ABSTRACT

The purpose of this study was to morphologically identify the pelagic larvae of cottid species of the Atlantic Coast of Canada and the Great Lakes, and to study their ecology in various bodies of water.

The larvae were caught in tow nets. Over 2000 larvae were examined for morphological characters (i.e., finfold, yolk sac and intestine, caudal fin, general and specific patterns of pigmentation, and cephalic spines) but about 400 were studied for detailed morphological description of various species. Over 300 larval specimens were studied for interspecific variations in 7 morphometric and 5 meristic characters. The morphological, morphometric, and meristic analyses of larval cottids from the western Atlantic, the Beaufort Sea, and the Great Lakes resulted in the description and identification of various larval phases of Myoxocephalus quadricornis labradoricus, M. q. thompsonii, M. scorpius, M. aeneus, M. octodecemspinosus, Triglops murrayii, Gymnocanthus tricuspis, Hemitripterus americanus, and Cottus bairdii.

Polymodal length frequency distributions of M. q. thompsonii from Lake Michigan showed that the subspecies spawns in late fall and winter, and its spawning period

extends into spring and early summer. Temperature seemed to limit the depth distribution of cottid larvae. In Lake Michigan, after the thermal stratification in late May, larvae of M. q. thompsonii were not caught in the top 20 fathoms of water column.

On the North Atlantic Coast of America, the maximum abundance of cottid larvae was found to be in late February and March. In the Gulf of St. Lawrence, larvae of M. scorpius and M. octodecemspinosus were more abundant than those of T. murrayii and H. americanus. Larvae of these species were concentrated in the shallower and more productive waters of the Magdalen Shallows. At the surface, more cottid larvae were caught during the night than during the day indicating a diurnal migration.

Cottid larvae were scarce in the open waters of the Bay of Fundy and the Gulf of Maine. Sampling in the Passamaquoddy Bay and the Boothbay Harbour area showed that the cottid larvae prefer shallow and enclosed estuarine areas.

Large concentrations of the yolk sac larvae of M. scorpius in the upper estuaries of Damariscotta and Sheepscot Rivers showed that contrary to the earlier reports, this species enters estuaries.

RESUME

Ce travail avait pour but d'identifier, par des caractères morphologiques, les larves pélagiques des Cottidés de la côte canadienne de l'Atlantique et des Grands Lacs et d'en faire une étude écologique.

Les larves furent capturées à l'aide de filets à plancton. Plus de 2000 d'entre elles furent utilisées pour l'étude de caractères morphologiques (i.e. la nageoire embryonnaire, le sac vitellin et l'intestin, la nageoire caudale, les types généraux et spécifiques de pigmentation et les épines céphaliques) alors que 400 furent utilisées pour la description détaillée des différentes espèces. Plus de 300 larves furent employées pour l'étude des variations de sept caractères morphométriques et de cinq caractères méristiques. L'analyse des caractères morphologiques, morphométriques et méristiques des larves de Cottidés de l'Atlantique ouest, de la Mer de Beaufort et des Grands Lacs a rendu possible la description et l'identification de plusieurs stades larvaires de Myoxocephalus quadricornis labradoricus, M. q. thompsonii, M. scorpius, M. aeneus, M. octodecemspinosus, Triglops murrayii, Gymnocanthus tricuspis, Hemitripterus americanus, et Cottus bairdii.

Les distributions de fréquences à modes multiples de M. q. thompsonii du Lac Michigan démontrent que les sous-espèces pondent vers la fin de l'automne et en hiver jusqu'au printemps. La température semble limiter la distribution verticale des larves de cottidés. Dans le Lac Michigan, après la stratification thermique de la fin de mai, on ne put capturer de larves de M. q. thompsonii dans les 20 brasses supérieures de la colonne d'eau. Sur la côte américaine de l'Atlantique nord, l'abondance maximale des larves de cottidés fut décelée à la fin de février et en mars. Dans le Golfe St-Laurent, les larves de M. scorpius et M. octodecemspinosus étaient plus abondantes que les larves de T. murrayii et H. americanus. Les larves de ces quatre espèces étaient concentrées dans les eaux moins profondes et plus productrices des hauts-fonds des Iles de la Madeleine. Une migration diurne-norturne a été remarquée suite à la capture d'un plus grand nombre de larves près de la surface durant la nuit.

Des larves de cottidés étaient assez rares dans la Baie de Fundy et le Golfe du Maine. L'échantillonage dans la Baie de Passamaquoddy et dans le havre de Boothbay a démontré que les larves de cottidés préfèrent les eaux peu profondes des estuaires.

De grandes concentrations de larves de M. scorpius, portant leurs sacs vitellins, dans les eaux intérieures des estuaires de la rivière Sheepscot et de la rivière Damariscotta indiquent que, contrairement à ce qui a déjà été publié, cette espèce pénètre dans les estuaires.

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facilities available for me to collect larval fish in Southbay, Lake Huron.

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The preliminary drawings of Figs. 5B, C, D; 6A, B, C, D; 11C, D, E; and 13A, B, C, D, E, F were drawn by

Mr. Don Pentz, staff artist of the National Museums of Natural Sciences, Ottawa.

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I. INTRODUCTION

The taxonomy and ecology of pelagic fish larvae is an important aspect of the fishery biology. Fish larvae are usually different from adults in morphological characteristics and ecology. The identification of fish larvae and observations on their ecology help to determine more accurately the composition of the fish fauna in a given area, to determine the spawning grounds and spawning aggregations, to predict and elucidate the spawning period and its duration, and other aspects of biology.

The tremendous fertility of fish i.e. up to several million eggs from a single female in some species, results in the presence of an almost astronomical number of fish eggs and larvae in the pelagic zone. This makes it possible to catch them much more easily than the adult fish using relatively less expensive tow nets and trawls than the heavy and elaborate gear used to collect adult fishes. It, therefore, involves less effort on the part of the fishery biologist to determine the fish fauna of a given area.

Some Russian workers (Vodyanitsky, 1930; Rass et al. 1949) realizing the importance of pelagic larval fish studies undertook vast research projects which added much to the knowledge of the composition

of their fish fauna. For instance, Rass et al. (1949) by studying the larval fish collections added two cottid species (Cottus lilljeborgi and Gymnocanthus tricuspis orientalis) to the fish fauna of the Barents Sea.

Perhaps one of the finest works on the ecology of larval fish on the Atlantic Coast is by Sette (1943) concerning the early life history of the Atlantic mackerel, Scomber scombrus. Sette attempted to interpret growth, drift, and mortality of the egg and larval populations. This paper is considered a classic example of work on early life histories of fishes of the Northwest Atlantic.

Despite the importance of the study of the early life histories of fishes, it is suprising to note that little attention has been given to the taxonomy of larval fishes. Among the early works, the most comprehensive account of fish eggs and larvae of the Canadian Atlantic Coast was given by Dannevig (1919). However, there was very little mentioned about the cottid larvae and the account was not free of misidentifications. Dannevig reported larvae of Cottus (=Enophrys) bubalis from the Gulf of St. Lawrence, although this cottid species is not distributed on the Atlantic Coast of North America and is limited to the European side of the Atlantic. This is not surprising since Dannevig's knowledge was mainly on European fishes. The observations on the distribution

and abundance of larval fish by Dannevig was based only on the collections made during the summer months, and a number of species which are abundant as pelagic larvae at other times of the year were either not reported or their occurrence was considered very rare. For instance, Dannevig reported that cottid larvae were very rare in the Gulf of St. Lawrence. My studies in the Gulf of St. Lawrence showed that cottid larvae were one of the most abundant types during May and perhaps still more abundant in April when maximum hatching took place.

Other than Dannevig's work there are some isolated and fragmentary works available on the pelagic fish larvae in the Canadian waters of the Northwest Atlantic (Frost, 1936; Dunbar, 1947; Steele, 1957, Templeman, 1959; Templeman and Sandeman, 1959; Serebryakov, 1963). Information on Canadian fish larvae is also derived from the works in U.S. waters (Perlmutter, 1939; Merriman and Sclar, 1952; Bigelow and Schroeder, 1953; Wheatland, 1959) and from Greenland waters (Koefoed, 1907; Hansen, 1949). Very little, however, is said or reported about cottid larvae in these papers. Koefoed (1907) described larvae of Triglops pingelli, Gymnocanthus tricuspis and Myoxocephalus scorpius. Perlmutter (1939) illustrated a larva of Myoxocephalus aeneus without any description or justification for identification. Merriman and Sclar (1952) reported cottid larvae from Block Island Sound and

attempted to separate two species, Myoxocephalus octodecemspinosus and Myoxocephalus aeneus on the basis of differences in lengths. Most of the fishery biologists on the Atlantic Coast, therefore, derive information from the identification keys compiled for European seas (Ehrenbaum, 1905; Schmidt, 1907; Pertseva, 1936; Rass et. al. 1949; Duncker et. al. 1959).

In the Great Lakes and other lakes of Canada, presence of larval fish in the pelagic zone has been often observed by biologists. Fish's 1932 paper on the early life histories of fishes in Lake Erie is the most comprehensive account. Fish for the first time realized and advocated the importance of the understanding of larval fish ecology in the development of fisheries in the Great Lakes. However, some of the descriptions of larval cottids in Fish's paper were found to be invalid and are pointed out in this thesis. Among the more recent works are those of Faber (1967, 1970) laying emphasis on the early life histories and the identification of fish during larval phases of development.

The study of pelagic larvae of the family Cottidae is particularly interesting since they are benthic fish and have adhesive demersal eggs. Hence cottid larvae have totally different ecological requirements than the adults. Most cottids of the Atlantic Coast of Canada are rocky littoral forms and generally exhibit the nest building habit and parental care of eggs by the male (Bigelow and

Schroeder, 1953). Some species e.g., Triglops murrayii, T. pingelli and Icelus bicornis have an anal papilla in the male. It has been said that some species have internal fertilization.

Cottids form a major part of the benthic fish population of the Canadian and American Atlantic Coast and the Great Lakes. On the North Atlantic Coast of America adult cottids are often found in the stomachs of some commercially important fish, e.g., cod (Bigelow and Schroeder, 1953) and in the Great Lakes they form a major food for lake trout (Trautman, 1957; Hubbs and Lagler, 1967). An understanding of larval stages of cottids is, therefore, necessary.

The purpose of this study was to determine morphological criteria to identify larval cottids to the species level and to study their ecology and distribution along the Atlantic Coast of Canada and in the Great Lakes.

A morphological, meristic, and morphometric analysis of larval fish collections from the Atlantic Coast, the Labrador Coast, the Beaufort Sea, and the Great Lakes enabled me to identify seven species (Myoxocephalus scorpius, M. aeneus, M. octodecemspinosus, Triglops murrayii, Gymnocanthus tricuspis, Hemitripterus americanus, Cottus bairdii) and two subspecies (Myoxocephalus quadricornis labradoricus[1] and M. q. thompsonii) of cottids during different phases of their larval development. Key

[1]Walters (1955) considered all the marine forms of M. quadricornus as M. q. quadricornis, but Hutchinson (1967) has maintained their subspecific status.

characters are pointed out to distinguish the species from each other.

In this study I attempted to use larval fish collections to determine spawning time and duration of some species of cottids; this removed misconceptions about their biology.

The horizontal distribution of cottid larvae was determined in different bodies of water, and the environmental factors which could limit this distribution are discussed.

In this study I also observed the seasonal and vertical distribution of cottid larvae to determine the limiting effect of thermal stratification during summer.

II. MATERIALS AND METHODS

For describing the larvae of various species a sequential method was used which consisted of the following steps. a) Segregation of species at various phases of larval development by easily recognizable characters such as pattern of pigmentation. b) Study of these segregated larvae by short length intervals to observe transitional stages in morphology. c) Analysis of meristic characters and their comparison with already established meristic data for the adults. d) Analysis of morphometric characters by the relative growth method.

This approach was applicable only for the species which were represented by a large sample size i.e., Myoxocephalus quadricornis labradoricus, M. q. thompsonii M. scorpius, M. aeneus, M. octodecemspinosus, and Triglops murrayii. The specimens of Gymnocanthus tricuspis, Hemitripterus americanus, and Cottus bairdii were not sufficient for thorough morphometric and meristic studies.

Description of Larvae

Over 400 larvae were studied for the detailed morphological description but about 2000 were also examined morphologically as they were sorted from plankton samples. For each specimen the following characters were recorded: Finfold, yolk sac and/or

intestine, caudal fin and notochord, pelvic fin, pectoral fin, general and specific pigmentation pattern, and all the cephalic spines. After recording these characters, the shape, number, and pattern of these characters were examined by 2 mm length intervals in order to describe the most typical morphology and the transition of characters during the larval development. All these characters except the pigmentation were examined after staining the specimens in a solution of Alizarin red S as described by Evans (1948).

Morphometric Studies

Seven morphometric characters were recorded on over 300 specimens of various species. The following measurements were recorded (Fig 1): Total length, from end of snout to end of caudal fin; Standard length, from end of snout to the tip of urostyle; Head length, from end of snout to the posterior most margin of the auditory region; Diameter of orbit, horizontal diameter of the eyeball excluding the membrane covering it; Interorbital width, minimum distance between the two eyes; Preanal length, from tip of snout to the posterior margin of the anus; and Body depth, the depth of body just behind the anus and excluding the dorsal and anal fin pterigiophores. All measurements

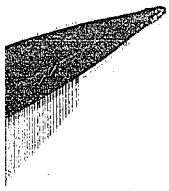


Fig. 1. Various body parts measured for relative growth analysis of cottid larvae. HL, head length; ED, eye diameter; IW, interorbital width; PRAL, preanal length; BD, body depth; T.L., total length; ST. L., Standard length.

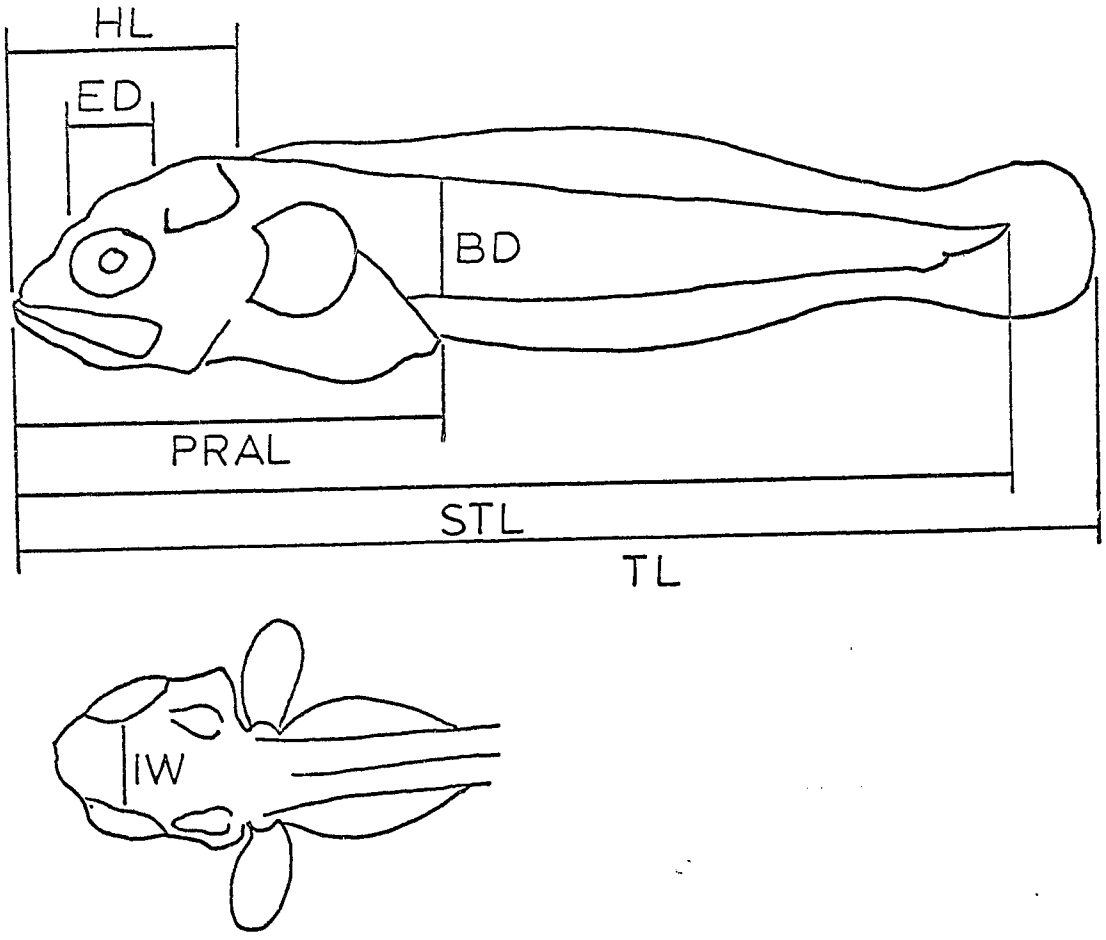


Figure 1

were recorded under a vernier microscope manufactured by the Precision Tool and Instrument Company, England. The scale was read to the nearest hundredth of a millimeter. The relative growth of the body parts was examined by the allometric equation, i.e., log y = log b + k log x, where x is the total length of the larva and y the length of the body part. The computations of regression analysis were done after the logarithmic transformation of the data. The significance of difference between regression coefficients was tested by a Student's t - test at P = 0.05 and 0.01 (Steel and Torrie, 1960; pages 173-175). The significance of correlation coefficients was also tested according to Steel and Torrie (pages 188-191).

Meristic Characters

The following five meristic characters were recorded on the same specimens as used for morphometric studies: Total number of myomeres, second dorsal fin rays, anal fin rays, pectoral fin rays, and caudal fin rays. Special care was taken to count the number of myomeres. Generally it was necessary to use transmitted light to count these parts. The mean value of each character in every 2 mm length group was compared between various species. The significance of differences between means was tested by a t - test for small sample size at

P = 0.05, 0.01, and 0.001 (Freund and Williams, 1964; pages 266-268).

For the morphometric and meristic studies, the specimens of Myoxocephalus quadricornis labradoricus were collected at Tuktoyaktuk Harbour, N.W.T. and those of M. q. thompsonii from South Bay, Lake Huron, and from southern Lake Michigan off Saugatuck. The specimens of other species i.e., M. scorpius, M. aeneus, M. octodecemspinosus and Triglops murrayii were collected in the Boothbay Harbour area, Maine.

The specimens of other three species i.e., Gymnocanthus tricuspis, Hemitripterus americanus, and Cottus bairdii which were not subjected to extensive morphometric and meristic analyses due to small sample size, came from coastal Labrador, Boothbay Harbour area, and Little John Lake, Wisconsin respectively.

Sampling Methods

Sampling methods varied for different areas. These methods are described in detail in the ecology sections for each area. In most cases metric system of measurements was used. However, in some instances measurements were taken in British System. For the convenience of the reader the following table is included.

Inch - 2.54 cm.	Foot - 30.48 cm.
Fathom - 1.82 m.	Mile - 1,609.35 m.

III. MORPHOLOGICAL STUDIES OF COTTID LARVAE

Terminology of the larval development has been extremely contradictory and confusing. Balon (1958, 1959, and 1960) reviewed the literature thoroughly and has recently (1971) proposed a new scheme for classifying various intervals in the life of a fish. He has used three terms to indicate these intervals: period, phase, and step. The "period" is the longest interval of development which is then divided into "phases" and finally each phase into several "steps". These intervals are summarized as follows:

1. The Embryonic Period starts with fertilization and ends at the beginning of exogenous feeding. The period is characterized by endogenous nutrition.

1.1 Cleavage phase lasts from fertilization to the beginning of organ formation (organogenesis).

1.2. Embryonic phase is from the start of organogenesis to hatching.

1.3 Eleuterembryonic phase begins with hatching and extends to the beginning of exogenous feeding. This phase is usually very short among cottids.

2. The Larval Period starts with exogenous nutrition.

2.1. Protopterygiolarval phase is the interval between the transition to exogenous feeding and the beginning of the differentiation of embryonic finfold (i.e., beginning of the appearance of rays in the unpaired fins).

2.2. Pterygiolarval phase lasts from the beginning of the differentiation of the unpaired fins to the complete disappearance of embryonic finfold.

The interval between these thresholds are called steps by Balon. During these steps no changes occur which would be noticeable in the biology of the fish.

Larval development is described in 2 mm intervals. For the species which were not represented by the whole series of developmental stages, specific stages are described. Balon's terminology is used wherever necessary.

Distinction of Cottid Larvae

The families Cottidae and Scorpaenidae are related, and basic larval characteristics are common among these families. The following larval characters are common to both the families. 1) The shape of the body is more or less pin-shaped, swollen in the anterior region and pointed in the posterior region. 2) The intestine forms a loop on the right side and terminates at the anus in the midventral line just in front of the ventral part of the finfold. The anterior part of the intestine, during

early eleuterembryonic phase is much enlarged. 3) The pectoral fins, in all larval phases, are fan-shaped with a broad base, and lack pigmentation. 4) The pigmentation basically consists of, cephalic concentrations, peritoneal concentrations, and a medio-ventral row of melanophores (Fig 2). This basic pattern of pigmentation is maintained throughout the larval development, along with the characteristic pigmentation patterns of the species.

On our coast of the Atlantic, the family Scorpaenidae is represented by only one species, Sebastes marinus the larvae of which can be readily distinguished from the cottid larvae by the presence of a row of discrete, stellate melanophores in the posterior region of the mid-dorsal line, and by the presence of diffused peritoneal pigmentation which sometimes extends on the trunk. None of the larval cottids on the Atlantic coast have these two characteristics.

Larvae of the family Liparidae superficially resemble those of the Cottidae and Scorpaenidae. Liparid larvae can be separated from the cottid larvae by the presence of small melanophores on the pectoral fins throughout larval development. The other features which distinguish liparid larvae from the cottid larvae are the presence of diffuse pigmentation and the presence of a ventral sucker in the later developmental phases.

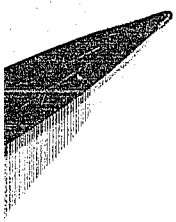


Fig. 2. Terminology of important morphological characters used in the description of cottid larvae. A and B, melanophores; C, spines

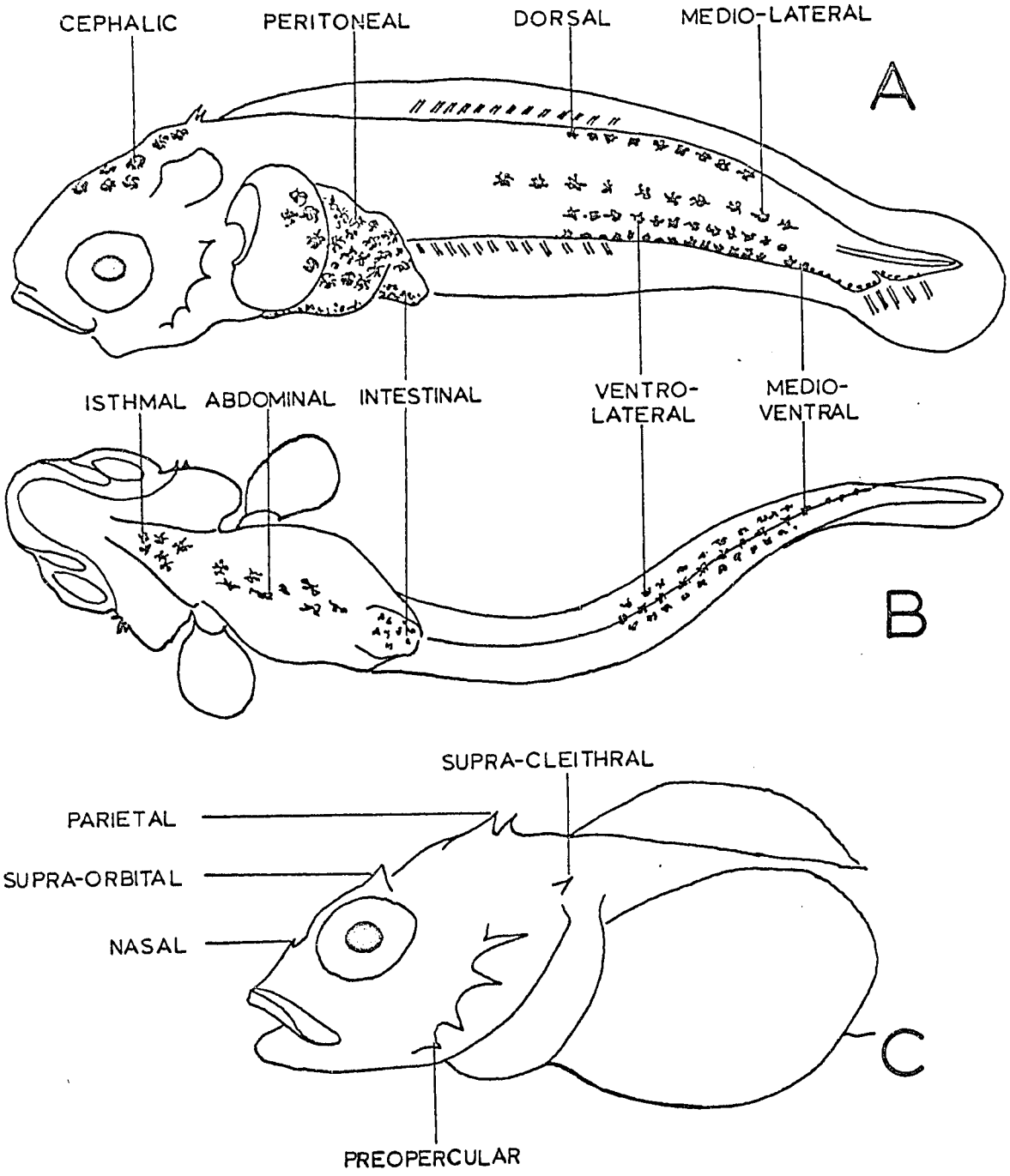

CEPHALIC
PERITONEAL
DORSAL
MEDIO-LATERAL
A
ISTHMAL
ABDOMINAL
INTESTINAL
VENTRO-LATERAL
MEDIO-VENTRAL
B
SUPRA-CLEITHRAL
PARIETAL
SUPRA-ORBITAL
NASAL
C
PREOPERCULAR

Figure 2

The examination of plankton material from the Atlantic Coast revealed the presence of only six species of larval cottids. These species were Myoxocephalus scorpius, M. octodecemspinosus, M. aeneus, Triglops murrayii, Gymnocanthus tricuspis, and Hemitripterus americanus. The other cottid species (M. scorpioides, Artediellus uncinatus, Cottunculus microps, Cottunculus thompsonii, Icelus spatula, I. bicornis, T. nybelini) known to occur as adults in the areas studied (Leim and Scott, 1966) were not found in the plankton samples studied. Due to the small number of specimens of G. tricuspis and H. americanus, a thorough morphometric and meristic analysis was not possible. Myoxocephalus quadricornis labradoricus were examined from Tuktoyaktuk Harbour, N.W.T. and M. q. thompsonii from Lakes Michigan and Huron. Specimens of Cottus bairdii were examined from Little John Lake, Wisconsin.

Important morphological terms used in the description of larvae are illustrated in Fig. 2.

The text describes the development and transition of characters through the larval development, and does not necessarily describe the specific stages depicted in the figures.

A. Description of Larvae

1. Myoxocephalus quadricornis labradoricus (Girard)

This subspecies is circumpolar and lives in cold brackish waters. It has freshwater derivatives, believed to be glacial relics, in Eurasia, North America and on some islands of the Canadian Arctic Archipelago (Andriyashev, 1954; Hutchinson, 1967; McPhail and Lindsey, 1970). This species provides an interesting case of subspeciation, and a number of subspecies, throughout its range of distribution, have been named. M. q. labradoricus is distributed along most of the coasts of the Artic Ocean (Hutchinson, 1967).

This species is essentially a shallow water, coastal estuarine form and rarely descends to depths greater than 15-20 metres. It lives permanently near the coast without accomplishing any noteable migration. According to Andriyashev (1954) "fry of the year" enter into estuarine areas. Johansen (1912) found its association with the littoral region so striking that he called this species a typical fish of the littoral region. It grows up to 365 mm (McPhail and Lindsey, 1970) and spawns in late fall or winter, according to most authors. My ecological observations in Tuktoyaktuk Harbour suggest that it spawns at least until March. Mukhomediarov (1967) reported December to late February as the spawning period

in the White Sea. The eggs of M. quadricornis in the Baltic are laid in clups and the egg mass is cared for by the male (Westin, 1969).

The eggs are of various shades. According to Sundevall (1855) they are light green, or brownish to green or dark brown. Andriyashev (1954) reported near-ripe ovarian eggs from 2.4 - 2.9 mm in diameter.

The following description of the larvae is based on the collection made at Tuktoyaktuk Harbour, N.W.T., near the Mackenzie River Delta.

Description of Larval Stages

Fig. 3

12 - 14 mm Stage (Range 12.35 - 14 mm, Mean 13.24)

The yolk is completely absorbed at this stage. Finfold is complete. There is a preanal fin on the mid-ventral part of the intestine. It is short lived, and disappears in relatively older larvae of this length group. Most of the larvae have no fin rays in the dorsal and anal fins, but show various degrees of mesenchymal accumulation. Some larvae, irrespective of length, have begun to develop second dorsal and anal fin rays. The former range from 8-13 and the latter from 10-15. The first dorsal fin shows only mesenchymal concentrations. The two hypurals are formed in all the larvae, and the caudal fin rays range from 4-7. Notochord is generally straight at the posterior

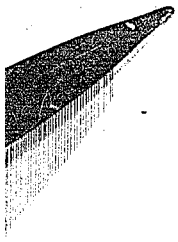
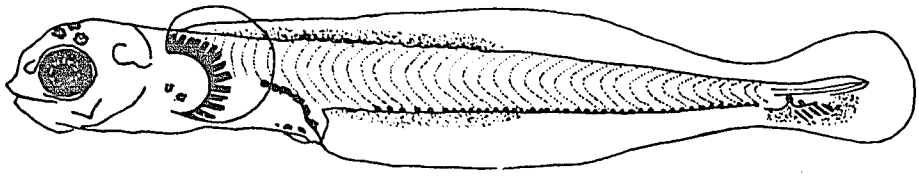
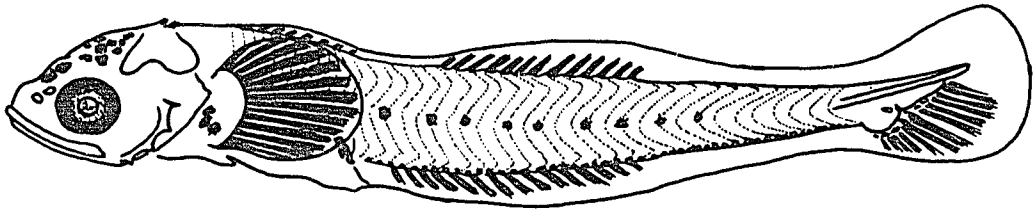


Fig. 3. Developmental stages of Myoxocephalus quadricornis labradoricus. A, 12.8 mm larva; B, 14.5 mm larva; C, 14.5 mm larva, ventral view; D, 17.0 mm juvenile.

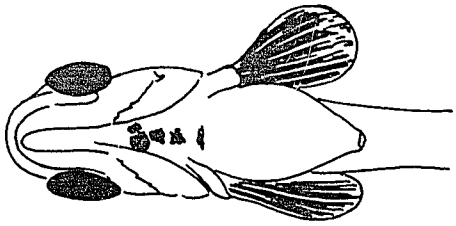
A



B



C



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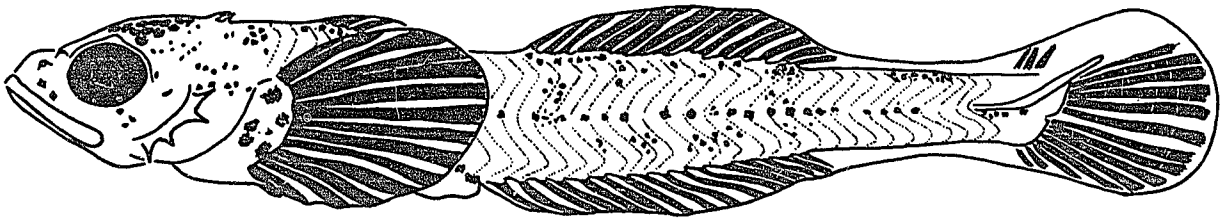


Figure 3

end but in some larvae of about 13 mm in length shows tendencies to turn up. Pectoral fin rays begin to form at about 12.5 mm length and Pelvic fins are visible as small buds in some larvae. The Pelvic fin rays cannot be seen at this stage. Large stellate melanophores cover the head and a few melanophores are present immediately behind the head, just in front of anterior edge of the finfold. Some specimens have up to 3 melanophores on the isthmus, generally lying end to end. Peritoneal melanophores cover only the dorsal part of the peritoneum and do not extend laterally. A few ventral intestinal melanophores are also present just in front of the anus. Medio-ventral melanophores are usually 40-65 in number. These are very small and are not stellate in shape. There are about 6 or 7 relatively larger medio-lateral melanophores, lying in a row almost along the lateral line. These melanophores appear when the larvae have reached a length of 13 mm or more. In some larvae few (2-3) stellate melanophores can be seen at the base of the pectoral fin. Some larvae have 1-2 small melanophores directly behind the nostril and some also have 1-2 small melanophores on the premaxilla. Pigmentation is generally more pronounced than in the freshwater larvae of M. g. thompsonii. Myomeres are generally chevron-shaped, but some older larvae from 13.5 to 14 mm length begin to show a piscine pattern of myomeres. There are 41-45 myomeres. Preopercular

spines are 2-4 depending upon the length of the larvae. Very few larvae show the development of parietal spines. Parietal spines are always two in number. Nostrils are single and show no signs of a constriction.

14 - 16 mm Stage (14.27 - 15.9 mm, Mean. 15.5 mm)

The finfold begins to narrow down between the first and second dorsal fins when the larvae reach about 14 mm in length. The fin rays have appeared in all the fins and there are 13-15 second dorsal and 14-17 anal fin rays. The number of spines in the first dorsal fin varies between 6 and 9. They start appearing when the larva has reached a length of about 14.5 mm. The number of caudal fin rays is quite variable (4-17). The notochord is upturned at the posterior end and there are 15-17 well developed pectoral fin rays. Pelvic fins are well developed but the fin rays are not formed. Melanophores increase in number. Small, non-stellate melanophores start appearing under the dorsal fins at about 16 mm length which is the beginning of the juvenile pigmentation. Some melanophores also appear behind the orbit and cheeks. All myomeres are piscine-shaped and range from 43-46. All the larvae have 4 preopercular spines and 2 parietal spines. Only one specimen of 14.3 mm length had only 3 preopercular spines. The 4th spine was hidden under the skin. Each nostril is partitioned

into two, an anterior and a posterior nostril, at a length of about 14.5 mm. In the older larvae of this length group the two nostrils are far apart but in the younger larvae they lie close together.

16 - 18 mm Stage (Range 16.07 - 17.4 mm, Mean 16.4 mm)

In this length group very few changes take place. In more advanced larvae the unpaired fins are completely differentiated but the finfold still connects the second dorsal and anal fins with the caudal fin. The pigmentation becomes heavier and at about 17.5 mm the larvae show very advanced juvenile pigmentation. Small melanophores appear about the maxilla and premaxilla, behind the occipital and cleithral region, at the bases of the first and second dorsal fins, and anal fin and on the dorso-posterior aspect of the tail. Medio-ventral melanophores sink deep into the dermis and cannot be seen.

The morphology of the largae of M. q. labradoricus described above, conform very closely with the descriptions of larvae given by Dundevall (1855), Johansen (1912) and Zygina (1963). However, certain features described by Zygina are different from my observations. Zygina reported a longitudinal row of melanophores along the middle line of the abdomen and the isthmus as a regular feature of the protopterygiolarval phase and the

pterygiolarval phase. In 63 larvae which I examined this pattern of pigmentation was not a regular feature. None of the larvae had abdominal melanophores and only about 10% of the larvae showed melanophores on the isthmus. Furthermore, the postorbital spine observed during the larval period by Zygina was not present in my larvae.

2. Myoxocephalus quadricornis thompsonii (Girard)

The deepwater sculpin, Myoxocephalus quadricornis thompsonii, is a fresh water derivative of a circumpolar estuarine species. It is found in the deep cold lakes of northern North America. From Lake Michigan they have been reported from waters as deep as 860 feet (R.F. Anderson, in personal communication to late Mr. W. Van Vliet). In Great Bear Lake they have been reported from depths as great as 1200 feet (McPhail and Lindsey, 1970) and in some northern lakes they have been reported in extremely shallow waters, i.e. 6 ft. (McPhail and Lindsey, 1970). The largest reported specimen in the Arctic lakes measured only 69 mm standard length, in contrast to a 199 mm fish from Lake Ontario.

Previously this species was believed to spawn during summer (Dymond et al., 1929; McAllister, 1959) but my ecological studies in southern Lake Michigan and Lake Huron show that the spawning takes place in fall and winter and extends into spring and early summer.

There is very little information regarding the nature of eggs of deep water sculpin. The eggs are probably laid in the same manner as in M. q. labradoricus. Jacoby (1953) reported 1.5 to 2.2 mm diameter eggs in ripe ovaries.

The following description of larvae is based on the larvae collected from Lake Michigan in May, 1964 and Lake Huron in March, 1970.

Description of Larval Stages

Fig. 4

8 - 10 mm Stage (Range 8.75 - 10 mm, Mean 9.43 mm)

Most of the larvae within this length group have at least some yolk. Finfold is complete and does not show accumulation of mesenchyme except in the region of hypurals and caudal fin rays. Mesenchyme in the region of hypurals and caudal fin rays starts appearing at about 8.5 mm length. Posterior part of the intestine is short and the anus is situated in the mid-ventral line at the anterior end of the ventral part of the finfold. Notochord is straight. Pectoral fin is fan-shaped with a broad base which shows accumulation of mesenchyme at its base. Pelvic fins are not formed. Smaller specimens do not have any pigmentation. Melanophores on the dorsal part of the peritoneum start appearing at about 9.5 mm length and range from 1-8 in number. Very few larvae have up to 6 very small melanophores lying in a longitudinal row in the

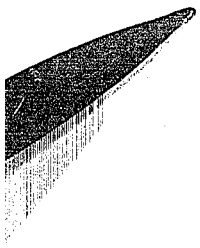


Fig. 4. Developmental stages of Myoxocephalus quadricornis thompsonii. A, 9.0 mm larva; B, 10.5 mm larva; C, 12.5 mm larva; D, 14.9 mm larva; E, 17.1 mm larva.

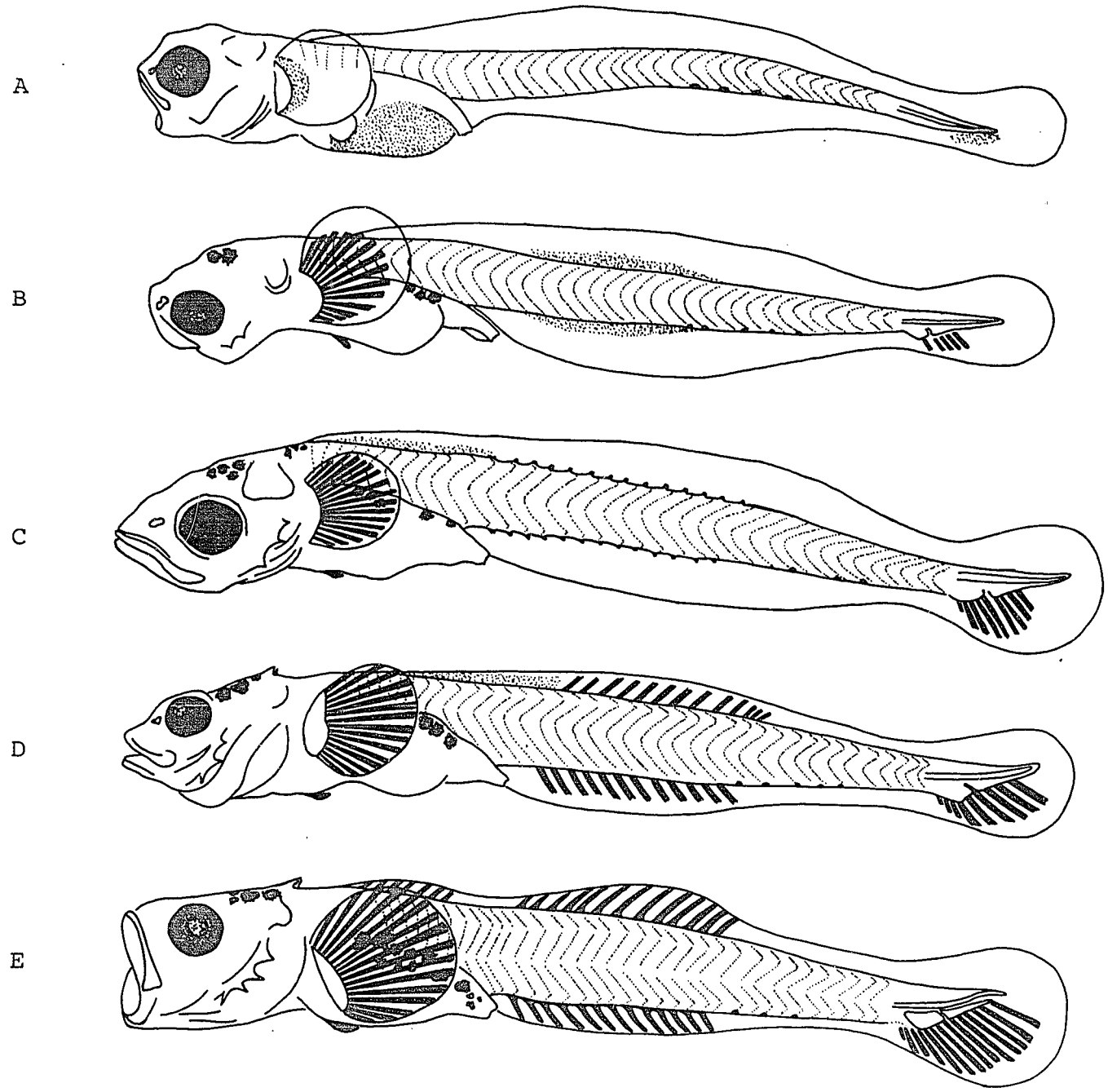


Figure 4

mid-ventral line of the caudal region (medio-vental row). Myomeres are chevron-shaped. The total number of myomeres range from 37-43. No spines can be seen on the head. There is a single nostril just in front of each eye.

10 - 12 mm Stage (Range 10.3 - 11.99 mm, Mean 10.97 mm)

Yolk is completely absorbed at a length of about 10.5 mm. Finfold is still complete. Immediately after yolk resorption a small preanal fin can be seen on the mid-ventral line below the intestine. The preanal fin is very short lived and disappears at about the 12 mm length. The intestine has elongated considerably. Mesenchymal concentrations can be seen in the regions of second dorsal and anal fins. Caudal rays and the two hypurals start to appear at about 10.5 mm. The caudal rays range from 5-10 in number. The notochord shows a tendency to turn upward at a length of about 11-12 mm. Rays in the pectoral fins begin to form and range from 14-16. Pelvic fins appear as small buds at a length of about 10.5 mm, but the rays are not visible. Even in this length group, some of the larvae from Lake Michigan do not have any pigmentation. Others have 2-3 stellate peritoneal melanophores. Some larvae, as small as 10.5 mm, have stellate melanophores on and behind the head. As observed in the previous stage, the medio-ventral row of melanophores is not a regular feature, but some larvae have as many as 5. One to two preopercular

spines appear at about the 10 mm length. Nostrils are still single but a constriction is obvious.

12 - 14 mm Stage (12.2 - 14 mm, Mean 13.05 mm)

Finfold is still complete. At about the 12 mm length second dorsal and anal fin rays begin to appear. There are 7-13 second dorsal fin rays and 10-13 anal fin rays. Various degrees of mesenchyme accumulations are apparent in the region of the first dorsal fin. There are 9-13 caudal fin rays. Posterior end of notochord exhibits various angles with the longitudinal axis of the body. All the larvae have about 16-17 pectoral fin rays. Pelvic buds enlarge slightly but the pelvic fin rays are still not apparent. All the larvae have peritoneal and cephalic concentrations of melanophores. Medio-ventral melanophores range from 0-6. At about the 13 mm length, myomeres start assuming a piscine shape and range from 33-42. The older larvae, in this length group, have 4 preopercular spines while the younger larvae have only 2 or 3. A single parietal spine appears at about 13 mm length. Nostrils are still single but in some older larvae each nostril is divided into two.

14 - 16 mm Stage (Range 15-15.99 mm, Mean 15.61 mm)

The finfold, in older larvae, starts to narrow down between the first and second dorsal fin regions. Both the

second dorsal and anal fin rays range from 12-14. The first dorsal fin spines appear at about 16 mm length and range from 3-8. There are 9-15 caudal fin rays. Notochord is upturned at the posterior end. Pectoral fin rays are well developed and range from 15-18. Pelvic fin rays are much more developed than in the previous stages but the fin rays are still not visible. Cepahlic concentrations of melanophores are much more pronounced. The medio-lateral melanophores are as many as 6 in number but in some larvae they are absent. Number of myomeres is 37-42. All the larvae have 4 preopercular and 2 parietal spines.

16 - 18 mm Stage (Range 16.09 - 17.55 mm, Mean, 16.77 mm)

Although the finfold becomes considerably narrowed between the first and the second dorsal fins and in the tail region it is not disrupted in these regions. The second dorsal and anal fin rays range from 13-17 and from 12-16 respectively, but are usually 12-14 in both these fins. There are about 5-7 spines in the first dorsal fin. The caudal fin has up to 18 rays. Pectoral fin rays are 17-18 and well developed. The pelvic fin rays are still not distinguishable. Head is covered over by large stellate melanophores dorsally. The dorsal peritoneal melanophores have increased in number. Medio-ventral melanophores, as observed in previous length groups, are present in very few specimens. In this length group they are up to 4 in

number. Preopercular and parietal spines are 4 and 2 respectively.

The larvae of deep water sculpin from Lake Huron are generally similar to the ones from Lake Michigan. However, the pigmentation in Lake Huron larvae is slightly more pronounced and heavier.

Nordqvist (1914) described three stages of freshwater Myoxocephalus quadricornis from Vattern Lake, Sweden. The stages described by Nordqvist are similar to the larvae of M. q. thompsonii from the Great Lakes. The only significant difference is the presence of up to 20 medio-ventral melanophores which is a regular feature of the larvae from Vattern Lake. Larvae of thompsonii from Lakes Michigan and Huron generally lacked this pigmentation or had very few in number i.e., never more than six.

3. Myoxocephalus scorpius (Linnaeus)

This species is distributed on both sides of the North Atlantic Ocean and in the adjacent waters of the Arctic Ocean, from Alaska eastward to Hudson Bay and Baffin Island and south to New York (Leim and Scott, 1966). It is also found in Greenland, Iceland, Spitzbergen, Nova Zembla, Siberia, and Northern Europe south of the Bay of Biscay. These fish usually prefer shoal waters and a great majority of them live shoaler than 10 fathoms. (Bigelow and Schroeder, 1953). It is basically a cold water fish since it is found in waters colder than 15.5^{o} C.

In winter it can tolerate temperatures close to freezing. This species usually grows up to 60 cm in length but specimens as long as 90 cm have been reported (Leim & Scott, 1966).

According to Bigelow and Schroeder (1953), the spawning season of M. scorpius on the Atlantic coast of North America is from November to February, with the chief egg production in December. Ennis (1970) has reported that, in Newfoundland waters, the spawning starts in late November or early December and lasts for about one month.

