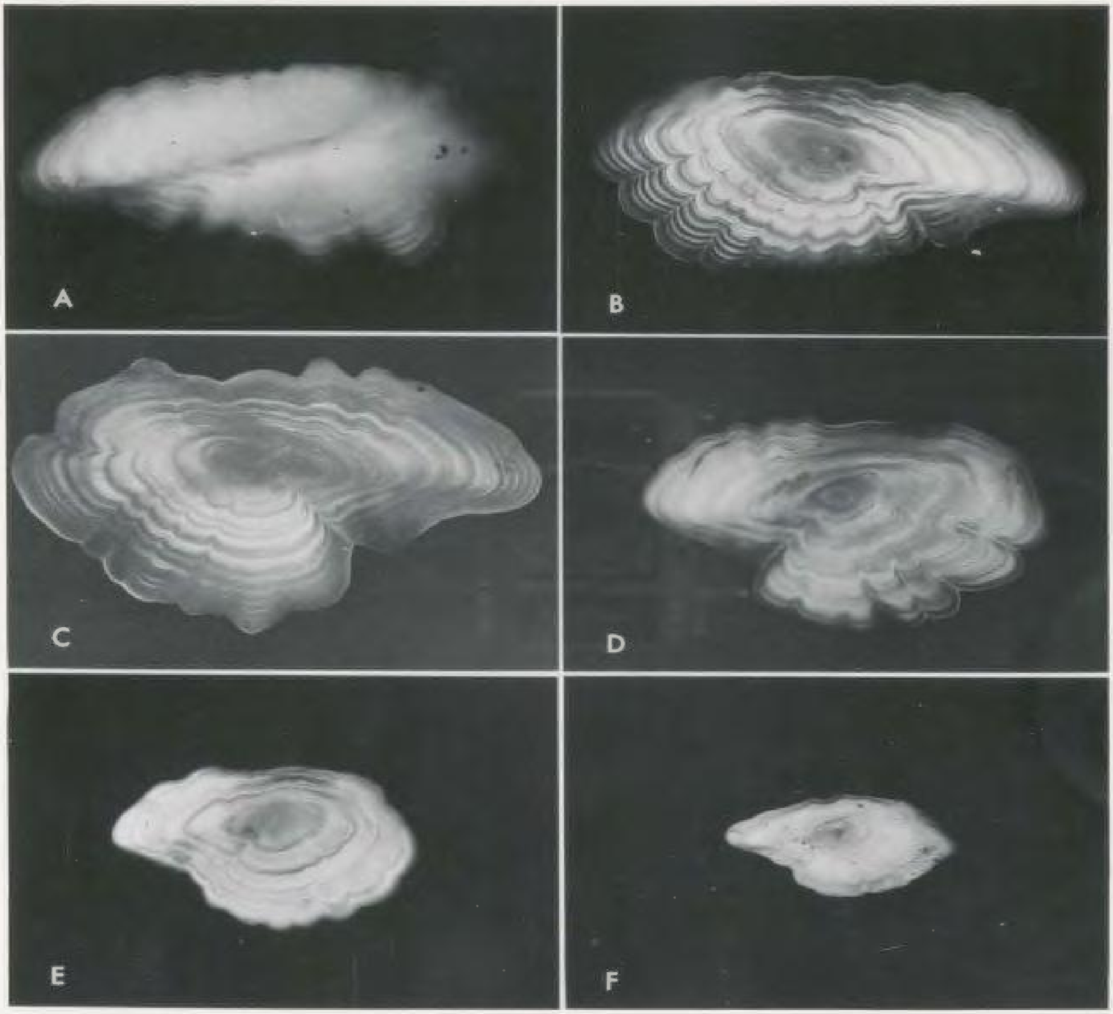

Fig. 6. Shorthorn sculpin otoliths. A. Unground otolith showing sulcus from 11+ male, 38.3 cm in length, taken November 20, 1966 at Freshwater Bay. B. Ground otolith from same fish showing embryonic nucleus and annuli. C. Otolith from 12+ female, 43.2 cm in length, taken July 14, 1967 at Bay Bulls. D. Otolith from 6+ female, 36.5 cm in length, taken November 6, 1966 at Freshwater Bay. E. Otolith from 4+ male, 23.6 cm in length, taken October 16, 1966 at Freshwater Bay. F. Otolith from 2+ male, 13.9 cm in length, taken May 6, 1967 at Bay Bulls. All approximately x10.

