LABORATORY AND FIELD STUDIES OF THE FOOD SELECTIVITY AND GROWTH OF IMPORTED MOSQUITOFISH, GAMBUSIA AFFINIS IN NEWFOUNDLAND

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LABORATORY AND FIELD STUDIES OF THE FOOD SELECTIVITY AND GROWTH OF IMPORTED MOSQUITOFISH, *GAMBUSIA AFFINIS* IN NEWFOUNDLAND

by

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ABSTRACT

A series of laboratory experiments supplemented by field observations of caged mosquitofish (Gambusia affinis Baird and Girard) were employed to investigate the food selectivity of these predators. Various food organisms of approximately similar size were utilized. These included insect larvae, fish eggs, young fish and microscopic organisms. The probable effectiveness of this viviparous poeciliid as a predator on Newfoundland freshwater fish, was evaluated on the basis of these investigations.

Variation in the forage organisms' external appearance, body covering, behaviour and activity affected Gambusia's ability to utilize different organisms. Also, certain organisms both with soft and hard body coverings, were not taken by the fish.

Conditioning does not lead Gambusia to select fish eggs and young fish. However, the latter were readily eaten, especially in the absence of other food. Mosquitofish selected smaller eggs and young fish when available. The maximum sizes of eggs taken by small (33 - 36 mm in length) and large (38 - 46 mm) Gambusia approximated 4.2 mm and 4.7 mm in diameter respectively. Mosquitofish of these same size-ranges took young sticklebacks up to 18 mm and 20 mm in

length respectively. However, the maximum size of soft-bodied tadpoles preyed upon in this fashion proved much larger than that of sticklebacks. Tadpoles were in fact preyed upon when approximately two-thirds as long as the largest female mosquitofish. Observations of Gambusia predation upon other food organisms were made as well. Cannibalism by female Gambusia upon both adult males and young was also noted.

The ingestion of microscopic phytoplankton seemed to be on a completely random basis. No special preference for any particular algae over others was shown by the fish. That is to say, the higher the incidence of a given food organism in the tank, the higher its incidence in mosquitofish stomach contents.

Lowered temperatures adversely affected the growth rate of mosquitofish both in tanks and in cage under stream conditions. Growth rate of fish in aquaria was fast at temperatures of 22.8 - 25.7°C, slower at 14.5 - 17.0°C and poor at 5.5 - 6.1°C. The amount of food taken also decreased with lowered temperatures. Under stream conditions, steady losses in weight and the amount of food eaten were also detected. This is considered to have been due to rapid diurnal changes of water temperature, especially towards the lower end of the range. However, lowered temperatures did not seem to be fatal to the fish, more than 50% of them surviving for 12 weeks.

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INTRODUCTION

The top-minnow or mosquitofish, *Gambusia affinis* (Baird and Girard) belongs to the viviparous family Poeciliidae of the order Cyprinodontes. For many years it has been considered an important predator of the surface-feeding larvae of anopheline mosquitoes. The food habits of this small fish have long been studied (e.g. Hildebrand, 1921, 1923; Sokolov and Chvaliova, 1936; Rice, 1940; Self, 1940; Hess and Tarzwell, 1942; Hunt, 1952; Harrington and Harrington, 1961). These authors reported that *Gambusia* chiefly feeds upon insect larvae, mosquito larvae comprising the main food item of the stomach contents of fish taken from the field. Because of its ability to consume large number of mosquito larvae (thus reducing their population) and hence to some extent inhibiting the transmission of certain vector-borne diseases, notably malaria and yellow fever; and also because of its cold hardiness and generally high resistance to adverse environmental conditions, *Gambusia affinis* has been exported to many countries for vector control. "In 1921, the fish was successfully introduced into Spain from the USA. This fish soon to become the best-known of all larvivores, was taken from Spain to Italy in the following year. The resultant Italian stock was the source of similarly successful introductions into Yugoslavian islands in the Adriatic in 1924, Transcaucasia in the same year, Algeria and Corsica and Greece in 1928. From Corsica, mosquitofish were taken to Egypt and thence to Cyprus, Syria and the Sudan. In the North America continent, there were even successful acclimatizations in Utah, Chicago, Illinois and Canada" (Bibliography by Gerberich and Laird, 1966).

Most of the reported feeding habits of mosquitofish have been based on analysis of the stomach contents of fish taken from the field. This procedure certainly reveals food commonly utilized by the fish. However, it fails to give a clear picture as to whether in the natural environment, food is used because it is more abundent, small and more easily caught, or simply preferred by the mosquitofish.

Many of the organisms present in the habitats from which Gambusia has been taken, could not be found in the stomach contents following dissection. This does not necessarily mean that the fish simply dislike these organisms. It could be due to their lesser accessibility to the fish. Seal (1910) stated that most mosquitofish appeared to gorge themselves with whatever was available. This might not be wholly true, for Fermi (1926) stated that Gambusia only ate organisms having a soft cuticle and left those with a hard body covering. Thus, an analysis of food selectivity demands a definition of the availability of a potential food particle, taking into account not only its abundance but also its visibility, activity etc. (Ricker, 1937; Allen, 1941).