The eggs are deposited in rocky crevices and holes between 25 - 35 ft deep waters. Eggs are held together in clumps which adhere to the bottom firmly. The colour of eggs varies between reddish yellow (Breder & Rosen, 1966) and reddish pink (Ennis, 1970). The deposited eggs are 2.0 - 2.5 mm in diameter (Andriyashev, 1954) and the ripe ovarian eggs are up to 2 mm in diameter (Ennis, 1970). Each egg has an oil globule of 0.4 - 0.5 mm in diameter (Andriyashev, 1954). The incubation period lasts for about 3 months (Ennis, 1970). The following description of the larvae is based on the collections from Boothbay Harbour and the Gulf of Maine.

Description of Larval Stages

Figs. 5, 6

6 - 8 mm Stage: (Range 7.54 - 7.72 mm, Mean 7.63 mm)

All the larvae have yolk-sacs. A large oil globule

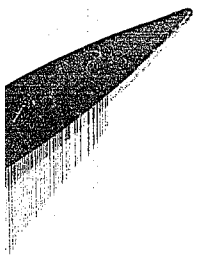
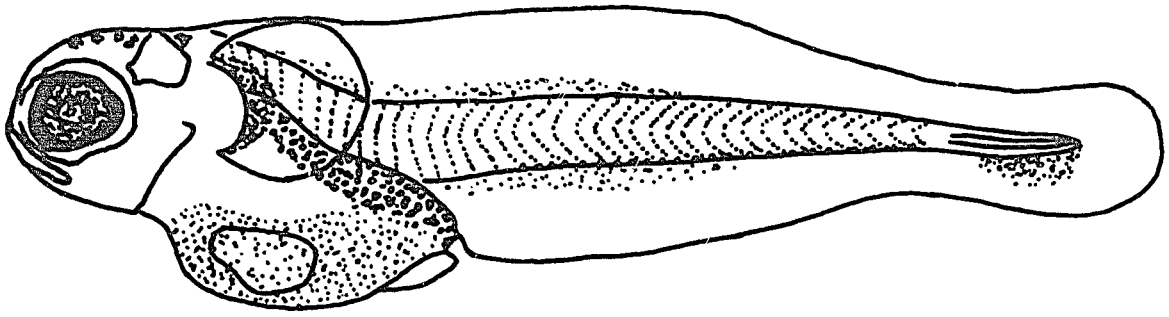


Fig. 5. Developmental stages of Myoxecephalus scorpius. A, 7.6 mm larva; B, 8.5 mm larva; C, 8.5 mm larva, ventral view; D, 10.4 mm larva.

A



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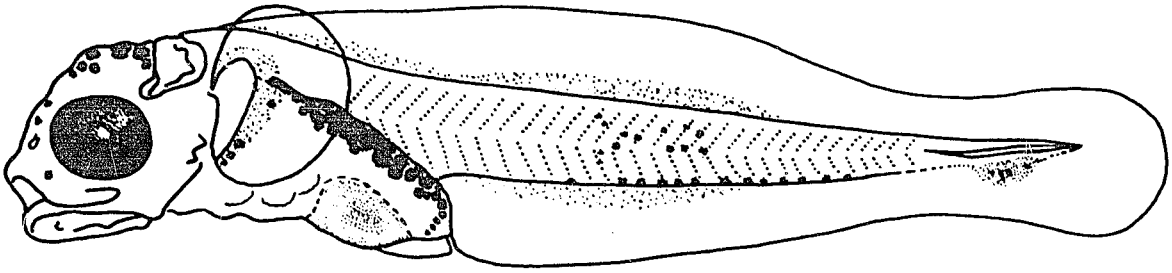

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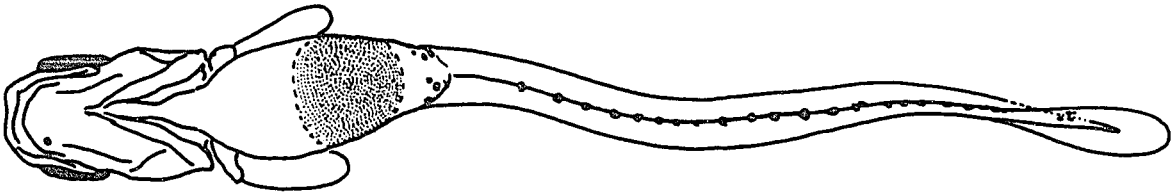

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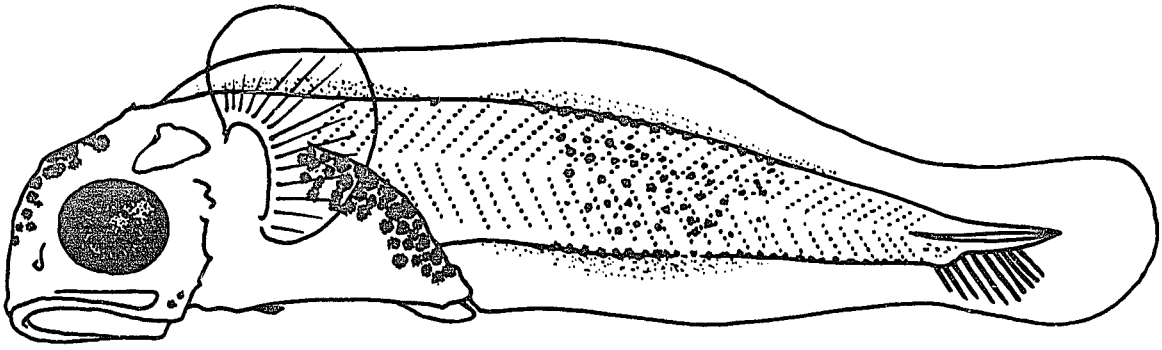


Figure 5

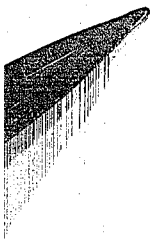


Fig. 6. Developmental stages of Myoxocephalus scorpius. A, 14.0 mm larva; B, 14.0 mm larva, ventral view; C, 17.4 mm larva; D, 17.4 mm larva, ventral view.

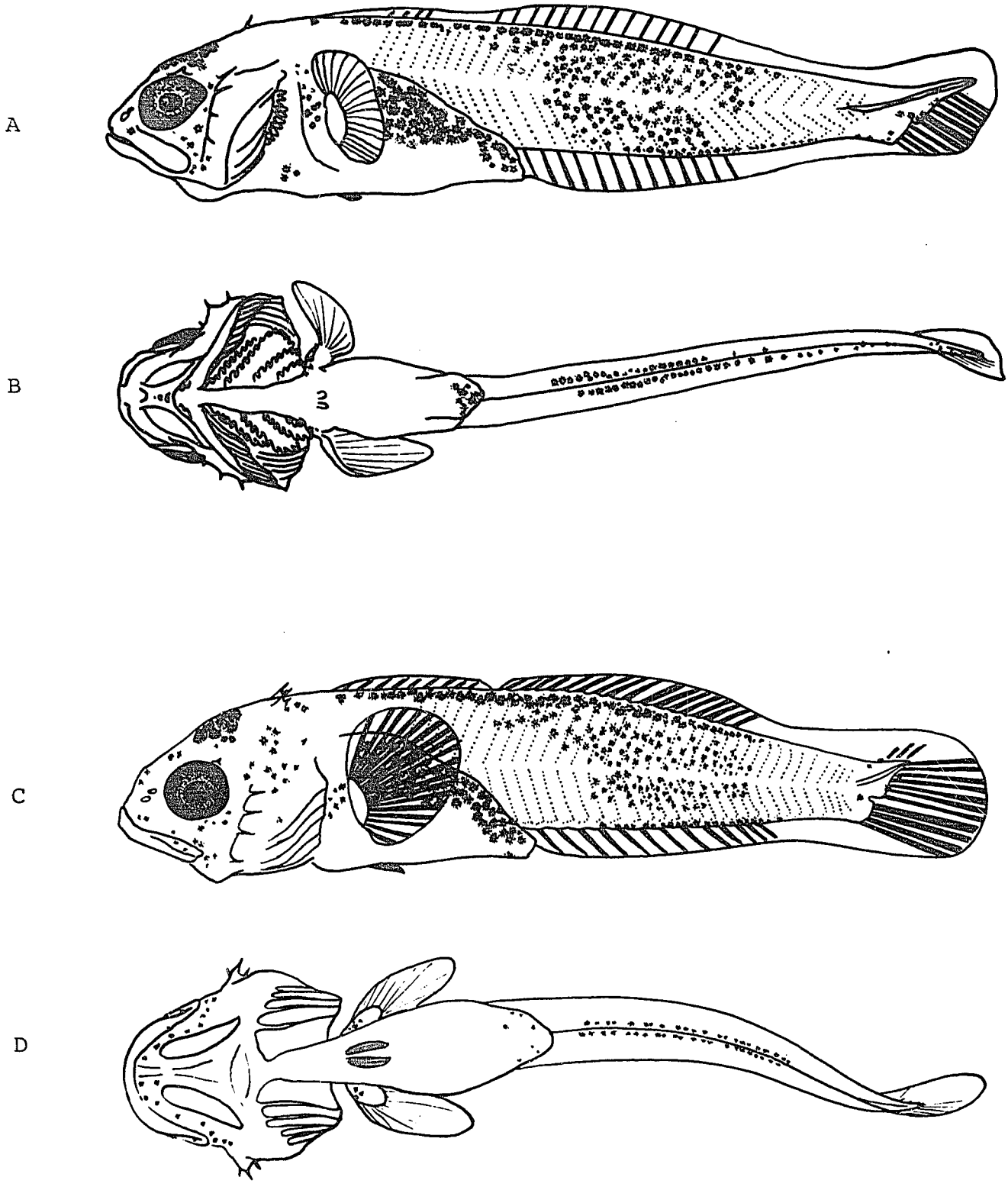


Figure 6

0.5 to 1.0 mm in diameter is present in the anterior part of the yolk sac. Finfold is complete and shows accumulation of mesenchyme in the regions of dorsal and anal fins. Some accumulation of mesenchyme is noticeable in the region of future hypurals and caudal rays. Anus is situated in the midventral line just in front of the anterior end of the ventral finfold. On the ventral side of the intestine, just in front of the anus, there is a small preanal fin. Notochord is straight at the posterior end. Pectoral fin is fan-shaped with a broad base. Pectoral fin rays are not developed yet, but mesenchyme is accumulated at the base of the fin. Pelvic fins are not formed. Pigmentation is quite well developed at this stage. Stellate melanophores cover the dorsal side of the head (cephalic concentrations) and dorso-lateral part of the peritoneum. There is a series of 16-26 smaller melanophores along the base of the ventral part of the finfold (medioventral row). These melanophores usually start from the 16th or 17th myomere. In some larvae even at this early stage 2-3 very small melanophores could be seen on the lateral side of the tail, between the anus and the caudal fin. This is the beginning of a rectangular patch of pigmentation which is the most characteristic feature of the larvae of this species of the genus Myoxocephalus. There are 2-3 melanophores ventral to the base of pectoral fins. Myomeres are chevron-shaped and are 38-41 in number. There are no spines on the head at this

stage. There is a single nostril on either side of the head immediately anterior of the eye.

8 - 10 mm Stage: (8.08 - 10.0 mm, Mean 9.05 mm).

Yolk is absorbed by the time the larvae are about 9 mm long. Finfold is still complete, and there are various degrees of mesenchyme accumulation at the bases of the first and second dorsal and anal fins. The mesenchyme in the region of hypurals and fin rays is denser and at a length of about 9.0 mm the 2 hypurals can easily be seen and caudal fin rays start to form, ranging from 3-6 in number. The preanal fin on the ventral side of the intestine still exists. Notochord at the posterior end is straight, but shows a tendency to turn upward at about 10 mm length. Pectoral fins enlarge in size and there is a heavy accumulation of mesenchyme at the bases of the fins. In some larvae, within this length group, the pectoral fin rays have appeared, but cannot be easily counted. Pelvic fins appear at about 9 mm length but the rays are not visible. Cephalic melanophores increase in number and so do the peritoneal melanophores, and the ones on the lateral side of the tail. Very small melanophores begin to appear on the ventral side of the intestine, just in front of the anus. The medio-ventral melanophores also increase in number ranging from 16-49 but usually averaging 20-35. Occasionally 1-2 melanophores appear behind the nostrils

which are still single and have not started to constrict. Myomeres are chevron-shaped and range from 37-40 in number. Spines on the head are still not developed in most of the specimens. Some larvae have 1-3 preopercular spines and a single parietal spine.

10 - 12 mm Stage (Range 10.45 - 11.89 mm, Mean 11.23 mm)

Finfold is complete. Second dorsal and anal fin rays are still not formed. Mesenchyme can be seen in the regions of the first and second dorsal, and anal fins. There are about 6-10 caudal fin rays. The preanal fin disappears gradually during this stage. The posterior end of the notochord starts to turn upward. Some larvae have developed 15-17 pectoral fin rays. Pelvic fin rays are not differentiated. There is a general increase in pigmentation. After about 11 mm length, the lateral patch of melanophores gradually extends dorsally and ventrally towards the basis of the unpaired fins. Some small melanophores appear anteriorly on the ventral aspect of the lower jaw, and 1-2 melanophores at the angle of the jaws. At about 11 mm length each nostril develops a constriction in the middle. The myomeres start to assume piscine shape at about 10 mm length and range from 36-39 in number. There are 2-4 preopercular spines and a single parietal spine.

12 - 14 mm Stage: (Range 12.04 - 13.61, Mean 12.89).

At about 12.5 mm length the finfold starts to narrow between the first and the second dorsal fins. The second dorsal and anal fin rays start to form and range from 12-14, and 9-13 respectively. Most of the larvae still have not developed any rays in the first dorsal fin except for a few which have up to 7 rays. Caudal fin rays increase in number and range from 9-12. At about 12.5 mm length the posterior end of the notochord is distinctly upturned. All specimens within this length group have well developed pectoral fin rays which range from 15-17. Pelvic fins are slightly enlarged in size. Lateral patch of pigmentation becomes more pronounced by the addition of more melanophores. Most of the melanophores of the original, single midventral row sink in the dermis and 24-33 slightly larger melanophores appear on each side of the midventral line. The constriction in each nostril is more pronounced. In all the specimens the myomeres are piscine-shaped and range from 37-39. All specimens have 4 preopercular spines and only one parietal spine.

14 - 16 mm Stage: (Range 14.39 - 15.34 mm, Mean 14.78 mm)

Finfold in all the larvae, within this length group, is considerably narrowed between the first and the second dorsal fins, and in the region of the tail behind the second dorsal and anal fins. The number of rays in the

second dorsal and anal fins has increased and is 13-17 and 12-14 respectively. In most larvae 5-10 first dorsal fin spines can be seen. Caudal fin rays range from 11-14. There are 17-19 well developed rays in the pectoral fins. Pelvic fin rays are still not clearly visible, although the fins themselves have increased in size. Pigmentation undergoes very little change. The constriction in each nostril divides each into an anterior and a posterior nostril. There are typically 4 preopercular spines and 1-2 parietal spines.

16 - 18 mm Stage (16.17 - 15.54 mm, Mean 16.35 mm)

At about 17 mm length the finfold is almost incomplete in some larvae. In some larvae the space between the first and second dorsal can be seen. However, the second dorsal and the anal fins are still continuous with the caudal fin. There are 15-17 dorsal fin rays and 13 in the anal fin. The number of spines in the first dorsal is 8-10. Three to four rays can be seen dorsal to the posterior upturned end of the notochord. Pectoral fin rays are 18 in number. Four rays are visible in each pelvic fin in the older larvae, the outer one being the spine. Pigmentation is very pronounced. The lateral rectangular patch of melanophores extends anteriorly. Numerous branched melanophores appear on cheeks, and on upper and lower jaws. Nostril on each side is completely constricted into two. All

specimens have 4 well developed preopercular spines and 2 parietal spines. A small supraorbital spine and a supracleithral spine appear at this stage. No traces of the nasal spines can be seen.

The larvae of Myoxocephalus scorpius described here conform with the description of larvae given by previous authors (Ehrenbaum, 1905; Koefoed, 1907; Jensen, 1909; Dunbar, 1947). However, the length at which certain characters appear varies. This obviously is due to differences in rates of development in various geographical areas.

4. Myoxocephalus octodecemspinosus (Mitchill)

The longhorn sculpin, M. octodecemspinosus, is a strictly North American species. It is found abundantly in the coastal waters from eastern Newfoundland and the north shore of the Gulf of St. Lawrence, south regularly to New Jersey and reported to the Atlantic Coast of Virginia (Bigelow and Schroeder, 1953). It has been found in temperatures as high as 19°C and as low as 0.5°C. Morrow (1951) reported that the longhorn sculpins migrate offshore in the spring and move back inshore in late August and September. However, he showed no correlation between the temperature and the pattern of migration. The longhorn sculpin grows up to about 45 cm (Leim and Scott, 1966).

Bigelow and Schroeder (1953) have reported November to January and perhaps February as the spawning months for

longhorn sculpin off the southern coast of New England. According to Morrow (1951), the spawning season in the Block Island Sound area extends from late November to January, with the maximum spawning activity in late December and January. Morrow has given evidence that the younger longhorn sculpins spawn earlier in the season than do the older fish. The longhorn sculpins become sexually mature in their third year.

Eggs are laid in clumps, and are often associated with the sponge, Haliclona oculata (Morrow, 1951). No parental care has been reported. The ripe ovarian eggs are about 0.85 mm in diameter. The eggs swell when they come in contact with water (Morrow, 1951). An average female produces about 8,000 eggs each year. Majority of the eggs are coppery green, but reddish brown, brown or orange eggs have also been reported. Warfel and Merriman (1944) have also reported purple coloured eggs. Development of a fertilized egg usually requires about three months.

There is no record of the description of the larvae of longhorn sculpin in the published literature. Some authors i.e. Merriman and Sclar (1952), Herman (1963) and Graham and Boyar (1965) have reported longhorn sculpin larvae in the Long Island Sound, Narragansett Bay and the coastal waters of Maine respectively, but the validity of identification is doubtful.

The following description of the larvae of longhorn sculpin is based on specimens from Boothbay Harbour, Maine and the Gulf of St. Lawrence.

Description of Larval Stages
Fig. 7

6 - 8 mm Stage: (Range 7.00 - 7.99 mm, Mean 7.63 mm)

Amount of yolk varies in the larvae within this length group. Although only a few larvae have yolk sacs even fewer have no yolk at all. No oil globule is apparent in the yolk at this stage. Finfold is complete and accumulation of mesenchyme is noticeable in the regions of second dorsal, anal, and caudal fins. Only one specimen measuring 7.68 mm in length had a few caudal rays formed, but it was difficult to determine the exact number. Anus is situated in the midventral line just in front of the anterior end of the ventral part of the finfold. Unlike M. scorpius there is no preanal fin. Notochord is straight at the posterior end and the two hypurals do not appear before the larva reaches a length of about 7.5 mm. Pectoral fin is fan-shaped with a broad base. All the larvae show dense accumulation of mesenchyme at the base of pectoral fin. Pelvic fins start appearing as buds at about 8.0 mm length. There are large melanophores on the dorso-lateral aspect of the peritoneum. Very small melanophores are present ventrally at the posterior end of the intestine, just in front of the anus. There are 3-4 large melan-

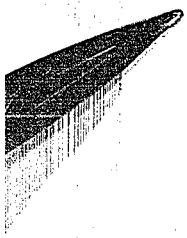


Fig. 7. Developmental stages of Myoxocephalus octodecemspinosus. A, 7.0 mm larva; B, 9.5 mm larva; C, 9.5 mm larva, dorsal view; 9.5 mm larva, ventral view; E, 10.7 mm larva; F, 12.5 mm larva; G, 14.5 mm juvenile.

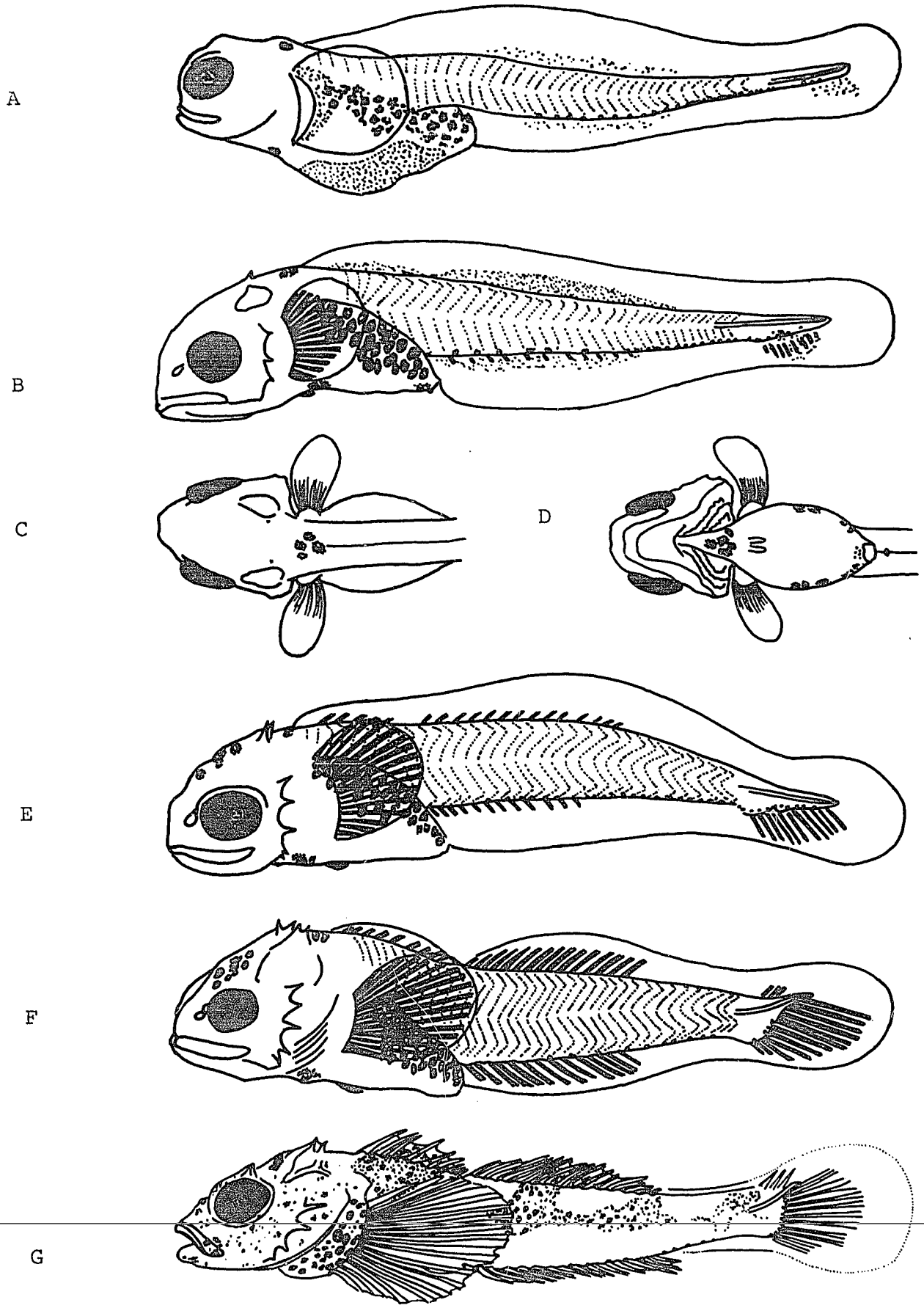


Figure 7

ophores on the isthmus, usually lying in a cluster. A series of medio-ventral melanophores are present at the base of the ventral finfold starting from the 15th or 16th myomere and extending posteriorly almost up to the hypural region. This row generally breaks just before reaching the hypural region. In the anterior part of their range they are slightly apart from each other, but posteriorly they are placed very close to each other. Their number ranges between 16 and 30. There are no melanophores on the chondrocranial region of the head, but a few melanophores are present just behind the head. There are 37-40 myomeres which are chevron-shaped. A single nostril is visible on either side just in front of the eyes. Two to three preopercular spines appear when the larvae reach a length of about 7.5 mm. The top ones appear first. At about 8 mm length a single parietal spine is visible.

8 - 10 mm Stage (Range 8.03 - 9.92 mm, Mean 8.9 mm)

Yolk is completely absorbed at a length of 8.5 mm Finfold is complete. The anal fin rays start to appear when the larvae have reached an approximate length of 9.5 mm. They are 10-12 in number. Mesenchymal accumulation is obvious in the regions of first and second dorsal fins. Caudal rays begin to form quite early within this length group but are difficult to count. At about 9.5 mm length they are countable and range from 8-11. Posterior end of

the notochord starts to curve up at about 9.5 mm length. The two hypurals are visible in all the specimens. Pectoral fin gradually increases in size. There are about 16-19 pectoral fin rays. The pectoral fin rays are countable only in the larger larvae in this length group. At about 8 mm length, the pelvic fins are visible as small buds. The peritoneal melanophore increase in size and number. No other changes in the pigmentation can be seen. Myomeres range from 36-40 and are generally piscine-shaped after 9 mm length. Nostrils do not show any constriction. There are 3-4 preopercular spines and 1-2 parietal spines.

10 - 12 mm Stage: (Range 10.14 - 11.50 mm, Mean 10.88 mm)

Finfold is still complete. All specimens have rays in the second dorsal and anal fins and their number ranges from 11-16 and 12-14 respectively. The spines in the first dorsal fin appear at about 11 mm length. Caudal rays range from 5-14. Posterior end of the notochord is upturned in most of the larvae. Pectoral fin rays are well developed and range from 17-19. Pelvic fins are still like buds and the pelvic fin rays cannot be counted. Melanophores on the head, and the peritoneum increase in size and in number. The small melanophores on the ventral side of the intestine, near the anus, disappear gradually. Medio-ventral melanophores range from 11-30. Myomeres range from 35-40. Each nostril begins to

constrict at 10.5 mm. Most specimens have 5 preopercular spines and 2 parietal spines.

12 - 14 mm Stage (Range 12.09 - 13.29 mm, Mean 12.68 mm)

The first and the second dorsal fins are almost separated, but the caudal fin is still connected with the second dorsal and the anal fins. The number of second dorsal and anal fin rays remains much the same i.e., 12-16 in second dorsal fins and 13-14 in the anal fins. The fin rays in the first dorsal fin increase in number and range from 5-9. Caudal rays also increase in number (9-15). The number of pectoral fin rays does not change (17-19) but the fin grows larger. In some larvae one can count the pelvic fin rays which are 3 in number. Pigmentation is similar to the previous stage. Medio-ventral melanophores are gradually reduced in number (11-30) and in some larvae they are totally absent. At about 12.5 mm length the constriction in each nostril splits them into two. There are 5 preopercular spines, 2 parietal spines and in some a single otic spine.

14 - 16 mm Stage (Range 14.5 - 15.1 mm, Mean 14.9 mm)

The first and second dorsal fins are distinct from each other, but the remnants of the embryonic finfold are still visible in the region of the caudal peduncle. All the fins have increased in size and have assumed the shape of fins in the adults. The number of first dorsal spines

(8-9), the second dorsal fin rays (15-16), the anal fin rays (14-15), and the pectoral fin rays (17-18) are the same as in the adults. Each pelvic fin has a single spine and 3 rays. The adult pigmentation has started to appear. Small melanophores of various sizes appear laterally to form the four saddle bars which are characteristic of the adult longhorn sculpins. The melanophores of these bars extend on to the first dorsal and the second dorsal fins. The peritoneal melanophores are still present and their pattern and shape is similar to the one observed in the previous stages. A few medio-ventral melanophores are still present, but most of them have disappeared in the dermis. Small melanophores line the edges of the two hypurals. Large melanophores appear on the base of the pectoral fins and some small melanophores appear on the pectoral fins, and on the sides of the head. There are four well developed preopercular spines, the first one being the longest. In the adults the lower three spines are lost and the top one grows very prominently. There are 2 parietal spines and a single supraorbital spine. The nasal and supracleithral spines are not prominent and are difficult to see unless the skin is removed. These specimens were caught in an Issacs-Kidd midwater tow near the mouth of Grand River on the 26th of May, 1969.

5. Myoxocephalus aeneus (Mitchill)

The adults of this species are found only in coastal waters of North America. According to Bigelow and Schroeder (1953) and Leim and Scott (1966) the species ranges from the coastal waters of New Jersey to northern Nova Scotia and Gulf of St. Lawrence. Recently Ennis (1969) has reported M. aeneus all around the island of Newfoundland. It is generally found from tide mark down to 15 fathoms or so (Bigelow and Schroeder, 1953). According to all the authors mentioned above M. aeneus can tolerate a wide range of temperatures, as low as 0° C in winter to 20° C in the summer. It is found in a variety of habitats, in shallow waters (less than 3 ft) in well protected areas on mud, sand and gravel bottom and in bed rock side pools (Ennis 1969). In the Gulf of St. Lawrence and on the Nova Scotian coast, it is also found in estuaries. This is the smallest sculpin on our coast and rarely exceeds 15 cm in length.

The spawning season lasts all winter in New England (Bigelow and Schroeder, 1953). Cox (1921) reported a ripe female in June from Magdalen Islands in the Gulf of St. Lawrence. Ennis (1969) collected ripening specimens in autumn and early winter. Eggs are 1 mm in diameter, have green colour, and are deposited on the bottom where they adhere to stones, seaweeds or other objects.

There is no description of the larvae of M. aeneus in the literature. Perlmutter (1939) reported the occurrence of larvae of M. aeneus in the Block Island Sound area in the last two weeks of May. Larvae ranged from 4.5 - 12.1 mm. He illustrated a 6 mm larva without any description. In 1952 Merriman and Sclar separated M. aeneus larvae from M. octodecemspinosus larvae on the basis of size and shape of the body. According to them M. aeneus larvae are smaller in size and have relatively more stubby and well rounded bodies.

The following description of larvae is based on collections from Passamaquoddy Bay, Boothbay Harbour, and the Gulf of Maine.

Description of Larval Stages

Figs. 8, 9

4 - 6 mm Stage (Range 5 - 6 mm, Mean 5.93 mm)

Yolk is completely absorbed at about 5.5 mm. Finfold is complete. Mesenchymal concentrations can be seen in the regions of first and second dorsal fins, anal fins and the caudal fin. The concentration of mesenchyme is usually denser in the region of the hypurals. Notochord is straight. Anus is situated in the midventral line just in front of the anterior end of the ventral finfold. Pectoral fin is fan-shaped with a broad base. Pectoral fin rays appear at about 6 mm length and are about 15 in number.

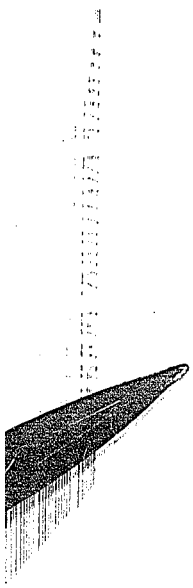


Fig. 8. Developmental stages of Myoxocephalus aeneus. A, 5.0 mm larva; B, 5.0 mm larva, ventral view; C, 7.1 mm larva; D, 7.1 mm larva, dorsal view; E, 7.1 mm larva, ventral view.

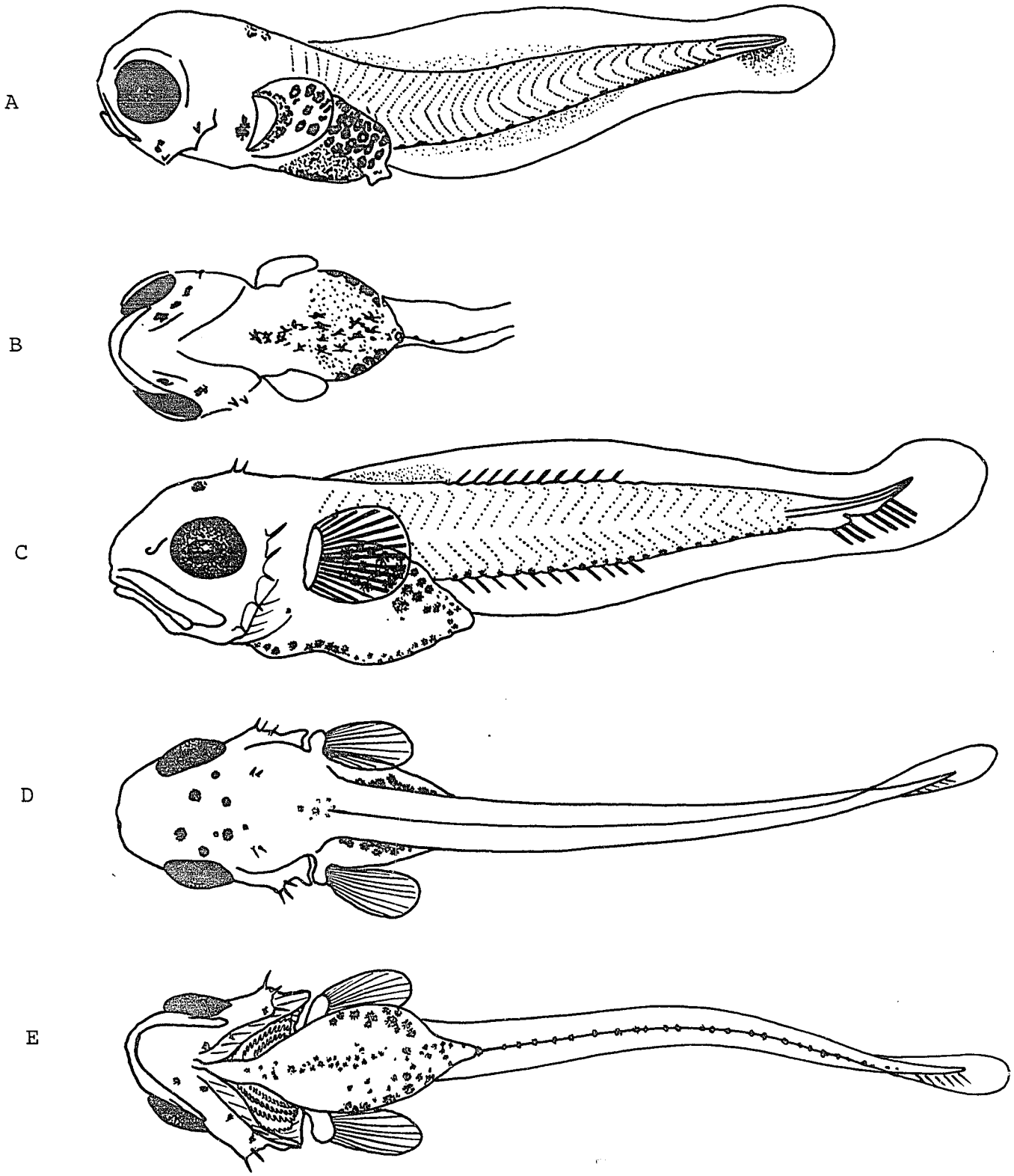


Figure 8

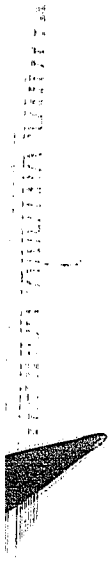
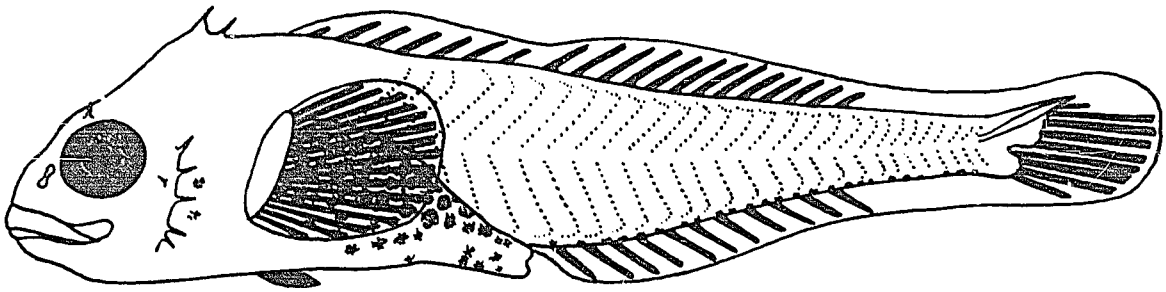
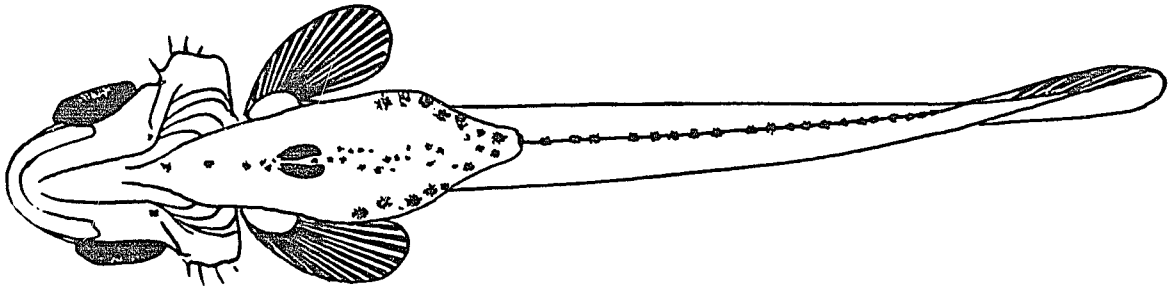


Fig. 9. Developmental stages of Myoxocephalus aeneus. A, 9.7 mm larva; B, 9.7 mm larva, ventral view; C, 11.8 mm juvenile.

A



B



C

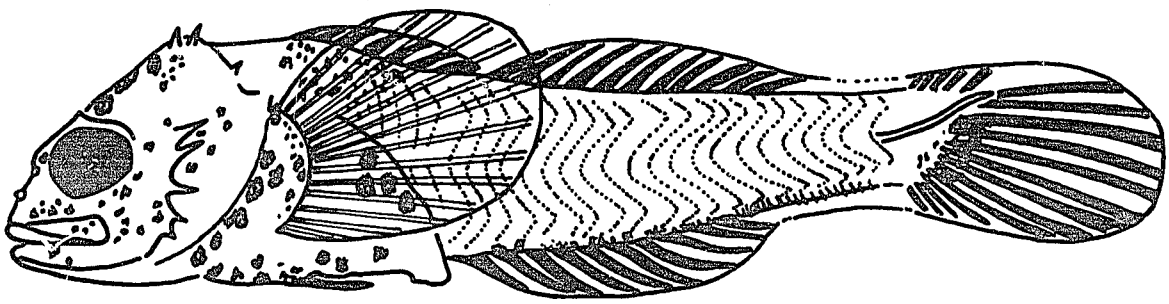


Figure 9

Pelvic fins are not visible. Large melanophores are present on the dorso-lateral aspect of the peritoneum there are 1-2 small melanophores on the angle of the jaws, at the base of the pectoral fins. Some melanophores are present on the ventral side of the lower jaw. The cephalic pigmentation is restricted to a few stellate melanophores just behind the head. On the ventral side of the abdomen there are 1-3 rows of stellate melanophores starting from the isthmus to the anus. Immediately in front of the anus some very small melanophores can be seen. There is a row of medio-ventral melanophores at the base of the ventral and caudal part of the finfold. These melanophores usually start at the 8th or 9th myomere and extend as far as the hypurals. They range from 15-38 in number. Posterior to the region of anal fin these melanophores are relatively smaller and very close to each other. Myomeres are chevron-shaped and range from 31-35. There are 3-4 preopercular spines already developed. Only a single parietal spine is developed. However, in the yolk-sac larvae the parietal spine is generally not developed. A single rounded nostril can be seen in front of each eye.

6 - 8 mm Stage (Range 6.44 - 7.75 mm, Mean 7.14 mm)

Finfold is still complete but begins to narrow down between the first and second dorsal fins at about 8 mm length. The rays in the second dorsal fins and the anal

fins appear at about 7 mm length. There are 10-13 rays in the second dorsal fins and 10-11 in the anal fins. The first dorsal fin spines appear at about 8 mm length. Caudal fin rays appear at about 7 mm length and range from 4-8. The two hypurals appear also at about 7 mm length and at the same time the notochord starts to turn up. Pectoral fins have 13-17 rays. Pelvic fins appear as small buds at about 7.5 mm length. At about 6 mm length melanophores start appearing in the chondrocranial region. Medio-ventral melanophores range from 19-45 in number. The number of myomeres does not change, but they start assuming piscine shape after 7 mm length. The number of preopercular spines is variable. There are 4-6 preopercular spines but usually they are 4 in number. Generally, at this stage, there is a single parietal spine, but larvae with 2 parietal spines are not uncommon. Nostrils are still single and show no signs of constriction.

8 - 10 mm Stage (Range 8.08 - 9.8 mm, Mean 8.85 mm)

Finfold is very narrow between the first and the second dorsal fins and in posterior region of the caudal peduncle. All the fin rays are well developed. There are 11-15 second dorsal fin rays, 8-11 anals and 16-9 first dorsal spines. The caudal fin rays range from 8-13. Notochord is distinctly upturned at about the 9 mm length. Pectoral fins have much enlarged and have 14-17 fin rays.

The pelvic fin rays start to appear at about the 8.5 mm length and are 4 in number, the outer one being the spine. There are no changes in the pigmentation. Myomeres range from 30-34. Nostrils on each side start constricting at about 8.5 mm length and at 9.0 to 9.5 mm length they are completely constricted into two. There are 4-6 preopercular spines and 2 parietal spines. Some specimens have one supracleithral spine and one supraorbital spine.

10 - 12 mm Stage (Single specimen 11.8 mm in total length)

The finfold gradually becomes incomplete but its remnants can be seen in the posterior part of the caudal peduncle. The first dorsal spines (8), the second dorsal fin rays (11), anal fin rays (10), and the pectoral fin rays (14) are well developed. A few fin rays appear on the dorsal side of the upturned notochord. The spines are well developed. The pigmentation is heavier, and the adult pigmentation begins to appear below the first dorsal fin. Melanophores increase in number all over the head region. The medio-ventral melanophores, behind the anal fin, become vertically elongated and their branches extend on the remnants of the finfold. In the region of the anal fin the medio-ventral melanophores gradually sink into the dermis and disintegrate. Some melanophores appear on the caudal fin. The nostrils are completely separated and the anterior nostril appears tubular.

6. Triglops murrayii Günther

This species ranges from Cape Cod northward to Ungava Bay, Greenland, Iceland, and the Atlantic Coast of Europe. Musick and Able (1969) have reported this species from the Bay of Fundy, the Gulf of Maine, the Great South Channel and Georges Bank. Little is known about its biology on the North American Coast. It is found at depths ranging from 50 to 250 metres in the Barents Sea (Andriyashev, 1954). The same author reported $0^{o}C$ - $12^{o}C$ as the temperature range and 23.6‰ to 34‰ as the slinity range in USSR seas. On our coast this species grows up to about 20 cm.

Earlier this species was thought to spawn in midsummer (Bigelow and Schroeder, 1953). This belief was based on the record of a ripe female from Cape Breton in July (Cox, 1921). Andriyashev (1954) reported ripe females in September from the Barents Sea. Musick and Able (1969) collected running ripe females in October in the Gulf of Maine. Occurrence of ripe individuals in various months probably suggests a long spawning period or intermittent spawning during the season. Eggs are pinkish in colour (Cox, 1921) and ripe ovarian eggs are 2 - 2.5 mm in diameter with many oil globules. Musick and Able (1969) reported 3-15 oil droplets. The same authors counted 1965-2739 ovarian eggs per fish.

No description of larval stages is available in the literature. Pelagic larvae 7-15 mm long have been

reported off the coast of Murman from April to June (Andriyashev, 1954). The description of larvae is based on collections from the Boothbay Harbour area.

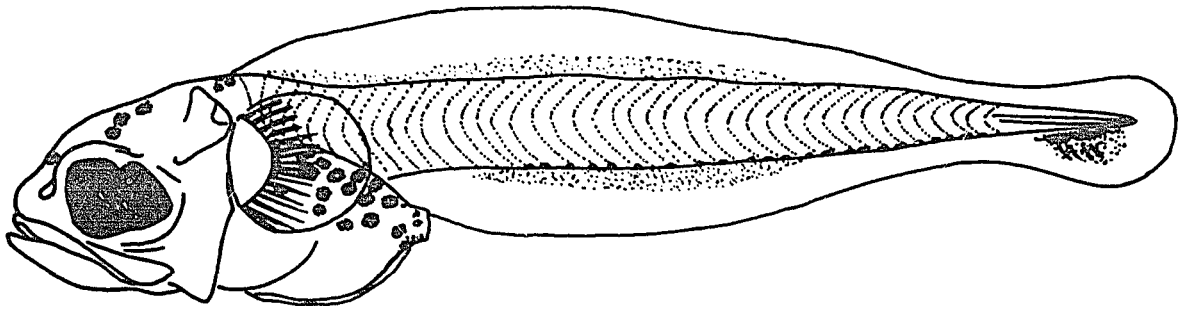
Description of Larval Stages
Fig. 10

8 - 10 mm Stage: (Range 8.38 - 9.6 mm, Mean 9.13 mm)

Larvae within this length group have no yolk. Finfold is complete and mesenchyme accumulation is apparent in the regions of the first and second dorsal fins and the anal fin. Caudal and pectoral fin rays appear at about the 8.5 mm length. The two hypurals appear at the same time as the caudal fin rays. There are 4-8 caudal fin rays and 17-21 pectoral fin rays. Pectoral fin is fan-shaped with a broad base, like in the various species of Myoxocephalus. Anus is placed in the midventral line just in front of the finfold, and the intestine is very short. Notochord is straight at the posterior end. Pelvic fins are apparent as small buds at about the 9 mm length, but pelvic rays are not visible. Melanophores are of brownish colour; they are stellate and sparsely distributed on the head, just behind the head and on the dorsolateral peritoneum. Small concentration of very tiny melanophores is present on the ventral side of the intestine near the anus. There are 20-24 small medio-ventral melanophores. There is a single nostril, on each side, just in front of the eye. Nostrils show no constriction at this stage. Myomeres are chevron-shaped

Fig. 10. Developmental stages of Triglops murrayii. A, 8.4 mm larva; B, 11.6 mm larva; C, 18.9 mm larva; D, 23.4 mm juvenile; pectoral fin rays omitted for the clarity of the underlying pigmentation.

A



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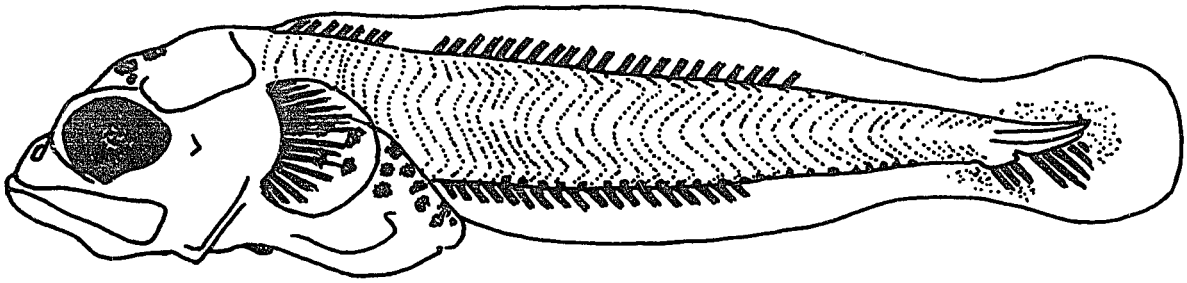

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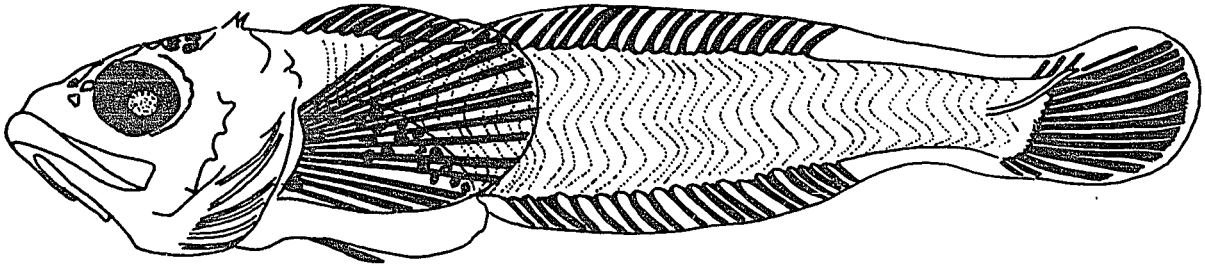


D

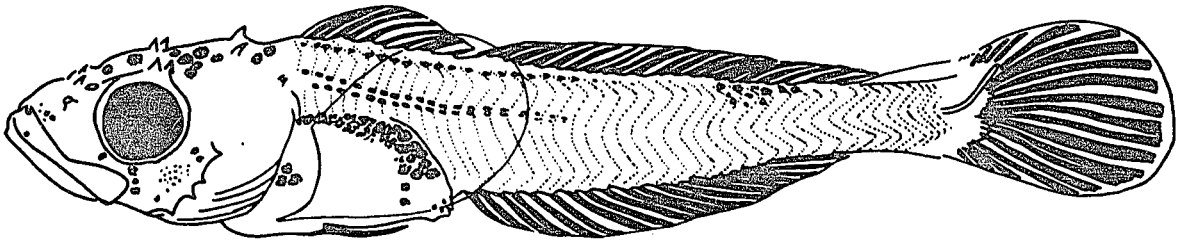


Figure 10

and range from 43-46 in number. There are no spines on the head at this stage.