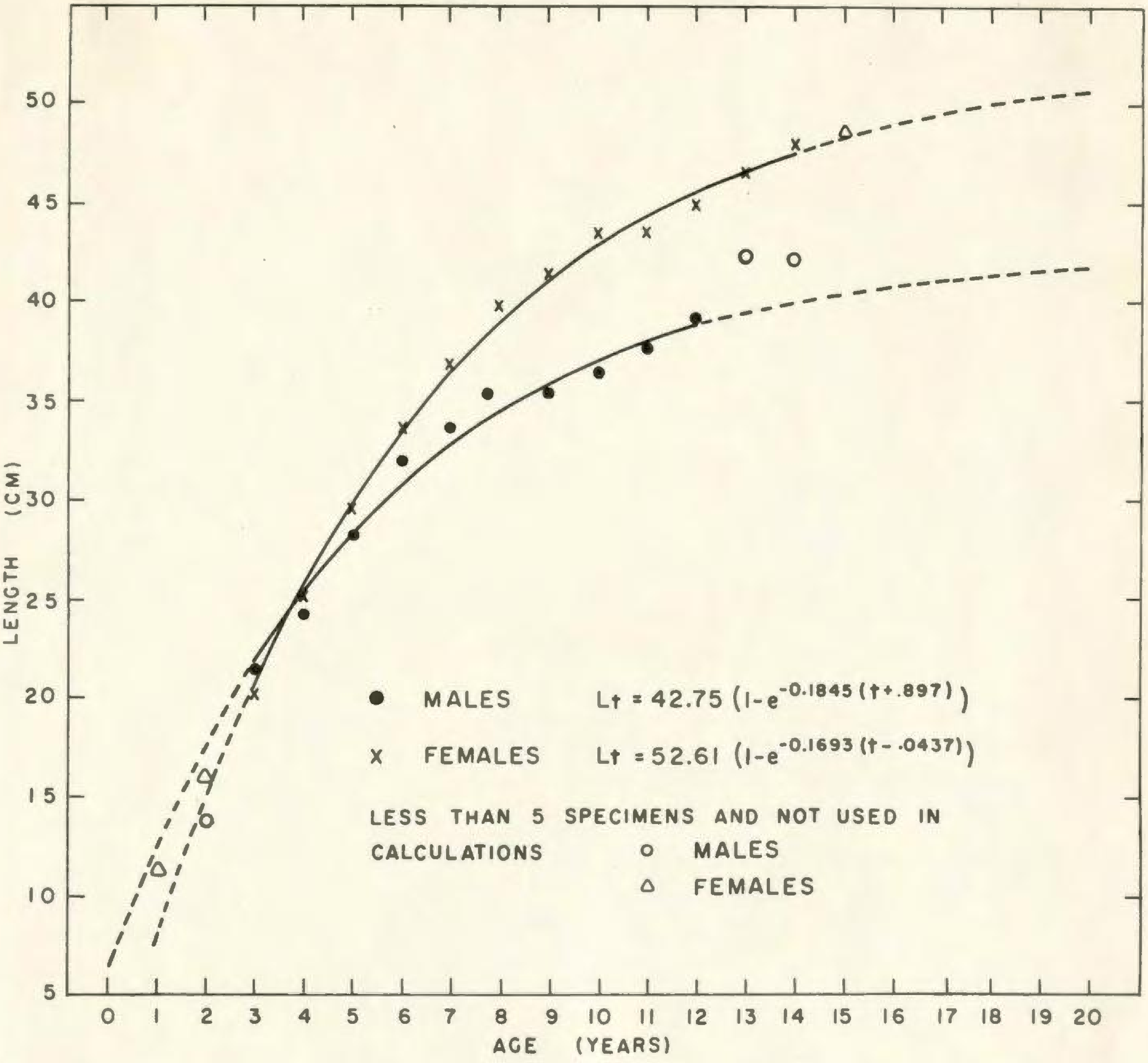

Fig. 7. Growth curves of male and female shorthorn sculpins from Bay Bulls and Freshwater Bay.