Furthermore, it has more recently been reported (Myers, 1965; Wheeler, 1971) that populations of certain indigenous species of fish have been greatly reduced following introductions of Gambusia, such adverse effects not necessarily becoming obvious for many years. These authors were expressing anxiety for fear that the mosquitofish were not only cannibalistic, but were also able to destroy valuable small fish of other species. They have called for attention to the heavy predation of Gambusia on other more valuable forage fish. However, no direct evidence has been presented as to whether the eggs or the young of these local fish were devoured by the mosquitofish.

Elton (1927) states that any one species of animal eats only food within a certain size range. So far, there is no evidence given by any author on the optimal size preferred and the largest possible size eaten by a mosquitofish. This is due to the fact that under natural conditions, from examination of stomach contents only, it is sometimes difficult to assess if an organism has been ingested intact or in smaller pieces.

Many investigators have found fishes to be selective in their feeding (Allen, 1939; Kutkuhn, 1957; Ivlev, 1961; Brooks and Dadson, 1965; Hunt, 1965; Galbraith, 1967; Parsons and LeBrasseur, 1970). Ivlev (1961) also stated that the selectivity of food by fish is influenced by a number of interacting factors including accessibility, abundance, size of food items and also the habits of the predator. Thus, the non-vulnerable and poorly utilized form of food organisms in the pond environment might become vulnerable and readily utilized in the confinement of tanks. Sweetman (1936) stated that, "if parasitism and predation were strictly specific, the problem of biological control would be relatively simple". Thus, it is considered useful to determine the food selectivity of Gambusia when various food organisms are given the same accessibility to the fish.

Selectivity is defined as the extent to which a predator eats one size or species of food item rather than another. Preference is the instinctive desire to consume one size or species of food item rather than another and accessibility is a measure of the degree of difficulty faced by the predator in locating a particular food item. Selectivity is thought (Ivlev, 1961) of as a function of two factors (accessibility and preference) operating simultaneously. Accessibility is a function of prey and preference is a function of predators.

The various species of *Gambusia* are either tropical or subtropical fish. Although many cases have been reported on the successful acclimatization of *Gambusia affinis* in colder waters by many authors in various temperate areas in Europe, Northern America and USSR, little has been reported about the actual temperature effect on the growth of this poeciliid fish.

The purpose of this study is (1) to determine the extent and the maximum size of food organisms especially fish eggs and young fish possibly eaten by *Gambusia*, (2) to determine which items are most readily taken by confining individual mosquitofish in tanks, feed them with an equal number of different food organisms of approximately the same edible size, (3) to determine the feeding of *Gambusia* on microscopic algae in aquaria and its feeding habits in caged confinement under stream conditions, and finally to determine the influence of temperatures on the food consumption and growth of mosquitofish both in laboratory and in cage under natural conditions. Comments are also made on other possible factors influencing its growth rate, on its possible growth in this new, Newfoundland environment as well as its possible effect on the local species of fish.

METHODS AND MATERIALS

The mosquitofish - *Gambusia affinis* (Baird and Girard) (Fig. 1) - used in these investigations were imported from the Division of Biological Control, University of California, Riverside, California, USA. They arrived in good condition in two well-oxygenated sealed plastic bags in a foam-insulated picnic chest. The fish were transferred to two 70-litre aquaria containing pond water at room temperature. The water was aerated, filtered and changed from time to time. For the first week, commercial fish food (Hartz Mountain) was used as food. Later, other brands were used - BiOrell (Mollic flakes, USA) and TetraMin (staple food, Germany).

Gravid females were removed from the aquaria and isolated in a breeding cage suspended in another aquarium tank. After the young were born, the mother fish and the breeding cage were removed. These young were raised in the tank and used later in the experiments.

The fish used for the experiments on food selectivity were chosen from the mature stock held in the laboratory for about six months.