10 - 12 mm Stage: (Range 10.10 - 11.95 mm, Mean 11.4 mm)

Finfold is complete. Fin rays in the second dorsal and anal fins begin to form at about the 10.5 mm length and are 21-22 in the dorsal fin and 18-20 in the anal fin. The first dorsal fin spines appear at about 11 mm length. Caudal fin has 5-12 rays and 2 distinct hypurals are visible. Notochord starts curving up after about 11 mm length. Pectoral rays are still not fully developed and range from 15-20. Pelvic rays are still not visible. The number of melanophores on head increase and some large stellate melanophores can be seen at the base of pectoral fins. The ventral intestinal melanophores gradually disappear. Nostrils are still single. Myomeres are 43-45 and have started to assume a piscine shape. Spines on head are still not distinctly visible.

12 - 14 mm Stage: (Range 12.34 - 14.0 mm, Mean 12.92 mm)

At about 14 mm length, the finfold start to narrow down between the first and the second dorsal fins. Specimens smaller than 14 mm do not show this tendency. Only 19-23 second dorsal fin rays are developed and the first dorsal spines are 8-11 in number. Anal fin rays range fron 20-22. Notochord is upturned at about 13 mm

length and there are 7-12 caudal fin rays. Pectoral fin rays are well developed and range from 16-19. Pelvic fin rays are still not countable. Nostril on each side starts constricting at about 13 mm length. Pigmentation does not change. Myomeres have assumed piscine shape. Spines on the head start appearing. There are 3-4 preopercular spines which are relatively shorter than in the species of Myoxocephalus. In older larvae, within this length group, there are 1-2 parietal spines and always 2 supraorbital spines.

14 - 16 mm Stage: (Range 14.25 - 16.0 mm, Mean 15.13 mm)

The finfold still connects the first and second dorsal fins, however, it is quite narrow around the caudal peduncle. There are 21-22 second dorsal fin rays and 8-10 first dorsal fin spines. There are about 21 rays in the anal fin. Caudal rays increase in number and range from 11-14. Pectoral fin is more enlarged and reaches almost to the anus. The number of pectoral fin rays does not change (17-19). Pelvic fin rays are now visible and are 3 in number. The middle one is the longest as in the adult specimens (McAllister, 1963). At about 15 mm length, the nostrils on each side are constricted into two i.e., an anterior and a posterior. During this stage, in some specimens, 1-2 large stellate melanophores appear on the isthmus. These melanophores are usually arranged in a linear fashion. There are 4 short

preopercular spines, 1-2 parietal spines, 2 supraorbital spines and a single otic spine.

16 - 18 mm Stage: (Range 16.2 - 17.4, Mean 16.89 mm)

Very few changes take place during this stage. Caudal fin rays increase in number (12-20), and rays above the upturned notochord start appearing (3-6). Medio-ventral melanophores start sinking in the dermis at about 17 mm length and are very difficult to see.

18 - 20 mm Stage (Range 18.45 - 19.7 mm, Mean 19.09 mm)

Caudal fin rays keep increasing in number (16-20), the cephalic spines become more prominent and the anterior nostril becomes tubular. The first dorsal fin is distinct from the second dorsal but the caudal fin is still connected to the second dorsal and the anal fins.

Soon after the 20 mm stage some important changes take place in the larvae. The caudal fin becomes free from the anal and finally from the second dorsal fin. Pectoral fin, like all the other fins, increases in size and extends beyond the posterior end of the first dorsal fin. The pigmentation on head becomes more pronounced. Melanophores of various sizes appear on the cheek, snout, upper and lower jaws. Melanophores on the dorsal peritoneum start to lose their original shape and the dendrons anastomose with those of the neighbouring melanophores.

Some melanophores appear under the second dorsal. This is the beginning of the juvenile pigmentation. The medio-ventral melanophores disappear completely. Lateral line appears in the anterior part of the body behind the head. Dorsal row of spines appear at the bases of first and second dorsal fins.

A single nasal spine appears just in front of each posterior nostril. The supracleithral spines are now two and are quite distinct. The anterior nostril is now very prominently tubular. The larva looks like the adult exept for the pigmentation which is added up at a length of 25-30 mm.

In still larger specimens (25-30 mm) the four lateral saddle bars are well developed, one associated with the first dorsal fin, two with the second dorsal fin and one with the caudal peduncle. This pattern of pigmentation is characteristic of the adult specimens (see drawing in Leim and Scott, 1966).

Koefoed (1907) described larvae of Triglops pingelli from Greenland waters which differ from those of T. murrayii in two main features. In pingelli at about 10 mm there appears a row of melanophores on either side of the base of the second dorsal, and at 11 mm a medio-lateral row of melanophores. In T. murrayii these rows of pigmentation are not present at any stage of the development. Koefoed also noticed that in T. pingelli the caudal rays, and the

second dorsal and anal fin rays appear at 11 mm and 12.5 mm respectively. In T. murrayii the caudal rays appear at about 8.5 mm and the second dorsal and anal rays appear at about 10.5 mm. These differences in the development of fin rays could be due to environment. Koefoed reported a 16.5 mm larva of pingelli from a polar current east of Greenland in which the rays were just beginning to appear.

7. Gymnocanthus tricuspis (Reinhardt)

The arctic staghorn sculpin, Gymnocanthus tricuspis is a circumpolar species found in the Arctic Ocean. On the east coast of North America it extends south to the Gulf of St. Lawrence. Bigelow and Schroeder (1953) have reported a specimen from Eastport, Maine. However, this species is essentially a cold water, Arctic fish and has only been taken where the temperature was 0° - 5° C. In the northern seas of the Soviet Union it is found in a wide range of salinity i.e., 16 - 37‰ (Andriyashev, 1954). This sculpin is most abundant below 10 fathoms of water but occasionally it is encountered in 1-2 fathoms of water. The maximum depth of capture is known to be 95 fathoms (Backus, 1957). The individuals of this species generally burrow themselves in sandy and muddy bottoms but are also found on pebbly and rocky bottoms. This sculpin grows up to 10 inches (Leim and Scott, 1966).

Spawning habits of this species, in our waters, are not known. According to Andriyashev (1954) mature females have been reported in Kara Sea and White Sea in late September. The ripe ovarian eggs from these localities were 2 mm in diamater.

The following description of the larvae of G. tricuspis is based on the collections from the coastal waters of Labrador made in May and June, 1967.

Description of Larval Stages

Fig. 11, 12

12.16 mm Stage

At this stage the yolk is completely absorbed. The finfold is complete. Second dorsal fin rays (14), anal fin rays (17) and caudal fin rays (6) are beginning to form. The first dorsal rays are not formed yet but mesenchyme is visible. Posteriorly the notochord is straight but in some specimens shows tendencies to turn up. The two hypurals are clearly visible. Pectoral fin is fan-shaped with a broad base and reaches the 8th myomere. Pectoral fin rays are well developed and 17-18 in number. Pelvic fins appear as small buds on the mid-ventral line, between the bases of the two pectoral fins. Anus is situated in the mid-ventral line just in front of the anterior end of the ventral finfold. Intestine is

Fig. 11. Developmental stages of Gymnocanthus tricuspis. A, 12.2 mm larva; B, 13.9 mm larva; C, 15.9 mm larva; D, 15.9 mm larva, dorsal view; E, 15.9 mm larva, ventral view.

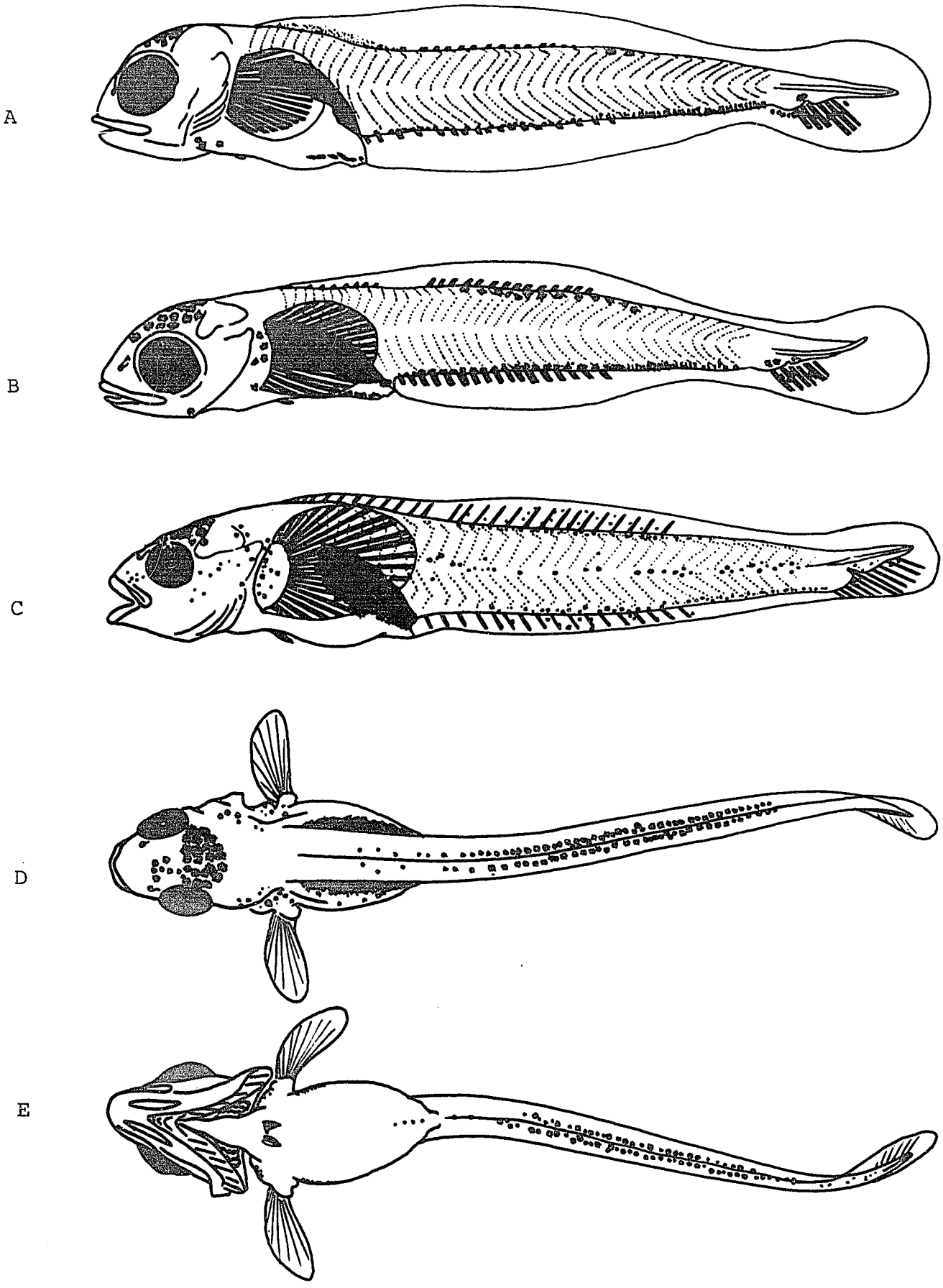


Figure 11

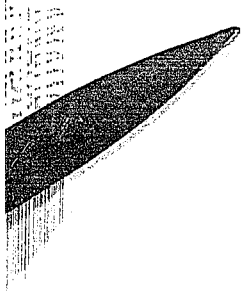


Fig. 12. Gymnocanthus tricuspis. 15.9 mm larva, enlarged head region showing structure of preopercular spines.

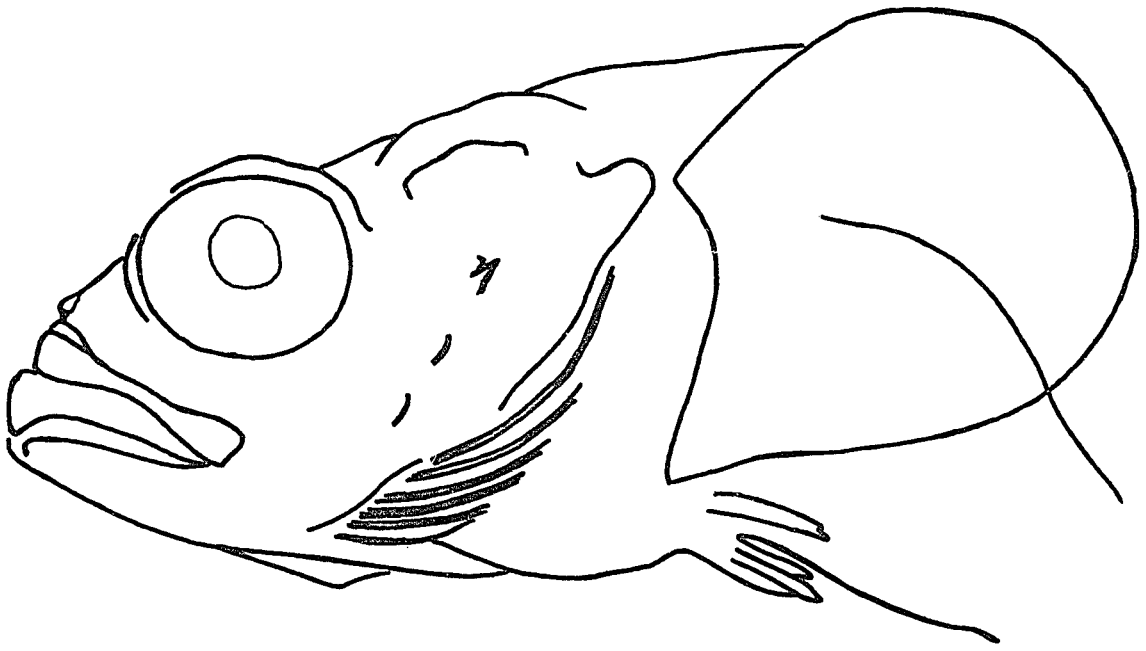


Figure 12

very short and hardly distinguishable from the main visceral mass. The peritoneal pigmentation is black and the melanophores are so close to each other that they cannot be distinguished. This patch of pigmentation is restricted only to the dorsal aspect of the peritoneum, and does not extend very much in the ventrolateral directions. There are about 3-7 long melanophores, placed almost end to end in the mid-ventral line on the abdomen just in front of the anus. One to three, usually large and stellate, melanophores are present on the ventral side of the isthmus, just in front of the pelvic fins. The head is covered by large stellate melanophores. On the dorsal side there are 2-3 large stellate melanophores placed on either side of the posterior end of the second dorsal fin. This is the beginning of a double row of melanophores which later extend anteriorly on either side of the dorsal finfold. On the ventral side there is a single row of 20-35 vertically elongated melanophores between the posterior end of the anal fin and the anterior hypural. This single row of melanophores extends anteriorly all along the base of the anal fin, but the melanophores instead of vertically elongated are normal and stellate. There are discrete stellate melanophores at the base of hypurals and between the caudal fin rays which appear to be the continuation of the ventral row of pigmentation described above. One

to two melanophores can also be seen on the hypurals, below the notochord. There are about 39 or 40 myomeres which are of piscine shape. No spines on the head could be seen at this stage. There is a single nostril on either side of the head just in front of the eyes, and no constriction is visible in them.

13.9 mm Stage

The finfold is still complete but the rays in the median fins are much more developed; and the spines in the first dorsal fin have started to appear. Not all the first dorsal fin spines have appeared. There are only seven spines developed while in the adults there are about 11. The number of fin rays in the second dorsal fin (14) and anal fin (17) is well established and falls within the range reported in the adults (Bigelow and Schroeder, 1953) and the larvae (Koefoed, 1907). Notochord is upturned. Pectoral fin has enlarged and its distal end almost reaches the 11th myomere. The pectoral fin rays are about 17-18 in number and are well developed. The pelvic fin rays are three, middle one being the longest. Some changes in the pigmentation are noticeable. The dorsal row of pigmentation on either side of the dorsal finfold extends anteriorly. Four to five melanophores appear on the base of the pectoral fin, and 1-2 melanophores at the angle of the

jaws. The medio-ventral melanophores, at the base of the anal fin sink in the skin but can still be seen. The nostrils start constricting. No spines could be seen in the head region.

15.97 mm Stage

At this stage the number of fin rays in all the fins except the caudal fin are established. About 11-12 spines in the first dorsal fin, 14-15 rays in the second dorsal fin, and 17-18 anal fin rays. All these values correspond very closely with the data given by Koefoed (1907) on the larvae of G. tricuspis from Greenland waters. Pectoral fin is well developed and has enlarged considerably. The posterior end of the pectoral fin reaches the anal opening on the 13th myomere. Very important changes occur in the pattern of pigmentation. Along the lateral line appear a row of 30-32 melanophores. All these melanophores do not fall in a line. Some small melanophores could also be seen which do not fall in the same row. The single row of melanophores at the base of anal fin and behind the anal fin appear as two rows, one on either side of the medio-ventral line. However, in the anterior and posterior extremities the melanophores are still single. Small melanophores also appear on the second dorsal and anal fins. The number of melanophores increases in all parts of the body and small melanophores

are visible in the opercular region and also below the nostrils. The elongated melanophores noticed on the ventral side of the peritoneum, just in front of the anus, become much reduced in size and finally disappear. The nostrils are still not completely constricted. Another striking feature at this stage of development is the appearance of three spines on the preopercular bone, two lower blunt ones and a top sharp one. The two lower spines remain blunt all through the life of the fish while the top sharp spine branches into three in the adults. In no specimen examined by me, the top sharp spine had three branches. These spines can only be seen in stained specimens and under high power of the microscope.

The only description of the larvae of G. tricuspis, in the literature, is by Koefoed (1907). He described three stages of 10.7 mm, 12.7 mm and 15.5 mm length from Greenland. Koefoed's description generally conformed with my description of larvae from the coastal waters of Labrador, but with two exceptions. According to Koefoed, anteriorly there is a row of melanophores on either side of the base of the dorsal finfold, which is continuous with the cephalic concentrations of melanophores. The larvae from Labrador that I examined did not have this character at any stage. Koefoed, however, has not illustrated this character in his drawings but has only

mentioned in the text. The second feature which is not contradictory with Koefoed's description is that the single medio-ventral row of melanophores becomes double at about 15 mm length. Koefoed did not record this feature.

Kyushin (1970) described the development of eggs and larvae of Gymnocanthus herzensteini from the coastal waters of Hokkaido. The larvae had typical heavy, black pigmentation on the dorsal part of the peritoneum and also 3-4 large melanophores at the origin of the dorsal finfold. However, these melanophores did not form two rows on either side of the dorsal finfold, as reported by Koefoed for G. tricuspis.

8. Hemitripterus americanus (Gmelin)

The sea raven, Hemitripterus americanus is distributed only along the Atlantic Coast of North America, southward to Chesapeake Bay, north to Anticosti, Strait of Belle Isle, and Grand Banks (Bigelow and Schroeder, 1953). This species is rare on the Labrador Coast. It is one of the largest sculpins on the Atlantic Coast of America. Various authors (Bigelow and Welsh, 1953; Warfel and Merriman, 1944) have recorded specimens as long as 19.5 inches to 25 inches and weighing up to 7 pounds.

Sea ravens are found only on rocky bottoms, pebbles and hard sand, but never on sticky and muddy bottoms. They are found to a depth of 100 fathoms (Leim and Scott, 1966) and there is no limit to their vertical wanderings (Bigelow and Schroeder, 1953). According to the latter authors this species can tolerate freezing point of salt water and the upper limit to their preferred temperature is about 15° to 16° C.

Spawning starts in October and lasts until late December. The eggs are adhesive in nature and are chiefly deposited on the bases of the finger sponge, Chalina (Warfel and Merriman, 1944). These eggs are larger than the eggs of any other sculpin (3.9 to 4 mm in diameter). The colour of eggs is pale yellow, amber or light orange, which approximates the colour of the living sponge. According to Bigelow and Schroeder the eggs are yellow when spawned, but soon change their colour to amber. Approximately 10% of the surface area of the egg is dominated by small oil globules. In the Japanese species H. villosus the small oil globules eventually join together and form a large single oil globule (Kyushin, 1968). The egg membrane is very thick and the eggs are so heavy that they sink to the bottom. The eggs hatch within six weeks of incubation (Warfel and Merriman, 1944). According to the same authors hatching is a slow and difficult process in sea ravens. Larvae

characteristically emerge head first through a round opening which is slightly larger than the head but little larger than the abdomen. The larvae have to await the absorption of a part of the abdominal yolk before they could free themselves completely. The larvae when first hatched range from 9.9 to 14.1 mm according to Warfel and Merriman (1944). The following description of larvae is based on the specimens collected from Boothbay Harbour area and the Gulf of St. Lawrence.

Description of Larval Stages

Figs. 13, 14

11.9 mm Stage

As mentioned earlier the length at hatching is about 12 mm, according to Warfel and Merriman (1944), and the range from 9.9 to 14.1 mm. Shortly after hatching the larvae still have some yolk. However, the larva described in this section did not have any yolk. Finfold is complete and there are about 9 caudal rays. The two hypurals cannot be seen. Notochord is straight. There is accumulation of mesenchyme in the region of first and second dorsal fins and the anal fin. About 15 pectoral fin rays are apparent in the pectoral fin. The pectoral fin is typically fan-shaped with a broad base. Anus is situated in the mid-ventral line, just in front of the anterior end of the ventral part of the finfold. The viscera is compact and is covered by a tough periotneum. Pelvic fins are apparent as small buds

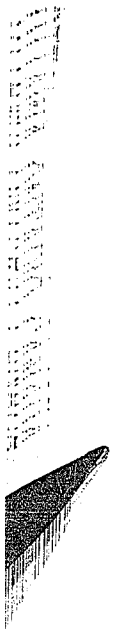


Fig. 13. Developmental stages of Hemitripterus americanus. A, 11.7 mm larva; B, 11.7 mm larva, dorsal view; C, 11.7 mm larva, ventral view; D, 14.5 mm larva; E, 14.5 mm larva, dorsal view; F, 14.5 mm larva, ventral view.

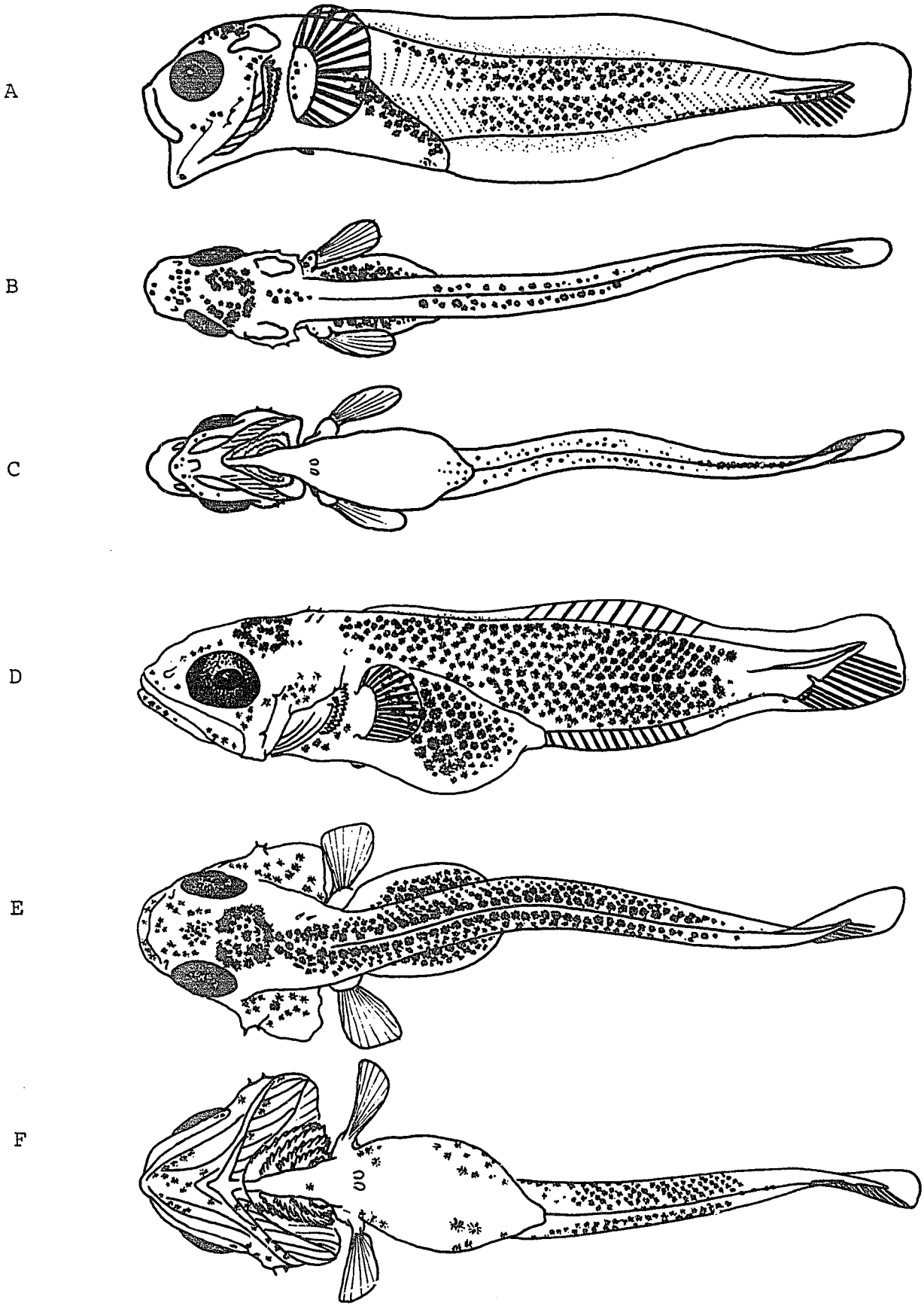


Figure 13

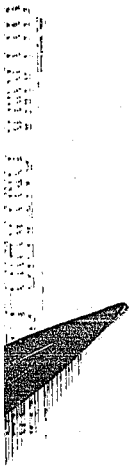


Fig. 14. Hemitripterus americanus. 18.8 mm larva.

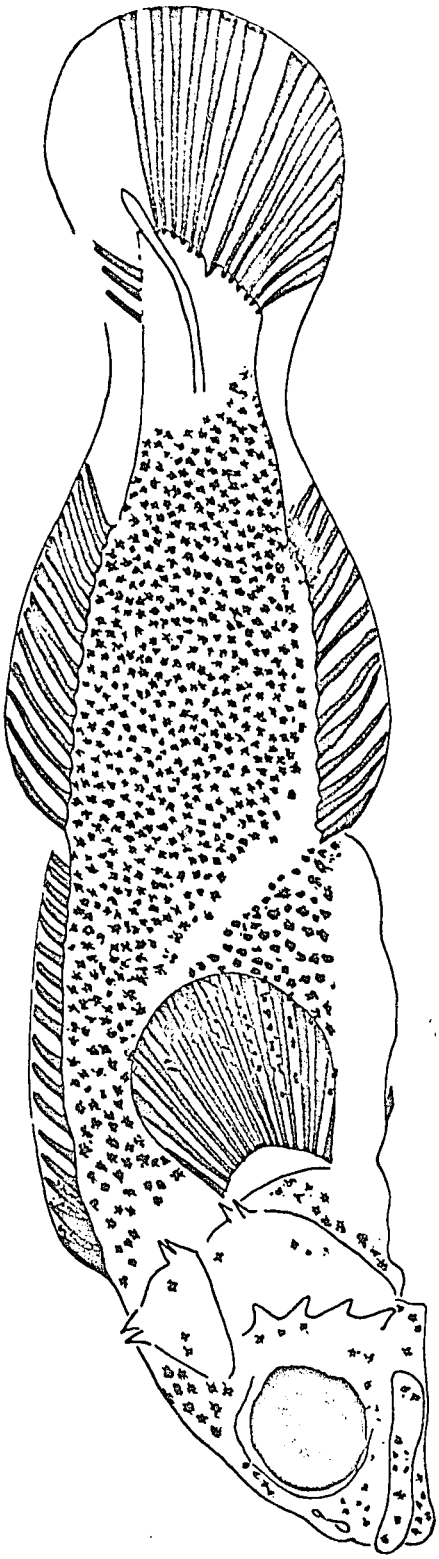


Figure 14

lying medio-ventrally between the two pectoral fins. Pigmentation is heavy. There are stellate melanophores covering the dorsal part of the head, the dorso-lateral aspect of the peritoneum and the lateral side of the body. This lateral patch of melanophores is denser and more extensive than the similar patch observed in Myoxocephalus scorpius. There are small melanophores on the ventral side of the posterior end of the intestine. Some small melanophores are present on the ventral side of the lower jaws. Pigmentation is also present on cheeks, and below and behind the orbit. A row of about 24 melanophores is present ventrally at the base of the ventral finfold (medio-ventral row) but posterior to the region of anal fin. These small melanophores can be easily seen in the posterior part of the tail but in the anterior half of the tail they are lying deep in the skin and cannot be seen easily. There are about 4 melanophores at the base of the caudal fin rays. Some melanophores are present at the base of the pectoral fins ventrally. There are about 39 myomeres and they are chevron-shaped. The only spines visible are 3 small ones on the preoperculum. There is a single nostril on either side of the head just anterior to the eyes.

The preanal length is nearly 1/3 of the total length and the depth of the body is about 1/8 of the total length.

13.9 mm Stage

By this stage the yolk is completely absorbed. Finfold is still continuous but has considerably narrowed down in the region of the first dorsal fin. The fin rays in the second dorsal and anal fins have appeared. There are about 11 second dorsal fin rays and about 14 anal fin rays. The caudal rays also increase in number and there are about 12 of them. The two hypurals can be easily seen and the notochord starts turning up. In the region of the first dorsal fin mesenchyme accumulation is apparent. The number of pectoral rays does not increase, but the fin rays are much more developed; and there is no significant increase in the length of pectoral fins. Pelvic fins still look like small buds and the pelvic fin rays cannot be seen. The visceral mass enlarges and a typical bulging profile of it is typical of the larvae of this species. The pigmentation increases generally. The peritoneal pigmentation extends latero-ventrally and when seen from the ventral side several stellate melanophores can be seen on the ventral aspect of the peritoneum. There are occasional melanophores on the isthmus, but this is not a regular feature of this species. The lateral patch of melanophores is denser and extends antero-posteriorly, and joins the pigmentation on the head. The medio-ventral row of melanophores sink deep in the skin and cannot be seen unless seen in strong transmitted

light. The myomeres are still chevron-shaped. There are 4 preopercular spines, 2 parietal spines and 2 otic spines. The single nostril on either side begin to constrict.

The preanal length increases considerably and is about 1/2 the total length. The body depth also increases and is about 1/6 in total length. The larvae at this stage look generally tougher and stronger than in the previous stage.

18.8 mm Stage

At this stage the first and second dorsal fins are completely differentiated and the number of fin rays in these fins are established. There are about 17 spines in the first dorsal fin, 13 rays in the second dorsal fin, and 14 rays in the anal fin. At this stage the first three spines of the first dorsal fin are a little larger than the one behind them. This is a characteristic feature in the adults. These numbers correspond with the fin ray formula in the adults. There is a total of 16 caudal fin rays, 13 associated with the hypurals and 3 above the notochord. The notochord is upturned. The only change in pigmentation is the appearance of small melanophores on the first and second dorsal fins and the anal fins. The number or preopercular, parietal and otic spines remains constant. Two spines appear on the

opercular bone. The myomeres are piscine-shaped. The constriction in the nostrils is very pronounced but not complete.

The proportions of preanal length and body depth with the total length do not change.

Warfel and Merriman (1944) described a newly hatched larva of H. americanus which they hatched in the aquarium. The larva was about 12 mm long and resembled the 11.7 mm larva illustrated in Fig 13. The newly hatched larva described by Warfel and Merriman had already developed the heavy, lateral pigmentation. Newly hatched larvae of H. villosus show this feature too (Kyushin, 1968).

9. Cottus bairdii Girard

There are two widely recognized subspecies, Cottus bairdii bairdii and C. b. kumlieni. According to Hubbs and Lagler (1967) C. b. bairdii is distributed from the southern parts of Canada and from Minnesota through Wisconsin to Northern Illinois and Indiana, throughout the Great Lakes region (including Lake Erie but excluding the other Great Lakes and the inland lakes inhabited by C. b. kumlieni) to Quebec and New Brunswick. The southern limit of C. b. kumlieni is limited to the entire margins of Lakes Superior, Michigan, Huron, and Ontario and the eastern basin of Lake Erie, the finger lakes and the St. Lawrence, also in a very few inland lakes of Michigan where conditions approach those of the Great Lakes, and Lake Attawapiskat, James Bay Drainage.

This species generally prefers streams of clear water, having a rocky or a sandy gravel bottom. Permanency of stream flow is a prime requisite. In lakes they are found along rocky shores, washed by wave action (Trautman, 1957). Individuals grow up to 4.5 inches but are usually from 1.8 - 4 inches in length.

Spawning of this species occurs in the spring and early summer (Smith, 1923; Hann, 1927; Ricker, 1934; Koster, 1936; Simon and Brown, 1943; Bailey, 1952). The most detailed account of the spawning habits of this

species is given by Koster (1936). The eggs are deposited on the ceiling of the nest which is prepared by the male. The colour of eggs is from pale yellow to orange. The female leaves the nest after spawning but the male stays guarding the nest. Similar behaviour was noted by Van Vliet (1964) for Cottus cognatus. Larvae hatch in about a month after spawning. Yolk is absorbed in 3-6 days (Koster, 1936; Bailey, 1952) and the young begin to leave the nest. Both C. b. bairdii and C. cognatus have been found guarding nests containing young that had already begun to feed. After complete absorption of the yolk, the larvae of C. b. punctulatus measure about 9.5 mm and resemble the adults except for the size (Bailey, 1952).

The young of C. bairdii described in the following were collected in June from Little John Lake in northern Wisconsin. Collections were made with tow nets. Larvae of C. bairdii were present only in the bottom hauls. C. bairdii is the only sculpin present in this lake, therefore there is no doubt regarding the identification of the young specimens. The five specimens examined ranged from 7.5 - 10.3 mm in total length.

Description of Larval Stages

Fig. 15

7.5 mm Stage

This was the youngest specimen in the collections. The fin rays at this stage are well developed in all the fins and correspond to the adult fin ray formula. The first dorsal fin has 8 spines. The second dorsal and anal fins have 16 and 13 rays respectively. The first and the second dorsal fins are continuous with each other and so is the caudal fin with the second dorsal and the anal fins. The pelvic fins are fairly well developed and the 3 rays could be easily seen. The posterior end of the notochord is completely upturned and there are about 11 well developed caudal fin rays associated with the two hypurals. Small, generally non-stellate melanophores are present on the head, peritoneum, trunk and the tail. The trunk and tail pigmentation shows the development of saddle bar pattern, typical of the adult pigmentation. Nostril on each side is still single but shows a deep constriction. There are 31-32 piscine-shaped myomeres. The preopercular spines are hidden under the skin and are hardly visible.

10.3 mm Stage

At this length, the pigmentation is more like that in the adults. There are three preopercular spines visible, the

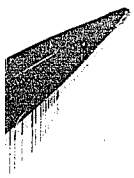


Fig. 15. Developmental stages of Cottus bairdii. A, 7.5 mm larva; B, 7.5 mm larva, dorsal view; C, 7.5 mm larva, ventral view; D, 7.5 mm larva, shape of myomeres; E, 10.3 mm juvenile.

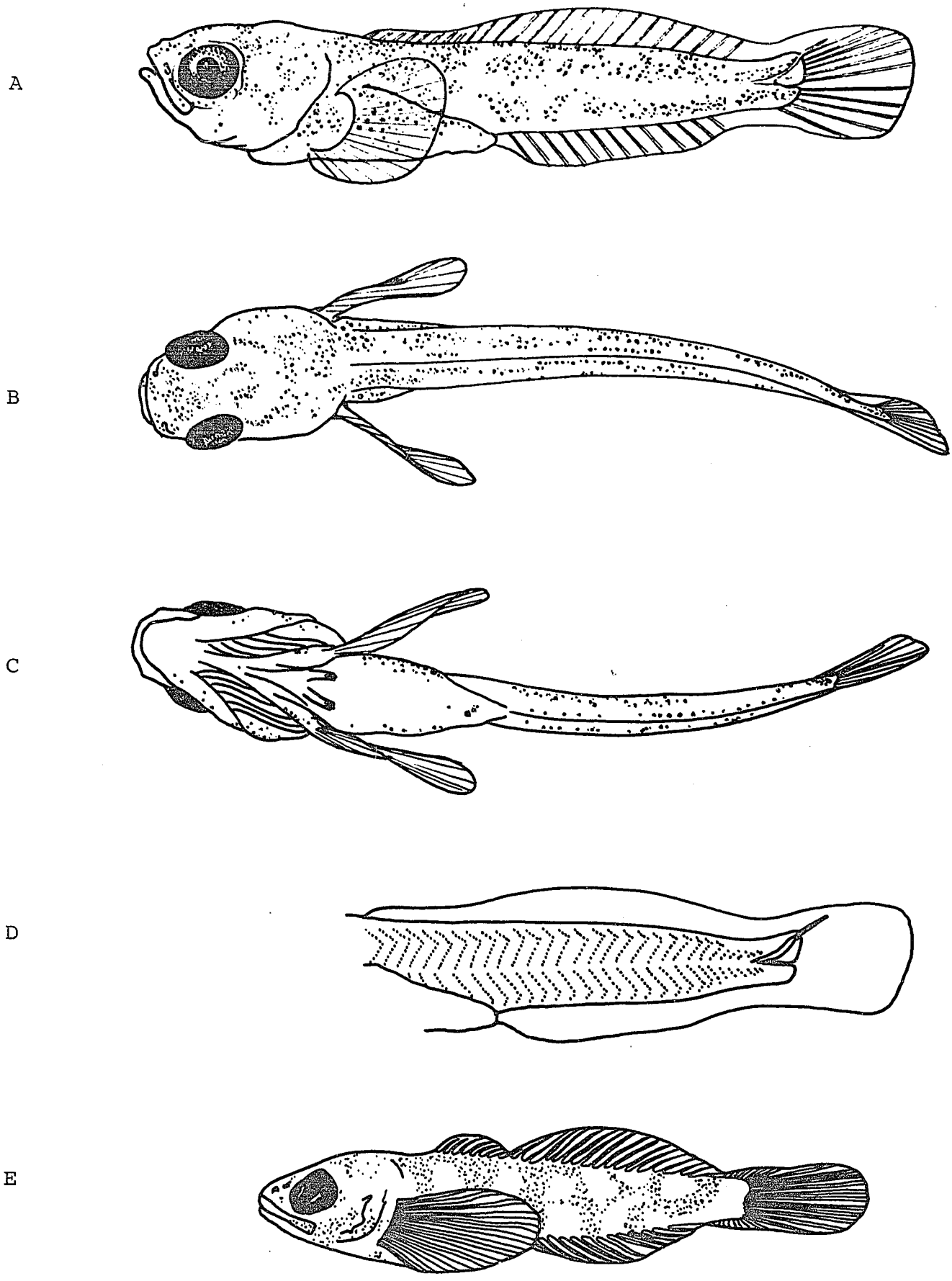


Figure 15

top one being the longest. The nostril on each side is completely constricted into two. The two nostrils lie far apart from each other and the anterior nostril is tubular. The finfold has completely disappeared and the fins are almost as well developed as in the adults.

Fish (1932) confused the identification of the larvae of Cottus bairdii from Lake Erie. Faber (1970) has already pointed out this mistake in the literature, but without any evidence. Fish described 5 stages of larval development (6.6 - 11 mm length) as C. b. kumlieni and a 6 mm larva as C. b. bairdii. Larvae of Cottus generally hatch in a very advanced stage of development. According to Koster (MS, 1936), the yolk sac larvae of C. bairdii (7.9 mm) already have bud-like pelvic fins, the beginning of fin rays in the fins, and when the yolk is half used (9.3 mm) the future pigmentation on the lateral sides is clearly visible. Koster also observed that 10 mm long larvae of C. bairdii were very similar to the adults in appearance. Bailey (1952) observed that after the complete absorbtion of yolk, larvae of Cottus bairdii punctulatus were about 9 mm long and closely resembled the adults except for the size. Okada (1960) reported that the embryos of Cottus pollux had already developed the lateral pigmentation. The youngest larva of C. bairdii studied by me (Fig 15) had well developed pigmentation all over the body, and the lateral

pigmentation showed signs of lateral saddle bar pattern of the adults. The 10 mm larva (Fig 15) had distinctive 4-5 saddle bars on the lateral sides. In Fish's (1932) description, even the longest larva (11 mm) did not have any signs of lateral pigmentation. These larvae were much thinner than the larvae of Cottus bairdii studied by me. The body depth of Cottus bairdii larvae at about 7 mm length was 11% of total length, while the body depth of the larvae of similar size illustrated by Fish was only about 6% of the length. The body depths of larvae of Myoxocephalus quadricornis thompsonii of similar lengths were also 6% of body length. The larvae of C. b. kumlieni and C. b. bairdii described by Fish actually resemble very closely to the larvae of M. q. thompsonii in the lack of lateral pigmentation, in having thinner bodies, 4 preopercular spines and about 4 medio-ventral melanophores.

B. Morphological Comparisons of Larvae

1. Morphometric Characters

Relative growth rates of two subspecies (Myoxocephalus quadricornis labradoricus and M. q. thompsonii) and four species (M. scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii) are compared here. The number of specimens for the other species was not sufficient for a morphometric study.

Five head and body measurements i.e., head length, diameter of eye, interorbital width, preanal length, and body depth were subjected to regression analysis on total lengths (For details of statistical procedures see "Materials and methods"). The relative growth terminology used in this study is that of Martin (1949). The results of t - tests for significance of differences between regression coefficients are given in Appendix Tables 1-5. Comparisons involved only a single growth stanza.

Head Length

In all species the growth of the head relative to the total length showed tachyauxesis (i.e., grew faster than the whole), and all the regressions showed a linear relationship. The correlation coefficients ranged from 0.85 to 0.98 (Table 1). Kyushin (1968, 1970) also observed tachyauxesis of head length in the larval growth of two cottid species (i.e., Hemitripterus villosus and Gymnocanthus herzensteini). The relative growth rate was the slowest in M. aeneus (K = 1.114) and the fastest in

TABLE 1. Regressions of lengths of head and body parts on total lengths of the larvae of *Myoxocephalus quadricornis thompsonii*, *M. q. labradoricus*, *M. scorpius*, *M. octodecemspinosus*, *M. aeneus* and *Triglops murrayii*.

Species	Character	No. of Specimens	Total length Range & Mean (mm)	Correlation coefficient	Regression coefficient	Standard error of Regression coefficient	Y - intercept
thompsonii	Head length	46	8.6-17.54 (12.17)	0.9784*	1.462	0.0294	-1.2747
	Diameter of eye	57	8.70-17.54 (11.584)	0.9334*	0.828	0.0309	-1.0409
	Interorbital width	46	"	0.8098*	0.685	0.0474	-1.0586
	Preanal length	57	"	0.9897*	1.212	0.0170	-0.6483
	Body depth	"	"	0.9769*	2.081	0.0441	-2.3200
labradoricus	Head length	61	12.35-17.4 (14.75)	0.9178*	2.241	0.0329	-2.2095
	Diameter of eye	"	"	0.5917*	1.184	0.0549	-1.4120
	Interorbital width	"	"	0.5263*	0.822	0.0452	-1.1124
	Preanal length	"	"	0.9424*	1.765	0.0213	-1.3398
	Body depth	"	"	0.9172*	2.720	0.0401	-3.0629

Table 1 Cont'd

Species	Character	No. of Specimens	Total length Range & Mean (mm)	Correlation coefficient	Regression coefficient	Standard error of Regression coefficient	Y - intercept
scorpius	Head length	47	7.54-16.54 (11.43)	0.9613*	1.399	0.03974	-1.134
	Diameter of eye	"	"	0.9515*	0.992	0.03182	-1.067
	Interorbital width	"	"	0.9174*	1.182	0.05083	-1.447
	Preanal length	"	"	0.9856*	1.276	0.02169	-0.661
	Body depth	"	"	0.9776*	2.226	0.04750	-2.256
octodecemspinosus	Head length	43	7.3-13.29 (9.81)	0.9133*	1.265	0.04245	-0.976
	Diameter of eye	"	"	0.9433*	1.094	0.02899	-1.192
	Interorbital width	"	"	0.8687*	1.034	0.04437	-1.240
	Preanal length	"	"	0.9604*	1.187	0.02591	-0.578
	Body depth	"	"	0.9432*	2.135	0.05661	-2.071

Table 1 cont'd

Species	Character	No. of Specimens	Total length Range & Mean (mm)	Correlation coefficient	Regression coefficient	Standard error of Regression coefficient	Y - intercept
aeneus	Head length	32	5.85-9.8 (7.76)	0.8501*	1.114	0.04102	-0.805
	Diameter of eye	"	"	0.8531*	0.928	0.03378	-1.057
	Interorbital width	"	"	0.7950*	1.040	0.04719	-1.203
	Preanal length	"	"	0.9097*	1.283	0.03484	-0.660
	Body depth	"	"	0.9452*	2.283	0.04692	-2.075
murrayi	Head length	33	7.58-19.7 (13.67)	0.9714*	1.141	0.0315	-0.821
	Diameter of eye	"	"	0.9357*	0.798	0.0339	-0.885
	Interorbital width	"	"	0.8577*	0.825	0.0559	-1.086
	Preanal length	"	"	0.9770*	1.081	0.0266	-0.498
	Body depth	"	"	0.9819*	1.545	0.0336	-1.561

* Significant at P = 0.001

labradoricus (K = 2.241). Generally, the species with faster relative growth rates had smaller heads than the ones which had slower relative growth rates. Jean (1945) and Martin (1939, 1949) showed the same trend in a number of teleost species. However, some other authors i.e., Tester (1937) and Hile (1937) have respectively shown that the slow growing members of a year class of the Pacific herring, Clupea pallasii, and the cisco, Leucichthys artedi have longer heads and other body parts than the faster growing members of the same year class.

The head grew much faster in labradoricus than in thompsonii and the growth constants of the two subspecies were significantly different. The slope of the two subspecies crossed each other at an approximate length of 15 mm (Fig 16). Before reaching this length the larvae of labradoricus had smaller heads than the larvae of thompsonii.

The head in labradoricus grew faster than in any other species from the Atlantic coast (Fig 16) and within the range of lengths observed had smaller heads than the other species. The larvae of thompsonii also had faster rate of growth for head length than the rest of the species except M. scorpius (Fig. 16).

Among the four species from the Atlantic Coast (M. scorpius, M. octodecemspinosus, M. aeneus, and T. murrayii) the head in M. scorpius grew faster than in M.