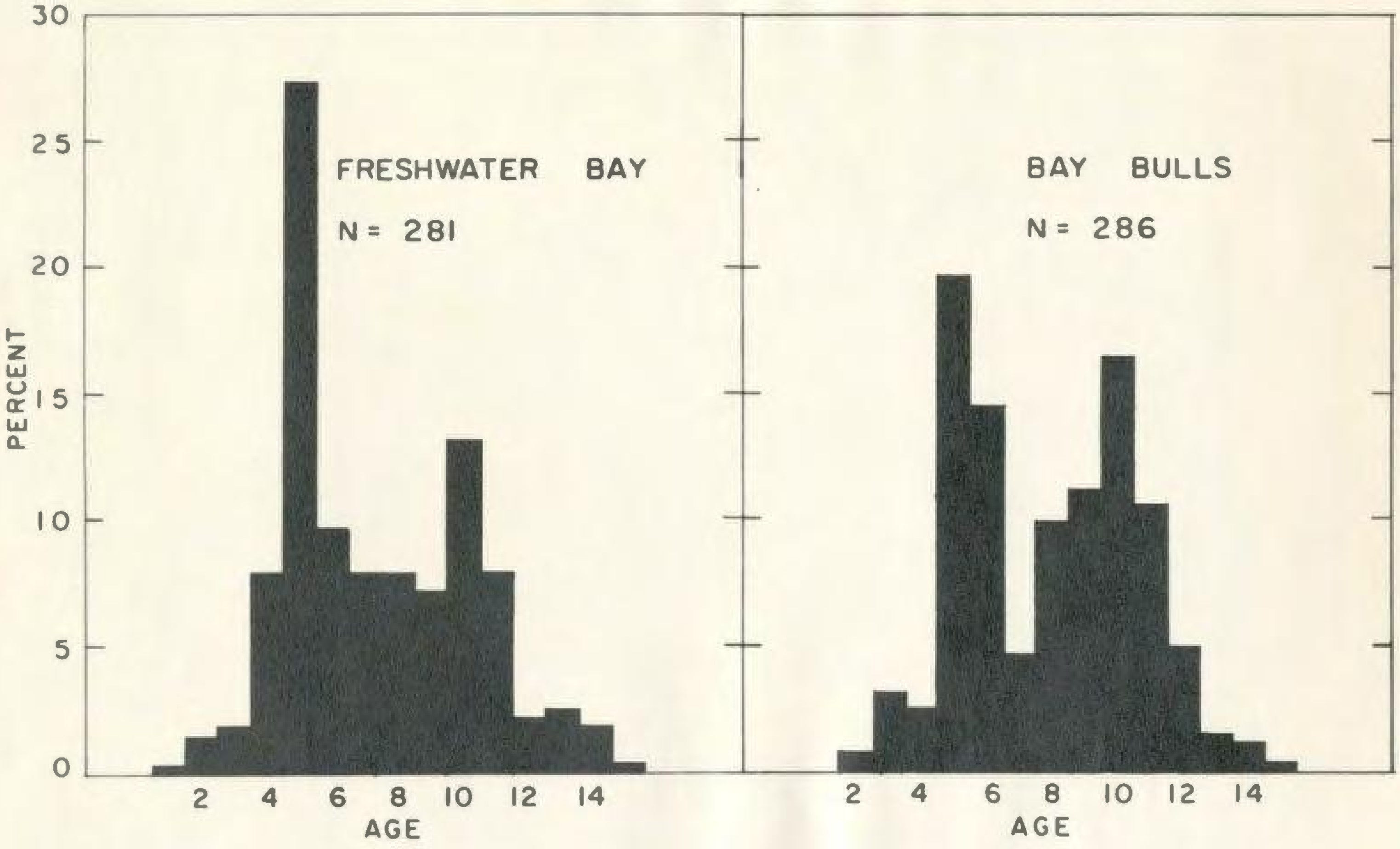

Fig. 8. Age composition of Bay Bulls and Freshwater Bay populations of shorthorn sculpins.