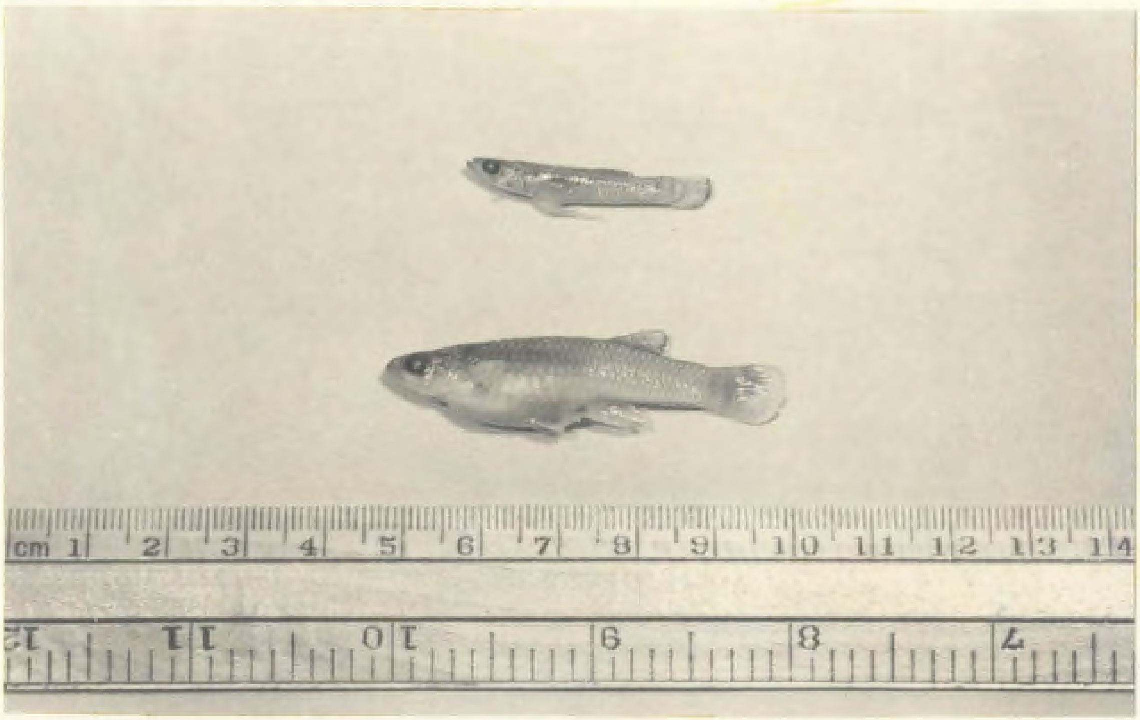

Fig. 1. Picture showing male (above) and female (below) mosquitofish.

Description of Apparatus

A V-shaped wooden trough (Fig. 2) was used for measuring the diameter of fish eggs. It was mounted on a wooden stand, and a thin plastic ruler, with the metric scale downwards was fixed to its inner surface.

The rectangular aquarium (Fig. 3) measured 70 cm × 35 cm × 35 cm. It could hold almost 70 litres of water when filled. The outer surface of one glass wall was coated with a sheet of white paper to provide better observation of the fish and food organisms kept in it. A plastic plate (34.5 cm × 33.0 cm) was used to partition the fish off at one end of the tank. It fitted exactly across the tank and divided the space into two portions.

Aquarium tanks and battery jars (Figs. 4, 5 and 6) were used to accommodate fish at different water temperatures. The outer aquarium tanks (Figs. 4 and 5) measured 75 cm × 46 cm × 38 cm and held four glass battery jars (30.5 cm × 20 cm × 17.8 cm) which were propped up with bricks. One hole was present on the wall at each end of the tank (Fig. 5). The inlet was 2.5 cm higher than the outlet hole. Tap water came in from the former and flowed out through the latter at a constant rate.

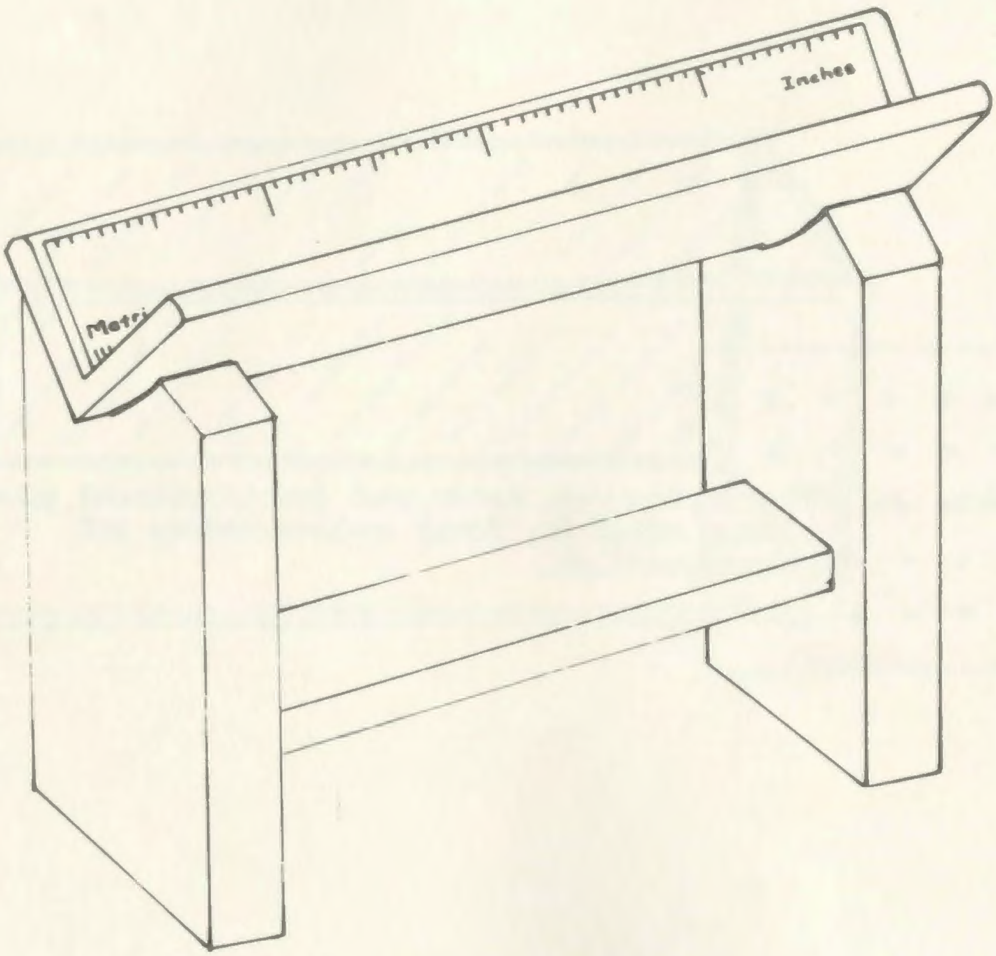
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Fig. 2. The V-shaped board for measuring diameter of fish eggs.