Fig. 16. Relative growth of head lengths in cottid larvae. A, Myoxecephalus quadricornis labradoricus; B, M. q. thompsonii; C, M. scorpius; D, M. octodecemspinosus; E, M. aenus; F, Triglops murrayii.

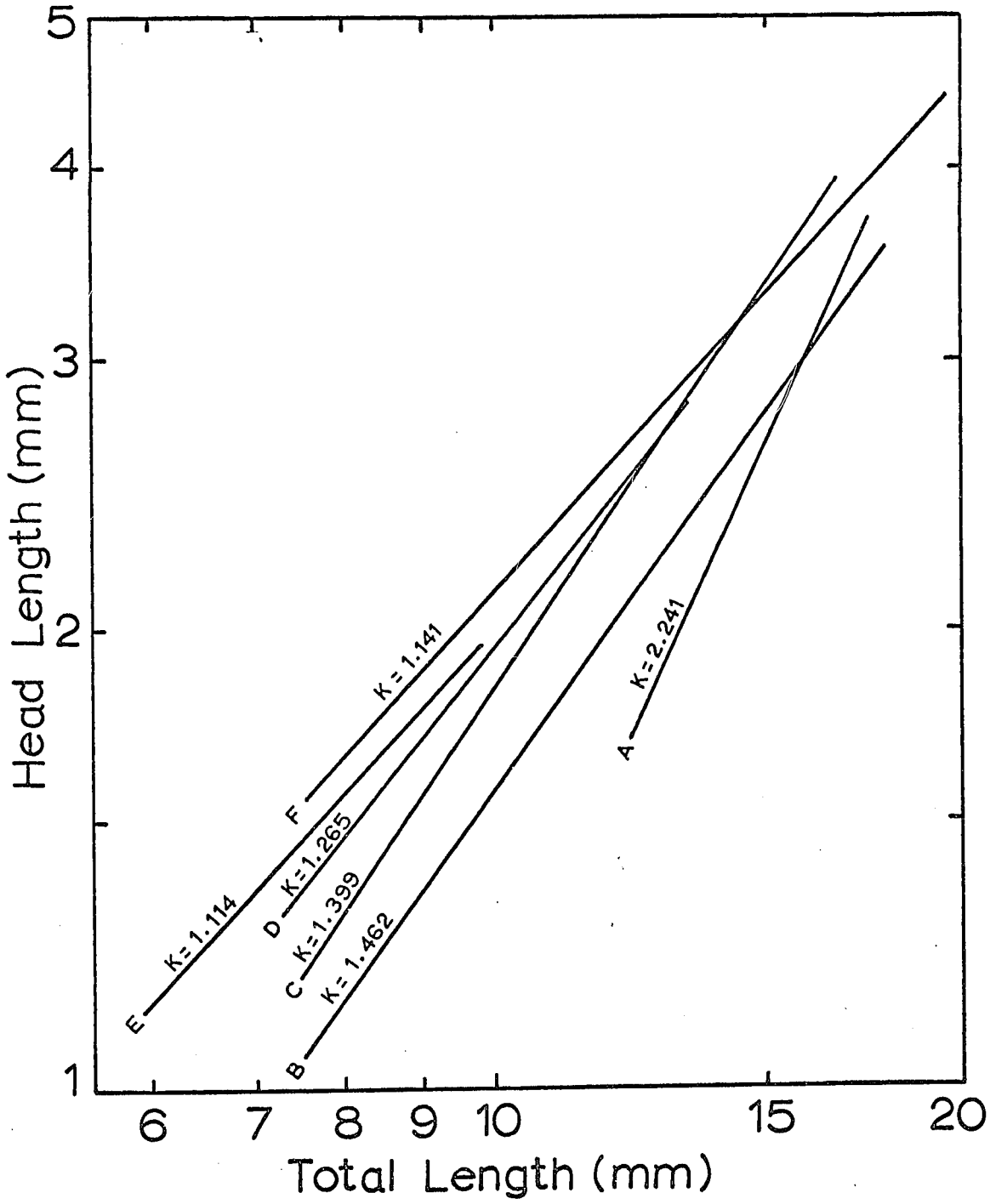

Head Length (mm)
Total Length (mm)
1
2
3
4
5
6
7
8
9
10
15
20
A
K=2.241
B
K=1.462
C
K=1.399
D
K=1.265
E
K=1.114
F
K=1.141

Figure 16

aeneus and T. murrayii. The other comparisons did not show any significant differences.

Diameter of Eye

The correlation coefficients for this character showed a good linear relationship except in labradoricus. In labradoricus it was 0.591 (Table 1). This poor correlation may be due to the fact that the eyes were badly preserved in labradoricus and measurements were often difficult to take. The other correlation coefficients varied from 0.853 to 0.952. The eyes grew differently in different species. In labradoricus and M. octodecemspinosus the growth of eyes showed tachyauxesis (Table 1, Fig. 17). Since the correlation coefficient in labradoricus was poor, the nature of relative growth cannot be interpreted with certainty. In the other species the growth of eyes exhibited bradyauxesis (i.e., grew slower than the whole). The growth constants in M. scorpius and M. octodecemspinosus were 0.992 and 1.094 respectively and almost approached isauxesis (grew at the same rate as the whole). Although generally the eyes grow slower than the body (Shapiro, 1938; Martin, 1949) yet differences in the nature of growth of eyes relative to the length have been noticed. Kyushin (1968, 1970) observed tachyauxesis in Hemitripterus villosus and bradyauxesis in Gymnocanthus herzensteini.

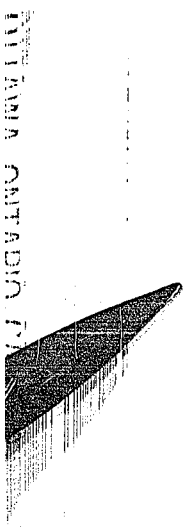


Fig. 17. Relative growth of eyes in cottid larvae. A, Myoxocephalus quadricornis labradoricus; B, M. q. thompsonii; C, M. scorpius; D, M. octodecemspinosus; E, M. aeneus; F, Triglops murrayii.

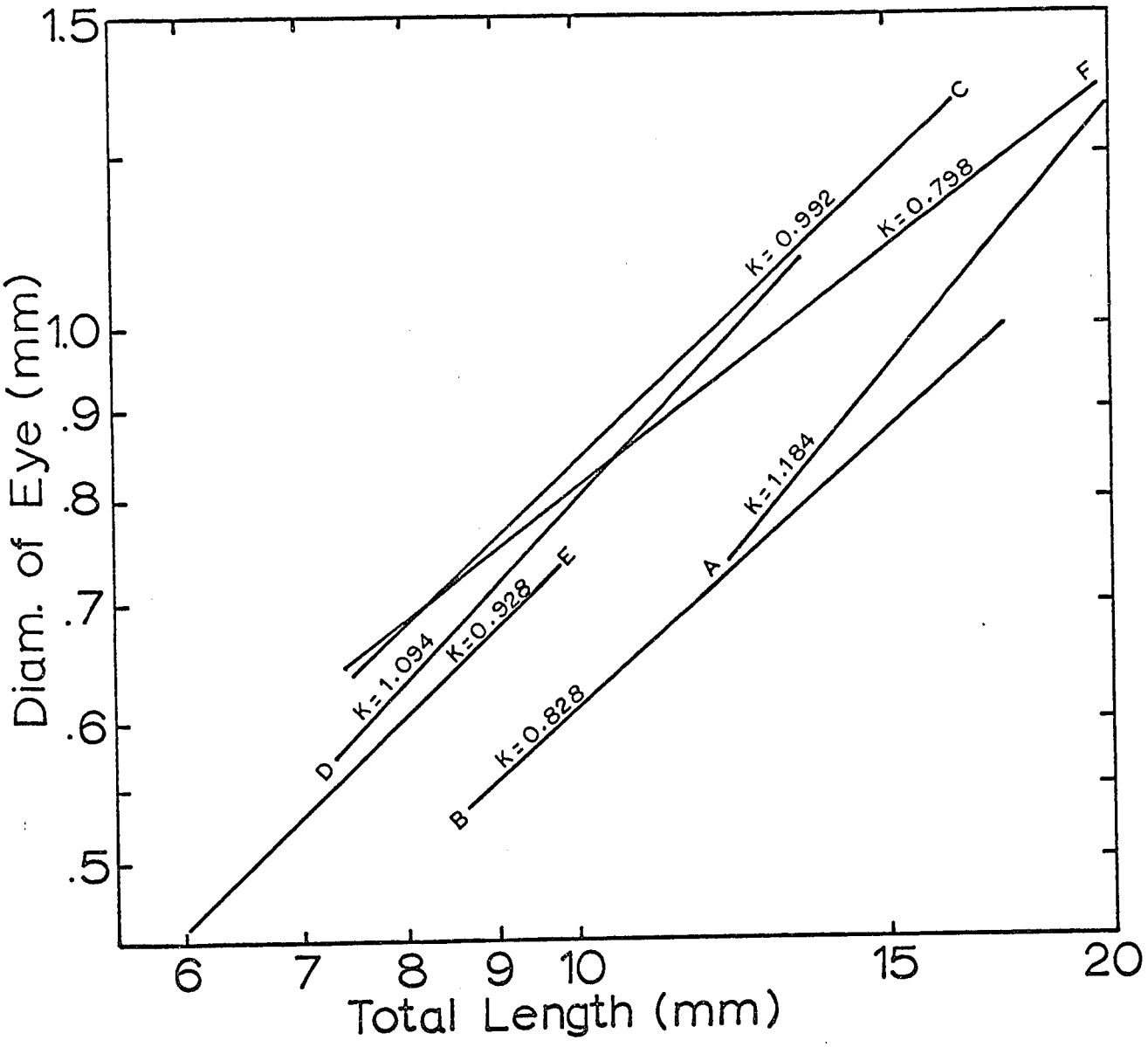

1.5
1.0
.9
.8
.7
.6
.5
Diam. of Eye (mm)
6
7
8
9
10
15
20
Total Length (mm)
A
B
C
D
E
F
K=1.184
K=0.828
K=0.992
K=1.094
K=0.928
K=0.798

Figure 17

The eyes grew fastest in labradoricus and slowest in thompsonii. The correlation coefficient in labradoricus was however poor.

Very few significant differences in relative growth rates of eye were observed among other species. Both M. scorpius and M. octodecemspinosus showed higher regression coefficients (0.992 and 1.094 respectively) than thompsonii and T. murrayii. No other significant differences in relative growth rates were observed. Although the relative growth rate of eye did not differ among some species yet the size of eyes differed. For instance, the growth constants of thompsonii (K = 0.828) and T. murrayii (0.798) did not differ from each other yet the eyes in thompsonii were much smaller than in T. murrayii (Fig 16). Such parallelism in slopes has been shown in a number of teleost species (Martin 1949).

Interorbital Width

As observed in the case of the relative growth of eye, the correlation coefficient of interorbital width in labradoricus was very poor (0.526). The correlation coefficients in other species expressed a good linear relationship and ranged from 0.809 to 0.917 (Table 1). The growth of this part showed bradyauxesis in labradoricus and thompsonii, and tachyauxesis in the other

Fig. 18. Relative growth of interorbital widths in cottid larvae. A, Myoxocephalus quadricornis labradoricus; B, M. q. thompsonii; C, M. scorpius; D, M. octodecemspinosus; E, M. aeneus; F, Triglops murrayii.

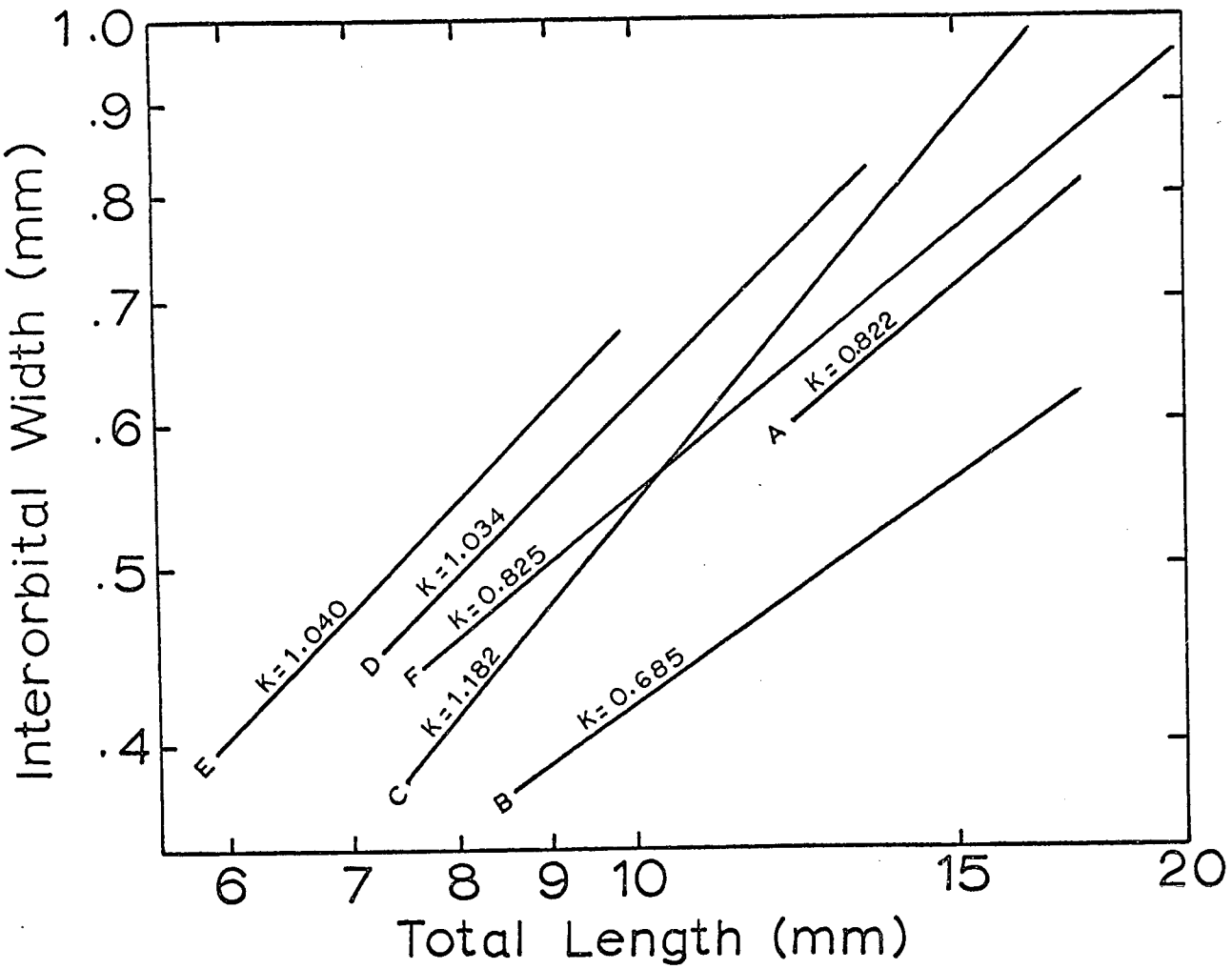

1.0
.9
.8
.7
.6
.5
.4
Interorbital Width (mm)
6
7
8
9
10
15
20
Total Length (mm)
E
K=1.040
D
K=1.034
F
K=0.825
C
K=1.182
A
K=0.822
B
K=0.685

Figure 18

species. The relative growth of interorbital width, in M. aeneus and M. octodecemspinosus approached isauxesis (i.e. K = 1). The regression coefficients in these species were 1.040 and 1.034 res ectively.

The interorbital width grew fastest in M. scorpius and slowest in thompsonii. The relative growth rate in M. scorpius differed from thompsonii and T. murrayii. The slopes of M. scorpius and T. murrayii crossed each other at an approximate length of 10.5 mm (Fig 18). The larvae of M. scorpius, below this point had smaller interorbital widths than T. murrayii, but showed wider interorbital widths after 10.5 mm length. The interorbital widths of thompsonii were much narrower than those of M. scorpius. Both M. octodecemspinosus and M. aeneus had faster relative growth rates for interorbital widths than thompsonii (Fig 18). No other significant differences were observed. Although the relative growth rates of thompsonii and T. murrayii did not differ from each other yet thompsonii showed narrower interorbital widths than T. murrayii. M. aeneus had the widest interorbital widths (Fig 18) which differed from all the other species except M. octodecemspinosus.

Preanal Length

The relative growth of preanal length showed tachyauxesis in all the species. The correlation

Fig. 19. Relative growth of preanal lengths in cottid larvae. A, Myoxocephalus quadricornis labradoricus; B, M. q. thompsonii; C, M. scorpius; D, M. octodecemspinosus; E, M. aeneus; F, Triglops murrayii.

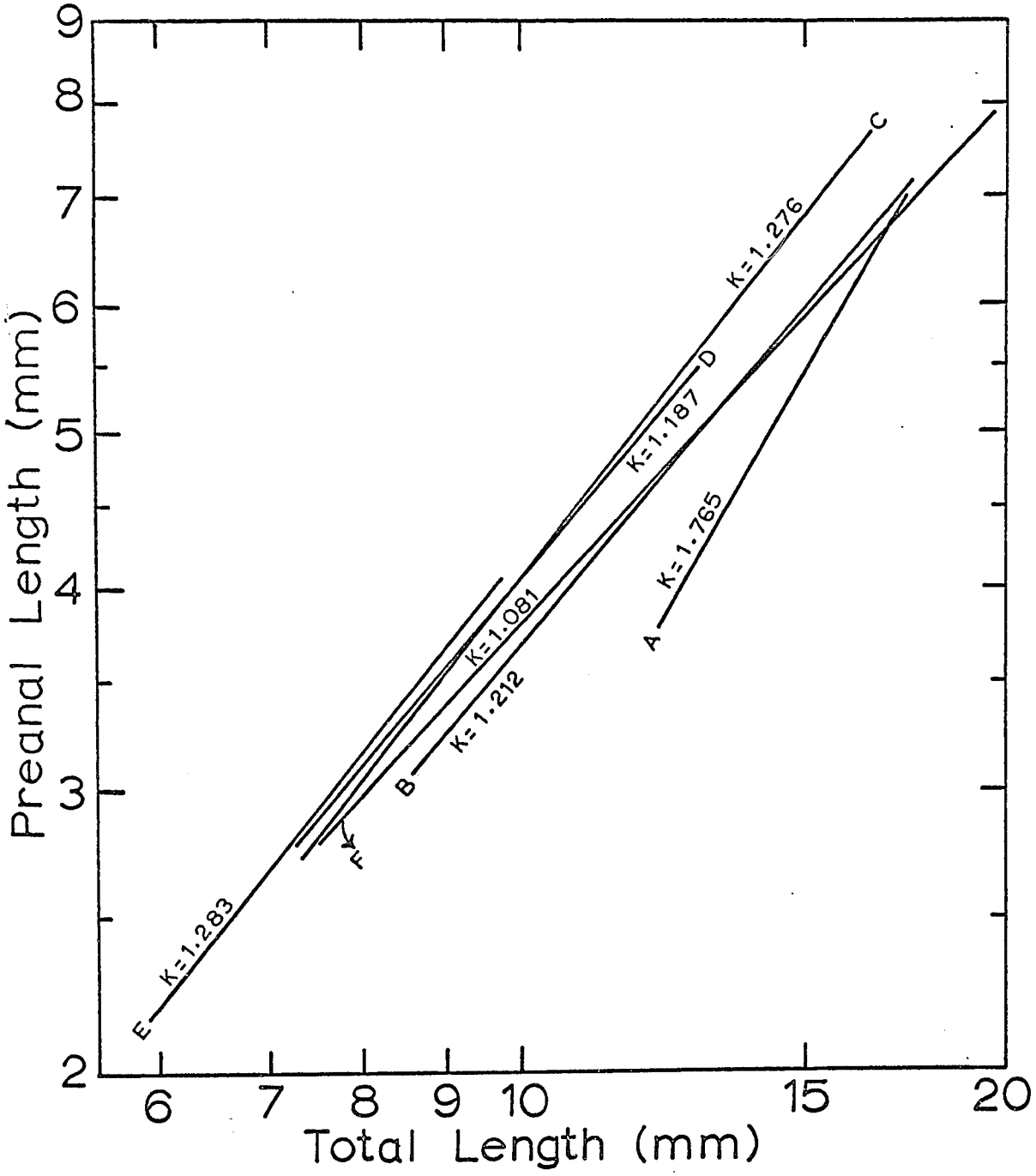

Preanal Length (mm)
Total Length (mm)
2
3
4
5
6
7
8
9
6
7
8
9
10
15
20
K=1.276
K=1.187
K=1.765
K=1.081
K=1.212
K=1.283
A
B
C
D
E
F

Figure 19

coefficients were highly significant and ranged from 0.909 - 0.989 (Table 1). Other authors have also demonstrated tachyauxesis in such lengths as preanal length and the postanal length. Martin (1949) observed tachyauxesis of the postanal length in ribbon fish, Trachypterus rex-salmonarum. Kyushin (1968, 1970) reported tachyauxesis of the preanal length in two cottid species, Hemitripterus villosus and Gymnocanthus herzensteini.

The relative growth rate of the preanal length was the slowest in T. murrayii (K = 1.081) and the highest in labradoricus (K = 1.765).

The preanal length in labradoricus increased significantly faster than in thompsonii or in any other species (Table 1, Fig. 19), and were generally smaller than the rest of the species.

The relative growth constant of T. murrayii differed from M. scorpius, labradoricus and thompsonii but not from M. octodecemspinosus and M. aeneus. However, the preanal lengths of T. murrayii were smaller than M. scorpius, M. octodecemspinosus, and M. aeneus (Fig. 19).

Body Depth

This character showed very good linear relationship with the total length in all the species. The correlation coefficients ranged from 0.943 to 0.981. The relative growth of the body depth showed a pronounced tachyauxesis

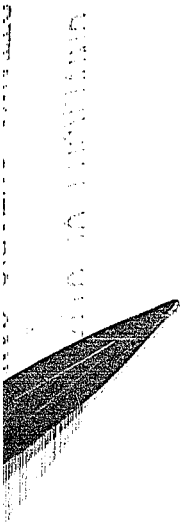


Fig. 20. Relative growth of body depths in cottid larvae. A, Myoxocephalus quadricornis labradoricus; B, M. q. thompsonii; C, M. D, M. octodecemspinosus; E, M. aeneus; F, Triglops murrayii.

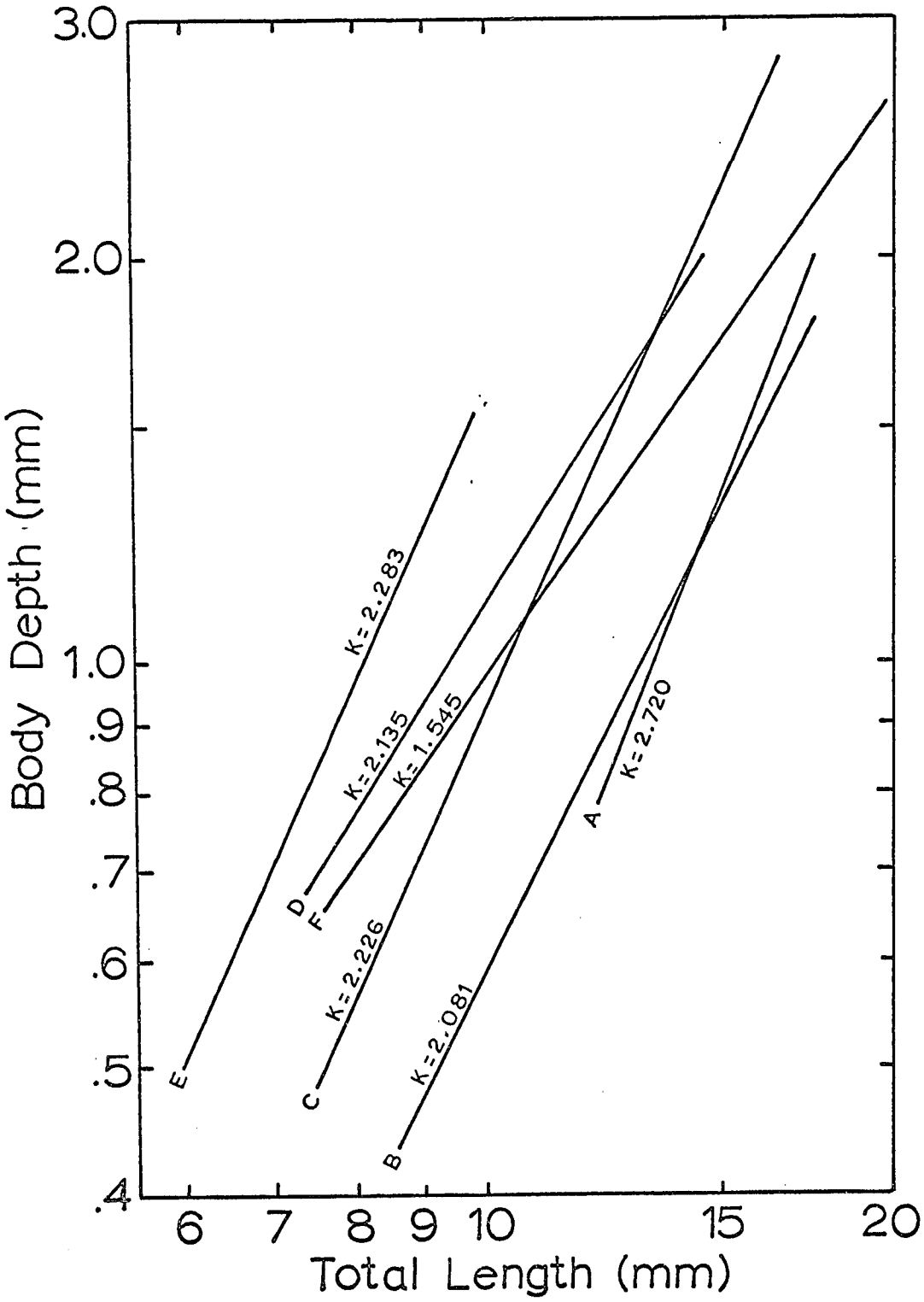

3.0
2.0
1.0
.9
.8
.7
.6
.5
.4
Body Depth (mm)
6
7
8
9
10
15
20
Total Length (mm)
E
K=2.283
D
K=2.135
F
K=1.545
C
K=2.226
B
K=2.081
A
K=2.720

Figure 20

in all the species. The body depth increased most rapidly in labradoricus and at slowest rate in T. murrayii.

The relative growth constant in labradoricus (K = 2.72) differed from the relative growth constant in thompsonii (K = 2.081) as well as all the other species (Table 1, Fig. 20). The body depths were smaller in labradoricus and thompsonii than in any other species. There was a great deal of overlap in body depths between labradoricus and thompsonii. The relative growth rate in thompsonii was significantly higher from T. murrayii (K = 1.545) only.

The relative growth rate in T. murrayii was slower than that of any other species (Table 1). M. aeneus had the greatest body depths than either M. scorpius, M. octodecemspinosus and T. murrayii. The slope of M. scorpius crossed the slopes of M. octodecemspinosus and T. murrayii at approximately 13 mm and 11 mm lengths respectively. The larvae of M. scorpius smaller than these respective lengths had relatively smaller body depths than M. octodecemspinosus and T. murrayii.

In an examination of the deviations from isauxesis in the relative growth of different body parts, Martin (1949) observed a gradient of relative growth along the body axis of the fish. He noted that the anterior parts generally grow more slowly longitudinally and posterior parts faster than the body as a whole. This generaliza-

tion was found to be true in this study only in the head region. The horizontal diameter of eye, in all the cottid species, grew slower than the head (Table 1). The preanal length, on the other hand, in general grew more slowly than the head.

2. Meristic Characters

Five meristic characters (i.e., total number of myomeres and the number of fin rays in the second dorsal, anal, pectoral and caudal fins were studied for two subspecies (Myoxocephalus quadricornis labradoricus and M. q. thompsonii) and four species (M. scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii). The meristic counts of the larvae of thompsonii from Lake Michigan were also compared with the meristic counts in the larvae of thompsonii from Lake Huron. The number of specimens for the other species was not sufficient for a thorough statistical analysis of the meristic characters.

The meristic characters were compared to observe the progress of development of these characters in various species and at various stages of larval development. The results of t - tests for the significance of differences between means are given in Appendix Table 6.

Myomeres

The number of myomeres generally corresponds very closely with the number of vertebrae (Galkina, 1969). The values of myomere counts observed in this study for various species were comparable to the values of vertebral counts in the adults of the same species (See Cowan, 1968 for vertebral counts in the species of Myoxocephalus and Jensen, 1944 for Triglops murrayii).

The mean values of myomeres in labradoricus larvae was higher than in thompsonii larvae at all the stages of development (Fig 21). The range of myomere counts, however, slightly overlaped between the two subspecies (in labradoricus the number was 41-46 as opposed to 37-42 in thompsonii). Cowan (1968) mentioned a range of 40-42 vertebrae for adult labradoricus from MacKenzie River Mouth which corresponds with the values of myomere counts in the larvae from the same area. There is no information regarding the vertebral counts of thompsonii in the literature. In order to check the correlation of myomere counts and the vertebral counts in thompsonii 24 adult specimens from Lake Michigan, 16 miles south of Manistique were radiographed and the vertebrae counted. The number varied between 35 and 40 with a mean value of 37.4. This mean was compared with the mean value of 40.9 vertebrae for labradoricus reported by Cowan. The two mean values were significantly different by the Student's t - test at P = 0.01. Fish (1932) reported a total of 33 myomeres in the larvae of thompsonii from Lake Erie which is considerably lower than the range observed in labradoricus. This value is also lower than the lowest value for the number of myomeres observed in thompsonii from Lake Michigan. However, counts of two specimens given by Fish is probably not representative of the larval population.

The results of the myomere counts in the larvae of

Fig. 21. Variation in myomere counts in the larvae of cottid species of various length groups. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means. N1, number of larvae examined; N2, number of larvae in which the myomeres were countable.

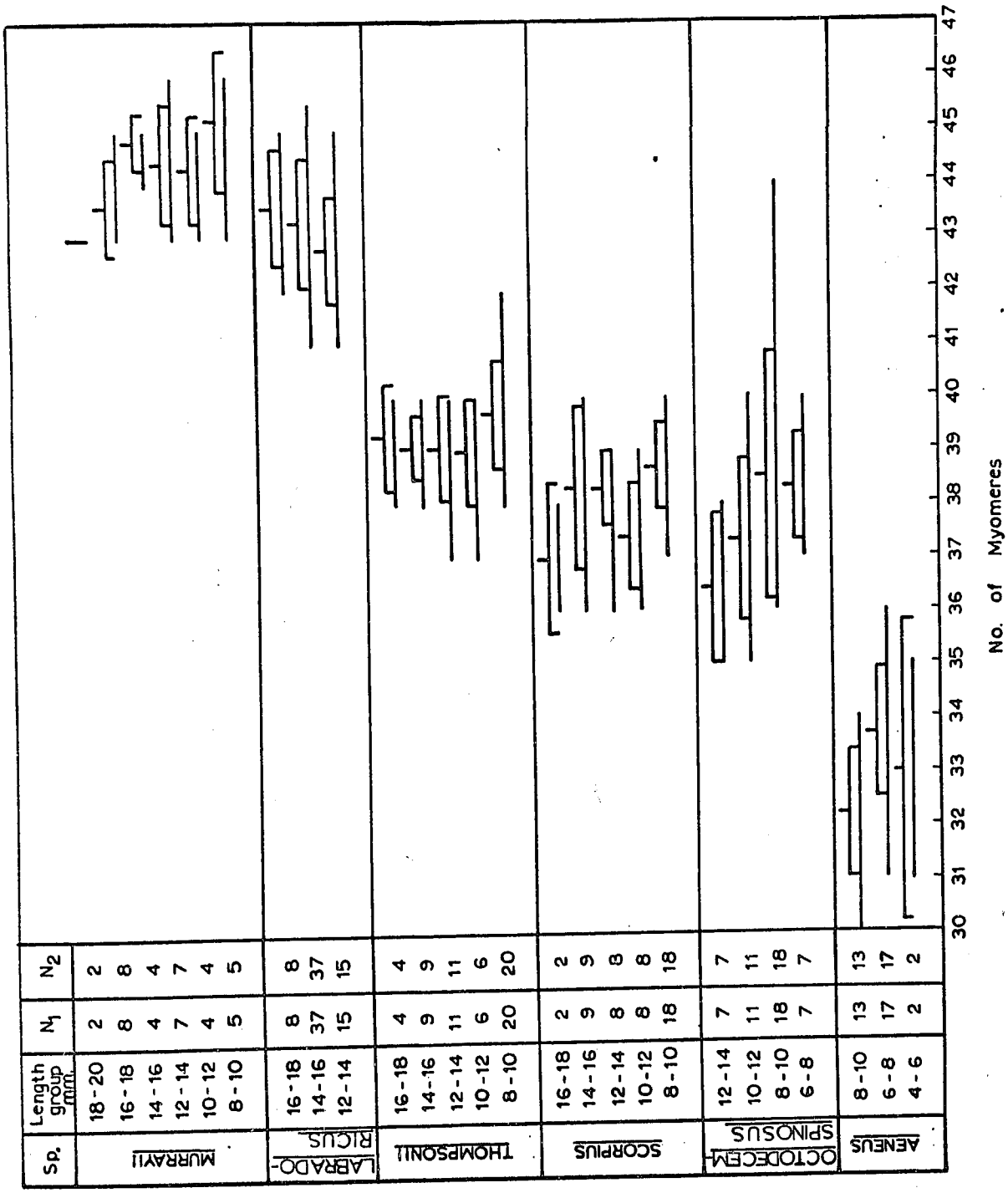

Sp.
Length group mm.
N1
N2
MURRAYII
18-20 2 2
16-18 8 8
14-16 4 4
12-14 7 7
10-12 4 4
8-10 5 5
LABRADORICUS
16-18 8 8
14-16 37 37
12-14 15 15
THOMPSONII
16-18 4 4
14-16 9 9
12-14 11 11
10-12 6 6
8-10 20 20
SCORPIUS
16-18 2 2
14-16 9 9
12-14 8 8
10-12 8 8
8-10 18 18
OCTODECEMSPINOSUS
12-14 7 7
10-12 11 11
8-10 18 18
6-8 7 7
AENEUS
8-10 13 13
6-8 17 17
4-6 2 2
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47
No. of Myomeres

Figure 21

thompsonii from Lake Huron are given in Fig. 26. The range of myomere counts in Lake Huron larvae was similar to the one observed in the larvae of thompsonii from Lake Michigan. The average number of myomeres increased with the length of the larvae in the Lake Huron population but not in the Lake Michigan population.

The lowest myomere count was observed in aeneus. The number of myomeres ranged from 30-36. The range overlapped slightly with the range of myomeres in octodecemspinosus (35-44) and scorpius (36-40). The mean values of myomeres in aeneus, at various length groups (32.2 - 33.7), were significantly lower than the mean values observed in octodecemspinosus (36.4 - 38.5), scorpius (37.0 - 38.7), and murrayii (43.0 - 45.2). The range of myomere counts in octodecemspinosus and scorpius overlapped a great deal and no significant difference was observed between the means (Fig 21). T. murayii had the highest vertebral counts (43-46) of all species and the mean values differed significantly from the mean values in all the other species.

The mean values of myomere counts in labradoricus were relatively lower than in murrayii but higher than the rest of the species. In thompsonii, however, the number of myomeres overlapped considerably with the number of myomeres in either scorpius or octodecemspinosus. However, the mean values in thompsonii were higher than the mean values in octodecemspinosus and scorpius (only

at 8-10 and 10-12 mm length groups). No overlap was observed between thompsonii and aeneus.

Second Dorsal Fin Rays

The second dorsal fin rays, like all the other fin rays, increased in number with the length of the larvae (Fig 22) but appeared at different lengths in various species.

In both labradoricus and thompsonii the second dorsal fin rays appeared in 12-14 mm length group. These fin rays developed relatively faster in labradoricus than in thompsonii. Consequently at 14-16 mm stage the mean value in labradoricus (14.3) was significantly higher than the mean value in thompsonii (13.3). In 16-18 mm larvae the number of second dorsal fin rays was fully established and similar to the numbers observed in the adults. The mean value observed in labradoricus was 14.4 while in thompsonii it was 15.0. The two values were not significant from each other. Cowan (1968) reported a mean of 14.3 second dorsal fin rays for adult labradoricus from Mackenzie River Mouth, which was similar to the mean observed in this study. McAllister (1959) observed 10-15 second dorsal fin rays in adult labradoricus and 11-16 in thompsonii. These values were similar to the ones observed in this study (Fig 22).

The development of second dorsal fin rays in the

Fig. 22. Variation in second dorsal fin ray counts in the larvae of cottid species of various length groups. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means. N1, number of larvae examined; N2, number of larvae in which the second dorsal fin rays were countable.

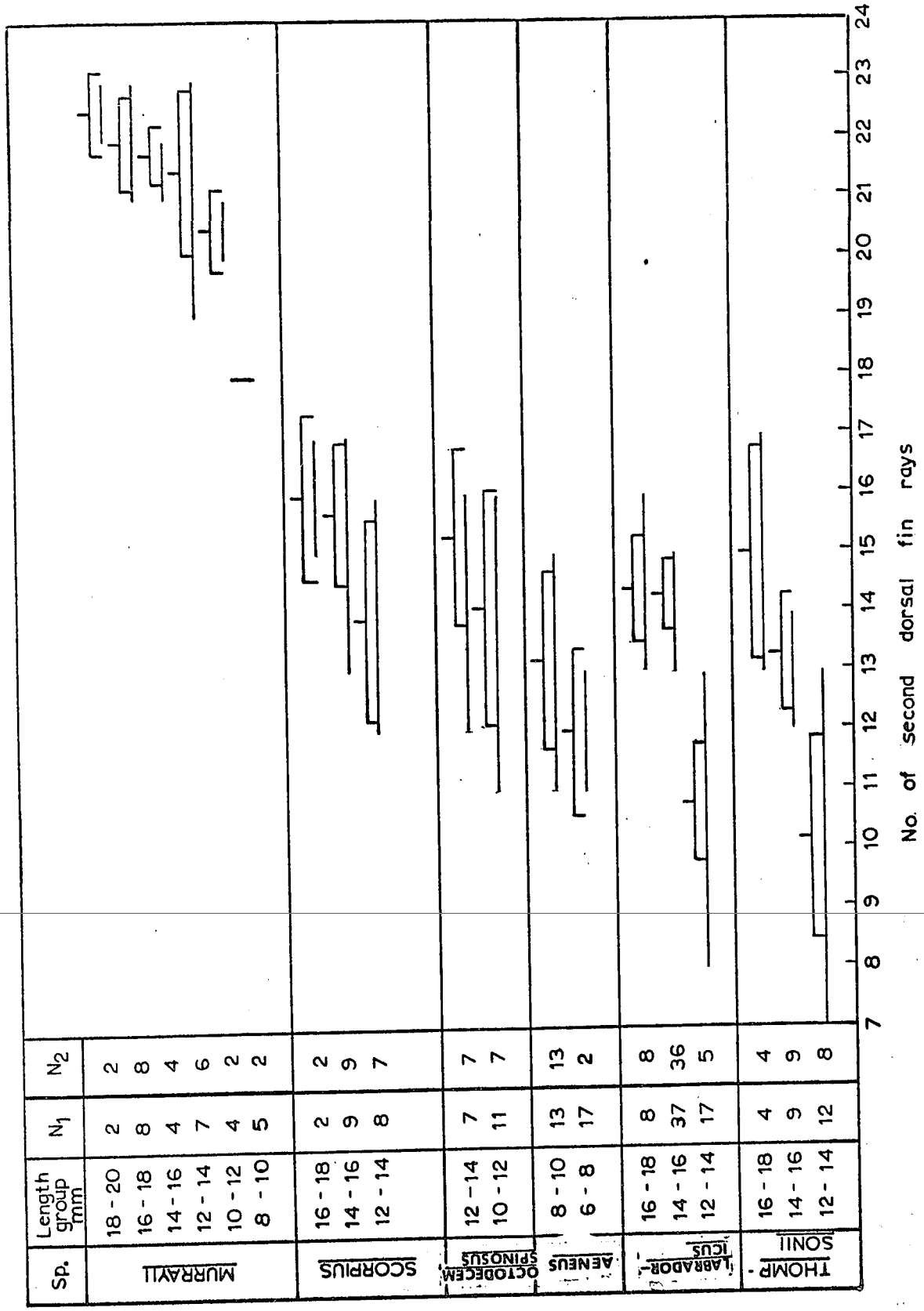

Sp.
Length group mm
N1
N2
MURRAYII
18 - 20
16 - 18
14 - 16
12 - 14
10 - 12
8 - 10
2 8 4 7 4 5
2 8 4 6 2 2
SCORPIUS
16 - 18
14 - 16
12 - 14
2 9 8
2 9 7
OCTODECEM SPINOSUS
12 - 14
10 - 12
7 11
7 7
AENEUS
8 - 10
6 - 8
13 17
13 2
LABRADOR- ICUS
16 - 18
14 - 16
12 - 14
8 37 17
8 36 5
THOMP- SONII
16 - 18
14 - 16
12 - 14
4 9 12
4 9 8
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
No. of second dorsal fin rays

Figure 22

larvae of thompsonii from Lake Huron (Fig 26) was slower than in the larvae from Lake Michigan. Despite the small sample size the larvae from Lake Huron at 14-16 mm stage had a significantly lower mean value (9.6) than in the larvae from Lake Michigan (13.3).

The second dorsal fin rays started to appear at the 6-8 mm stage in aeneus. In no other species did the second dorsal fin rays start to appear at such a short length. At 8-10 mm stage the number of second dorsal fin rays was established in aeneus. The range was from 11-15 with a mean value of 13.2. Cowan (1968) reported a range of 13-15 for specimens from Cape Cod with a mean of 13.8. The only other species in which the second dorsal fin rays had appeared at 8-10 mm stage was murrayii. Although the number of second dorsal fin rays at this stage was not established yet the mean value (18.0) was significantly higher than in aeneus.

In octodecemspinosus the second dorsal fin rays appeared at an earlier stage than in scorpius. The rays started to appear at 10-12 mm stage in octodecemspinosus while in scorpius they did not appear before 12-14 mm stage. At 10-12 mm stage octodecemspinosus had 11-16 second dorsal fin rays with a mean value of 14.1. The only other species which could be compared with octodecemspinosus at this stage was murrayii in which the range (20-21) did not overlap with the range in

octodecemspinosus and the mean value was significantly higher. At the 12-14 mm stage the number of second dorsal fin rays in octodecemspinosus was established and the range (12-16) and the mean (15.3) correspond with the range (15-17) and mean (15.4) reported by Cowan for the adult octodecemspinosus from the Southern Gulf of Maine. In scorpius, however, the second dorsal fin rays were in a relatively earlier stage of development. The range (12-16) was the same as in octodecemspinosus but the mean (13.9) was significantly lower than in octodecemspinosus.

In scorpius the number of second dorsal fin rays increased up to the 16-18 mm stage and at this stage the range (15-17) and the mean (16.0) were similar to the range (14-18) and mean (16.2) reported by Cowan for adult scorpius from the southern Gulf of Maine.

T. murrayii had the highest number of second dorsal fin rays than any other species and its range did not overlap with that of any other species. At about the 14-16 mm stage the number of second dorsal fin rays was fully established in murrayii and they ranged from 21-23 with a mean value of 22.0. McAllister (1963) reported a range of 22-25 second dorsal fin rays for murrayii. The values observed in this study fell within this range. However, when the mean was calculated from McAllister's data it was 23.1 which was higher than the mean value (22.3) observed in this study.

The second dorsal fin rays in both labradoricus and thompsonii developed more slowly than in aeneus, octodecemspinosus, scorpius, and murrayii (Fig 22). At the 12-14 mm stage when the second dorsal fin rays began to appear in labradoricus and thompsonii, the mean values of 10.8 and 10.2 respectively were significantly lower than the mean values in octodecemspinosus (14.1) scorpius (13.9) and murrayii (21.5).

Anal Fin Rays

The number of anal fin rays increased with the increase in the length of the larvae in all the species (Fig 23), and the time of appearance was also different.

In both labradoricus and thompsonii the anal fin rays appeared at the 12-14 mm stage. The mean numbers of anal fin rays in labradoricus at various stages were higher than the mean numbers in thompsonii. At the 14-16 mm stage, despite the overlap in ranges, the mean value of 13.6 anal fin rays in thompsonii was significantly lower than a mean of 15.4 anal fin rays in labradoricus. At this stage the number of anal fin rays was fixed and did not differ from the values of anal fin ray counts in 16-18 mm stage larvae. In labradoricus the range was 14-17 with a mean value of 15.4 anal fin rays. These values conformed with the range (14-16) and mean (15.4)

Fig. 23. Variation in anal fin ray counts in the larvae of cottid species of various length groups. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means. N1, number of larvae examined; N2, number of larvae in which the anal fin rays were countable.

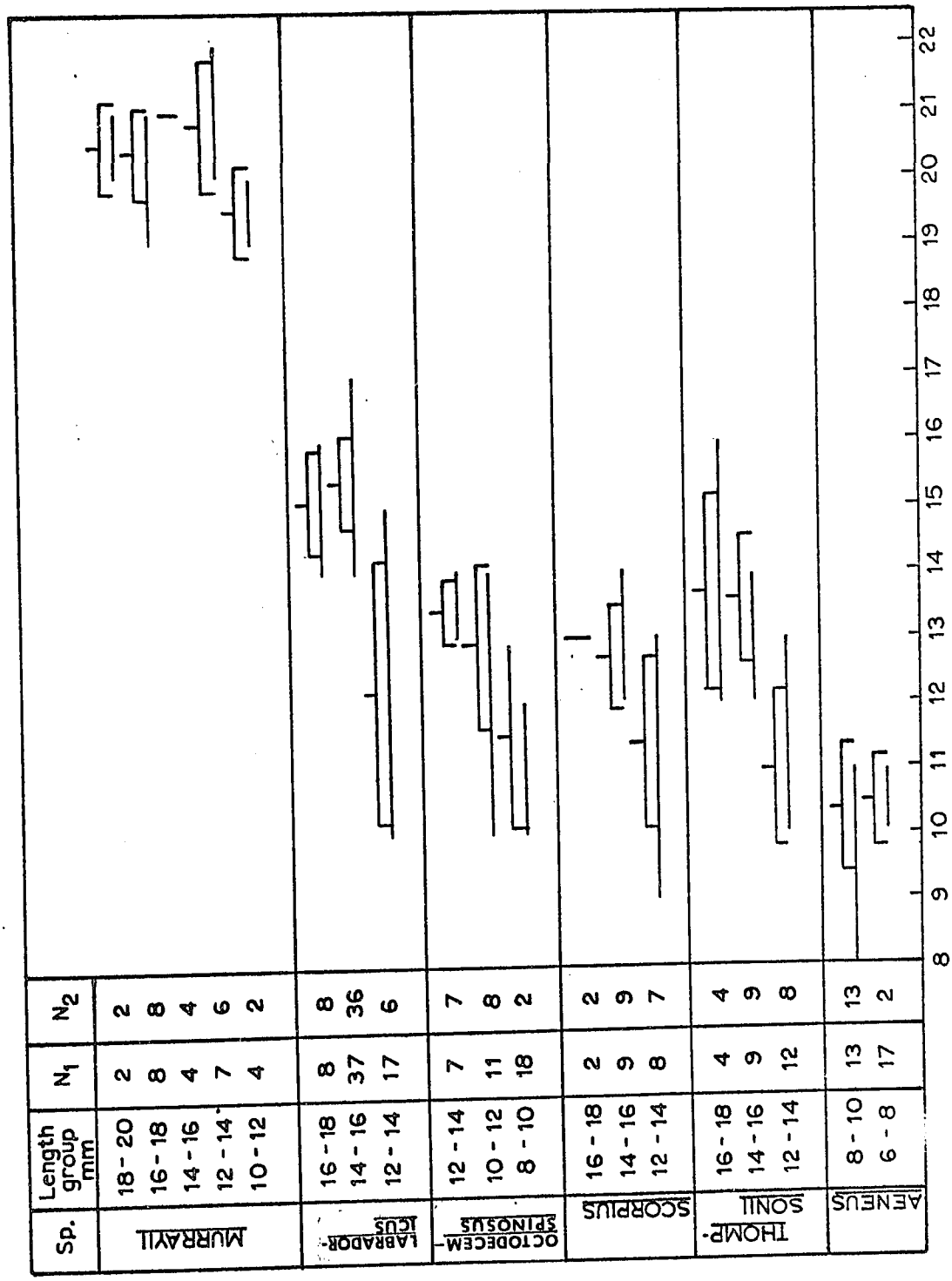


Figure 23

of anal fin rays in the adult labradoricus reported by Cowan (1968). McAllister (1959) reported a range of 12-16 anal fin rays for the adult labradoricus. This range agreed quite closely with my values, but the mean (13.69) calculated from McAllister's data was significantly lower than the mean observed in this study (15.4) or by Cowan (15.1). In thompsonii the anal fin rays ranged from 12-16 and the mean value was 13.6. McAllister (1959) observed a range of 11-16 anal fin rays and the mean calculated from his data was 13.26. My values were similar to McAllister's values and confirm that the number of anal fin rays is lower in thompsonii than in labradoricus.