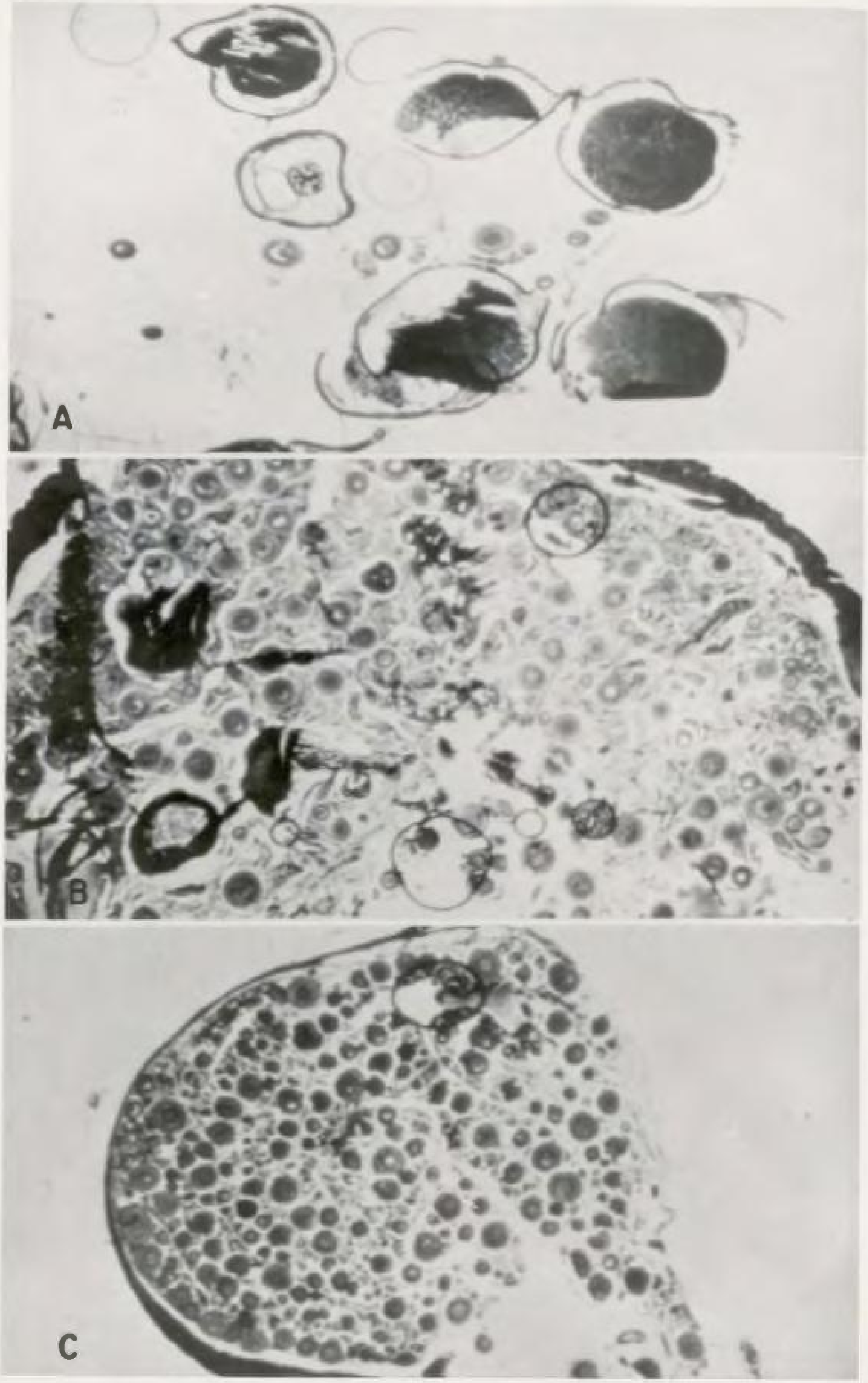

Fig. 9. Sections of ovaries. A. Ripe ovary taken December 21, 1966 at Bay Bulls (note three different sizes of ova). B. Spent ovary taken January 21, 1966 at Bay Bulls (note few residual ova and two other sizes). C. Immature ovary taken November 19, 1966 at Bay Bulls (note two sizes of ova about same as in B. This specimen taken one year before it would have matured for first time). All approximately x10.