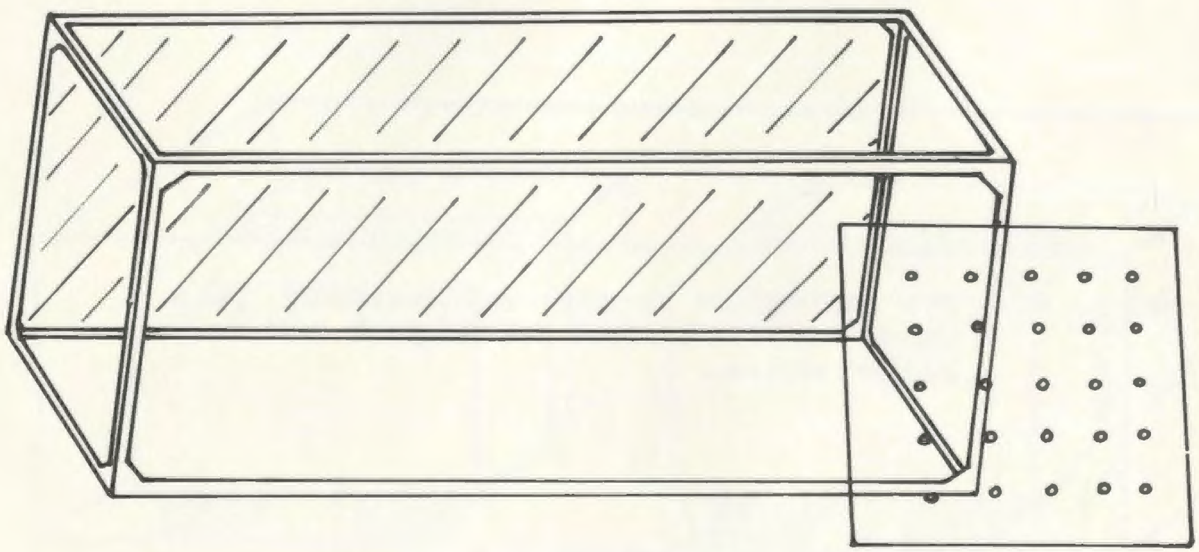


Fig. 3. The aquarium tank and partitioned plastic plate used in food selectivity of mosquitofish.

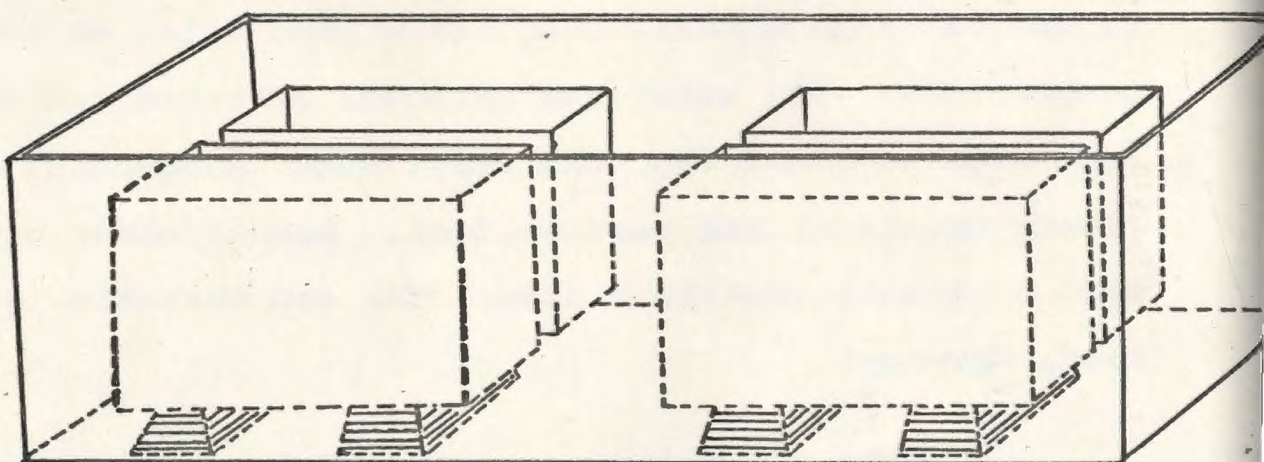
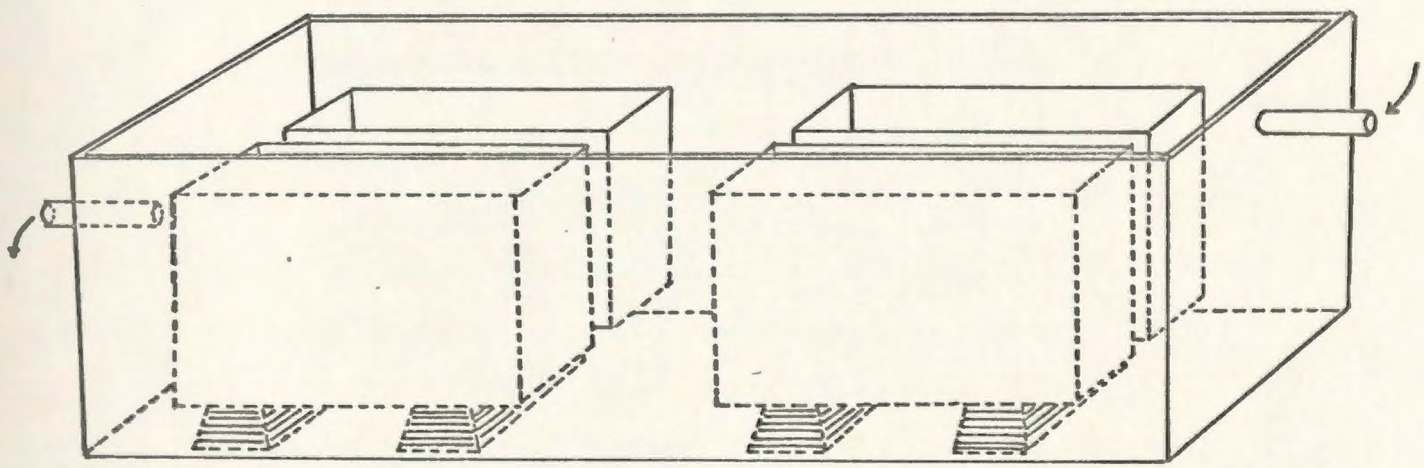