The development of anal fin rays in the larvae of thompsonii from Lake Huron was slower than in the larvae from Lake Michigan. The values of anal fin rays in Lake Huron larvae are given in Fig 26. At the 14-16 mm stage the mean value (10.6) of anal fin rays in Lake Huron larvae was significantly lower than the mean value in Lake Michigan larvae (13.6). The range, however, overlapped slightly i.e., 9-12 in Lake Huron and 12-14 in Lake Michigan.

In aeneus the anal fin rays started to appear at 6-8 mm stage, although they were present only in a few specimens i.e., 2 out of 17 (Fig 23). The values ranged from 10-11. The anal fin rays in aeneus seem to appear all at the same time. At 8-10 mm stage the anal fin rays

were well developed and their number was fixed. They ranged from 8-11 with a mean of 10.4 anal fin rays. Cowan (1968) reported 8-14 in the adult aeneus from the same latitudes. Although the range mentioned by Cowan exceeded the one observed in this study, the mean value (10.8) observed by him was similar to the one observed in this study (10.4).

In murrayii, the anal fin rays appeared at 10-12 mm stage and ranged from 19-20. In this species the anal fin rays seem to appear all at the same time. Very few anal fin rays were added in the latter larvae, and they ranged from 19-22 with the mean values varying between 19.5 to 21.0. At no stage in the larval development of murrayii did the range in number of anal fin rays overlap with that of the other species (Fig 23). McAllister (1963) reported 21-24 anal fin rays in the adults of murrayii. The range was slightly greater than mine. The mean calculated from McAllister's data was 22.5.

At the 8-10 mm stage some larvae of octodecemspinosus started developing about 10-13 anal fin rays. In M. scorpius, however, the anal fin rays did not appear before 12-14 mm stage. At 12-14 mm stage the anal fin rays were well developed in octodecemspinosus; and their range (13-14) and mean (13.5) were the same as reported by Cowan (1968) for the adult octodecemspinosus from southern Gulf of Maine. At this stage (i.e. 12-14 mm

stage) the anal fin rays in scorpius ranged from 9-13, and the mean (11.4) was significantly lower than the mean (13.5) observed in octodecemspinosus. The anal fin rays in scorpius were well developed at 14-16 mm stage and their range 12-14 and mean 12.7 were in agreement with the range (12-14) and mean (13.0) reported by Cowan for the adult scorpius from southern Gulf of Maine.

The anal fin rays in thompsonii developed a little faster than in octodecemspinosus, and at 12-14 mm stage the mean values of anal fin rays differed significantly (Fig 23).

Pectoral Fin Rays

Pectoral fin rays in some species, increased slightly in number as the larvae grew in size, but in others they appeared all at one time and no significant increase in number was evident through the larval development. In some species the pectoral fin rays appeared earlier than the others.

The number of pectoral fin rays in labradoricus was consistent at all stages of development (Fig 24). They ranged from 15-17 with a mean of 16.0. These values were similar to the range (15-17) and mean (16.4) reported by Cowan (1968). McAllister (1959) also observed similar range (14-17) and mean 15.73) for adult labradoricus. In thompsonii the number of pectoral fin rays gradually increased with the increasing length of

Fig. 24. Variation in pectoral fin ray counts in the larvae of cottid species of various length groups. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means. N1, number of larvae examined; N2, number of larvae in which the pectoral fin rays were countable.

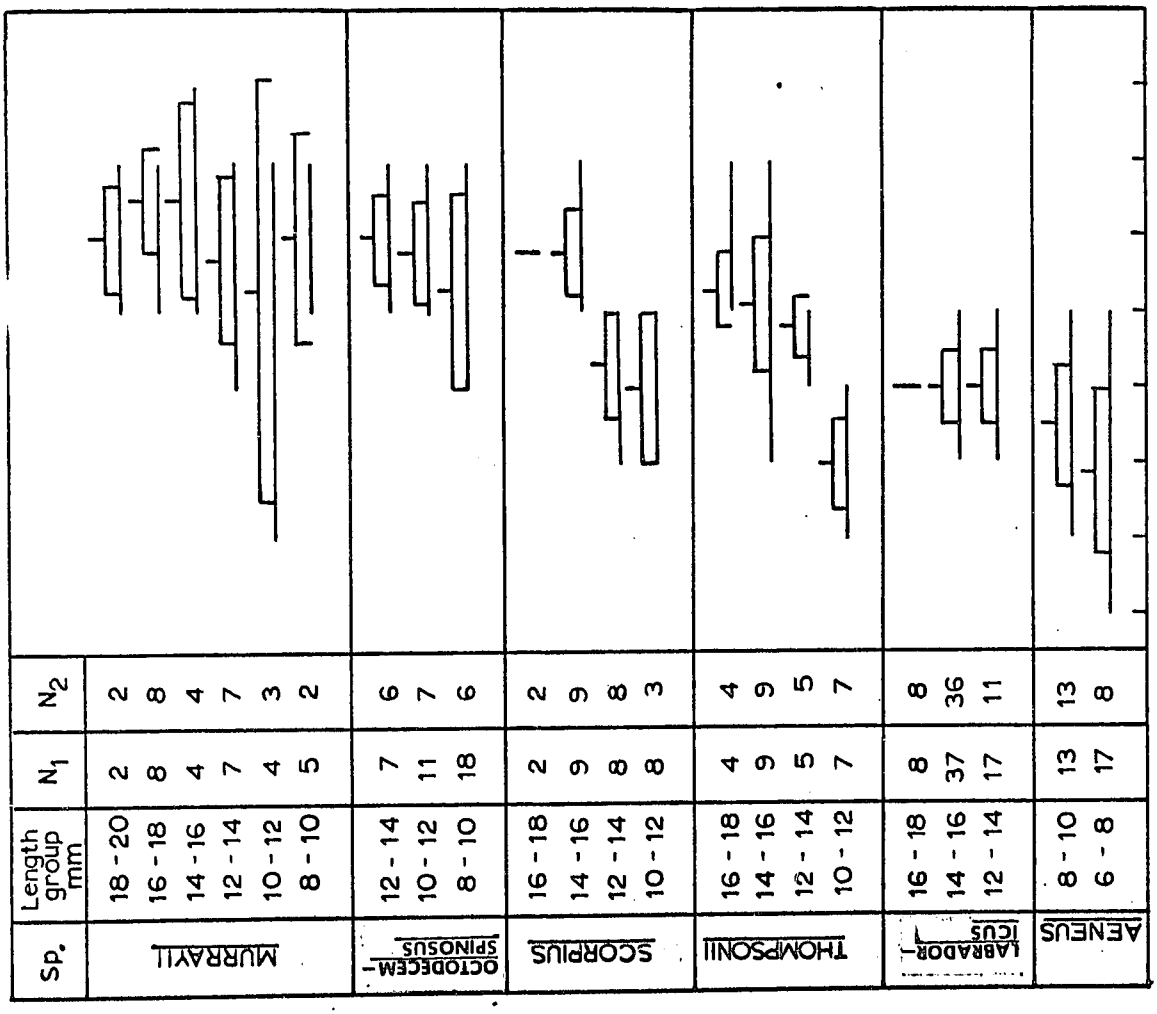


Figure 24

the larvae. At 14-16 mm stage the pectoral fin rays did not increase significantly and the range (15-19) and mean (17.1) were similar to the range (14-18) and mean (16.6) reported by McAllister (1959) for adult thompsonii. In the larvae examined in this study the number of pectoral fin rays gradually increased along with the total length of the larvae. At the 14-16 mm stage the pectoral fin rays did not increase significantly, and the range (15-19) and mean (17.1) were similar to the range (14-18) and mean (16.6) reported by McAllister for adult thompsonii. In the larvae examined in this study the number of pectoral fin rays was higher in thompsonii than in labradoricus McAllister had similar results for the adults.

The data on pectoral fin ray counts in the larvae of thompsonii from Lake Huron is given in Fig 26. No significant differences were observed in mean values between Lake Huron and Lake Michigan larvae, nevertheless, the development of pectoral fin rays in Lake Huron larvae was slower than in the larvae from Lake Michigan.

In aeneus, (13-17) pectoral fin rays started to appear at 6-8 mm stage (Fig 24) and the mean value did not change significantly at 8-10 mm stage. At 8-10 mm stage the pectoral fin rays were well developed, and ranged from 14-17 with a mean value of 15.5. These values correspond with the range (15-16) and mean (15.8) reported by Cowan (1968) for adult aeneus. In octodecemspinosus

and murrayii the pectoral fin rays started developing at 8-10 mm stage; and although their ranges (16-19 and 17-19 respectively) overlapped with the range (14-17) observed in aeneus, their mean values (17.3 and 18.0 respectively) were significantly higher than the mean (15.5) in aeneus (Fig 24).

In octodecemspinosus the number of pectoral fin rays was well developed and established at 10-12 mm stage, and the range (17-19) and mean (17.8) did not differ from the values in latter length groups (Fig 24). These values correspond closely with the range (16-18) and mean (17.5) reported by Cowan (1968) for adult specimens from the same latitudes.

In scorpius the pectoral fin rays developed more slowly than in octodecemspinosus (Fig 24). At 14-16 mm the number of pectoral fin rays was well established and ranged from 17-19 with a mean value of 17.8. These values conformed with the range (17-18) and mean (17.7) reported by Cowan (1968).

In murrayii, the number of pectoral fin rays increased slightly from small length groups to long length groups. The number is definitely established at the 14-16 mm stage and it ranged from 17-20 with a mean of 18.5. These values were in accord with the range (18-19) and mean (18.2) reported by McAllister (1963).

M. q. labradoricus differed, in particular from octodecemspinosus and murrayii in having smaller numbers of pectoral fin rays (Fig 24) at all comparable length groups, while thompsonii showed significantly smaller mean values than octodecemspinosus at comparable length groups. The ranges in all comparisons overlapped considerably.

Caudal Fin Rays

The number of caudal fin rays increased with the increasing length of the larvae, and appeared quite early during the larval development of all the species.

The development of caudal fin rays in labradoricus was slower than in thompsonii (Fig 25). Although the ranges at various stages overlapped, the mean value (7.1) of caudal fin rays in labradoricus at 12-14 mm stage differed significantly from the mean value (10.6) in thompsonii at the same stage.

The data on the caudal fin ray counts of thompsonii larvae from Lake Huron (Fig 26) showed that the development of caudal fin rays in the larvae from Lake Huron was slower than in the larvae from Lake Michigan. Despite the overlap in ranges of caudal fin rays at various length groups the mean value (7.8) in Lake Huron larvae at 12-14 mm stage differed significantly from the mean value (10.6) in Lake Michigan larvae.

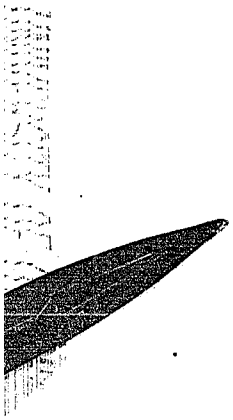


Fig. 25. Variation in caudal fin ray counts in the larvae of cottid species of various length groups. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means. N1, number of larvae examined; N2, number of larvae in which the caudal fin rays were countable.

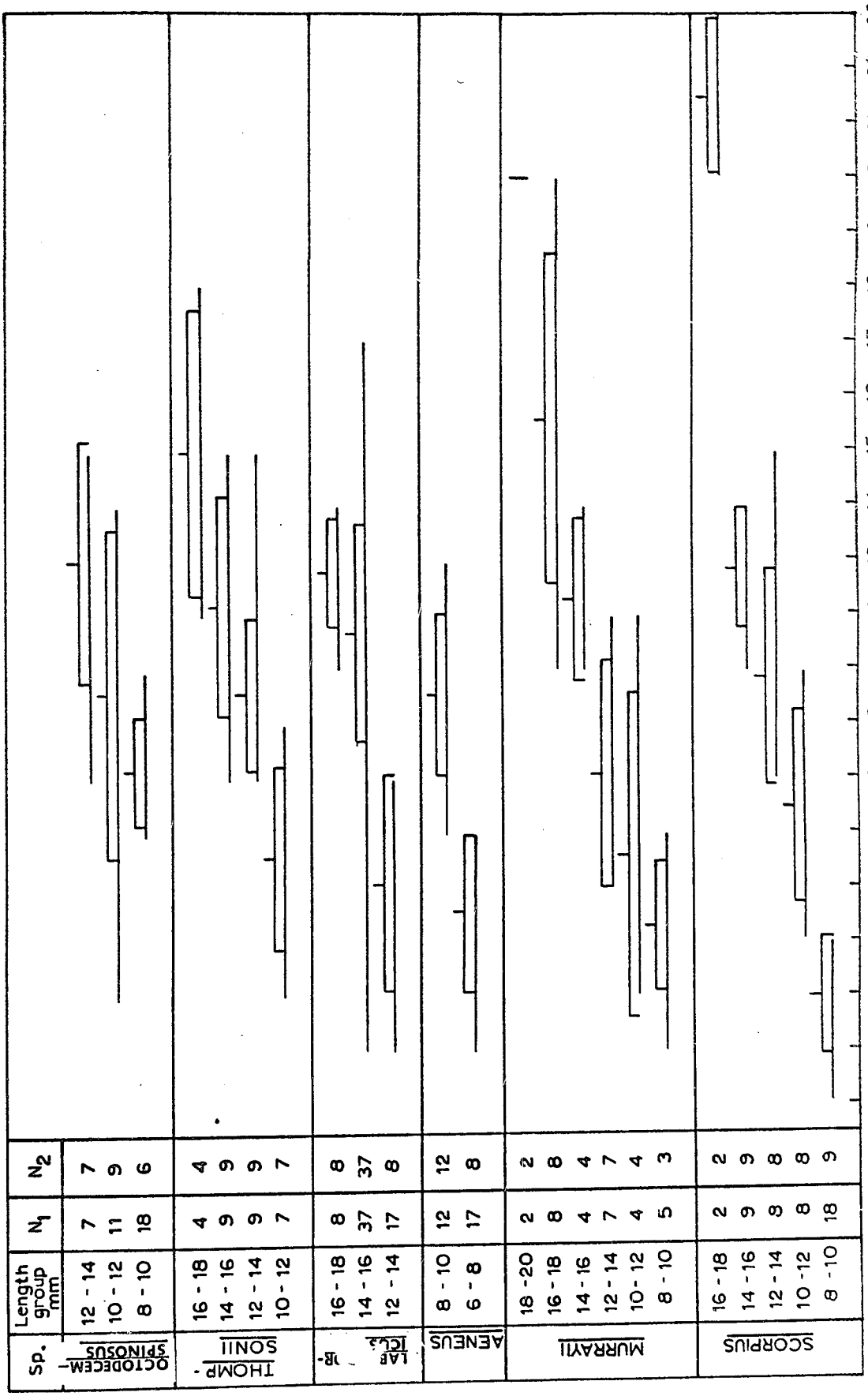


Figure 25

In aeneus the caudal fin rays started to appear at 6-8 mm stage (Fig. 25). At 8-10 mm stage caudal fin rays had appeared in scorpius, octodecemspinosus and murrayii. While the mean value (10.5) of caudal fin rays at 8-10 mm stage in aeneus differed significantly from the mean values in scorpius (8.5) and murrayii (6.3) it did not differ from the mean value (9.2) in octodecemspinosus.

As observed in other fin ray counts, the development of caudal fin rays in octodecemspinosus was relatively faster than in scorpius in earlier stages. At 8-10 mm stage the mean values (9.2 and 5.0 respectively) were significantly different. Some other significant differences were also observed but a great deal of overlap was evident.

Fig. 26. Variation in the counts of meristic characters in the larvae of various length groups of Myoxocephalus quadricornis thompsonii from Lake Huron. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means. N1, number of larvae examined; N2, number of larvae in which the meristic characters were countable.

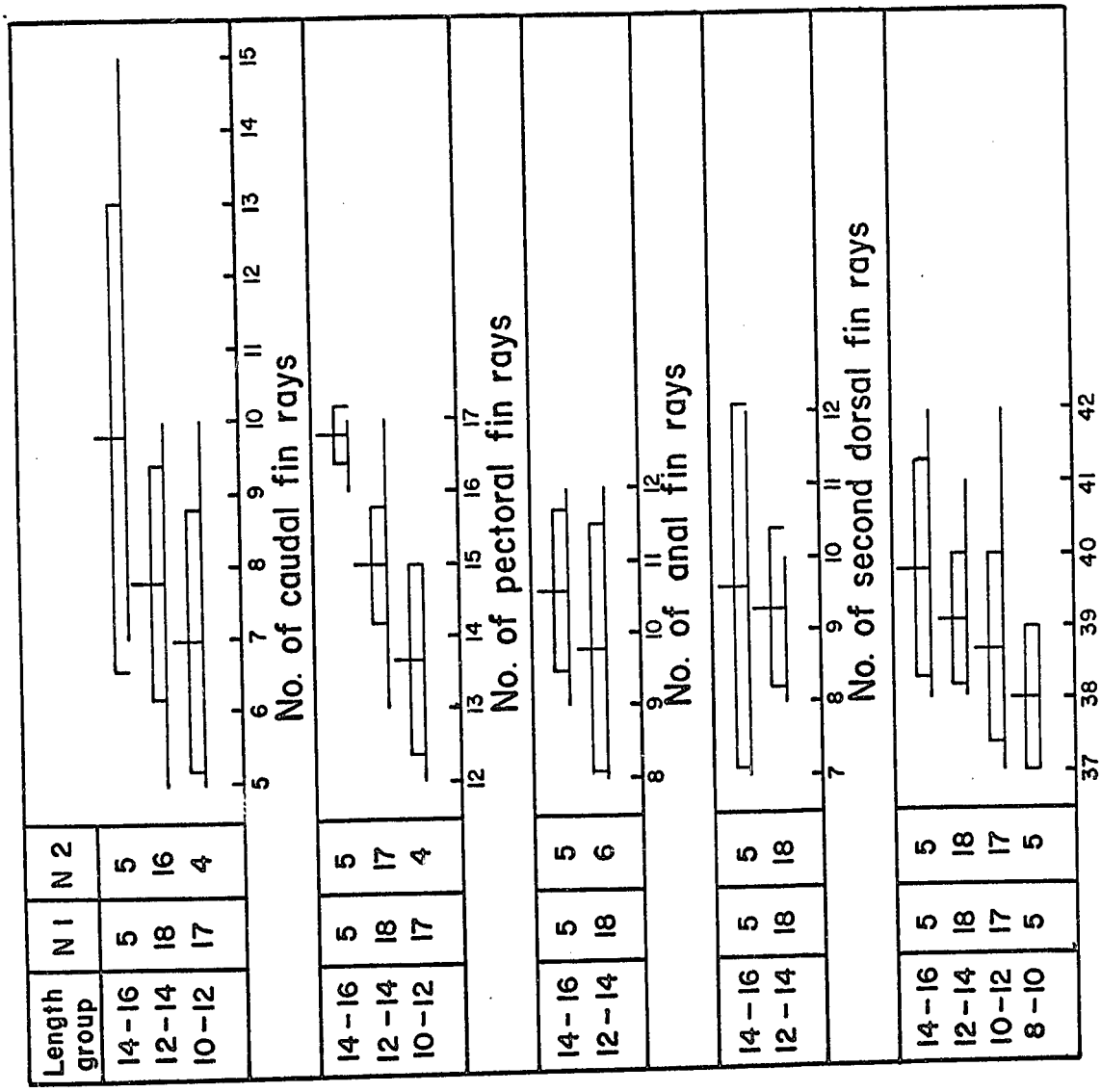


Figure 26

3. Summary of Morphological Characters For Separating Cottid Larvae

In this section important morphological characters are summarized to separate cottid species at various phases of larval development. The terminology used is the one proposed by Balon (1971).

Eleuterembryonic Phase: From hatching to the beginning of exogenous feeding.

During this phase the estuarine Myoxocephalus quadricornis labradoricus differs from the freshwater M. q. thompsonii in having a larger size (about 11 mm) at hatching in contrast to about 8 mm in thompsonii. The two subspecies can also be differentiated by the presence of a larger number (up to 65) of medio-ventral melanophores in labradoricus and the complete or partial absence of these melanophores in thompsonii (Figs 3, 4). The number of myomeres in labradoricus (41-45, $\bar{x}$ = 42.8) is also larger than the number of myomeres in thompsonii (38 - 42, $\bar{x}$ = 39.5).

Among the species from the Atlantic coast, M. aeneus has the smallest size at hatching (about 5 mm) and the smallest number of myomeres (31-35, $\bar{x}$ = 33). This species is also characterized by the presence of longitudinally arranged melanophores on the ventral side of the

abdomen (Fig 8). During this phase the larvae of M. scoprius could be distinguished from the other species in having small preanal fin (Fig 5), and by the presence of small melanophores on the lateral side of the tail in the later part of this phase. The larvae of M. octodecemspinosus can be readily distinguished by the presence of 3-5 large stellate melanophores on the isthmus and by the absence of melanophores on the dorsal side of the head. The larvae of Triglops murrayii superficially resemble the larvae of M. scorpius and M. octodecemspinosus but can be differentiated from them as well as from the others by having larger number of myomeres (43-46, x - 45). Larvae of Hemitripterus americanus resemble the larvae of M. scorpius in having lateral melanophores on the tail but can be easily differentiated from the latter in having larger size (hatching size 10 - 14 mm) and greater development of pigmentation on all parts of the body and head, and relatively deeper bodies (Fig 13). The larvae of Gymnocanthus tricuspis can be differentiated by the presence of typical peritoneal pigmentation which is formed by the compactness of melanophores giving it a uniformly painted appearance (Fig 11). In this phase and in the following phases of larval development Cottus bairdii can be distinguished from M. q. thompsonii in the earlier development of juvenile pigmentation and in having deeper bodies i.e. 11% of total length as compared to only 6% in M. q. thompsonii.

Protopterygiolarval Phase: From the complete absorption of yolk to the beginning of the differentiation of finfold

M. q. labradoricus in addition to having the differentiating characters mentioned in the previous phase, also differs from M. q. thomsponii in the development of 6-7 mediolateral melanophores on the lateral line (Fig 3).

The M. aeneus larvae have 4-6 well developed preopercular spines and 1-2 parietal spines. These spines are not as well developed in the other species on the Atlantic coast. With the appearance of pterygiophores and the fin rays, in the unpaired fins, the larvae of T. murrayii can be readily distinguished from the other species by the large number of second dorsal (19-23, $\bar{x}$ = 21.5) and anal (20-22, $\bar{x}$ = 20.8) fin rays. T. murrayii, during this phase is also characterized by 2 supraorbital spines. All the other species throughout their larval development never develop more than one supraorbital spine. The H. americanus larvae develop heavier pigmentation, typically swollen abdomen and much deeper bodies (Fig 13) than the M. scorpius to which they resemble most. Another distinguishing feature between H. americanus and M. scorpius is that the preanal length in the former species is about 1/2 of the total length and in the latter species it is less than 1/2 of the total length. Besides the distinctive peritoneal pigmentation in G. tricuspis, mentioned in the previous

phase, there appears a row of melanophores on either side of the mid-dorsal line just behind the second dorsal fin (Fig 11).

Pterygiolarval Phase: From the beginning of the differentiation of the finfold until the complete disappearance of finfold.

No distinguishing features, other than the ones mentioned in the previous stages, are added to separate M. q. labradoricus and M. q. thompsonii. Larvae of M. q. labradoricus start developing juvenile pigmentation at about 17 mm length while the larvae of similar lengths in M. q. thompsonii generally do not develop any juvenile pigmentation (Figs 3, 4).

In addition to the characters mentioned in the previous stages, the larvae of M. aeneus differ from the other species in developing the juvenile pigmentation at less than 12 mm length. On the other hand the larvae of M. octodecemspinosus and T. murrayii do not develop juvenile pigmentation until they have reached approximate lengths of 14 and 20 mm respectively (Figs 7, 10). The longest specimens of M. scorpius (17 mm) and H. americanus (19 mm) had not developed juvenile pigmentation. However, the larvae of these two species could be readily distinguished by the characters mentioned in the previous stages and

by the larger number of first dorsal fin spines in H. americanus (up to 17) than in M. scorpius (up to 9). The larvae of G. tricuspis start developing juvenile pigmentation at about 16 mm length and can still be differentiated from the larvae of the other species by the characters mentioned in the previous phases, and by the development of a row of melanophores along the lateral line.

C. General Discussion of Morphology

A thorough morphological and meristic study during various phases of larval development of the cottid larvae from the Atlantic Coast, the Great Lakes, and the Arctic enabled me to distinguish seven species (*Myoxocephalus scorpius*, *M. aeneus*, *M. octodecemspinosus*, *Triglops murrayii*, *Gymnocanthus tricuspis*, *Hemitripterus americanus*, *Cottus bairdii*) and two subspecies (*Myoxocephalus quadricornis labradoricus*, *M. q. thompsonii*).

This study helped to clarify a number of problems in the literature.

The morphological study produced evidence that the descriptions of the larvae of *Cottus bairdii kumlieni* and *Cottus bairdii bairdii* given by Fish (1932) were actually those of the early larval stages of *M. q. thompsonii*. The larvae of *Cottus bairdii* were found to differ from those of *M. q. thompsonii* in much earlier development of fin rays, and juvenile pigmentation, in having deeper bodies, and in much later development of preopercular spines. The earlier development of fin rays in *Cottus bairdii* is probably due to large egg size with large amounts of yolk (Koster 1936). Orton (1953) pointed out that fish with large yolk supplies achieve a greater amount of development before hatching.

Morphological differences were observed for the first time to separate estuarine M. q. labradoricus and the North American freshwater form M. q. thompsonii. The estuarine labradoricus can be separated from the freshwater thompsonii in having more myomeres and medioventral melanophores, by the presence of mediolateral melanophores and the melanophores on the isthmus, and by having generally faster growth rates. The meristic differences and the differences in relative growth appear to be environmentally controlled while the differences in the pattern of pigmentation are apparently genetic. Fujii (1969) pointed out that the pattern of melanophores is genetically controlled. It was interesting to note that larvae of European freshwater relics of M. quadricornis as described by Nordqvist (1914) lacked the mediolateral melanophores but they had the melanophores on the isthmus. This showed that freshwater glacial relicts of M. quadricornis in North America as well as in Europe have a tendency for a reduced larval pigmentation.

The larvae of three species of the genus Myoxocephalus (i.e. M. scorpius, M. aeneus, M. octodecemspinosus) can be distinguished by morphological and meristic features. There had been a tendency among biologists to lump these larvae under the group Myoxocephalus spp. (Herman, 1963; Kennedy and Powles, MS 1964). Some other authors (e.g., Merriman and Sclar, 1952) attempted to separate

these species by differences in lengths. Since these sculpins form a major part of the benthic fish community of our Atlantic Coast, the morphological distinction of these larvae at the species level solves a major problem in the taxonomy of larval Cottidae.

This morphological study of the cottid larvae also resolves the problem of separating the larvae of H. americanus and M. scorpius. The larvae of these two species can easily be confused with each other by their superficial resemblance in having a lateral patch of pigmentation on the tail (Figs. 5, 13). It was found that the larvae of H. americanus can be distinguished from those of M. scorpius by having deeper bodies and longer preanal lengths. During the protopterygiolarval phase and the pterygiolarval phase H. americanus can be distinguished by having about 17 first dorsal fin spines as opposed to about 10 in M. scorpius.

The morphological studies of cottid larvae also enabled me to describe the larvae of Triglops murrayii for the first time and to compare them with the descriptions of larvae of Triglops pingelli given by Koefoed (1907) and Dunbar (1947). The geographical ranges of these two species overlap and their pelagic larvae could easily be confused.

A number of differences in the relative growth rates of various species were observed. Since the two subspecies M. q. labradoricus and M. q. thompsonii come from different

environments, the differences in relative growth observed between the two were probably environmental rather than genetic. The number of myomeres which is known to be influenced by environmental factors were higher in labradoricus (Fig. 21). Generally, the northern races of a species have smaller heads and other body parts, and larger number of vertebrae than the sourthern races of the same species (Martin, 1949). These differences have been shown to be related to temperature. The two most potent factors, temperature and salinity, influencing the growth of fish were found to be different between the environments of the two subspecies. The eggs of labradoricus develop in estuarine waters at zero and subzero temperatures (bathythermographs of winter and spring at Tuktoyaktuk Harbour in Kelly, 1967), while the eggs of thompsonii develop in the freshwater where the termperature never reaches freezing point. A number of workers have shown positive correlation between relative growth rates and temperature (e.g., Jean, 1945; Martin, 1939, 1949), and the negative correlation between temperature and meristic counts is well established (e.g., Taning, 1952; Lindsey, 1954; Lindsey and Ali, 1965). The higher number of myomeres and vertebrae has also been shown to

be related to higher salinities. Hempel and Blaxter (1961) reported that the mean myomere count of larvae of Clupea harengus hatched from eggs incubated in salinities 5 to 50‰ was highest in higher salinities.

The morphological differences in relative growth and in the number of meristic characters among the larvae of various species of sculpins on the Atlantic coast appear to be genetic. All the cottid species on the Atlantic Coast of Canada spawn during fall and winter and, therefore, their eggs are incubated at similar temperatures at the bottom. The larvae of Myoxocephalus scorpius, M. aeneus, M. octodecemspinosus and Triglops murrayii, studied for relative growth analysis and meristic variations came from the same area near Boothbay Harbour, and the same dates. Therefore, it is suggested that the variations observed between species could not be caused by the environment.

The study of the development of fin rays and other morphological characters such as pigmentation in the larvae of thompsonii from different bodies of water indicated a correlation with temperature. The larvae of thompsonii from Lakes Michigan and Huron had relatively slower development of morphological characters (i.e., fin rays and pigmentation) than the larvae of thompsonii from Lake Erie described by Fish (1932). At 12.5 mm length larvae described by Fish had well developed fin rays and showed the beginning of juvenile pigmentation, and at 16.5 mm

length they had well developed juvenile pigmentation and fully developed fins. On the other hand the larvae of thompsonii from Lakes Michigan and Huron showed very little development of fin rays at 12.5 mm length and did not develop any juvenile pigmentation even at a length of 17 mm (Fig 4). The faster development of morphological and meristic characters in the larvae from Lake Erie can be attributable to relatively higher temperatures in this lake. Besides higher temperatures, the greater availability of food due to high productivity in Lake Erie (Beeton, 1969) can also be considered as an important factor causing the faster development of morphological and meristic characters. Rass (1948) also found that the development of fish larvae was faster in the warm relatively productive coastal waters than in the colder less productive waters. Rass pointed out that higher temperatures can cause high rate of assimilation resulting in a faster growth of larvae.

The number of fin rays in all the species increased with the increasing length of the larvae, but generally no correlation was observed between the length of the larvae and the number of myomeres. Kyushin (1968, 1970) reported no increase in the number of myomeres during the larval development of Hemitripterus villosus and Gymnocanthus herzensteini. Galkina (1969), however,

reported a positive correlation between the length of larvae and the number of myomeres in herring. The increase in the number of myomeres, during the larval phase, depends upon the degree of embryonic development achieved before hatching.

IV. ECOLOGICAL STUDIES OF COTTID LARVAE

Several authors have reported the pelagic existance of cottid larvae on the Atlantic Coast of Canada and the United States, but very little is known about their general ecology. Bigelow (1917) collected a total of 5 cottid larvae during a May - September cruise in the Gulf of Maine. He assigned these larvae to the genus Myoxocephalus. These larvae ranged from 8.5 - 11 mm in length and were caught in surface tow nets in the northern Gulf of Maine. Dannevig (1919) reported very few larvae of Myoxocephalus scorpius in June from the Magdalen Shallows in the Gulf of St. Lawrence. Fish and Johnson (1937) in their work on the biology of zooplankton of the Bay of Fundy and the Gulf of Maine caught larvae of M. scorpius and M. octodecemspinosus. They reported these larvae in extremely small numbers and only in April and May. Perlmutter (1939) reported the pelagic existence of the larvae of M. aeneus in the salt waters of Long Island. Dunbar (1947) reported larvae of M. scorpius, Triglops pingelli and Gymnocanthus sp. in the marine plankton samples from the eastern arctic Canada, collected during the summer months. Merriman and Sclar (1952), in a survey of the pelagic fish eggs and larvae of the Block Island Sound found two species (species distinction based on size) of cottid larvae in the

surface and bottom plankton hauls from February to May. Marak and Colton (1961) caught juveniles of M. octodecemspinosus in March and April in 1-m plankton nets in the Georges Bank area, Gulf of Maine. They were, however, not sure of the identification. Kennedy and Powles (1964) reported larvae of Myoxocephalus from the estern Gulf of St. Lawrence in May and early June. These larvae were caught by 1-m plankton nets towed at the surface.

In addition to these reports there is some information regarding the seasonal abundance of cottid larvae. Herman (1963), in a survey of the planktonic fish eggs and larvae of Narragansett Bay, observed that the most abundant larval fish captured from January through March, was the group classified as Myoxocephalus spp. Graham and Boyar (1965) reported that the larval cottids are one of the most abundant larval fish during spring in the coastal waters of the Gulf of Maine. No detailed literature is available on the distribution and biology of cottid larvae on the Atlantic Coast of North America.

In the Great Lakes the first published work on the collection of larval fish with nets is by Fish (1932). Fish for the first time reported pelagic existence of the larvae of deepwater sculpin, Myoxocephalus quadricornis thompsonii (in Lake Erie). Recently Faber

(1970) reported deepwater sculpin larvae from South Bay, Lake Huron, in the spring. He found them associated with the larvae of Coregonus clupeaformis, Osmerus mordax, Lota lota, and Coregonus artedi, along the steep shores of the inner basin of the bay.

All the observations mentioned above were the result of work on species other than cottids, and do not present an exhaustive account of the ecology of larval cottid species. The present study, therefore, was designed to study the various aspects of the ecology and distribution of the cottid larvae in the western Atlantic and the Great Lakes; and to review problems found in the literature.

A. The Great Lakes

1. Description of the Area

Sampling in Lake Michigan was done in connection with a project of the U.S. Bureau of Commercial Fisheries on "The seasonal and depth distribution of larval bloaters, Coregonus hoyi". Collections were made off Saugatuck, Michigan from 0.5 mile to about 20 miles offshore. The total depth of water varied between 5 - 90 fathoms.

Sampling in Lake Huron was done at South Bay which is a 25 km inlet into Manitoulin Island. The Bay is conveniently divided into an outer and inner basin by a

constriction of about 8 km from the mouth (Faber, 1970). The maximum depth in the outer basin is about 13 m and 54 m in the inner basin. All shorelines are sandy or rocky and subject to occasional wave action. Warming in South Bay starts in April and the thermal stratification is established in the middle of June (McCombie, 1967). Variations in the epilimnial temperatures are correlated with the air temperature but no correlation exists between the epilimnial and hypolimnial temperatures. During the summer epilimnion of the inner basin is generally warmer than the epilimnion of the outer basin.

2. Sampling Methods

In Lake Michigan collections were made from the U.S. Bureau of Commercial Fisheries research vessel R/V Ciscoe. Sampling methods as described by Wells (1966) are summarized as follows:

A 1-m plankton net of 565 nitex (0.66 mm mesh) was used. All tows were made at a speed of 3.5 knots. "Series of samples were taken at intervals of about 10 days from 9 April to 22 August, 1964. A few tows were made on October 15. A standard series of samples consisted of oblique tows at stations located at 5 fathom intervals of bottom depth from 5 to 50 fathoms. The oblique tows at each station were made by 10 fathom strata, except at depths not multiples of 10 fathoms (5, 15, ... fathoms).

where the lower most stratum was only 5 fathoms."

"For an 'oblique tow' the net, as it was lowered, was towed 1 min at each of 11 equally spaced levels in the upper 55 ft of the 10 fathoms stratum being sampled, and then brought up at constant speed. For 5 fathom strata the net was towed for 1 min at five levels four equally spaced in the upper 22 ft and the other at 25 ft. Thus the lowermost 5 ft were not sampled in any stratum, and the danger of striking bottom was minimized. The times required to sample 10-fathom and 5-fathom strata averaged 15.4 and 8.5 min, respectively."

"Fourteen 'standard series' of tows were made during the study. Nine were complete (all strata sampled), two lacked a few tows, and the remaining three were incomplete to a considerable degree. It usually required 3 days to complete a series over all bottom depths from 5 - 50 fathoms. All strata of a given station were always sampled on the same day. After the completion of a standard series, collections were usually made in selected strata at 60 fathoms and occasionally at 70, 80, and 88 fathoms. These samples are grouped with the standard series which they followed."

Three adjustments were made in the actual catches of the standard series, a) to compensate for the lack of opening - closing device in the net; b) to make the

catches in the 5 fathom strata proportional to those in the 10 fathom strata; and c) to make the total catches of standard series containing missing tows comparable for the analysis of seasonal abundance. For further details see Wells (1966).

Sampling at the mouth of South Bay, Lake Huron, was done by 26 inch diameter and 10 ft long tow nets of 30 Grit Gauze (0.75 mm mesh). All tows were made in duplicate. A 12 foot beam was clamped across the mid-section of a 14 foot motor boat and the nets were suspended at each end of the beam by pulleys. For details of this method see Faber (1968). Sampling was done from 16 to 19 March, 1970. Only about 1/10 of the bay was open, the rest was still covered with ice. Nets were towed for 10-15 minutes at a speed of about 1 knot.

Since sampling at South Bay was done only for 3 days, the data were not enough for a quantitative analysis. Most of the results, therefore, are based on Lake Michigan collections, and the data from South Bay were only used to support the results obtained from Lake Michigan collections.

3. Seasonal Abundance

Two peaks of abundance were noticed during the sampling period (April 9 to August 22) in Lake Michigan. One in the end of April and the other in the middle of

Fig. 27. Seasonal abundance of the larvae of Myoxocephalus quadricornis thompsonii based on the *adjusted catches in standard series on different dates in Lake Michigan, 1964.

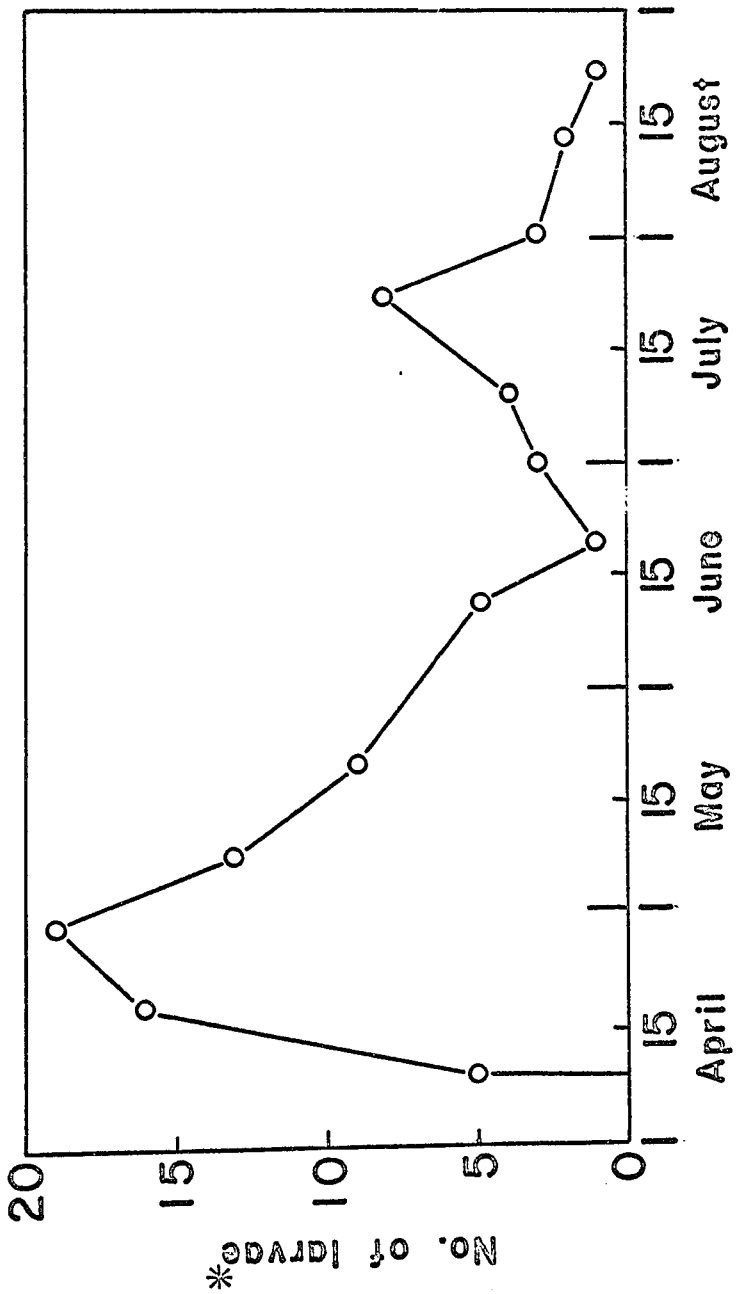


Figure 27

July (Fig 27). The deepwater sculpin larvae were few when the sampling started on the 9th of April, but their number increased rapidly till the 29th of April. The number of larvae, after this date, decreased gradually till the 19th of June. In July the number of larvae started rising again and showed a peak on the 22nd of July. The number of larvae decreased again after this date. Yolk-sac larvae were present both in April and July. However, the yolk-sac larvae in April (3%) were much less than in May (30%), June (50%), July (15%), and August (16%). The pattern of the abundance of larvae and the relative abundance of yolk-sac larvae suggest more than one spawning period. This is substantiated by the length frequency distributions of the larvae.

4. Length Frequency Distribution

The mean values and ranges of lengths during various months varied considerably (Table 2). In April and May the mean lengths were 11.44 and 11.84 respectively which were higher than the mean values (8.31 to 8.89) in the following months. This indicated that the total sample of larvae during the sampling period was a mixture of more than one normal distribution.

The analysis of polymodal length frequencies was done by plotting the cumulative frequencies on probability paper (Harding, 1949; Cassie, 1950). This method

TABLE 2. Number and total lengths of the larvae of *M. q. thompsonii* from Lake Michigan collected during April to August, 1964.

Months	No. of larvae	Yolk-sac larvae (%)	Total Length	
			Range	Mean
April	43	3	8.6-14.8	11.44
May	57	30	8.7-17.54	11.84
June	12	50	7.73-9.3	8.31
July	60	15	7.5-10.7	8.68
August	12	16	7.95-10.2	8.89

Fig. 28. Probability graph showing cumulative percentage length distribution of the larvae of Myoxocephalus quadricornis thompsonii caught in southern Lake Michigan from April to July, 1964.

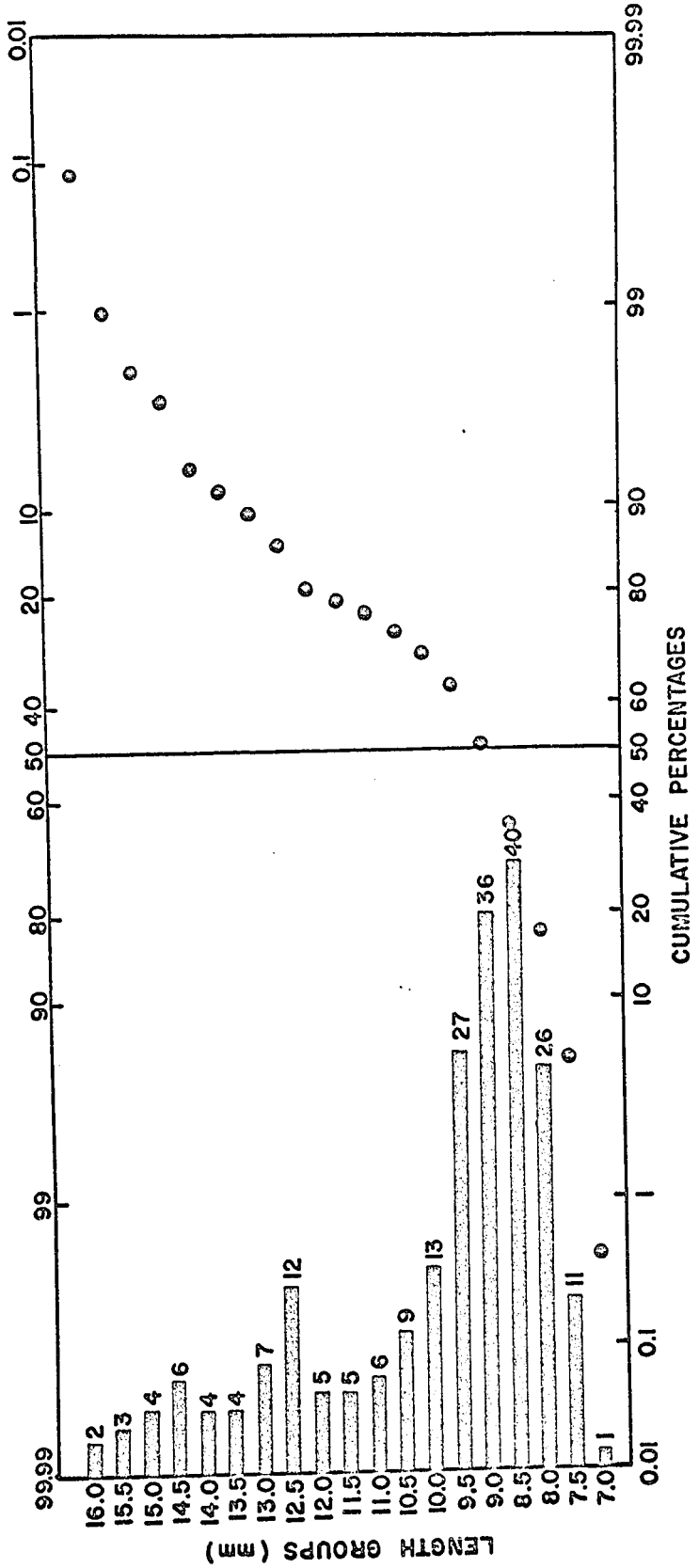

0.01
0.1
1
10
20
40
60
80
90
99
99.99
CUMULATIVE PERCENTAGES
LENGTH GROUPS (mm)
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
2
3
4
6
4
4
7
12
5
5
6
9
13
27
36
40
26
11
1

Figure 28

minimizes the subjective separations of the polymodal distribution, and is based on the assumption that the components of the distribution mixture are normal distributions. When the cumulative percentages of length frequencies are plotted aginst length frequencies, a normally distributed population assumes a straight line (Harding, 1949). When the length frequencies of the total sample (April to August) were plotted it did not assume a straight line and confirmed the polymodal nature of the population (Fig 28). However the extraction of component populations by the method described by Cassie (1950) was not feasible since the component distributions overlapped a great deal. Since the mean lengths in April and May were higher than in the summer months (Table 2) it was thought that the source of the polymodal nature of the total sample was in April and May. In order to test this hypothesis, the length frequencies of April and May sample; and June and July sample were plotted separately. April and May sample showed trends similar to the total sample (Fig 29) while the June and July sample assumed a straight line depicting a typical unimodal distribution (Fig 30). The larger larvae caught in April and May must have come from a late fall spawn while the smaller larvae from winter spawning. The length distribution of larvae caught in June and July indicated that they came from a spring or early summer spawn.