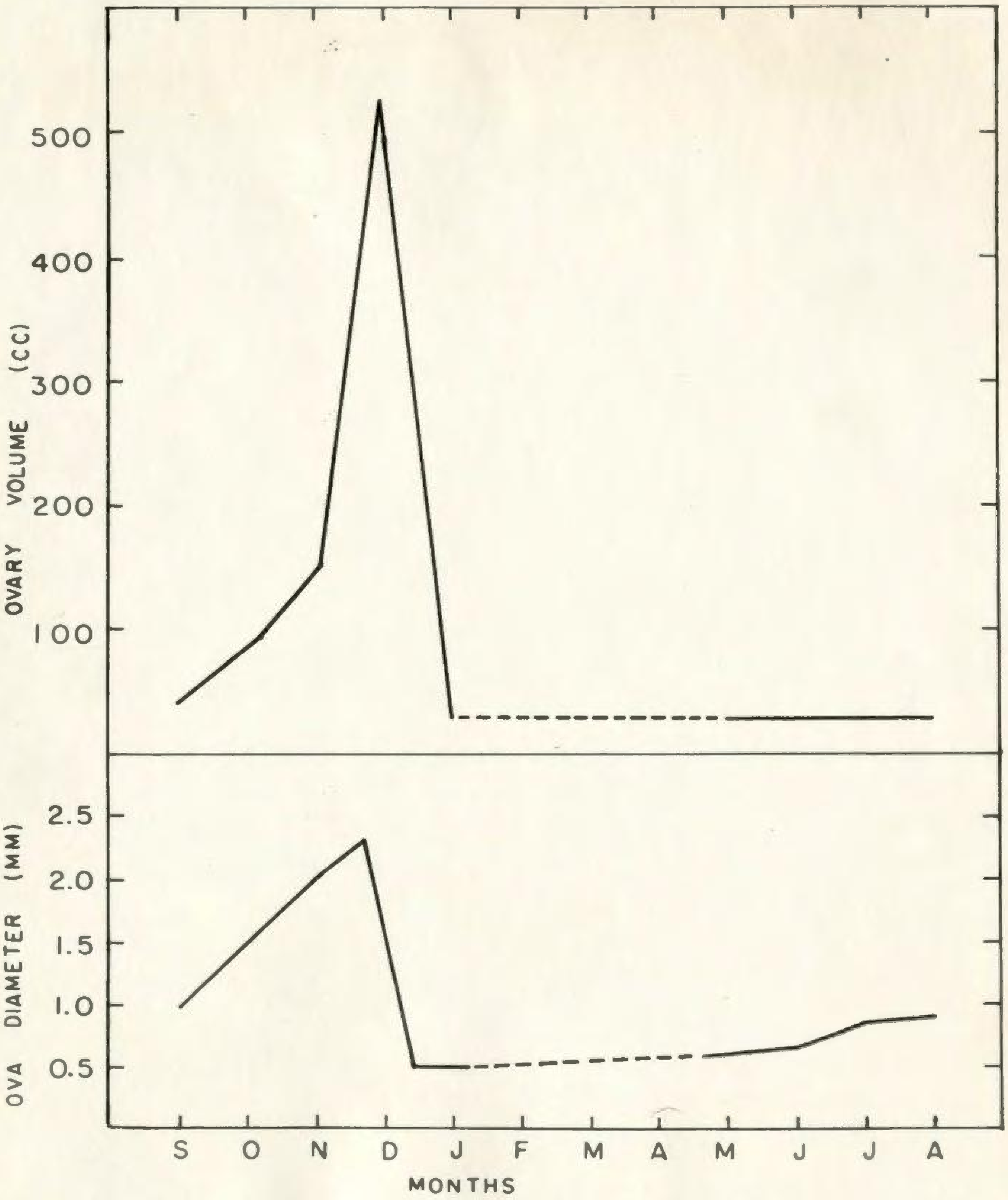

Fig. 10. Seasonal variation in diameter of maturing ova and volume of ovaries in shorthorn sculpins from Bay Bulls.