Fig. 4. The aquarium trough and battery jars used for fish kept at higher water temperature.

Fig. 5. The aquarium trough and battery jars used for fish kept at medium water temperature.



The aquarium tank (Fig. 6) measured 122 cm × 53 cm × 35 cm. A six-layer cooling coil containing anti-freeze coolant was placed close to the inner walls of the trough. The coil was connected to a generator with a fan, by means of which the returning, heat-laden anti-freeze was cooled. Water temperature in the tank could be controlled or lowered to a minimum of 4°C.

A wide V-shaped plastic board (Fig. 7) was used for measuring the experimental fish. There was a 1.5 mm cleft along the middle line of the board. Two thin plastic rulers, metric scales downwards, were fixed to the inner surfaces of the board. A thin transparent plastic sheet was attached at one end. The board could be completely covered by this sheet, which served to trap fish against the board.

The apparatus used for field experiments (Fig. 8) contained of two rectangular cages, one within the other. The inner (61 cm × 30.5 cm × 28 cm) was made of 5 mm thick plastic plates, all except the bottom one being perforated by holes 2 mm in diameter. These holes were evenly distributed with respect to the top plate. On the side ones, though, none were drilled less than 17.8 cm from the upper edge of the cage.

These holes allowed free water exchange. However, they were small enough to prevent the escape of the experimental fish. The cage had two lids. Fish and fish food could be introduced or removed without difficulty. Fish behaviour of any kind could be observed through the lids, whether opened or closed.

The outer, larger cage (76.2 cm × 45.7 cm × 36.9 cm) was made of aluminium plates through which evenly distributed holes 2 mm in diameter were drilled in the walls; no holes were drilled in the bottom. A single lid was hinged to the strong outer cage, which served to protect the inner plastic one from damage, and to ensure a steady and relatively calm environment for the fish kept in the inner cage. The space between the two cages served to reveal any escape of food organisms from the inner plastic cage. This system yielded good results.

Fig. 6. The aquarium tank and battery jar used for keeping fish at lowered water temperature.