Fig. 29. Probability graph showing cumulative percentage length distribution of the larvae of Myoxocephalus quadricornis thompsonii caught in southern Lake Michigan during April and May, 1964.

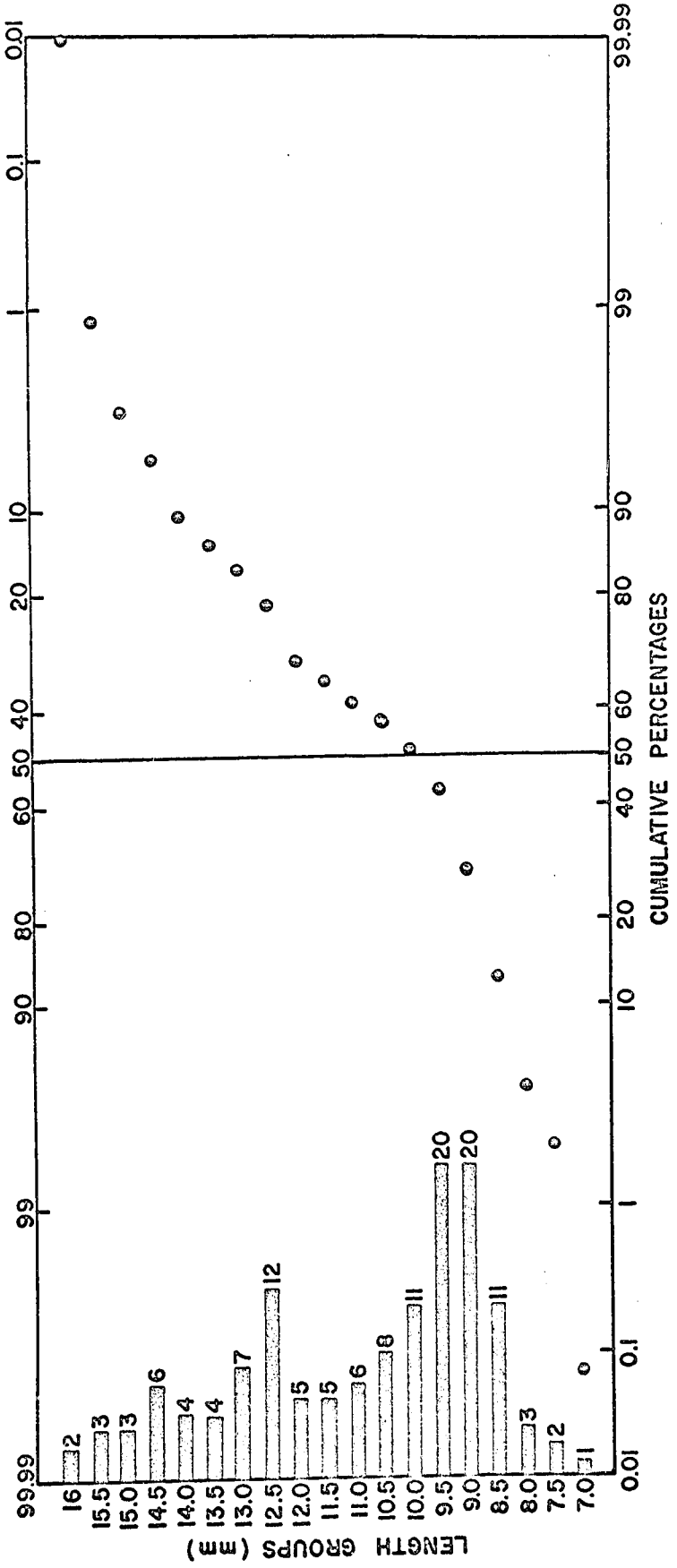

CUMULATIVE PERCENTAGES
LENGTH GROUPS (mm)
0.01
0.1
1
10
20
40
50
60
80
90
99
99.99
16
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
2
3
3
6
4
4
7
12
5
5
6
8
11
20
20
11
3
2
1

Figure 29

Fig. 30. Probability graph showing cumulative percentage length distribution of the larvae of Myoxocephalus quadricornis thompsonii caught in southern Lake Michigan during June and July, 1964.

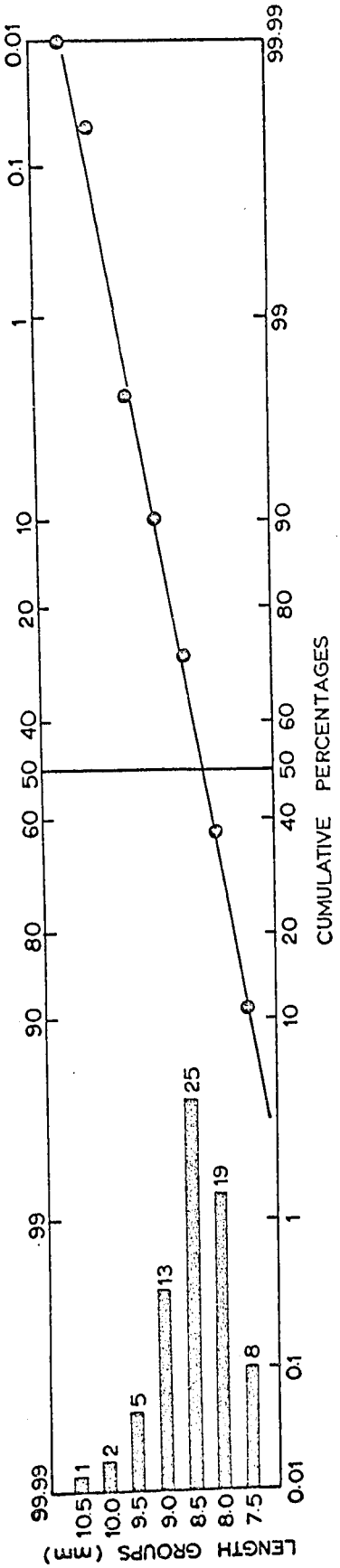

0.01
0.1
1
10
20
40
50
60
80
90
99
99.99
CUMULATIVE PERCENTAGES
LENGTH GROUPS (mm)
10.5
10.0
9.5
9.0
8.5
8.0
7.5
1
2
5
13
25
19
8

Figure 30

Further evidence of winter spawning was provided by the collections of deepwater sculpin in the middle of March from South Bay Mouth, Lake Huron. The length of larvae ranged from 9.39 - 15.18 mm with an average length of 12.1 mm. These larvae must have come from a winter spawn, and hatched under the ice. The Bay had just opened when the collections were made on March 16 - 18, and the ice was floating at the surface. Faber (1970) has also reported deepwater sculpin larvae from the same area in spring after 2-3 weeks of ice break. Faber (personal communication) never collected deepwater sculpin in the surface waters after the middle of May.

5. Depth Distribution

During the early part of the sampling period (April 9 to 29) in Lake Michigan, larvae of deepwater sculpin were relatively abundant in the top ten fathoms of the water column (Fig 31). Almost homothermal conditions prevailed during this period. With the surface warming during the following months no larvae were caught in the upper strata. Almost all the larvae were caught below 30 fathoms where the maximum temperature was 4.8°C. The temperature in the upper levels ranged from 10.9 to 22.8°C. Similar trends were observed by Wells (1966) for bloater larvae.

Fig. 31. Seasonal changes in depth distribution of the larvae of Myoxocephalus quadricornis thompsonii based on adjusted catches for all dates on which a complete series of tows was made at bottom depth of 50 fathoms. The width of panel for each month represents 30 larvae. The dotted lines show temperature profiles for each month adapted from Wells (1966).

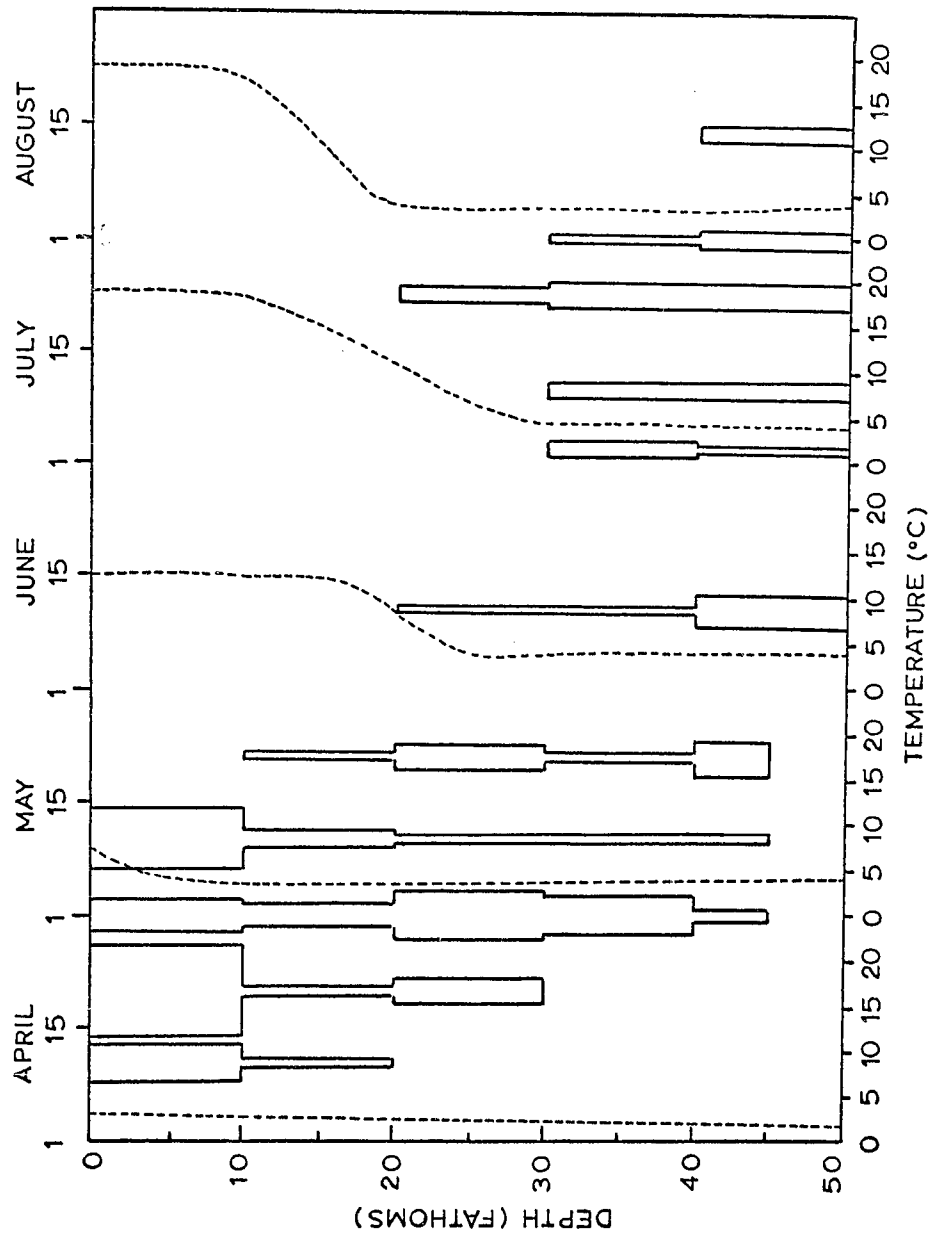

APRIL
MAY
JUNE
JULY
AUGUST
1
15
1
15
1
15
1
15
1
15
0
10
20
30
40
50
DEPTH (FATHOMS)
0 5 10 15 20 0 5 10 15 20 0 5 10 15 20 0 5 10 15 20 0 5 10 15 20
TEMPERATURE (°C)

Figure 31

6. Discussion

The results of this study show that the deepwater sculpin, in the Great Lakes, not only spawns in the summer but also in the winter months. Previously this species was thought to spawn only in the summer months. Dymond et. al. (1929) reported ripe ovarian eggs from Lake Ontario in late August. McPhail and Lindsey (1970) reported well developed ovarian eggs in the specimens found in the stomachs of lake trouts from Great Bear Lake taken in late July. However, all these reports were based on collections made during the summer months and cannot be taken as conclusive.

McAllister (1959) in an attempt to treat deepwater sculpin as a distinct species (M. thompsonii) from the European freshwater relicts and the marine forms of M. quadricornis, considered deepwater sculpin as a summer spawner in support of his argument. The European relicts of M. quadricornis are known to spawn in the winter (Smitt, 1893; Berg, 1949), but there is no evidence that they do not spawn in the summer. The only published record of larvae of European freshwater relict was given by Nordqvist (1914), from Vattern Lake, Sweden. These larvae were collected in May and their lengths ranged from 9 - 15.5 mm. However, no collections were made in the deeper waters in the summer. In the absence of data, therefore, there is a possibility that the European

relicts also spawn during the summer. It is suggested that during long isolation in the deep freshwater lakes the deepwater sculpin, developed the habit of spawning more than once. This is not surprising in view of the fact that the deepwater sculpin had to encounter a completely new environment with stressing physical and biological factors.

B. Kugmallit Bay, N.W.T.

1. Description of the Area

Sampling was done from July 10 to 29, 1970 in the coastal areas of Kugmallit Bay, eastern Beaufort Sea. The stations where collections were made are shown in Fig 32. Most of the sampling was done in Tuktoyaktuk Harbour. Tuktoyaktuk Harbour has rocky shores, but offshore the bottom is generally muddy and sandy. The area is under the influence of the Mackenzie River discharge. The water in the Bay is therefore, of a dirty brown colour with silt suspension. In July the surface (0-5 metres) water in some areas of Tuktoyaktuk Harbour warms up to 15° C. But below this depth the temperature is generally below 5°C (Kelly, MS 1967). During winter when the bay is covered over by ice, 0° C isotherms prevail. In July the surface (0-5 m) salinities are very low (about 5‰) but below this depth the salinities range from 20 - 30‰ .

2. Sampling Methods

Tows were made by a 26 inch. diameter, 10 ft. long, conical plankton net of 30 Grit Gauze (0.75 mm mesh). Some tows were made by Miller Sampler (Miller, 1961). A 36 inch long conical plankton net of 202 Nitex (0.2 mm mesh) was attached to the tube. All the tows were made

Fig. 32. Map of Tuktoyaktuk Harbour and Kugmallit Bay (inset). Open circles and solid circles show sampling locations in July, 1970. Solid circles show the locations where larvae of Myoxocephalus quadricornis labradoricus were caught.

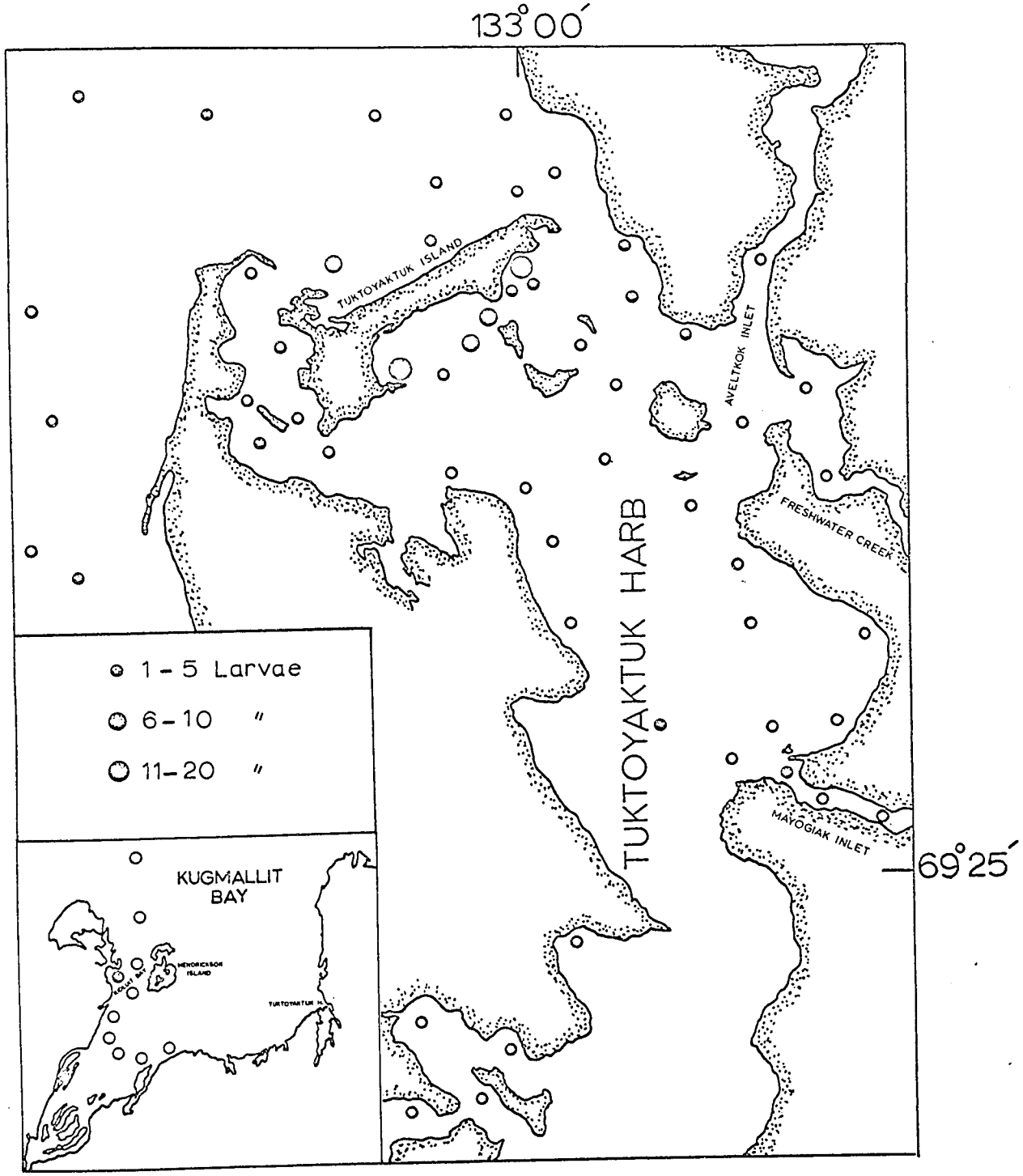

133°00´
TUKTOYAKTUK ISLAND
AVELTKOK INLET
FRESHWATER CREEK
TUKTOYAKTUK HARB
MAYOGIAK INLET
69°25´
1 - 5 Larvae
6 - 10 "
11 - 20 "
KUGMALLIT BAY
MEMORIC KSOK ISLAND
TUKTOYAKTUK

Figure 32

in duplicate. The Miller Samplers were towed for 10 minutes at a speed of 5 knots and the 26" diam. nets were towed for 5 minutes at a speed of 1.5 to 2 knots. A total of 134 tows (36 by Miller's and 98 by 26 inch. diam. net) were made. For further details see Marhue (1971).

3. Results and Discussion

A total of 84 larvae of Myoxocephalus quadricornis labradoricus were caught. Larvae of no other cottid species were found. In the tows made by Miller Sampler only 4 larvae were caught.

Larvae of labradoricus were caught in very shallow waters (5 - 10 ft) of Tuktoyaktuk Harbour. Most of the larvae were concentrated in the shallow waters near the Tuktoyaktuk Island (Fig 32). In the deeper waters of the harbour where the depths varied between 15 and 60 ft., the larvae were not caught. Only two larvae were caught in the Kidluit Bay, near the mouth of Mackenzie River. No larvae were caught in the open waters of the Kugmallit Bay. Although the waters of Tuktoyaktuk Harbour are under the influence of warm water discharge from the Mackenzie River, yet the warm surface layer of 5 - 15^{o}C is seldom thicker than 2-5 metres (Kelly, MS, 1967). However, the bathythermographs at various stations in Tuktoyaktuk Harbour suggest that the upper layer is subject to a great deal of temperature

Fig. 33. Length frequency distribution of the larvae of Myoxocephalus quadricornis labradoricus collected at Tuktoyaktuk Harbour in July, 1970.

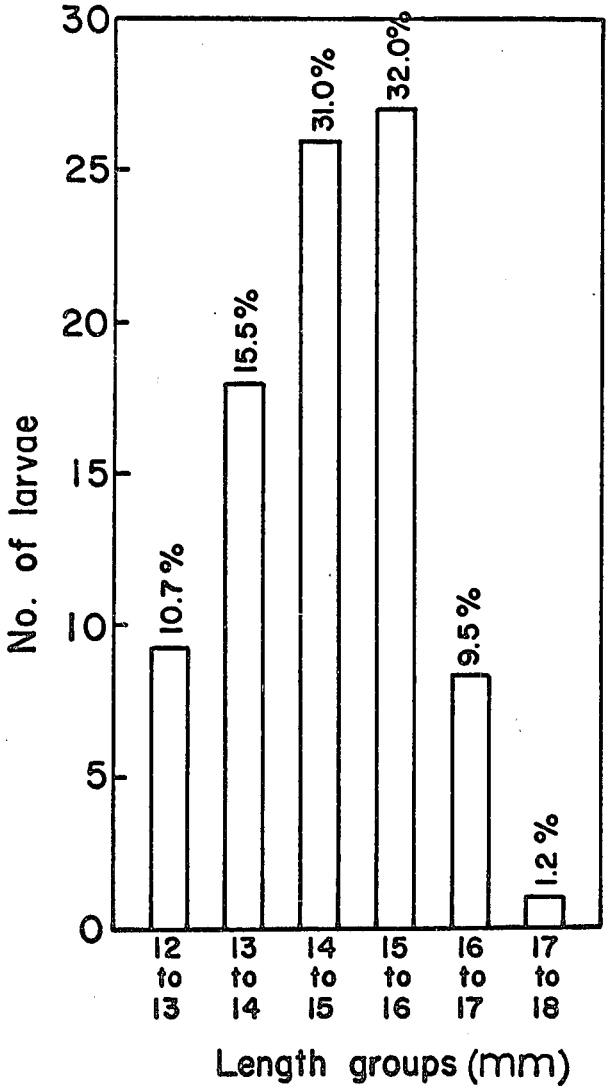

30
25
20
15
10
5
0
No. of larvae
10.7%
15.5%
31.0%
32.0%
9.5%
1.2%
12 to 13
13 to 14
14 to 15
15 to 16
16 to 17
17 to 18
Length groups (mm)

Figure 33

variations due to the northerly winds bringing in the cold, more saline water of the Beaufort Sea. On several occasions, during late July, the surface layer was as cold as 0.1°C.

There were no yolk sac larvae in the collections. Only about 10% of the larvae were from 12-13 mm in length (Fig 33). The length of labradoricus larvae at hatching is reported to be about 11 mm in the Laptev Sea (Zygina, 1963). Most of the larvae (78%) were in very advanced stages of development. Only about 10% were developing juvenile pigmentation and probably ready to settle down on the bottom. The length frequency distribution suggests that the hatching in our study area (Kugmallit Bay) starts much earlier in the season; perhaps in May and early June, as reported by Mukhomediarov (1967) in the White Sea. The same author has reported December to February as the spawning period and May as the hatching time in the White Sea. The incubation period of marine sculpins is generally very long. Myoxocephalus octodecemspinosus and M. scorpius have an incubation period of about 3 months (Morrow, 1951; Ennis, 1970). It appears, therefore, that the spawning of labradoricus in Beaufort Sea takes place in winter. Further support for the above deduction is provided by Zygina (1963). He collected labradoricus larvae in Laptev Sea in June and well developed larvae (14.5 to 14.8 mm) in July and August.

C. Gulf of St. Lawrence

1. Description of the area

The Gulf of St. Lawrence is a triangular body of water and has two main openings to the Atlantic Ocean, Cabot and Belle Isle Straits. (For a detailed map see Lauzier and Trites, 1958). It has an area of about 5,700 sq. mi. and receives approximately 500,000 sq. mi. of drainage from the St. Lawrence River. The Laurentian Channel is an important feature of the submarine physiography of the Gulf of St. Lawrence. It extends through the Gulf of St. Lawrence and into the estuary of the St. Lawrence River. The depth in the Laurentian Channel ranges approximately from 400 to 600 metres. From Cabot Strait inward, it shallows to 300 metres and terminates almost near the mouth of the Saguenay River. Cabot Strait provides the only opening to the deep waters of the Gulf of St. Lawrence. The currents of Laurentian Channel through Cabot Strait are characterized by a strong outflowing current along the Cape Breton side and an inflowing current along the Newfoundland side. (MacGregor, 1956) The strongest currents are in August and least in April and May. Southwest of the Laurentian Channel is the shallower area known as the Magdalen Shallows. One quarter of the area of the Gulf of St. Lawrence is shallower than 50 m., while less than

one fifth is deeper than 300 m (Lauzier et al. 1957).

The surface temperatures, in the southwestern part of the Gulf, are at a maximum between the middle of July and the middle of August (Lauzier, 1957). The maximum temperature below the surface usually occurs at a later date than at the surface. Long term variations of temperatures are inconsistent and small. The minimum surface salinities are from early to mid-summer depending on the location. The salinities are lowest (25‰) in the western part of the Gulf, near Grand River and highest (26.5‰) in the western part near Cheticamp, Nova Scotia.

In the southwestern part of the Gulf, the waters are highly stratified during the summer, a warm surface layer of lower salinity being separated from the cold layer by a sharp thermocline (Lauzier, 1957; Lauzier et al., 1957). The waters of the Laurentian Channel are highly stratified (Lauzier and Bailey, 1957), but instead of two layers there are three, a warm surface layer superimposed on an intermediate cold water layer overlying a deep warm layer. In winter, however, a single mixed layer of sub-zero temperatures overlies the deep warm layer. Lauzier and Trites (1958) noted that the vertical structure of the deepwater layer in the lower Laurentian channel and the general direction of flow of such a layer in Cabot Strait, suggest that the deep, warm waters are almost constantly supplied to the Gulf of St. Lawrence.

2. Sampling Methods

Plankton samples at 96 stations were taken between May 12 and 26, 1969 during Cruise E.E. Prince No. 45 of the Fisheries Research Board of Canada, Biological Station, St. Andrews. The range of sampling extended from the tip of Gaspé Peninsula east to the western coast of Newfoundland, and from the northern coast of Prince Edward Island north to the Magdalen Islands and the Laurentian Channel. Two methods were used for collecting plankton. Surface tows were made at 87 stations (Fig. 34), by a 1-M plankton net of 471 Nitex (0.47 mm mesh). This net was 3 m long. Each surface tow was made for 30 min. at an approximate speed of 2 knots. The midwater tows were made at 96 stations (Fig. 35) with an Isaacs-Kidd trawl. The diameter of the caudend was 53 cm and its length was 2 m. The codend was also made up of 471 Nitex. The Isaacs-Kidd was towed from surface to mid-depth at each station. The water column from surface to mid-depth was divided into six towing depths at each station and the net was towed for 5 minutes at each of these depths (i.e. total towing time 30 minutes).

In the same area 98 surface tows and 99 Issacs-Kidd tows were made between June 11 and 20, 1969 (Cruise E.E. Prince No. 47); 110 Issacs-Kidd tows between August 1 and 29, 1969 (Cruise E.E. Prince No. 52); and 18 Issacs-Kidd

TABLE 3. Number of various species of cottid larvae caught in the Gulf of St. Lawrence during May 12-26 and June 11-20, 1969. *Species in the Issacs-Kidd samples of cruise E.E. Prince No. 47 were not separated. Percentage of catch in parentheses.

Cruise and Date	Gear	*M. scorpius*	*M. octo.*	*M. aeneus*	*T. murrayii*	*H. americanus*	Total No. of larvae
EEP No. 45	Meter Net	2145 (71)	876 (29)	--	--	--	3021
May 12-26	Issacs-Kidd	70 (7.4)	782 (83.1)	--	61 (6.5)	28 (2.98)	941
EEP No. 47	Meter Net	30 (24.59)	82 (67.21)	8 (6.55)	--	2 (1.63)	122
June 11-20	Issacs-Kidd						83*

tows between September 12-18, 1969 (Cruise E.E. Prince No. 53). Methods of sampling were the same as described for cruise E.E. Prince No. 45.

3. Seasonal and Relative Abundance

In May (Cruise E.E. Prince No. 45) larvae of only two cottid species i.e., Myoxocephalus scorpius and M. octodecemspinosus, were represented in the surface tows. In the midwater tows, in addition to these two species, larvae of Triglops murrayii and Hemitripterus americanus were also present (Table 3). Larvae were much more abundant in surface tows than in the Issacs-Kidd tows. In the surface tows, larvae of M. scorpius (71%) were more abundant than those of M. octodecemspinosus (29%), while in the Issacs-Kidd tows the number of M. octodecemspinosus (83.1%) was higher than M. scorpius (7.4%), T. murrayii (6.5%), and H. americanus (2.9%).

In June (cruise E.E. Prince No. 47) larvae of M. scorpius, M. octodecemspinosus, M. aeneus, and H. americanus were present (Table 3) in the surface tows. The June samples of the Issacs-Kidd tows were lost before separating the species. However, the total number of cottid larvae (122) was again higher in surface tows than in Issacs-Kidd tows (83). In the surface tows the number of larvae of M. octodecemspinosus (67.21%) was higher than those of M. scorpius (24.59%),

Fig. 34. Distribution of cottid larvae in the Gulf of St. Lawrence based on catches in surface tows made by metre nets. (May 12 - 26, 1969) Open and solid circles show locations of sampling, and solid circles show the presence of cottid larvae in catches. A, Myoxocephalus scorpius; B, M. octodecemspinosus.

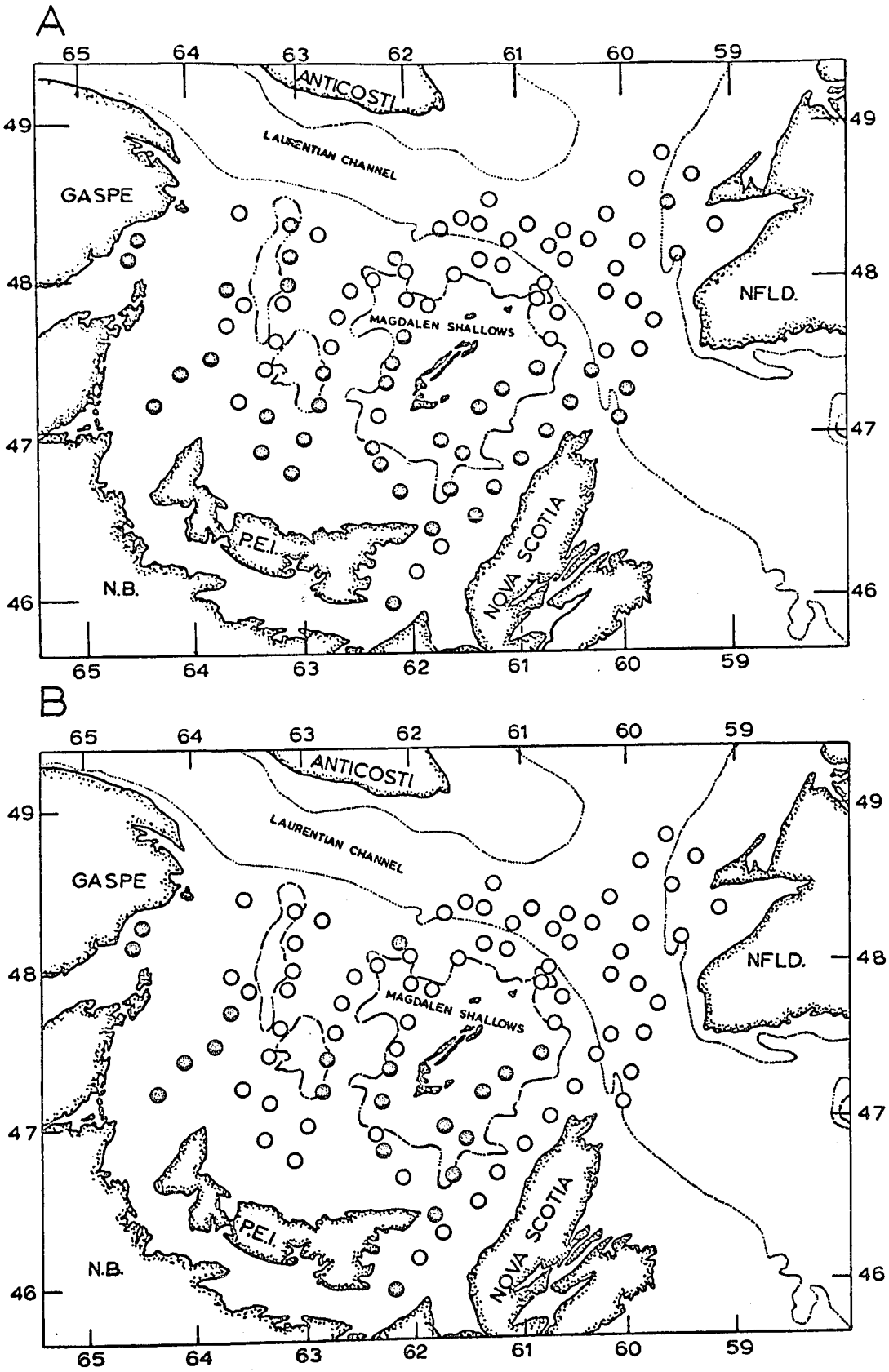
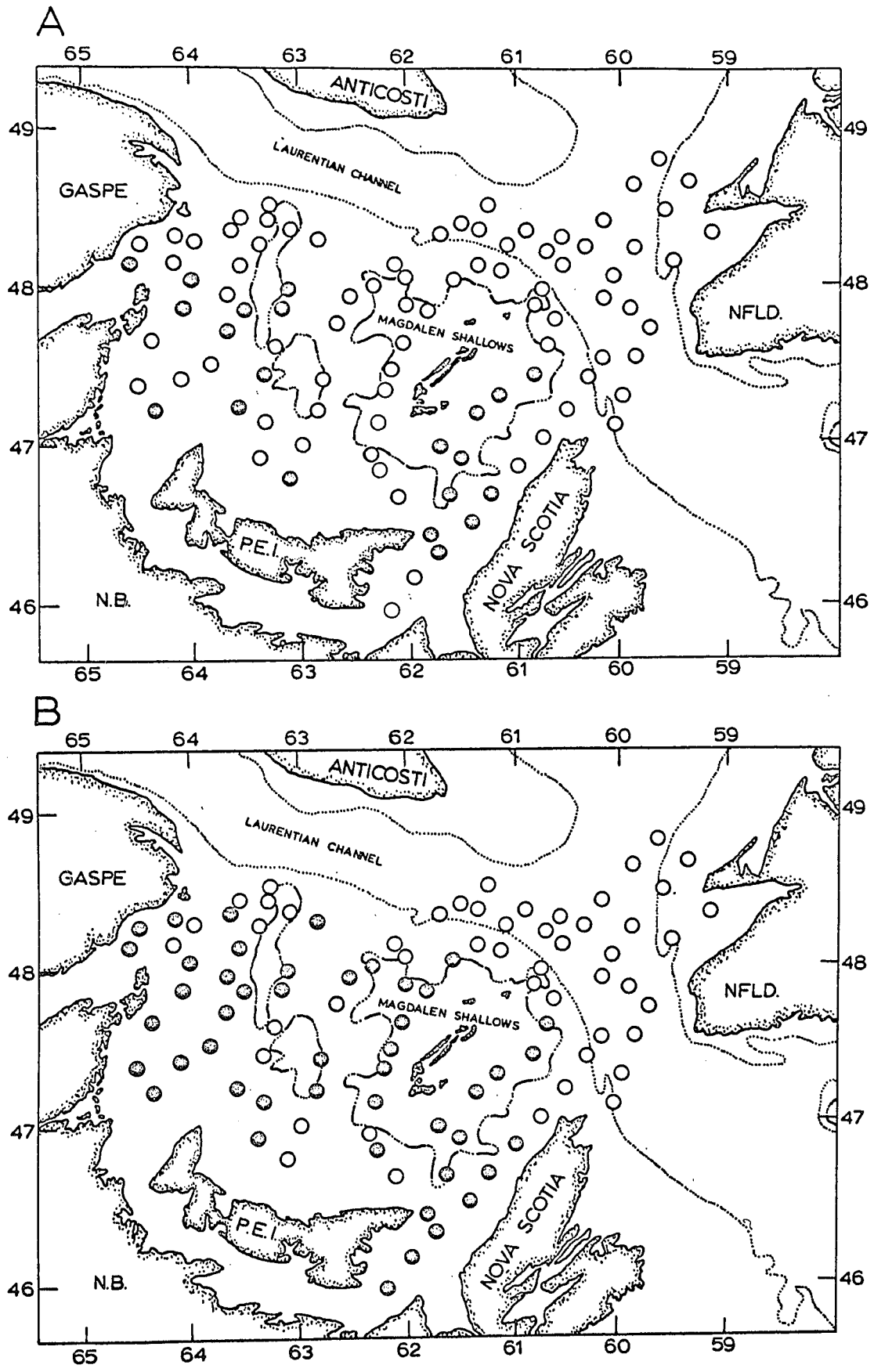

A
65
64
63
62
61
60
59
49
48
47
46
ANTICOSTI
LAURENTIAN CHANNEL
GASPE
NFLD.
MAGDALEN SHALLOWS
P.E.I.
N.B.
NOVA SCOTIA
B
65
64
63
62
61
60
59
49
48
47
46
ANTICOSTI
LAURENTIAN CHANNEL
GASPE
NFLD.
MAGDALEN SHALLOWS
P.E.I.
N.B.
NOVA SCOTIA

Figure 34

Fig. 35. Distribution of cottid larvae in the Gulf of St. Lawrence based on midwater to surface Issacs-Kidd tows (May 12 - 26, 1969). Open and solid circles show locations of sampling, and solid circles show the presence of cottid larvae in catches. A, Myoxocephalus scorpius; B, M. octodecemspinosus.


A
65
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63
62
61
60
59
49
48
47
46
ANTICOSTI
LAURENTIAN CHANNEL
GASPE
MAGDALEN SHALLOWS
NFLD.
P.E.I.
N.B.
NOVA SCOTIA
B
65
64
63
62
61
60
59
49
48
47
46
ANTICOSTI
LAURENTIAN CHANNEL
GASPE
MAGDALEN SHALLOWS
NFLD.
P.E.I.
N.B.
NOVA SCOTIA

Figure 35

Fig. 36. Distribution of cottid larvae in the Gulf of St. Lawrence based on midwater to surface Issacs-Kidd tows (May 12 - 26, 1969). Open and solid circles show locations of sampling, and solid circles show the presence of cottid larvae in catches. A, Hemitripterus americanus; B. Triglops murrayii.

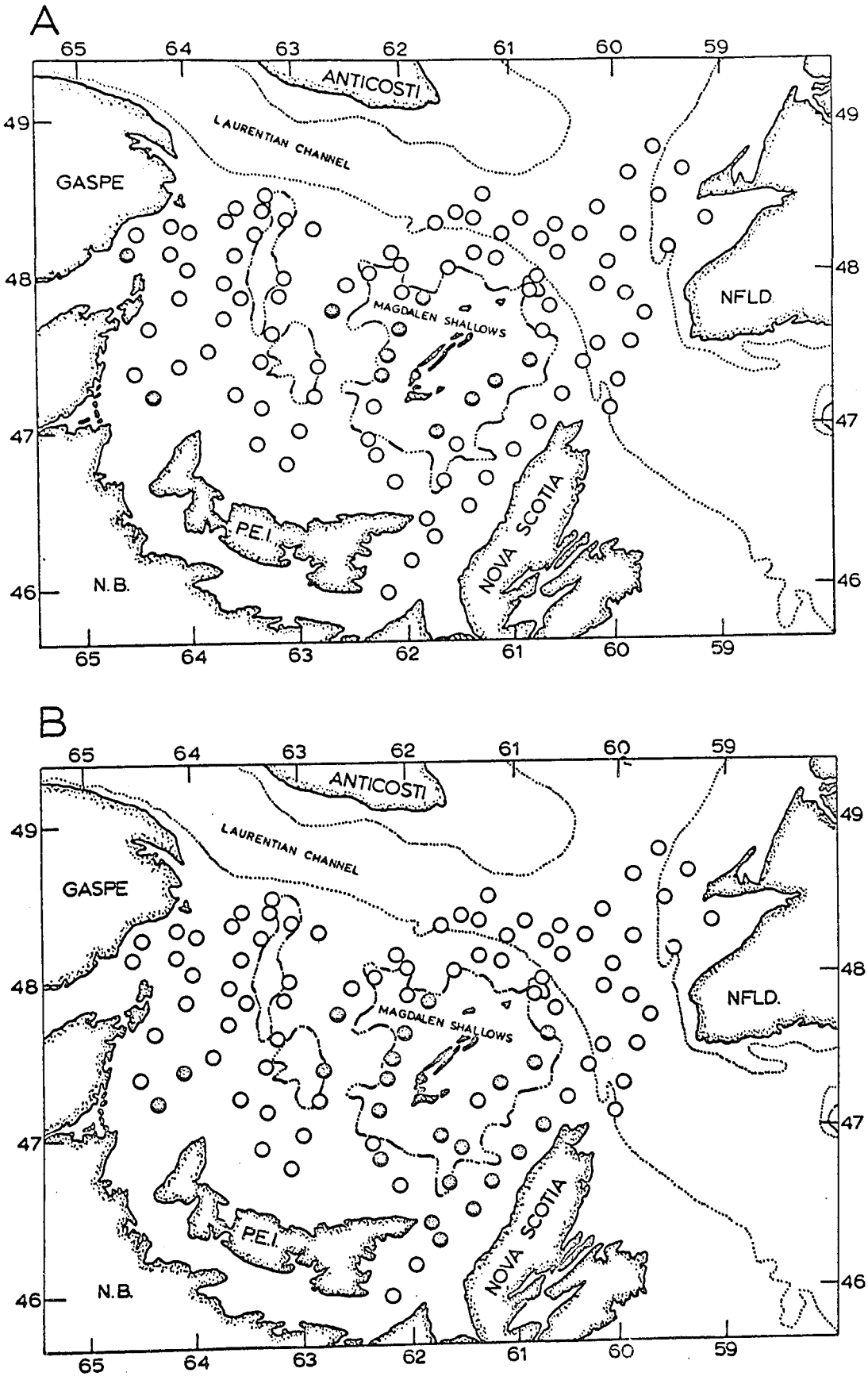
A
65
64
63
62
61
60
59
49
48
47
46
ANTICOSTI
LAURENTIAN CHANNEL
GASPE
MAGDALEN SHALLOWS
NFLD.
P.E.I.
N.B.
NOVA SCOTIA
B
65
64
63
62
61
60
59
49
48
47
46
ANTICOSTI
LAURENTIAN CHANNEL
GASPE
MAGDALEN SHALLOWS
NFLD.
P.E.I.
N.B.
NOVA SCOTIA

Figure 36

M. aeneus (6.55%), and H. americanus (1.63%).

In August and September cruises (E.E.P. 52 and 53) no cottid larvae were collected.

4. Horizontal Distribution

In both the surface tows and the Issacs-Kidd tows larvae of all cottid species were concentrated within the Magdalen Shallows. The Laurentian Channel was almost completely devoid of cottid larvae (Figs 34-36).

Figs 37-38 show the abundance of cottid larvae (per 100 minutes towing time) in relation to the total depth of the water column. In the surface tows the larvae were sampled at places where the water column ranged from 10 - 150 fathoms. However, maximum number of larvae were present where the water was only 10-20 fathoms deep. The number of larvae decreased considerably in catches where the water column exceeded 40 fathoms. In the Issacs-Kidd tows (Fig 38) the larvae were caught only in tows which were made when the water depth ranged from 10 - 80 fathoms, but the maximum number was again in catches made in waters of shallowest depths (10 - 30 fathoms). Since the number of tows was unequal, these data could only be treated qualitatively and without much statistical confidence. The number of cottid larvae per tow varied considerably.

Fig. 37. Distribution of cottid larvae in relation to depth of the bottom, based on surface tows made by metre nets in the Gulf of St. Lawrence (May 12 - 26, 1969). On the horizontal axis the numbers in the top two rows show range of bottom depth, and the bottom row shows the number of tows in parentheses.

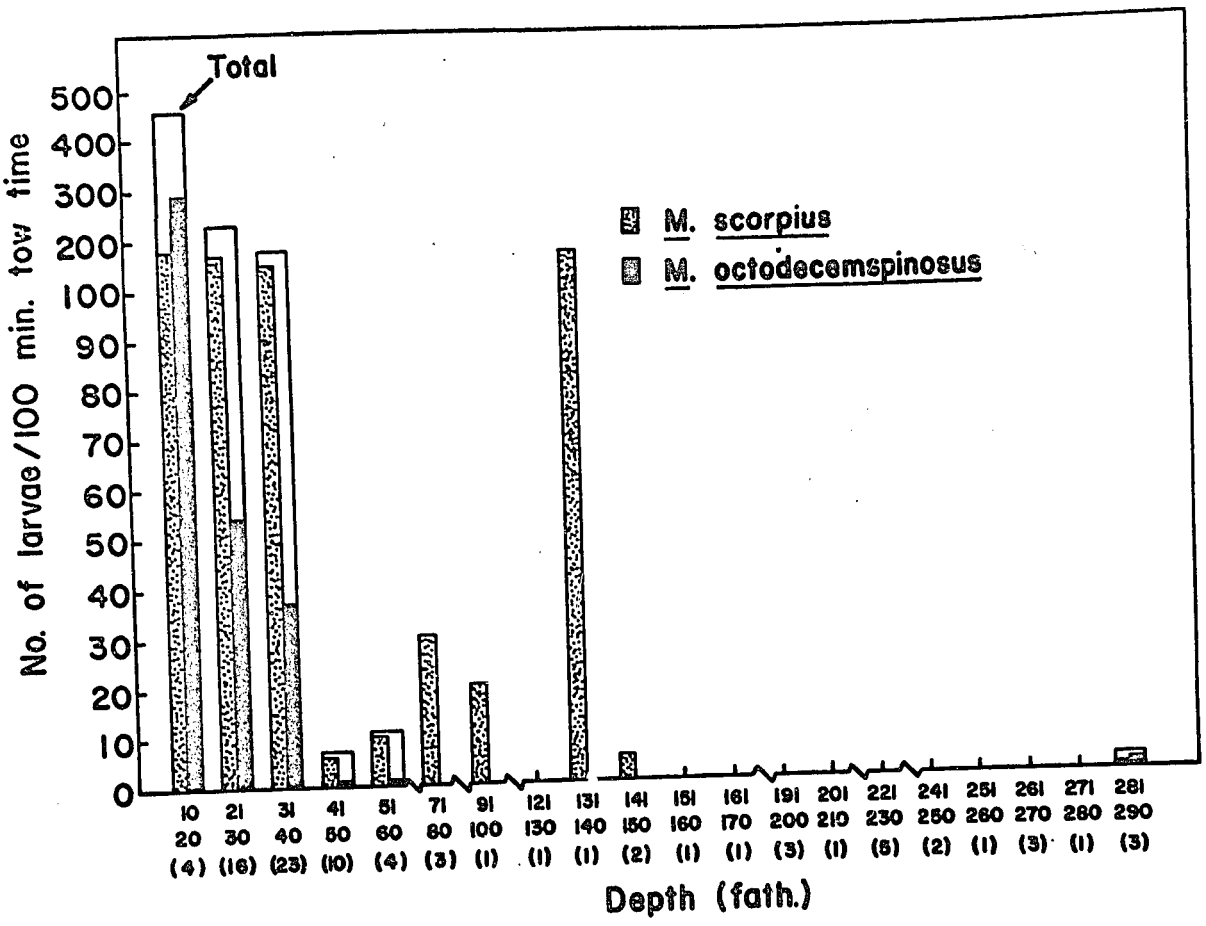
Total
M. scorpius
M. octodecemspinosus
No. of larvae/100 min. tow time
500
400
300
200
100
90
80
70
60
50
40
30
20
10
0
10 21 31 41 51 71 91 121 131 141 151 161 191 201 221 241 251 261 271 281
20 30 40 50 60 80 100 130 140 150 160 170 200 210 230 250 260 270 280 290
(4) (16) (23) (10) (4) (3) (1) (1) (1) (2) (1) (1) (3) (1) (6) (2) (1) (3) (1) (3)
Depth (fath.)