Fig. 11. A. Shorthorn sculpin guarding a batch of eggs. B. Shorthorn sculpin guarding 2 separate batches of eggs (part of second batch visible along the back above the dorsal fins). C. Unguarded batch of shorthorn sculpin eggs in crevice. D. Unguarded batch of shorthorn sculpin eggs with a sea star, *Asterias vulgaris*, advancing towards it.

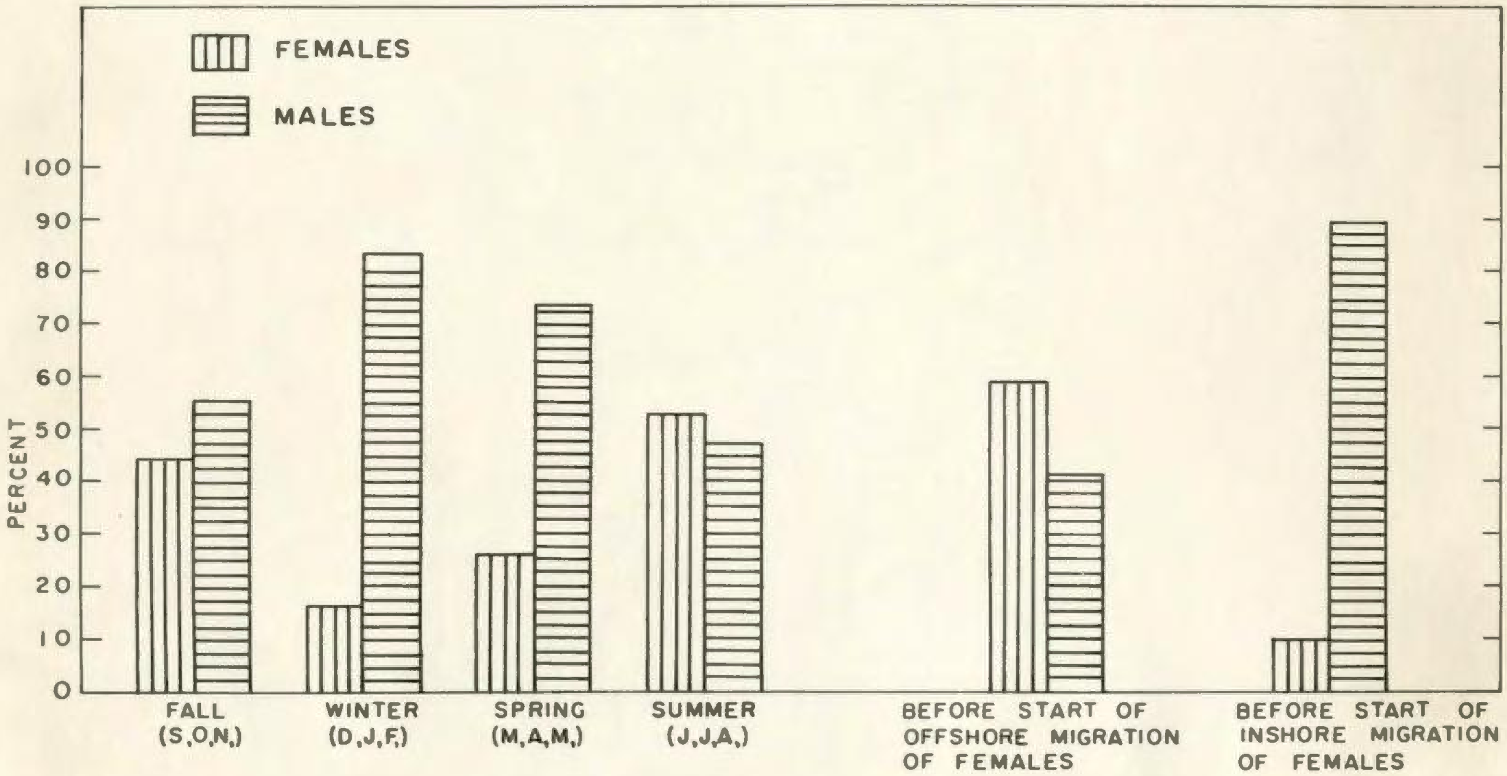

Fig. 12. Seasonal variation in sex ratios in shorthorn sculpins on the spawning grounds in Bay Bulls.