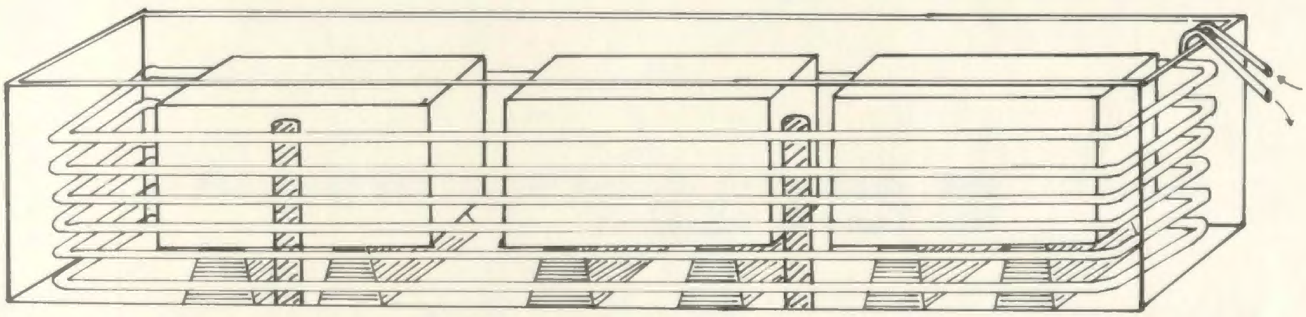
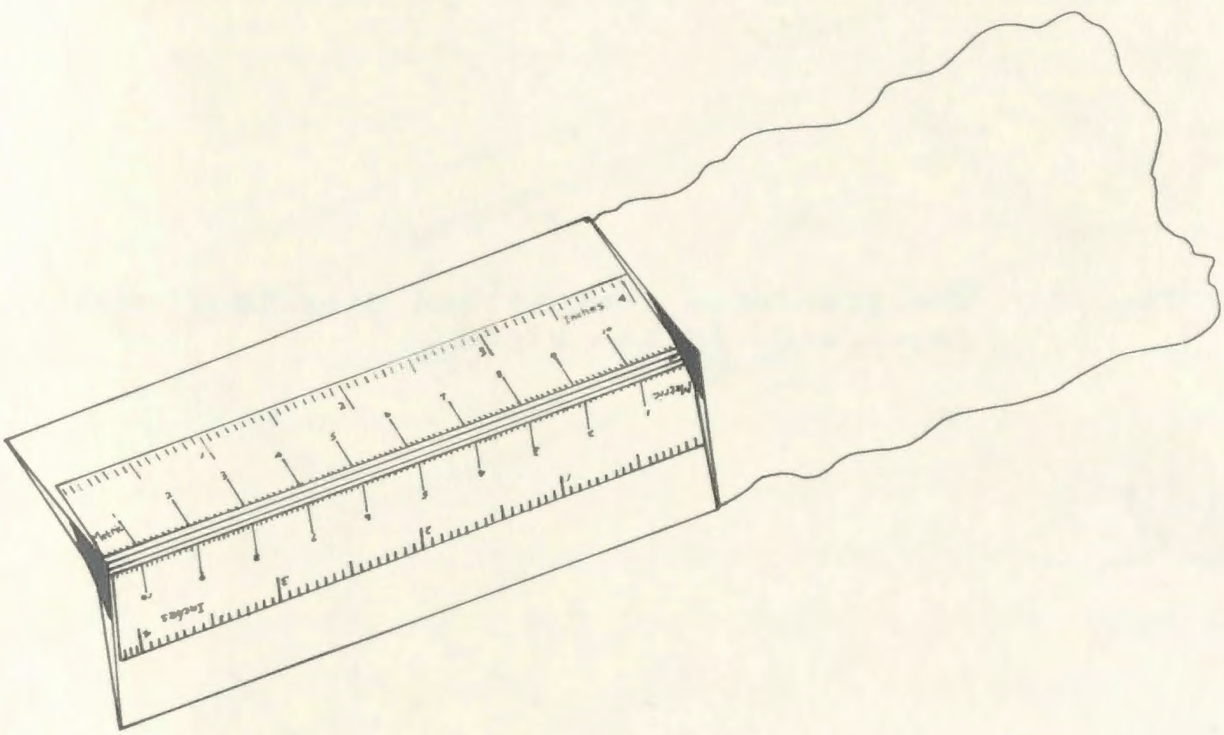


Fig. 7. The measuring board used for measuring the length of fish.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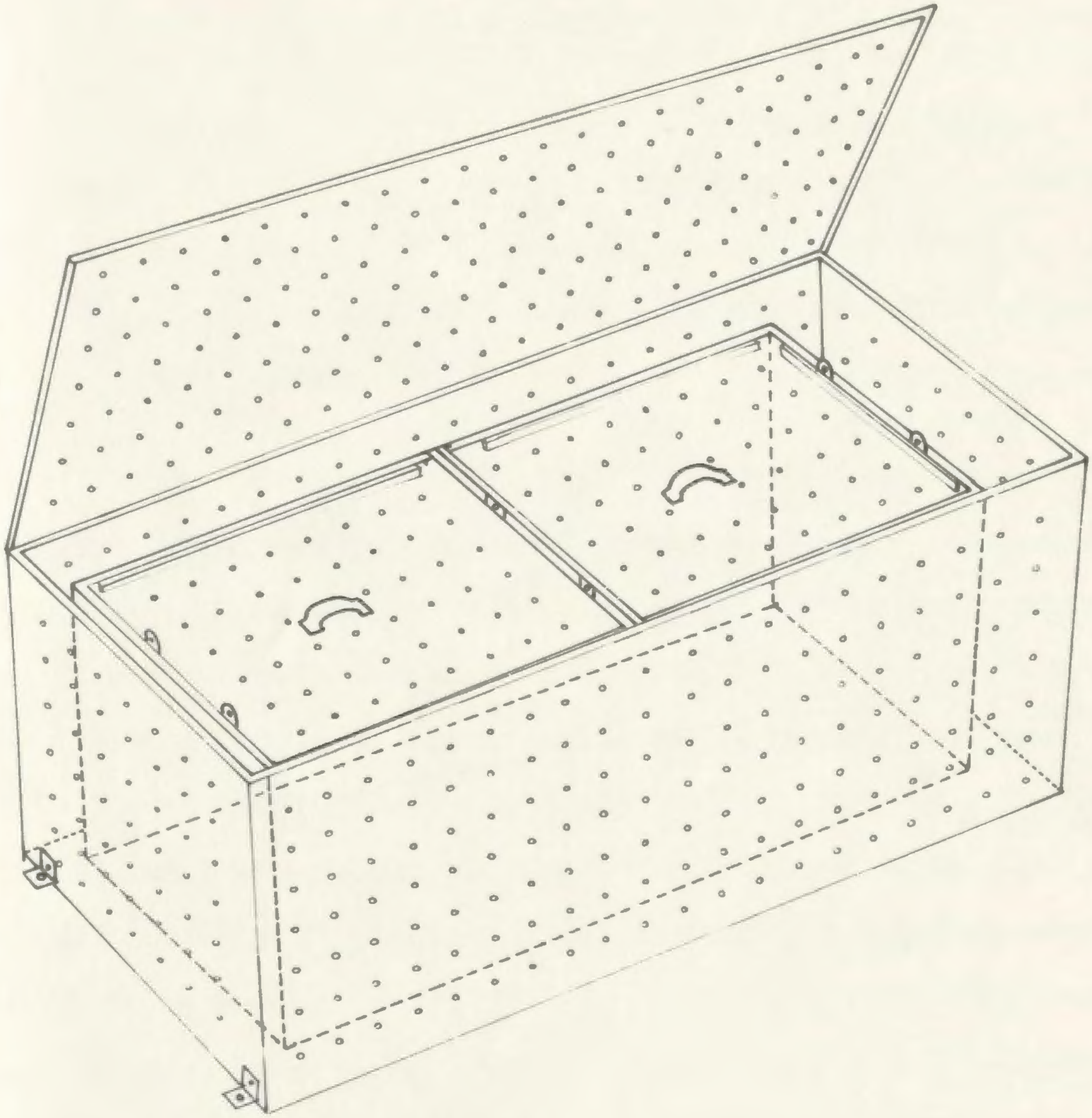
Inches