Figure 37

Fig. 38. Distribution of cottid larvae in relation to depth of the bottom, based on midwater to surface Issacs-Kidd tows in the Gulf of St. Lawrence (May 12 - 26, 1969). On the horizontal axis the numbers in the top two rows show range of bottom depth, and the bottom row shows the number of tows in parentheses.

5. Vertical Distribution

The surface tows and the Issacs-Kidd tows were made, during the day as well as at night, throughout the Gulf of St. Lawrence. The diurnal variation in surface catches of cottid larvae, in May is shown in Fig 39. Larvae began to appear at the surface in the late afternoon hours and were most abundant between 8 p.m. and 4 a.m. After 4 a.m. the number of cottid larvae dropped off drastically and from then on they were least abundant till about 4 p.m. In June the abundance of cottid larvae in the surface tows showed similar trends (Fig 40). Most of the larvae were taken between 10 p.m. and 4 a.m. An insignificant number of larvae was collected between 4 and 8 a.m.

The abundance of cottid larvae in the Issacs-Kidd tows did not show the same trends observed above (Fig 41). Larvae were caught more or less equally throughout the 24 hours, and no peaks of abundance were obvious. This suggested that although the cottid larvae were more abundant at the surface at night, their distribution in midwaters was more or less regular, both during the day and at night.

6. Discussion

A progressive decrease in larval abundance from May through August coincides with an increase in temperature.

Fig. 39. Distribution of cottid larvae in relation to time of the day, based on surface tows made by metre nets in the Gulf of St. Lawrence (May 12 - 26, 1969). Number of tows in parentheses.

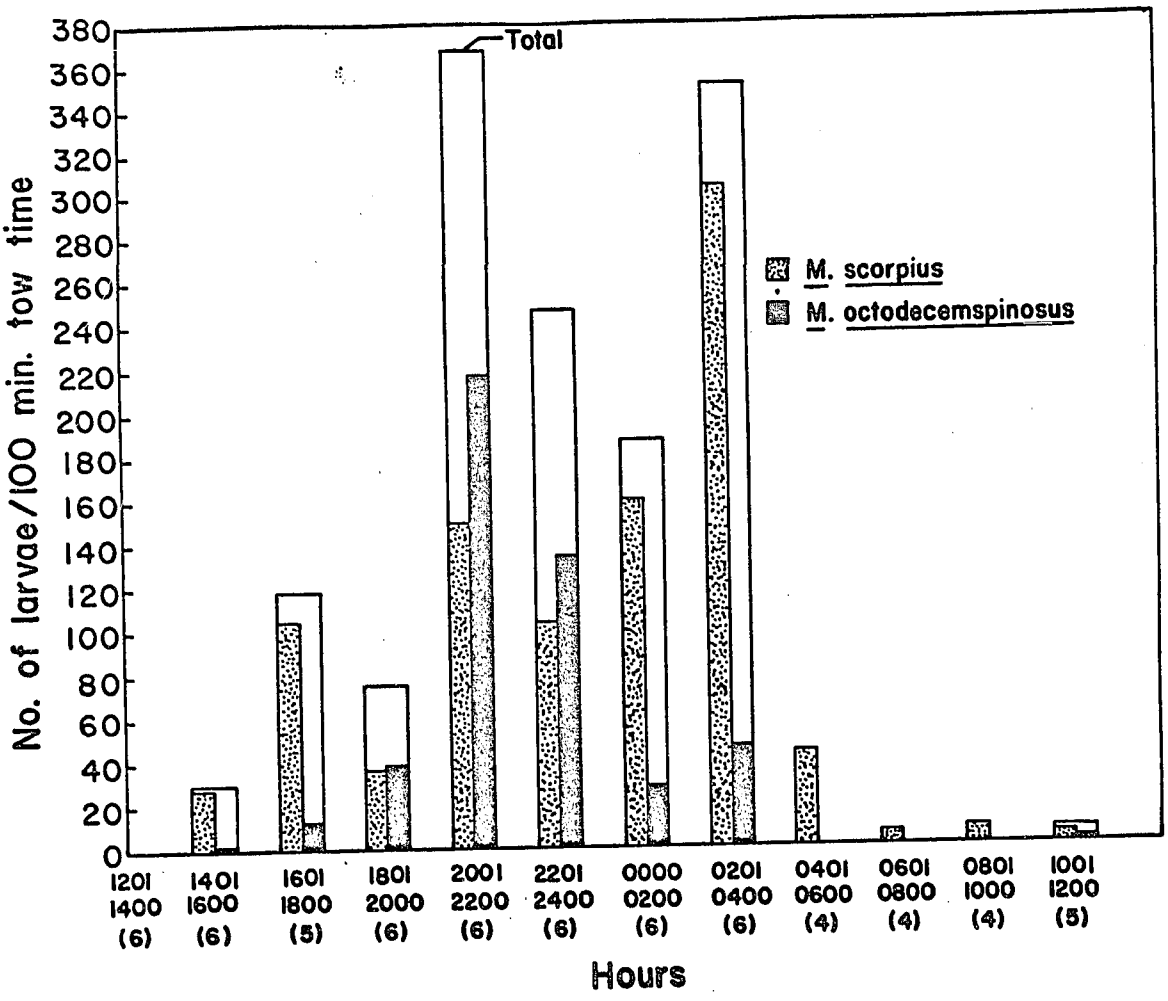
No. of larvae/100 min. tow time
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
Total
M. scorpius
M. octodecemspinosus
1201 1400 (6)
1401 1600 (6)
1601 1800 (5)
1801 2000 (6)
2001 2200 (6)
2201 2400 (6)
0000 0200 (6)
0201 0400 (6)
0401 0600 (4)
0601 0800 (4)
0801 1000 (4)
1001 1200 (5)
Hours

Figure 39

Fig. 40. Distribution of cottid larvae in relation to the time of the day, based on surface tows made by metre nets in the Gulf of St. Lawrence (June 11 - 20, 1969). Number of tows in parentheses.

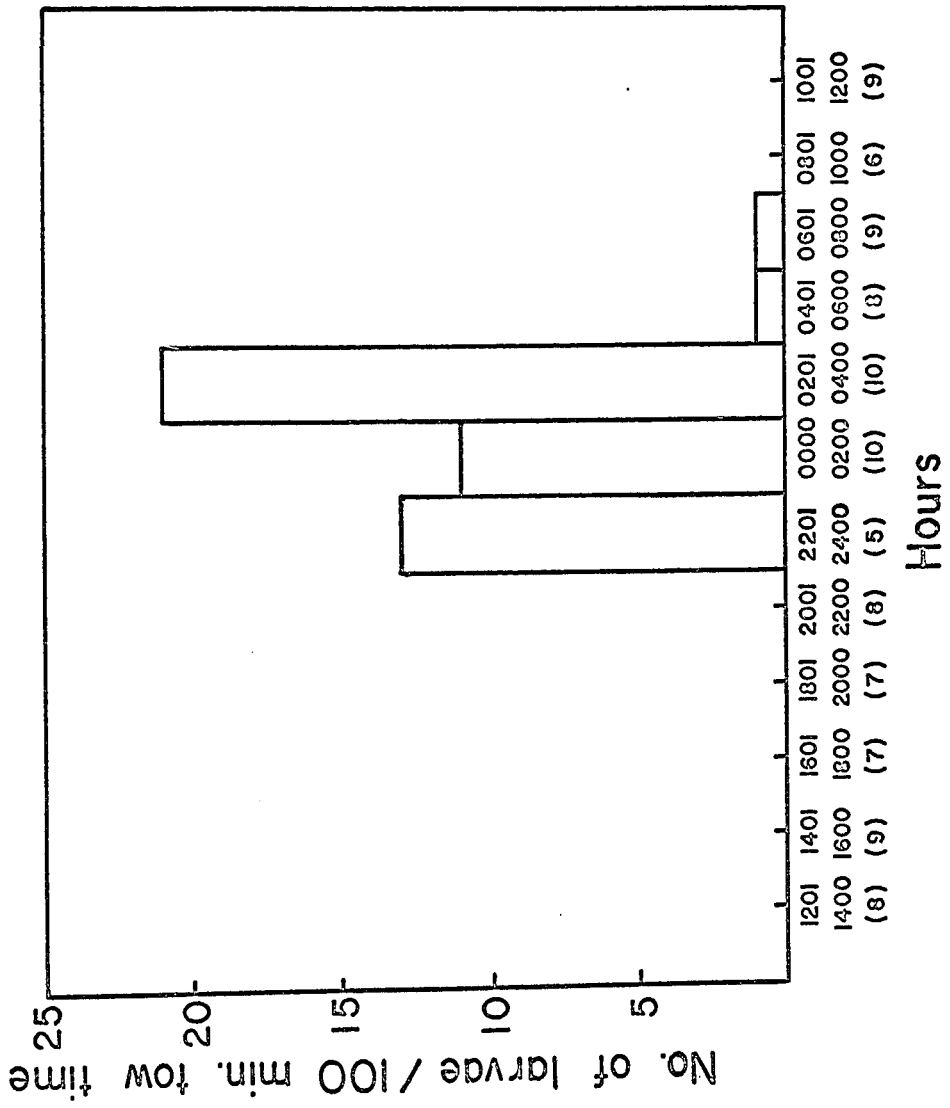
No. of larvae / 100 min. tow time
25
20
15
10
5
1201
1401
1601
1801
2001
2201
0000
0201
0401
0601
0801
1001
1400
1600
1800
2000
2200
2400
0200
0400
0600
0800
1000
1200
(8)
(9)
(7)
(7)
(8)
(5)
(10)
(10)
(3)
(9)
(6)
(9)
Hours

Figure 40

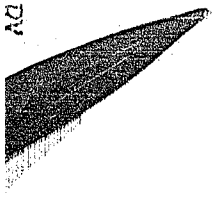

Fig. 41. Distribution of cottid larvae in relation to time of the day, based on midwater to surface Issacs-Kidd tows in the Gulf of St. Lawrence (May 12 - 26, 1969). Number of tows in parentheses.

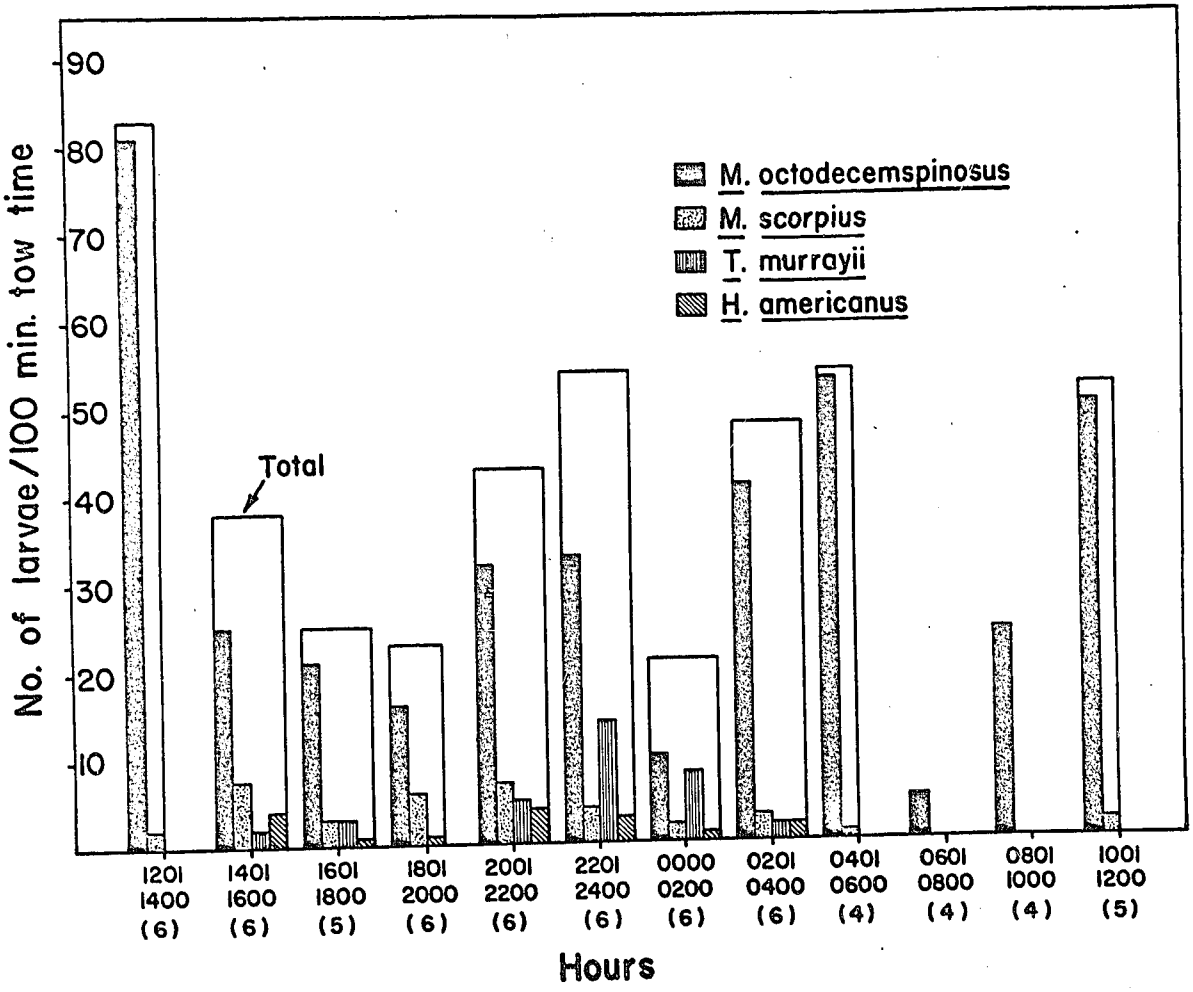
No. of larvae/100 min. tow time
90
80
70
60
50
40
30
20
10
M. octodecemspinosus
M. scorpius
T. murrayii
H. americanus
Total
1201 1400 (6)
1401 1600 (6)
1601 1800 (5)
1801 2000 (6)
2001 2200 (6)
2201 2400 (6)
0000 0200 (6)
0201 0400 (6)
0401 0600 (4)
0601 0800 (4)
0801 1000 (4)
1001 1200 (5)
Hours

Figure 41

During the sampling period in May, the average daily temperature at the surface ranged from 2.5° to 5.7°C (Fig 42). At this time cottid larvae were quite abundant in the surface tows and Isaacs-Kidd tows. During June the surface temperature ranged from 7.4° - 13.2°C and the number of larvae had decreased drastically in all the catches (Table 3). In August the average surface temperature was the highest (15° - 19.5°C) and no cottid larvae were caught during this time or in September when the surface termperature of water was about 15°C.

Lauzier (1957) and Lauzier et al. (1957) noted that the waters in the southwestern Gulf of St. Lawrence were highly stratified during the summer. A warm surface layer of low salinity separates the cold layer by a sharp thermocline (Fig 43). At the height of the summer (middle of July to the middle of August) the warm surface layer with high termperatures (13° - 17°C) is as thin as 5-10 metres. The waters below the thermocline are much colder than at the surface, and at 50 m., in mid-summer, water colder than that found either in spring or in autumn extends over the general area of the Gulf of St. Lawrence. Since the termperatures below the thermocline are colder and perhaps more favourable for these essentially cold water fish, they probably move down in the deeper waters.

However, the possible influence of other factors, e.g. photoperiod, on the abundance of larvae cannot be ignored.

Fig. 42. Daily average temperature of surface water in the Gulf of St. Lawrence during the sampling period of May to September, 1969.

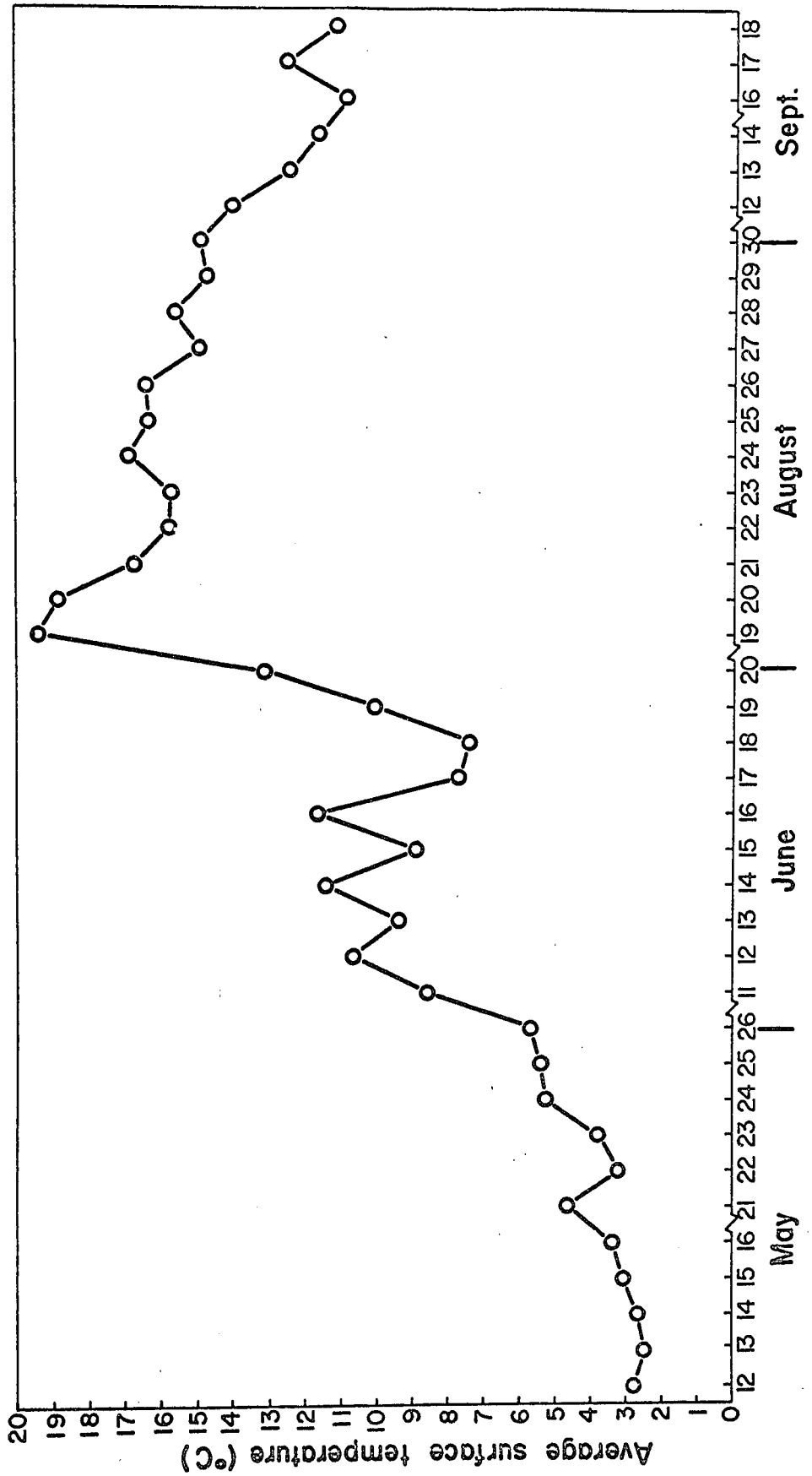
Average surface temperature (°C)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
May
June
August
Sept.

Figure 42

A possible reason for their absence during the summer months could be their avoidance of nets as the larvae in June were very well developed. Most of the larvae of M. octodecemspinosus had started to develop juvenile pigmentation laterally, in the form of saddle bars. But the larvae were not caught even in the Isaacs-Kidd (mid-water) tows. The Isaacs-Kidd trawl is a high speed sampler, particularly designed to eliminate the error of net avoidance by pelagic larval fish.

Differences in the numbers of M. scorpius and M. octodecemspinosus larvae observed in surface tows and midwater tows (Table 3) suggest that although both species are more abundant at the surface, larvae of M. octodecemspinosus are relatively more abundant in mid-waters. This pattern of vertical distribution suggests a partial segregation of larvae of the two species. Stevenson (1962), among many other authors, reported similar surface concentrations of the larvae of Pacific Herring, Clupea pallasi.

The absence of cottid larvae in the waters of the Laurentian Channel could be attributable to

Fig. 43. A, Monthly progress in development of surface layer in southern Gulf of St. Lawrence. B, Semi-monthly averages of water temperatures at two depths from North Rustico, P.E.I. (reproduced from Messieh, 1969).

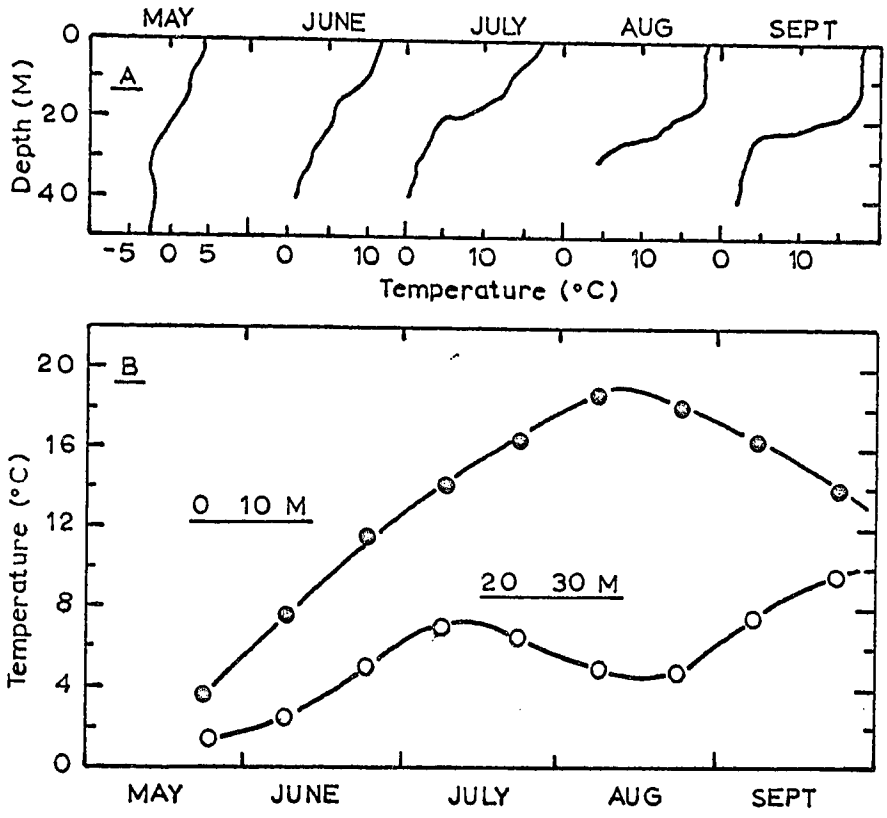
MAY
JUNE
JULY
AUG
SEPT
A
Depth (M)
0
20
40
-5 0 5 0 10 0 10 0 10 0 10
Temperature (°C)
B
0 10 M
20 30 M
Temperature (°C)
0
4
8
12
16
20
MAY
JUNE
JULY
AUG
SEPT

Figure 43

the strong currents in the channel. The currents through Cabot Strait have been studied by Dawson (1913), Sandstrom (1919) and MacGregor (1956). The circulation in Cabot Strait is characterized by an inflowing and an outflowing current. The inflowing current on the Newfoundland side is inconsistent and ranges from 0.25 m/sec to 0.75 m/sec in August. The outflowing current on the Cape Breton side of the Strait is relatively constant with a velocity as great as 1 m/sec at the surface. Bishai (1960) calculated experimentally the response of the larvae of Atlantic herring, Clupea harengus to various velocities of currents. Herring larvae (6.5 - 7.5 mm long) at a current velocity between 0.58 and 1.03 cm/sec maintained themselves against the current and swam upstream. At higher velocities, the larvae drifted passively with the current but nevertheless the rate of drifting was less than the current velocity. The velocities of currents reported through the Cabot Strait (up to 1 m/sec) would probably remove the Cottid larvae from the area.

The most plausible explanation for the absence of cottid larvae in the Laurentian Channel could be the fact that the cottid species on our Atlantic Coast are coastal, shallow water species (Bigelow and Schroeder, 1953; Leim and Scott, 1966). The adults of M. scorpius; M. octodecemspinosus and H. americanus are found in waters shallower than

50 fathoms. M. aeneus is found in waters up to 15 fathoms. Nothing is known about the depth distribution of T. murrayii on our coast but in the Barents Sea it is found in 50 - 250 fathoms of water. The depths in the Laurentian Channel range from 200 - 350 fathoms (Lauzier and Trites, 1958). All these species spawn in shallow waters and often migrate into estuaries (Bigelow and Schroeder, 1953). In the Gulf of St. Lawrence all the reports of these species are from the Magdalen Shallows and other shallow coastal areas. Therefore these species do not spawn in the Laurentian Channel. Larvae of these cottid species are good swimmers. I observed the larvae of M. aeneus and M. octodecemspinosus in aquaria at St. Andrews Biological Station, and noticed that even the yolk sac larvae swam quite vigorously when the water in the tank was disturbed. It is suggested that these larvae concentrate in shallower waters close to the spawning grounds and follow the main stream of the Gaspe Current which is slowly to the southeast.

The abundance of cottid larvae in the surface tows and Issacs-Kidd tows over the 24 hour period showed a tendency of cottid larvae to migrate in the surface waters at night. Such vertical migrations of larvae are, however, not uncommon among marine teleostean fishes, and have been reported in a number of species other than cottids (Russell, 1928; Bridger, 1956; Strasburg, 1960; Stevenson, 1962; Lewis and Wilkens, 1971).

Since diurnal variations in distribution of larval fish are associated with phototaxis and brightness discrimination (Blaxter, 1969) it has been generally argued that lack of larvae by day is due to greater ability of the larvae to escape sampling gear during the day than during the night (Bridger, 1956; Colton, 1965). By using high speed gear Colton (1965) found no significant differences in the day and night catches of larval and juvenile haddock and no variation in the depth distribution between day and night. However, behaviour differ from species to species and what is true for haddock larvae may not be true for the cottid larvae. In the absence of data, of catches at various depths by Isaacs-Kidd (high speed sampler), it is difficult to refute the night time surface concentrations of the cottid larvae observed in this study.

D. Passamaquoddy Bay, New Brunswick

1. Description of the Area

Passamaquoddy Bay is an inlet with narrow passages to the Bay of Fundy (Fig 44). It receives fresh water from the St. Croix, the Magaguadavic, and Digdeguash Rivers. The total area of the Bay is roughly 65 square nautical miles (Chevrier and Trites, 1960). It is shallow in the northern part and becomes progressively deeper towards the passages. Drift bottle experiments by Chevrier and Trites (1960) suggested a "counter-clockwise" circulation in the Passamaquoddy Bay, a variable flow through Letite passage, and a variable flow through western passage. Winds from the south and southwest in the summer tend to confine surface waters in the Passamaquoddy Bay, while the winds from the north and west during winter remove surface waters from the Bay.

2. Sampling Methods

Eighty plankton tows were made at 25 stations in a section of northern Passamaquoddy Bay (Fig 45). Sampling was done from April 22 to 30, 1970. All the tows were made with 1/2 metre nylon nets of 30 Grit Gauge (0.75 mm mesh) mostly in 2-10 fathoms of water. Some tows were made in waters 15-20 fathoms deep. The net was towed for 10 min. at an approximate speed of 2 knots. The dotted line in Fig. 45 separates the "outside" stations where the

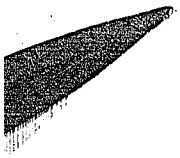

Fig. 44. Map of Passamaquoddy Bay showing main rivers, and passages to the Bay of Fundy. The arrow on the inset shows the location of Passamaquoddy Bay.

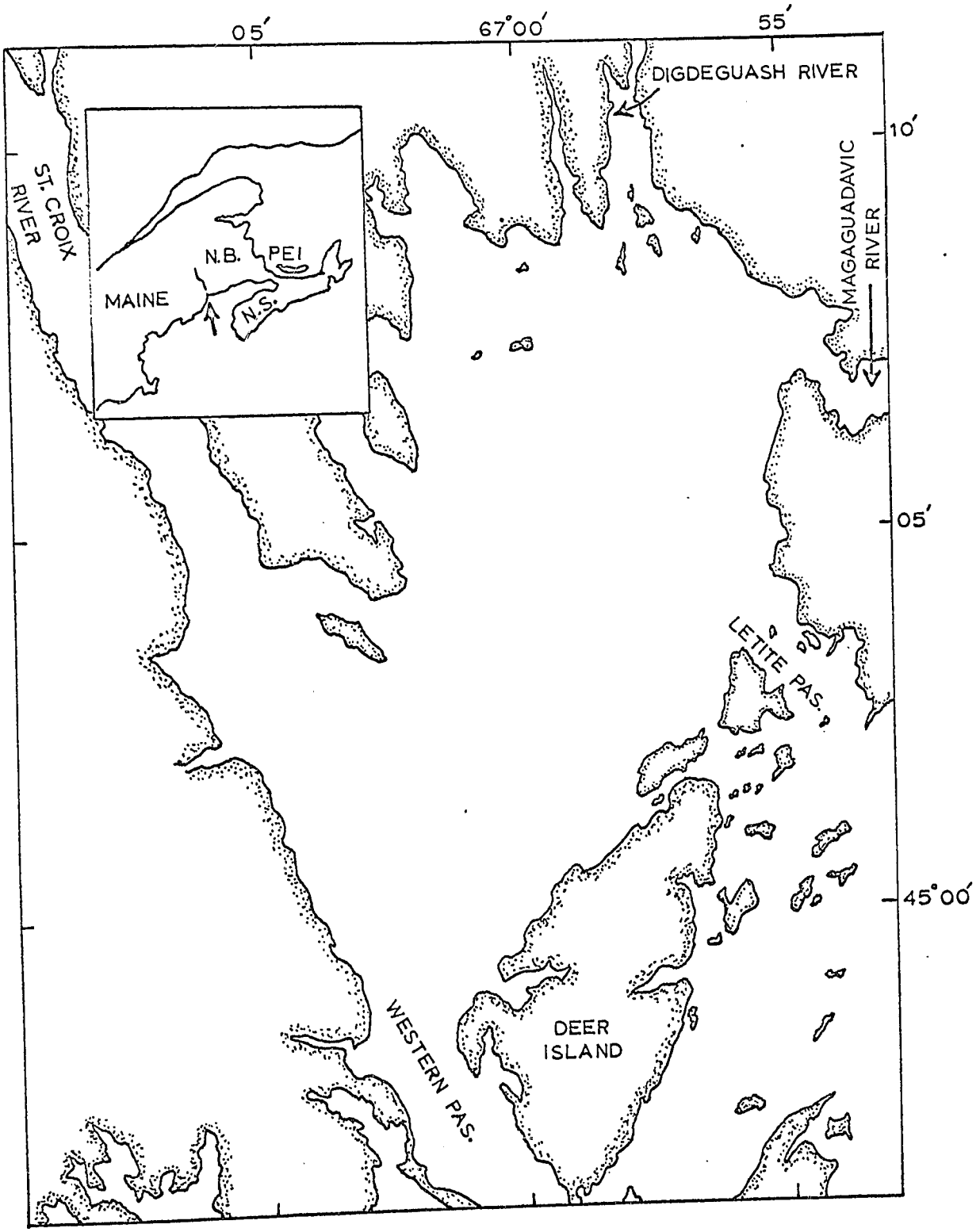
05′
67°00′
55′
DIGDEGUASH RIVER
10′
ST. CROIX RIVER
MAGAGUADAVIC RIVER
N.B.
PEI
MAINE
N.S.
05′
LETITE PAS.
45°00′
WESTERN PAS.
DEER ISLAND

Figure 44

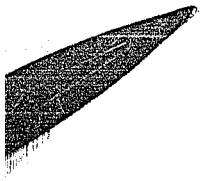

Fig. 45. Sampling area in the northern, Passamaquoddy Bay, New Brunswick. Open and solid circles show sampling locations. Solid circles show the number of cottid larvae (i.e. Myoxocephalus aeneus and M. octodecemspinosus) per 100 min. tow time. Dotted line divides the "inside" shallower stations from the "outside" deeper stations. Figures besides circles are station numbers.

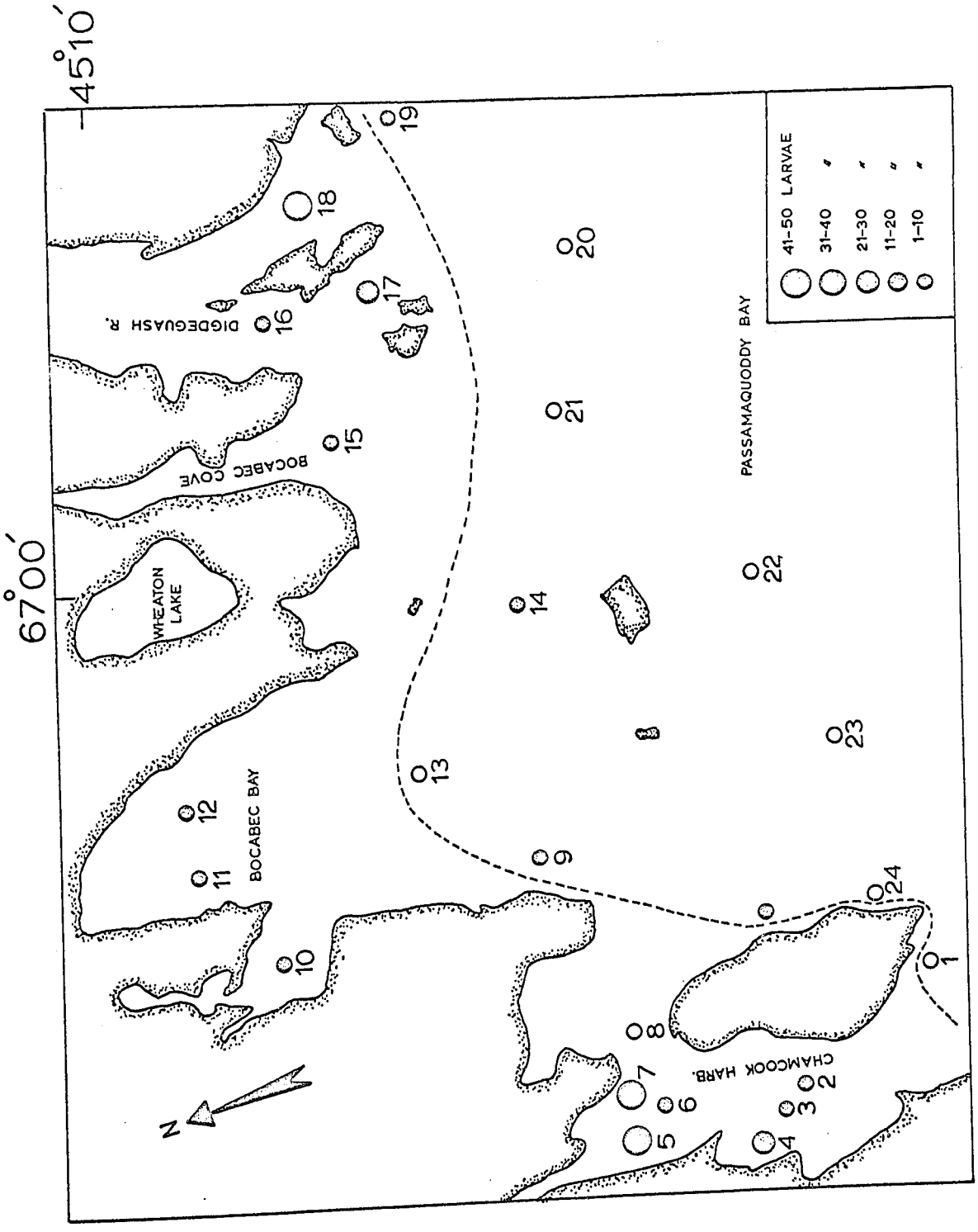
45°10'
67°00'
41-50 LARVAE
31-40 "
21-30 "
11-20 "
1-10 "
DIGDEGUASH R.
BOCABEC COVE
WHEATON LAKE
BOCABEC BAY
PASSAMAQUODDY BAY
CHAMCOOK HARB.
N

Figure 45

depth ranged from 15-35 ft. At the outside stations 37 tows were made while at the inside stations 43 tows were made.

3. Results and Discussion

Larvae of only two cottid species i.e., Myoxocephalus aeneus and M. octodecemspinosus were present in tows, seldom in large concentrations. The maximum abundance of cottid larvae in the Gulf of Maine area is usually in the middle of March (see section on seasonal abundance, Boothbay Area). A total of 91 larvae were caught. Larvae of M. aeneus were relatively more abundant (70%) than those of M. octodecemspinosus (30%). Some of the larvae of M. aeneus still had yolk while all the larvae of M. octodecemspinosus were fairly well developed. Fig. 46 shows the length frequency distribution of the two species. M. aeneus larvae showed a normal unimodal distribution while M. octodecemspinosus larvae did not show any particular mode. The small number of the larvae of M. octodecemspinosus and their length frequency distribution indicated that the species spawned earlier in the season than M. aeneus. M. octodecemspinosus spawns from late November to January (Morrow, 1951), while M. aeneus spawns from January to March (Bigelow and Schroeder, 1953). It is, therefore, quite reasonable to expect more larvae of M. aeneus than M. octodecemspinosus in late April

Fig. 46. Length frequency distributions of two species of cottid larvae caught in tow nets in Passamaquoddy Bay from April 22 - 30, 1970.

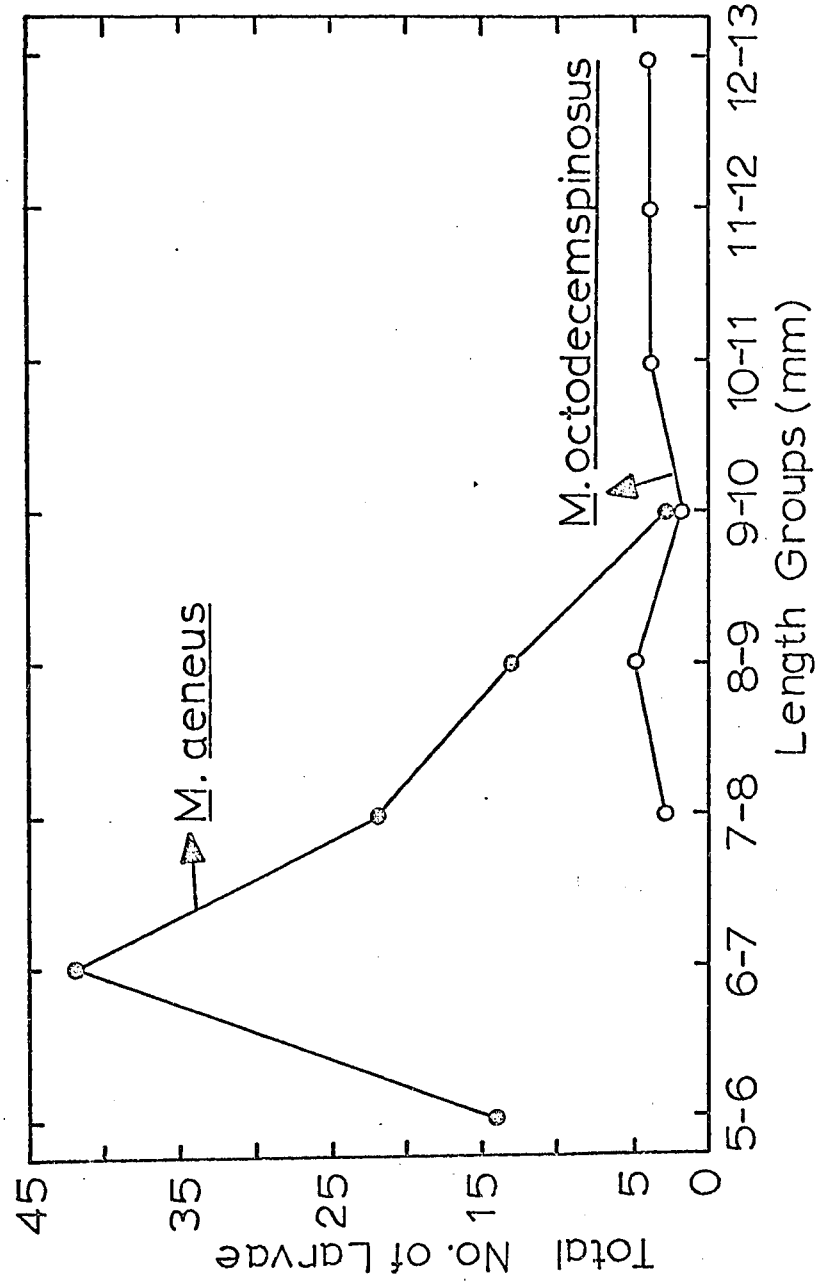
Total No. of Larvae
45
35
25
15
5
0
5-6
6-7
7-8
8-9
9-10
10-11
11-12
12-13
Length Groups (mm)
M. aeneus
M. octodecemspinosus

Figure 46

The horizontal distribution of the cottid larvae is shown in Fig 45. The arbitrary dotted line separates the "inside" stations from the "outside" stations. At the "inside" stations 43 tows and at the "outside" stations 37 tows were made. The number of larvae indicated at each station is the number per 100 minutes of towing. Larvae were most abundant at the "inside" stations where the water was shallower and relatively enclosed. Only 9% of the total number of cottid larvae were caught at the outside stations where the water was relatively deeper (100 - 180 ft.), while 91% were caught at the inner stations with shallower waters (10-30 ft).

Surface temperatures during the sampling period ranged from 6.8° - 9°C and the surface salinities varied between 15.1 and 28.3‰. See the table below.

Stn. No.	1	2	3	9	10	11	13	14	15
Temp. °C	--	--	--	9.0	--	--	8.0	6.9	8.0
Sal. ‰	27.4	28.3	27.1	20.4	25.5	27.0	21.5	19.5	17.1

Stn. No.	16	17	18	19	20	21	22	23
Temp. °C	6.8	--	7.0	7.2	7.0	7.5	8.0	7.1
Sal. ‰	21.9	22.9	17.7	16.2	15.1	22.1	15.1	17.5

Extreme fluctuations of salinities were observed due to the discharge from the Digdeguash River and other small streams.

E. Boothbay Harbour Area, Maine

1. Description of the Area

The Boothbay Harbour sampling area comprised the upper and lower parts of two estuaries, Sheepscot and Damariscotta; and extended about 4 miles offshore (Fig 47). These two rivers are of moderate size and flow southward to the Gulf of Maine. Stickney (1959) has given an account of the general ecology of the Sheepscot estuary. The Sheepscot estuary can be divided into two parts. The upper section within about six nautical miles of the river mouth, is typically estuarine with marked dilution by the river and subject to great seasonal and tidal variations in salinity. The lower section of the estuary extends about 14 nautical miles down to the Gulf of Maine. The depth in the upper estuary generally varies between 1 and 10 meters, and in the lower estuary between 20 and 60 meters. Most of the bottom in the upper estuary as well as the lower estuary is covered by a muddy sediment composed largely of silt with some fine sand and clay. The intertidal zone is, however, generally rocky.

2. Sampling Methods

Sampling was done by the U.S. National Marine Fisheries Service from January to May in 1968 and 1970. Each year 8 cruises were made. During each cruise a three stepped

Fig. 47. Boothbay Area showing eight sampling locations of 1968 and 1970 collections.

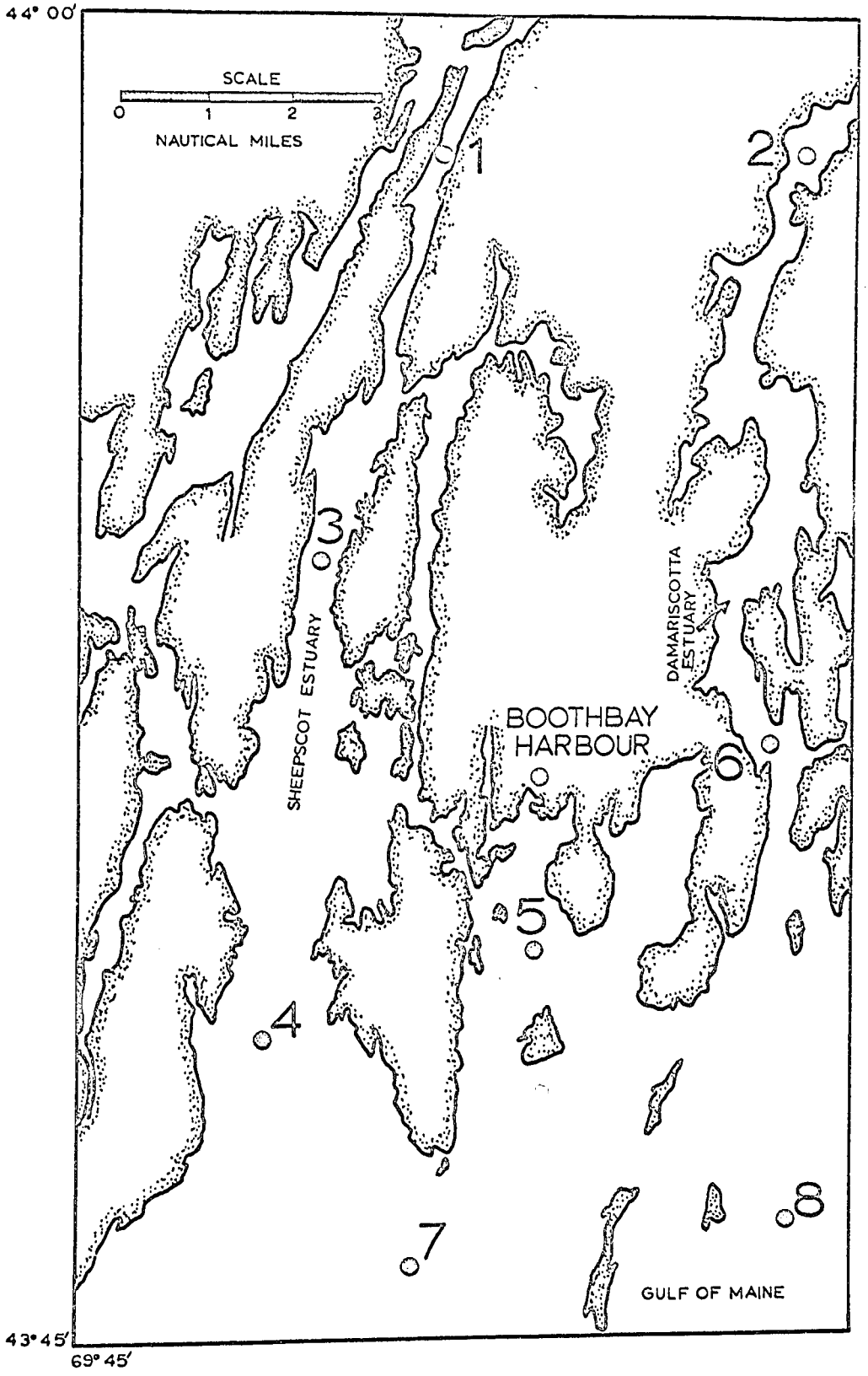
44° 00′
SCALE
0 1 2 3
NAUTICAL MILES
1
2
3
4
5
6
7
8
SHEEPSCOT ESTUARY
DAMARISCOTTA ESTUARY
BOOTHBAY HARBOUR
GULF OF MAINE
43° 45′
69° 45′

Figure 47

oblique tow of 1/2 hour duration was made at each station (Fig 47). The net was towed for 10 minutes at the bottom, middepth, and surface. Larvae were collected with tow nets (described by Graham and Vaughan, 1966).