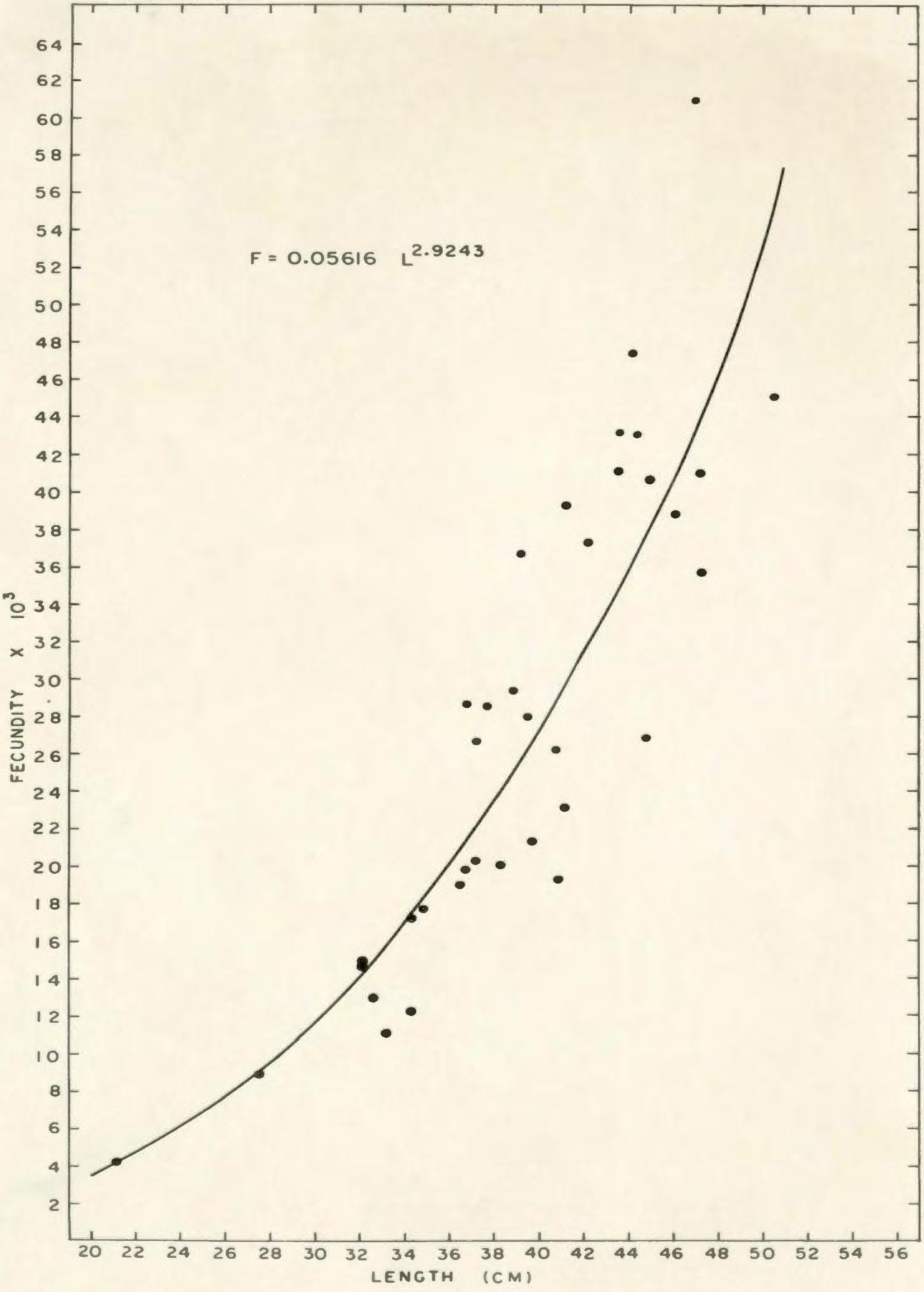

Fig. 13. Length-fecundity relationship of shorthorn sculpins from Freshwater Bay.