Fig. 8. The aluminium (outer) and plastic (inner) cages used in the stream.



LABORATORY EXPERIMENTS

Experiment I. Selectivity of food sizes by mosquitofish.

Eggs of brown trout (*Salmo trutta* L.) and young of three-spined stickleback (*Gasterosteus aculeatus* L.) were offered as food in this experiment. The eggs were obtained from trout of different sizes and degrees of maturation. These were captured from Long Pond in late Summer and Fall, 1969, by means of a gill net.

Soon after capture, the fish were brought back to the laboratory and dissected without delay. The ovaries, both mature and immature, were removed, kept in tightly-closed glass containers, and transferred to a deep-freezer. The membranous tissues surrounding and connecting the immature eggs were carefully removed with pointed forceps to expose the individual eggs before observations were made. Only seemingly healthy eggs were used. Those that showed evidence of damage or had been broken during tissue removal, were discarded. Measurements of diameter to the nearest mm was made by arranging 20 individual eggs in a row along the measuring board (Fig. 1). Average diameters were based upon ten readings.

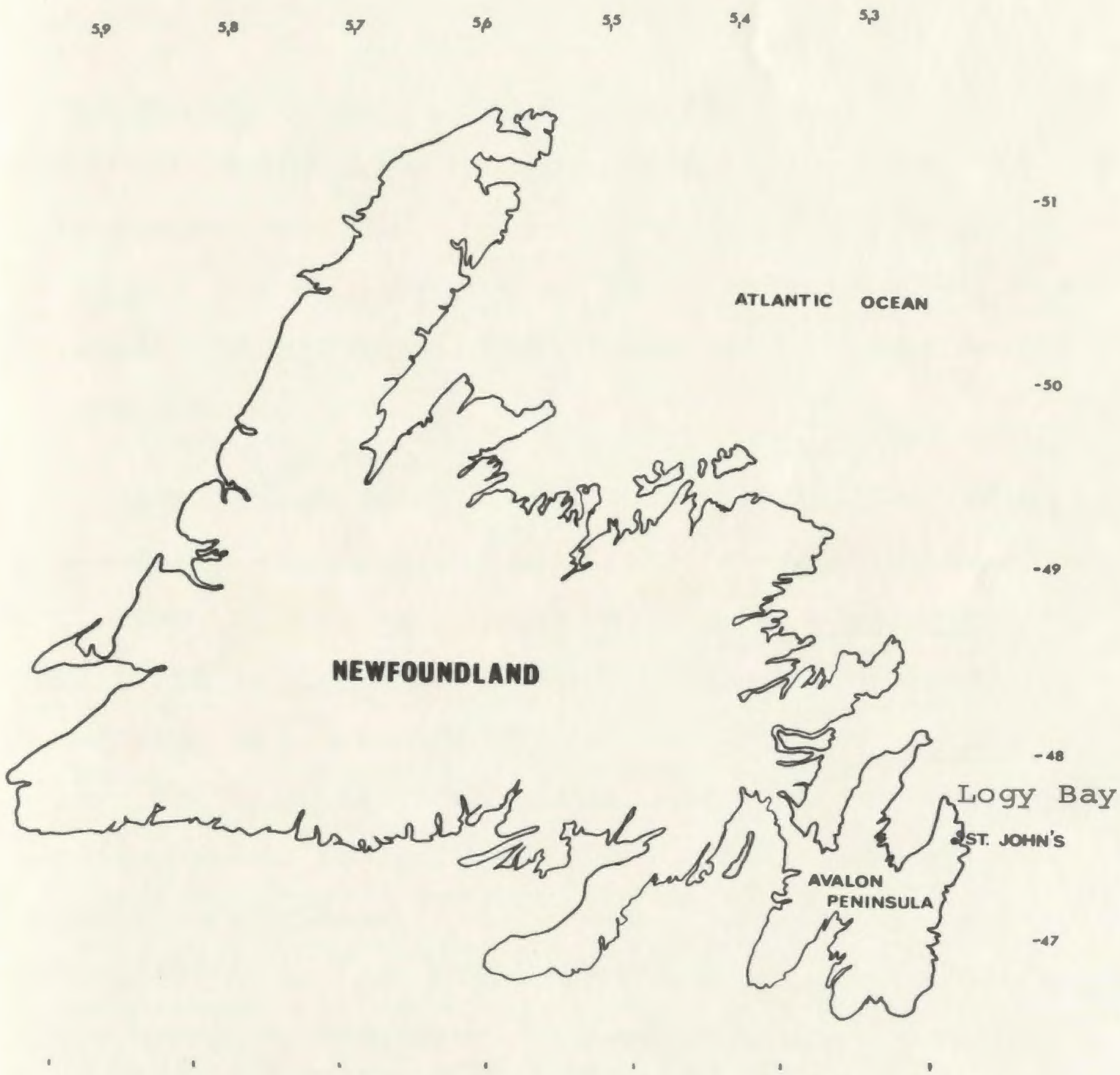
Young three-spined sticklebacks were captured from Long Pond with a fine meshed dip net. Their total length was quickly estimated on arrival at the laboratory, using a ruler, while gently holding the fish between thumb and forefinger. After such measurements, the fish were returned to small aquarium tanks which were marked with various lengths of the fish.