3. Seasonal Abundance

The total number of cottid larvae caught during each cruise from January to May is shown in Fig. 48. In both years, 1968 and 1969, the maximum number of larvae was caught from late February to the middle of March. The larvae were very few in January and early part of February, but in the later part of February the number increased sharply. In April and May the number of larvae decreased considerably and a negligible number of larvae was caught in May cruises (Fig 48). The surface temperature of water was the lowest when the cottid larvae were most abundant in February and March. In 1968 the average February - March temperature at surface was 0.7^{o} - 1.1^{o}C and in 1970 it was slightly higher i.e., 2.6^{o} - 2.8^{o}C (Fig 48). In April and May when the cottid larvae were least abundant the average surface temperature was the highest (4.2^{o} - 8.2^{o} C in 1968 and 5.1^{o} - 9.7^{o}C in 1970).

4. Species Composition and Length Distribution

Small samples drawn from the collections of each

Fig. 48. Seasonal abundance of cottid larvae in Boothbay area. Circles connected by dotted lines show average surface temperatures on sampling dates. A, 1968; B, 1970.

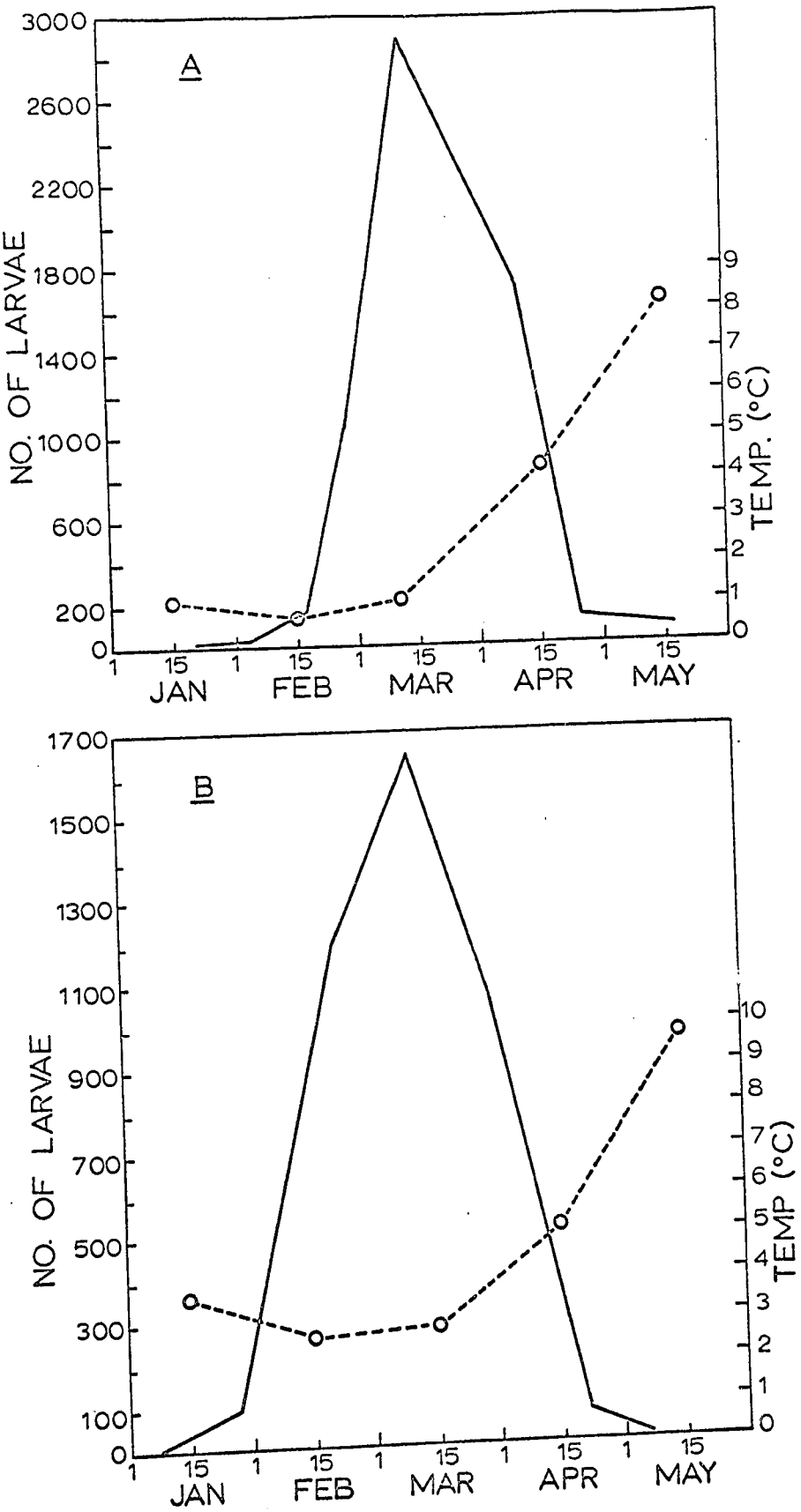
A
NO. OF LARVAE
TEMP. (°C)
3000
2600
2200
1800
1400
1000
600
200
0
9
8
7
6
5
4
3
2
1
0
1
15
JAN
FEB
MAR
APR
MAY
B
NO. OF LARVAE
TEMP (°C)
1700
1500
1300
1100
900
700
500
300
100
0
10
9
8
7
6
5
4
3
2
1
0

Figure 48

month of 1970 sampling were used to analyze the species composition. The total sample was not available for analysis. Larvae of 4 species of cottids were identified. These species were Myoxocephalus scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii. The larvae of M. aeneus were the smallest of all the other cottid larvae (Fig 49). Their average length, through the sampling period, varied from 6.93 - 8.21 mm as opposed to 7.86 - 11.6 mm in M. octodecemspinosus, 7.75 - 13.81 mm in M. scorpius, and 10.43 - 15.18 in T. murrayii. The larvae of T. murrayii showed the highest mean values and relatively larger variation in size within each sample. The larvae of M. scorpius were generally longer than those of M. octodecemspinosus but there was a great deal of overlap (Fig 49).

5. Horizontal Distribution

Most of the cottid larvae were taken at stations 1 and 2 in the upper estuaries and at station 6 in the lower Damariscotta estuary (Table 4). The depth at these stations varied between 18 and 24 meters. In the offshore stations 7 and 8 the number of larvae caught was negligible (.65% to 1.4%). The total depth of these offshore stations was 55 to 75 meters. Other stations showed intermediate values. In February and March when the cottid larvae are most abundant the salinities at the upper stations (i.e., 1 and 2) generally vary between 24‰

TABLE 4. Number of cottid larvae collected at each station and average depth at each station in the Boothbay Harbour Area (1968 and 1970 collections). Percentage of catch in parentheses.

Station No.	1	2	3	4	5	6	7	8
Depth (Metres)	20	18	22	29	15	24	55	75
No. of larvae (1968)	710 (11.6)	3159 (51.7)	234 (3.8)	139 (6.5)	397 (6.5)	1425 (23.3)	46 (0.8)	4 (0.65)
No. of larvae (1970)	111 (2.7)	3010 (74.3)	76 (1.8)	19 (0.5)	376 (9.3)	354 (8.7)	51 (1.3)	56 (1.4)

and 25‰ (Stickney, 1959) while at the offshore stations the salinity readings are about 30‰. The surface temperature variations between the upper stations and lower stations during the period of maximum abundance are very little (3-4°C).

6. Discussion

The seasonal abundance of the larvae confirmed the earlier reports that the cottids on the Atlantic Coast of North America spawn during the winter months with the maximum spawning in December and January (Bigelow and Schroeder, 1953). The maximum abundance of the larvae was in late February and the middle of March. The incubation period for cottids of our coast, at least in the species of the genus Myoxocephalus, is about 2-3 months (Morrow, 1951; Ennis, 1970). The maximum spawning of these species, therefore, must have taken place in December and January. In the literature M. scorpius and M. octodecemspinosus are known to spawn only during the winter. M. aeneus and T. murrayii also spawn during winter but Cox (1921) reported ripe females of M. aeneus in June and of T. murrayii in July from the Gulf of St. Lawrence. This must be an exceptional case, because young larvae of M. aeneus and T. murrayii in the Gulf of St. Lawrence or elsewhere were never found in this

Fig. 49. Seasonal variations in lengths of cottid larvae collected in tow nets at Boothbay area during 1970. Horizontal lines, ranges; vertical lines on bars, means; bars, two standard deviations of the means.

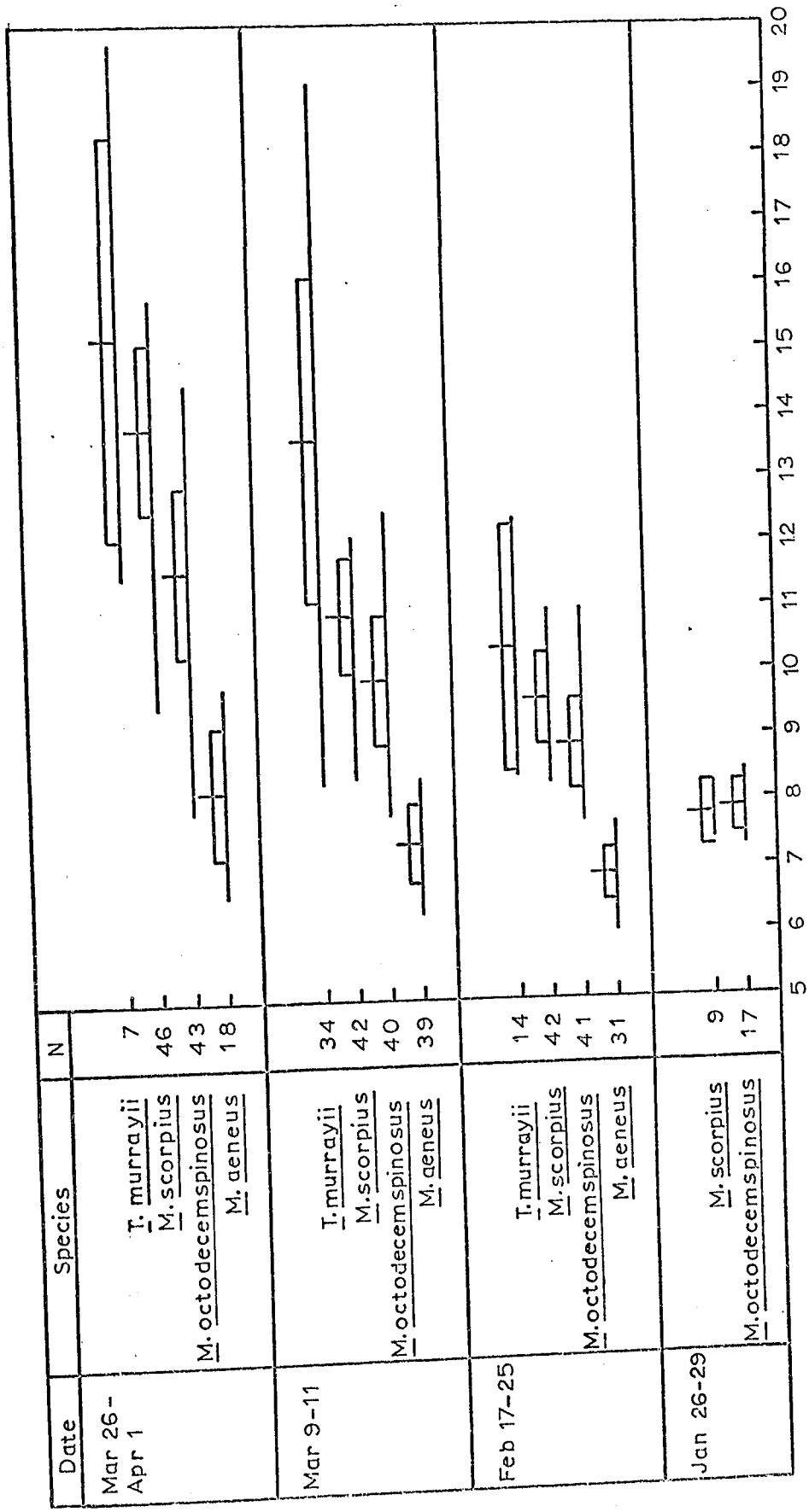
Date
Species
N
Mar 26-Apr 1
T. murrayii 7
M. scorpius 46
M. octodecemspinosus 43
M. aeneus 18
Mar 9-11
T. murrayii 34
M. scorpius 42
M. octodecemspinosus 40
M. aeneus 39
Feb 17-25
T. murrayii 14
M. scorpius 42
M. octodecemspinosus 41
M. aeneus 31
Jan 26-29
M. scorpius 9
M. octodecemspinosus 17
5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Total Length (mm)

Figure 49

study in June and July. T. murrayii is believed to have a long spawning period with intermittent spawning (Musick and Able, 1969). Running ripe females and males were collected from the Gulf of Maine in October by these authors. Probably due to this long and intermittent spawning period the larvae of T. murrayii showed a wider range of lengths (Fig. 49).

Horizontal distribution of the larvae in the Boothbay Area suggested that they tend to congregate in shallower waters where the water is less saline. The local concentrations at station 1, 2, and 6 could also be due to the great availability of locally produced plankton on which the cottid larvae feed during the pelagic phase of their life.

Graham and Boyar (1965) reported larvae of only two species (M. scorpius and M. octodecemspinosus from the Boothbay area. They collected the larvae of M. scorpius from January to May, and those of M. octodecemspinosus only in April and May. The lengths of M. scorpius ranged from 7.5 - 15.1 mm and those of M. octodecemspinosus from 6.4 to 6.8 mm. Lacking the descriptions of the larvae of T. murrayii and M. aeneus provided in this thesis, the authors combined the counts of these two species with those of M. scorpius and M. octodecemspinosus. The larvae reported by Graham and Boyar in April and May actually belonged to M. aeneus. In late March and April, the larave of

this species range from 6.6 - 9.8 mm in length with an average of 8.21, while the larvae of M. octodecemspinosus range from 7.9 - 14.5 mm in length with an average of 11.6 mm. The larvae of T. murrayii were also longer than those of M. aeneus (Fig 49). The average length of M. scorpius reported by Graham and Boyar is actually the average of both M. scorpius, M. octodecemspinosus, and T. murrayii. This is the reason why Graham and Boyar did not report the larvae of M. aeneus and T. murrayii from Boothbay Harbour area.

F. Bay of Fundy and the Gulf of Maine

1. Description of the Area

For details of the oceanography of the area see Bigelow (1927). Details of currents in the Bay of Fundy and the Gulf of Maine are given in the discussion, where the recent literature is also reviewed.

2. Sampling Methods

Plankton samples at 51 stations (Fig 50) were taken between April 29 and May 8, 1969 in the Bay of Fundy and the eastern Gulf of Maine including the northern part of Georges Bank and Browns Bank. Sampling was done by the Pelagic Group of the Fisheries Research Board of Canada, St. Andrews Station during cruise E.E. Prince No. 44. Three methods were used for sampling plankton. a) Vertical hauls were made at 51 stations with a 1-metre (diameter) nylon net of #0 mesh (12 to 15 meshes per cm). The net was dropped to 30 metres and then lifted up slowly to the surface. b) Oblique plankton tows at 20-10-0 m were made with the same net at 19 locations. The net was towed at a speed of about 2 knots for 5 minutes at each level. c) Issacs-Kidd tows at 30-15 m were made at 17 locations. The mesh size of Issacs-Kidd trawl codend was 0.5 mm. The net was made of No. 471 Nitex. The Issacs-Kidd trawl was towed for 15 minutes at each depth at a

Fig. 50. Map showing sampling stations in the Bay of Fundy and the eastern Gulf of Maine. Vertical hauls (30-0 m) were taken at all stations. 1, oblique tows (20 - 10 - 0m); 2, Issacs-Kidd tows (30 - 15m).

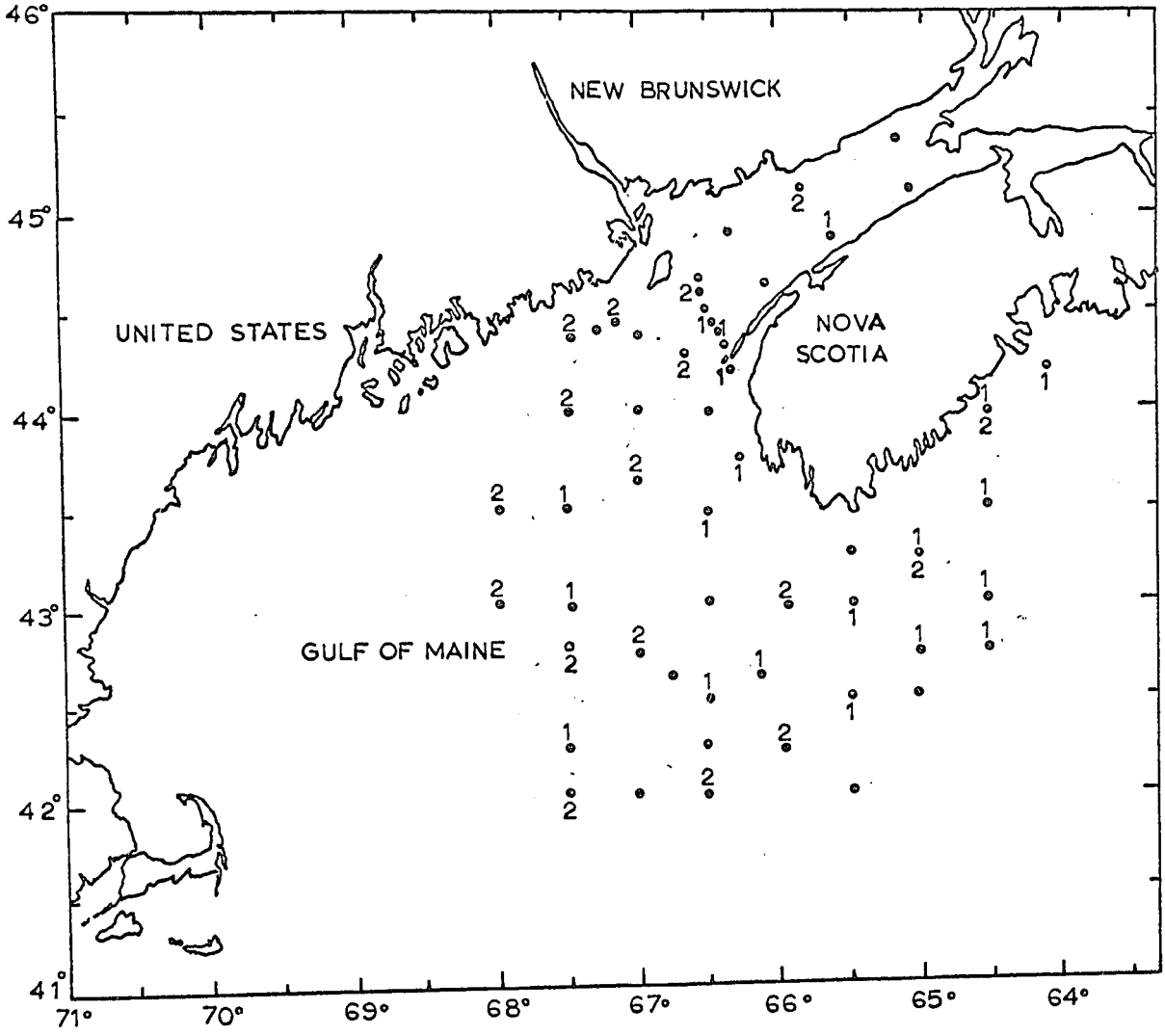
NEW BRUNSWICK
UNITED STATES
NOVA SCOTIA
GULF OF MAINE
46°
45°
44°
43°
42°
41°
71°
70°
69°
68°
67°
66°
65°
64°

Figure 50

speed of 4 knots. At night 23 vertical hauls, 7 oblique tows and 10 Issacs-Kidd tows were made; and during the day 27 vertical hauls, 12 oblique tows and 7 Issacs-Kidd tows were made.

3. Results and Discussion

A total of 8 cottid larvae were caught in only three Issacs-Kidd tows. In all the other tows no cottid larvae were caught. Four larvae of Myoxocephalus octodecemspinosus and two larvae of M. scorpius were caught at the entrance to the Bay of Fundy, one larva of M. octodecemspinosus at a station near the southern tip of Nova Scotia.

The results obtained in this study indicate a general scarcity of cottid larvae in the waters of the Bay of Fundy and the Gulf of Maine. Three possible explanations can be given for the scarcity of cottid larvae in this area. The first and the most plausible one is the fact that the cottid species on the Atlantic coast spawn inshore in shallower areas and estuaries. This has been shown by the horizontal distribution of cottid larvae in the Passamaquoddy Bay and Boothbay areas (pages 175-190). Some offshore drifting of these larvae is possible due to strong tidal flows but only in shallower productive areas such as the Magdalen Shallows of the Gulf of St. Lawrence. In the open waters of the Bay of Fundy and the Gulf of

Maine complicated oceanographic and ecological conditions persist which are probably not suitable for their survival. These oceanographic and ecological conditions are discussed below.

The second explanation of the scarcity of cottid larvae in the area is based on the lack of plankton coupled with the great rise and fall of the tide. A number of authors have reported that the production of zooplankton in the Bay of Fundy is extremely low (Bigelow, 1926; Fish and Johnson, 1937; Legare and MacLellan, 1960). Gran and Braarud (1935) said that the low productivity in the Bay of Fundy is due to the high turbidity of the water caused by great rise and fall of the tide. Due to this turbidity the light necessary for phytoplankton growth penetrates no deeper than 10 metres. However, some zooplankton from the Gulf of Maine, is carried to the Bay of Fundy only in the deep return current and the general counter-clockwise circulation of the Gulf of Maine (Bigelow, 1927). Very little of this zooplankton from the Gulf of Maine reaches the inner Bay of Fundy and is only available as food for fish and fish larvae in the outer Bay (Jermolajev, 1958). As a result, the Minas Channel and Chignecto Bay are practically devoid of zooplankton. However, Huntsman (1952) reported that the estuaries of Minas Channel have adequate production of phytoplankton and support large

populations of estuarine zooplankton and fish.

In the Gulf of Maine, apparently, the food for larval fish is not a problem because of tremendous productivity in the Georges Bank area. However, a complicated system of non-tidal circulation is operative in the area which can influence the dispersal and maintenance of pelagic fish larvae such as cottids.

Thirdly, the scarcity of larvae from the area could also be attributed to the non-tidal circulation in the Gulf of Maine. Briefly, the pattern of non-tidal circulation in the Gulf of Maine consists of two main eddies: the Gulf of Maine Eddy with a counter-clockwise circulation around the basin of the Gulf of Maine, and a Georges Bank Eddy with a clockwise circulation around Georges Bank (Fig. 51). According to recent studies by Day (1958) and Bumpus (1958, 1958) the two eddies are well pronounced in late spring, but weaken in the fall. The average rate of surface drift at this time is in the order of 1m/sec which would perhaps remove the pelagic larval cottids from the area. According to Bishai (1960) pelagic herring larvae drifted passively with the currents at velocities higher than 1.03 cm/sec.

Since Georges Bank supports big populations of longhorn sculpin and perhaps other sculpins, it would be proper to mention the interesting theory put forth by Colton and Temple (1961) regarding the fate of pelagic

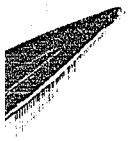

Fig. 51. Schematic representation of the dominant non-tidal circulation of the northwestern Atlantic, spring-summer (reproduced from Das, MS 1968).

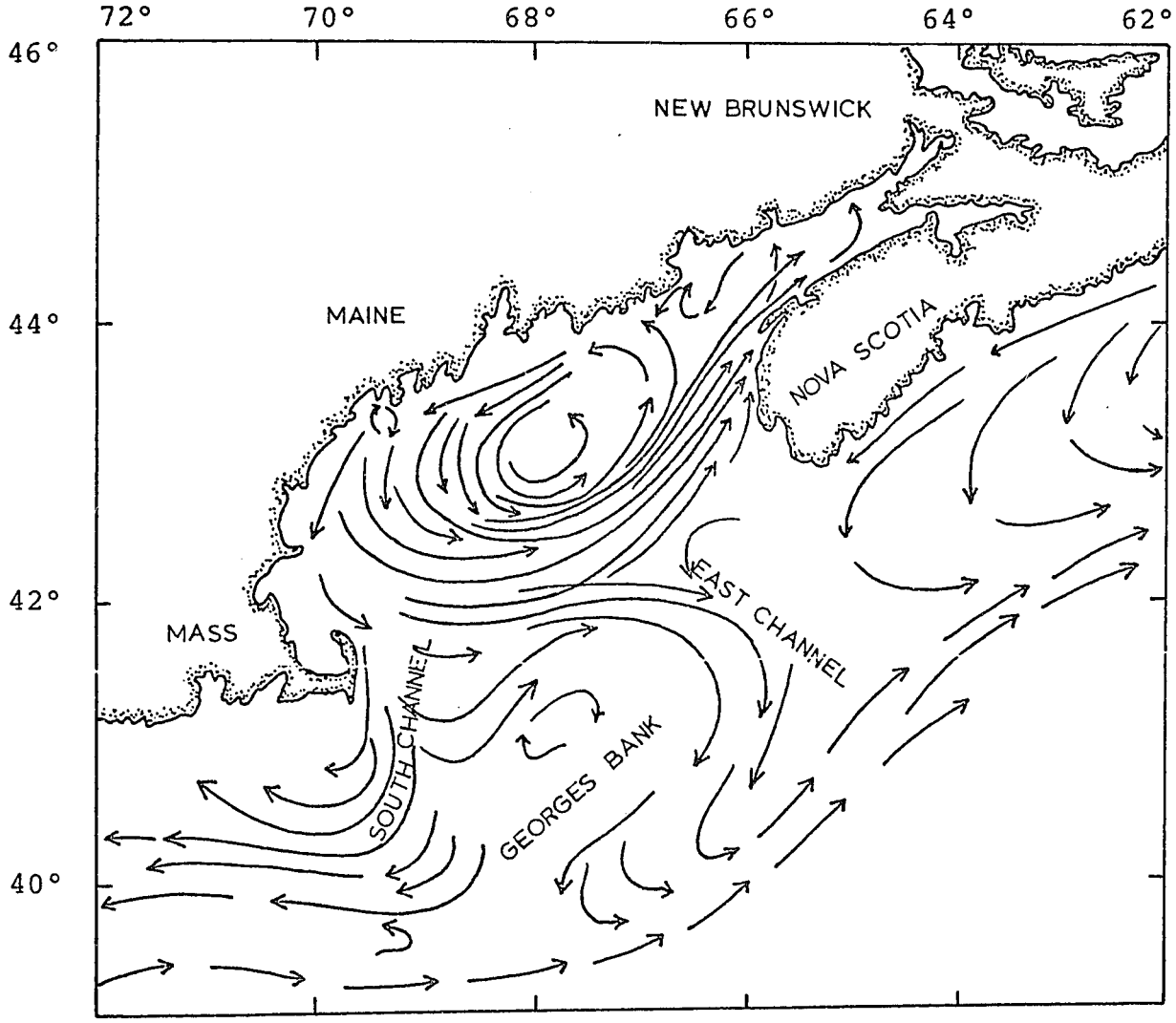
72°
70°
68°
66°
64°
62°
46°
44°
42°
40°
NEW BRUNSWICK
MAINE
NOVA SCOTIA
MASS
EAST CHANNEL
SOUTH CHANNEL
GEORGES BANK

Figure 51

fish eggs and larvae of the area. These authors noted that "with the exception of midsummer when the Georges Eddy is most pronounced and southerly winds predominate, surface drift over the Georges Bank area is offshore in the direction of the warmer slope water band" which flows in a north-easterly direction. From this they deduced that under average conditions most pelagic fish eggs and larvae would be carried away from the Georges Bank in the direction of the slope water and lost to the fishery; and only under exceptional hydrographic conditions an appreciable number of larvae and eggs would be retained on the Georges Bank or nearby coastal areas. Some evidence in support of this theory was produced by drift bottle, and transponding drift-buoy studies. However, as the authors have pointed out, this explanation regarding the fate of pelagic fish larvae and eggs over Georges Bank cannot be considered conclusive in the absence of more thorough information such as the effect of wind on non-tidal drift, the differential rate of drift between surface and depth, the vertical distribution of eggs and larvae, and the time and location of spawning.

G. General Discussion of Ecology

My ecological study of cottid larvae showed that by the examination of larval fish collections it is possible to estimate the spawning season of a species. The seasonal abundance and the length frequency distribution of the larvae of Myoxocephalus quadricornis thompsonii revealed that this subspecies spawns during fall and winter and its spawning season extends perhaps up to May and June. The seasonal abundance showed two peaks (Fig 27) one in the last part of April and the other in the middle of July. The length frequency distributions of the larvae (Figs 28-30) showed that the larvae caught in April and May were a mixture of fall and winter recruits while the June and July collections came from a late spring or early summer spawning. This clarified the earlier assumption (Dymond et al; 1929; McAllister, 1959) that this subspecies spawns only during the summer.

By the study of larval fish collections it is also possible to predict maximum spawning. The maximum abundance of cottid larvae in the Boothbay area was found to be in late February and March. Since the incubation period of cottids is generally 2-3 months (Morrow, 1951; Ennis, 1970) it was possible to say that the maximum spawning must have occurred during December and January. This confirmed the reports of spawning which were based

on either the observations on the European forms or by the reports of a few ripe females (Bigelow and Schroeder, 1953). The only comprehensive account of the spawning of cottids is by Morrow (1951) for the longhorn sculpin, M. octodecemspinosus.

Larval ecology generally reflects the ecology of the adults. It has been the contention that Myoxocephalus scorpius never enters estuaries (Bigelow and Schroeder, 1953). My study of larval cottids in the Boothbay area showed heavy concentrations of the larvae of M. scorpius in the upper estuaries of Damariscotta and Sheepscot Rivers about 10-15 miles inshore. This clearly shows that M. scorpius, like other sculpins on the Atlantic Coast, does enter the estuaries; and actually spawns there since yolk sac larvae were abundant earlier in the season. Faber (1963) also found similar relationship between the ecology of larval and adult perch in lakes. perch spawns in the littoral region but as adults they are spread all over the lake in the limnetic region. The distribution of perch larvae showed that the larvae were no more aggregated in the littoral region than in the limnetic region.

The ecological study of the larvae of M. q. thompsonii showed that the vertical distribution of the larvae during the summer could be influenced by temperature. The larvae of thompsonii were not caught in the surface

strata during the summer months when the termperatures (11-23°C) were much higher than in the spring (Fig 31). However, during the summer the larvae were caught in the deeper strata where the temperature (4.8°C) was almost as cold as the surface temperature in the spring. Wells (1966) also found temperature as a limiting factor for the larval bloaters, Coregonus hoyi in their vertical distribution during the summer. This may be true for all cold water fish. Evropeyzeva (1944) experimentally showed that the yolk sac larvae of burbot, Lota lota, avoided temperatures higher than 6°C, but with resorbtion of the yolk they could tolerate higher temperatures.

The horizontal distributon of the marine cottid larvae suggested that the species of the genus Myoxocephalus spawn in the estuaries, and in shallow and enclosed areas where the bottom is rocky. The rocky bottoms generally occur inshore, and often around emerging rocky islands (see concentrations of cottid larvae around islands in Tuktoyaktuk Harbour and Passamaquoddy Bay). (see sections on the horizontal distribution of larvae in Passamaquoddy Bay and Boothbay area). The horizontal distribution of cottid larvae in the Gulf of St. Lawrence further indicated that they prefer shallower, more productive areas like the Magdelan Shallows in the Gulf of St. Lawrence. The general scarcity of cottid larvae in the Gulf of Maine and Bay of Fundy could be due to the hydrographic differences between the Gulf of St. Lawrence and these bodies of water. Herman (1963) reported cottid

larvae as one of the most abundant larval fish groups in Narragansett Bay. Narrangansett Bay is a typical estuarine environment. Herman, however, did not collect offshore to show the variations in catches between offshore and inshore waters. However, the fact that the sampling in the Gulf of Maine and the Bay of Fundy was not done in waters deeper than 30 meters cannot be ignored. It is possible, therefore, that at least in the eastern part of the Gulf of Maine the cottid larvae were present in the deeper strata.

A number of advantages of spawning in estuaries could be set forth. Since the cottid eggs are demersal and generally laid in crevices and stones, they need constant flushing of water for aeration to avoid being coated by sediments. In the estuaries due to constant discharge from the rivers, the eggs are provided constant aeration and also washed by the flow of water. Another advantage could be related to reduced salinities in the estuarine environment. Several authors have shown experimentally that teleost larvae survive longer in lower salinities (Bishai, 1961; Holliday, 1965; Lewis, 1966). The lower salinities often lower the activity levels of the fish larvae (Holliday, 1965). The lowered activity reduces the expenditure of energy and consequently improves the chances of survival and the achievement of rapid growth rates. It may be argued that the sudden and extreme fluctuations of salinities may be lethal for the fish. A number of workers, however, have shown that the teleost larvae can tolerate very wide range of salinities. Holliday and Blaxter (1961) observed that herring larvae can tolerateе salinities

ranging from 1.4 to 60.1‰ for 24 hours but have a slightly reduced range over long periods. Keys (1931) found that a large proportion of Fundulus parvipinnus larvae transferred directly from sea water to freshwater, acclimated completely. Some other species e.g., Atlantic menhaden, Brevoortia tyrannus, have also been reported to use estuaries as nursery grounds during larval stages. Atlantic menhaden spawns in the ocean but the larvae after hatching migrate to lower estuaries (Reintjes, 1962; Higham and Nicholson, 1964).

The night time concentrations of cottid larvae at surface in the Gulf of St. Lawrence, indicated that cottid larvae at night are more concentrated in the upper strata than in the lower strata. At the surface, cottid larvae were most abundant between 8 p.m. and 4 a.m. This tendency of larvae to migrate in the upper strata has been reported in a number of teleost groups (Mito, 1967). However, the hours of maximum concentrations at night vary considerably among various groups.

V. SUMMARY

The purpose of this study was to develop morphological criteria to identify larvae of the family Cottidae of the Atlantic Coast of Canada and the Great Lakes, during various phases of larval development; and to study their ecology in various bodies of water.

Over 2000 cottid larvae were examined for identification criteria of the various species but about 400 were studied for detailed morphological description. The morphological characters (i.e., finfold, yolk sac and intestine, caudal fin, general and specific patterns of pigmentation, and all the cephalic spines) were recorded on each specimen. Most typical morphological characters within each 2 mm length group were described and the transition of characters was noted.

Seven morphometric characters (i.e., total length, standard length, head length, diameter of eye, inter-orbital width, preanal length, and the body depth) and five meristic characters (i.e., total number of myomeres, second dorsal fin rays, anal fin rays, pectoral fin rays and caudal fin rays) were studied on 300 larvae of various cottid species. A linear regression analysis was used to study the relative growth of various parts. The significance of differences in relative growth rates and means of meristic counts between species were tested by *t* - tests.

The ecological studies were based on larval fish collections made by tow nets from various areas i.e., Lakes Michigan and Huron, Tuktoyaktuk Harbour, N.W.T., the Gulf of St. Lawrence, Passamaquoddy Bay, Boothbay Harbour area, the Bay of Fundy and the eastern Gulf of Maine.

Thorough morphological, morphometric, and meristic analysis of larval cottid collections from the western Atlantic, the Beaufort Sea, and the Great Lakes resulted in the description of various larval phases of Myoxocephalus quadricornis labradoricus, M. q. thompsonii, M. scorpius, M. aeneus, M. octodecemspinosus, Triglops murrayii, Gymnocanthus tricuspis, Hemitripterus americanus, and Cottus bairdii. Morphological criteria were determined to identify these species during various phases of their larval development.

The larvae of M. q. labradoricus were found to be different from the larvae of M. q. thompsonii in having more myomeres and medio-ventral melanophores, by the presence of medio-lateral melanophores, and by having generally faster relative growth rates.

Evidence was produced by morphological study that the descriptions of the larvae of Cottus bairdii kumlieni and C. b. bairdii given by Fish (1932) were actually those of the early stages of M. q. thompsonii.

The larvae of Myoxocephalus scorpius, M. aeneus and M. octodecemspinosus, which used to be lumped as Myoxocephalus spp. were found to be morphologically distinguishable during various phases of development. For instance, during the eleuterembryonic phase, the larvae of M. aeneus could be distinguished from the other two species by the presence of longitudinally arranged melanophores on the ventral side of the abdomen. The larvae of M. scorpius were different from those of M. octodecemspinosus in having a preanal fin, and in having melanophores on the lateral sides of the tail during the later part of the eleuterembryonic phase.

Larvae of Triglops murrayii were described for the first time and distinguished from the larvae of T. pingelli by the absence of dorsal row of melanophores on either side of the base of the second dorsal fin, and by the absence of medio-lateral row of melanophores.

The polymodal length frequency distributions and the seasonal abundance of the larvae of M. q. thompsonii showed that the adults spawn during late fall and winter and the spawning season extends into spring and early summer. Seasonal changes in depth distribution of M. q. thompsonii, in Lake Michigan, indicated that the temperature could influence the depth distribution of cottid larvae.

The larvae of M. q. labradoricus at Tuktoyaktuk

Harbour were caught in shallow inshore waters. The length frequency distribution of the larvae, caught in July, 1970, suggested that in Tuktoyaktuk Harbour the species spawns in winter.

In the Gulf of St. Lawrence the cottid larvae were abundant during the sampling period in May. Very few larvae were caught in June; and in August and September no larvae were caught. Larvae of 5 cottid species (M. scorpius, M. aeneus, M. octodecemspinosus, Triglops murrayii and Hemitripterus americanus) were concentrated in the Magdalen Shallows, while the waters of Laurentian Channel were virtually devoid of cottid larvae. In the surface tows more larvae were caught during the night than during the day, indicating a diurnal vertical migration.

In the Passamaquoddy Bay, larvae of only two cottid species (i.e., Myoxocephalus aeneus and M. octodecem-spinosus) were caught during sampling in the last week of April. More larvae were caught in shallower waters. The length frequency distribution of larvae showed that M. octodecemspinosus spawns earlier in the season than M. aeneus.

Larvae of four cottid species (M. scorpius, M. aeneus, M. octodecemspinosus and Triglops murrayii) were caught in the Boothbay Harbour area. Contrary to the earlier belief, the distribution of M. scorpius larvae

in the upper estuaries suggested that the species enters estuaries. The larvae were most abundant from February to April. Most larvae were caught in the upper estuaries of Damariscotta and Sheepscot rivers. The seasonal abundance of the cottid larvae confirmed earlier reports that the cottids on the Atlantic Coast of North America spawn during winter with the maximum spawning in December and January. The great variation in sizes of the larvae of Triglops murrayii indicated a long spawning period for the species.

Cottid larvae were found to be scarce in the open waters of the Bay of Fundy and the Gulf of Maine. The most plausible explanation for this scarcity was thought to be the fact that cottid species on the Atlantic Coast spawn in shallow and enclosed, relatively productive areas where the bottom is rocky.

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VII. APPENDIX

TABLE 1. Significance of regression coefficients of head lengths on total lenghts of the larval of Myoxocephalus quadricornis thompsonii, M. q. labradoricus, M scorpius, M. octodecemspinosus M. aeneus and Triglops murrayii. Degrees of freedom in parentheses.

	octodecem-spinosus	aeneus	labradoricus	thompsonii	murrayii
scorpius	1.274 (86)	2.076* (75)	-5.672** (104)	-0.821 (89)	3.225** (76)
octodecem-spinosus		0.975 (71)	-6.027** (100)	-2.078* (85)	1.245 (72)
aeneus			-6.397** (89)	-2.913** (74)	-0.214 (61)
labradoricus				5.965** (103)	8.161** (90)
thompsonii					4.722** (75)

* Significant at P = 0.05

** Significant at P = 0.01

TABLE 2. Significance of regression coefficients of the diameters of eyes on total lengths of the larvae of Myoxocephalus quadricornis thompsonii, M. q. labradoricus, M. scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii. Degrees of freedom in parentheses.

	octodecem-spinosus	aeneus	labradoricus	thompsonii	murrayii
scorpius	-1.304 (86)	0.573 (75)	-1.007 (104)	2.567* (100)	2.720** (76)
octodecem-spinosus		1.439 (71)	-0.449 (100)	3.548** (96)	3.630** (72)
aeneus			-1.070 (89)	0.938 (85)	1.117 (61)
labradoricus				1.948 (114)	1.914 (90)
thompsonii					0.446 (86)

* Significant at P = 0.05

** Significant at P = 0.01

TABLE 3. Significance of regression coefficients of the interorbital widths on total lengths of the larvae of Myoxocephalus quadricornis thompsonii, M. q. labradoricus, M. scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii. Degrees of freedom in parentheses.

	octodecem-spinosus	aeneus	labradoricus	thompsonii	murrayii
scorpius	1.207 (86)	0.843 (75)	1.831 (104)	4.631** (89)	3.080** (76)
octodecem-spinosus		0.036 (71)	1.083 (100)	2.909** (85)	1.607 (76)
aeneus			0.967 (89)	2.175* (74)	1.199 (61)
labradoricus				0.716 (103)	-0.014 (90)
thompsonii					-1.222 (75)

* Significant at P = 0.05

** Significant at P = 0.01

TABLE 4. Significance of regression coefficients of preanal lengths on total lengths of the larvae of Myoxocephalus quadricornis thompsonii, M. q. labradoricus, M. scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii. Degrees of freedom in parentheses.

	octodecem-spinosus	aeneus	labradoricus	thompsonii	murrayii
scorpius	1.460 (86)	-0.074 (75)	-5.533** (104)	1.614 (100)	3.736** (76)
octodecem-spinosus		-0.864 (71)	-5.691** (100)	-0.479 (96)	1.545 (72)
aeneus			-3.681** (89)	0.846 (85)	1.887 (61)
labradoricus				7.013** (114)	7.067** (90)
thompsonii					2.962** (86)

* Significant at P = 0.05

** Significant at P = 0.01

TABLE 5. Significance of regression coefficients of the body depths on total lengths of the larvae of Myoxocephalus quadricornis thompsonii, M. q. labradoricus, M. scorpius, M. octodecemspinosus, M. aeneus, and Triglops murrayii. Degrees of freedom in parentheses.

	octodecem-spinosus	aeneus	labradoricus	thompsonii	murrayii
scorpius	0.683 (86)	-0.354 (75)	-2.761** (104)	1.549 (100)	7.348** (76)
octodecem-spinosus		-0.759 (71)	-2.820** (100)	0.432 (96)	4.696** (72)
aeneus			-2.093* (89)	1.331 (85)	5.241** (61)
labradoricus				7.929** (114)	7.442** (90)
thompsonii					6.255** (86)

* Significant at P - 0.05

** Significant at P - 0.01

TABLE 6. Comparison of means of meristic counts of the larvae of Myoxocephalus scorpius, M. octodecemspinosus, M. aeneus, M. quadricornis labradoricus M. q. thompsonii, and Triglops murrayii in various length groups. Under each Student's t value is given degrees of freedom within parentheses.

Comparison	Length group	Myomeres	Anal fin rays	Second dorsal fin rays	Pectoral fin rays	Caudal fin rays
Scorpius	8-10	0.289 (34)	--	--	--	-7.401*** (13)
vs	10-12	0.183 (17)	--	--	-3.319* (8)	-1.862 (15)
octodecemspinosus	12-14	3.491** (13)	-3.834** (12)	-1.682 (12)	-4.786*** (12)	-1.963 (13)
scorpius vs aeneus	8-10	17.370*** (29)	--	--	--	-9.084*** (19)
scorpius	12-14	-11.408*** (21)	-0.869 (11)	3.624*** (10)	1.093 (17)	3.800** (14)
vs	14-16	-10.614***	-10.067*** (43)	5.016*** (43)	9.287*** (43)	1.728 (44)
labradoricus	16-18	-7.312*** (8)	-3.549** (8)	2.072 (8)	--	10.398*** (8)
scorpius	8-10	-3.162** (36)	--	--	--	--
	10-12	-2.897* (12)	--	--	2.009 (8)	0.991 (13)
vs	12-14	-2.050 (17)	0.619 (13)	4.205*** (13)	-1.442 (11)	0.362 (15)
thompsonii	14-16	-1.429 (16)	-2.108 (16)	4.609*** (16)	1.942 (16)	0.920 (16)
	16-18	-2.385 (4)	-.622 (4)	0.676*** (4)	1.333 (4)	3.183* (4)

Table 6 Cont'd

Comparison	Length group	Myomeres	Anal fin rays	Second dorsal fin rays	Pectoral fin rays	Caudal fin rays
scorpius	8-10	-13.0*** (21)	--	--	--	1.464 (10)
vs	10-12	-10.89*** (10)	--	--	-0.757 (4)	0.555 (10)
	12-14	-12.850*** (13)	-14.700*** (11)	-8.875*** (11)	-2.837* (13)	1.616 (13)
murrayii	14-16	-8.179*** (11)	-18.78*** (11)	-9.403*** (11)	-1.363 (11)	0.839 (11)
	16-18	-8.548*** (8)	-14.295*** (8)	-8.459*** (8)	-1.352 (8)	2.619* (8)
octodecemspinosus	6-8	8.658*** (22)	--	--	--	--
vs aeneus	8-10	9.194*** (29)	0.808 (13)	--	3.842** (17)	-2.011 (16)
octodecemspinosus vs labradoricus	12-14	-11.540*** (20)	1.543 (11)	5.809*** (10)	7.360*** (15)	5.442*** (13)
octodecemspinosus	8-10	-2.123* (36)	--	--	--	--
vs	10-12	-2.474* (15)	--	--	8.035*** (12)	2.359* (14)
thompsonii	12-14	-4.435*** (16)	4.913*** (13)	6.118*** (13)	3.806** (14)	2.665* (14)
octodecemspinosus	8-10	-6.172*** (21)	--	--	-0.594 (6)	2.885 (7)
vs	10-12	-8.455*** (13)	-12.900*** (8)	-4.341** (7)	0.486 (8)	1.790 (11)
murrayii	12-14	-12.420*** (12)	-17.250*** (11)	-7.737*** (11)	0.504 (11)	3.375** (12)

Table 6 Cont'd

Comparison	Length group	Myomeres	Anal fin rays	Second dorsal fin rays	Pectoral fin rays	Caudal fin rays
Aeneus vs thompsonii	8-10	-19.460*** (31)	--	--	--	--
Aeneus vs murrayii	8-10	-20.040*** (16)	--	-4.255*** (13)	-3.966** (13)	3.980** (13)
labradoricus	12-14	6.955* (24)	1.444 (12)	0.608 (11)	-2.554 (14)	-4.311* (15)
vs	14-16	13.735* (44)	5.953* (43)	3.829* (43)	-4.534* (43)	-0.629 (44)
thompsonii	16-18	5.306* (10)	1.923 (10)	-0.810 (10)	-7.453* (10)	-2.215 (10)
labradoricus	12-14	-3.390** (20)	-9.421*** (10)	-14.270*** (9)	-4.502*** (16)	-1.888 (13)
vs	14-16	-2.454** (39)	-15.816*** (38)	-24.008*** (38)	-7.866*** (38)	-0.579 (39)
murrayii	16-18	0	-14.102*** (14)	-17.851*** (14)	-10.102*** (14)	-2.504* (14)
thompsonii	8-10	-10.394*** (23)	--	--	--	--
vs	10-12	-8.211*** (8)	--	--	-2.232 (8)	0
murrayii	12-14	-10.554*** (16)	-16.187*** (12)	-13.227*** (12)	-1.729 (10)	1.716 (14)
	14-16	-16.512*** (11)	-14.440*** (11)	-15.860*** (11)	-2.274* (11)	-8.866*** (11)
	16-18	-7.541*** (10)	-10.844*** (10)	-9.593*** (10)	-3.031* (10)	-0.339 (10)

* Significant at P = 0.05
** Significant at P = 0.01
*** Significant at P = 0.001