The mosquitofish used for these feeding studies were mature females. They were divided into two size groups, one averaging 35.5 mm in total length (range from 33.0 to 36.5 mm), the other 41.5 mm (range 38.0 to 46.0 mm).

Two series of experiments were conducted. In the first, experiemnts (each of seven days duration) were repeated five times. On each occasion, three mosquitofish from each size group were provided with eggs of a particular size as candidate food material. The fish were placed in two separate identical 70-litre aquarium tanks (Fig. 3), filled to a depth of 26 cm with stream water collected from the field site at Logy Bay, six miles from St. John's (Map 1). Before use, the water was filtered twice through glass wool. Water temperature was measured daily throughout each experiment, and proved to range from 21.5 to 23.5°C.

At the outset, the fish were isolated at one end of the aquarium tank by a plastic plate and starved for 12 hours. Only one size group of brown trout eggs for

Map 1. Map of Newfoundland.


5,9
5,8
5,7
5,6
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5,4
5,3
-51
ATLANTIC OCEAN
-50
-49
NEWFOUNDLAND
-48
Logy Bay
ST. JOHN'S
AVALON
PENINSULA
-47

example, 1.8 mm (1.7 - 1.9 mm) or 2.5 mm (2.4 - 2.6 mm) or 3.4 mm (3.3 - 3.5 mm) or 4.2 mm (4.1 - 4.3 mm) or 4.7 mm (4.6 - 4.8 mm) was offered, and evenly distributed in the tank.

The second series was conducted once in each size group and was continued for seven days. Brown trout eggs of three different size groups, 2.5 mm (1.8 - 2.7 mm), 3.8 mm (3.4 - 3.9 mm) and 4.5 mm (4.3 - 4.6 mm) were mixed and offered. Each day ten eggs of each size group were evenly distributed.

Soon after the eggs were introduced, the partition was removed and the released fish almost immediately began to feed. The numbers of eggs of different sizes eaten were recorded twice daily. The first count was made 30 minutes after the eggs were introduced and the other at the end of 12 hours. The feeding behaviour of the fish was carefully observed and noted in the first 30 minutes. Observations were made from a distance, care being taken to avoid movements that would frighten the fish. When half or more than half of an egg had been devoured, it was counted as "eaten". The uneaten eggs were removed from the tank, and the debris from broken eggs, also faeces, were siphoned out at the end of 12 hours. Fresh water was added to restore the original level. The fish were again isolated at one end of the tank, and were not fed for the next 12 hours. This procedure was repeated for seven days.

A similar method was followed in a study of prey size selectivity by mosquitofish. This time, young of three-spined sticklebacks were offered instead of fish eggs. Only healthy, fast swimming Gasterosteus were used. When half or more than half of the body length of the prey had been consumed, it was counted as "eaten". Sticklebacks that were merely nibbled at, or which were killed but not eaten, were not counted.

Experiment II. Effect of conditioning of mosquitofish to food eggs or food fish.

Twelve fully grown female mosquitofish were divided into two groups, each of which was subdivided into two aliquots (34 - 36 mm and 38 - 45 mm total length). They were placed separately in four 70-litre aquaria (70 cm × 35 cm × 35 cm), three mosquitofish of each size group being confined for seven days in a tank containing water 26 cm deep. During this period, six of the fish were fed twice daily with Brown trout eggs 3.8 mm (3.7 - 3.9 mm) in diameter, and the other six with young Gasterosteus. The eggs and the young sticklebacks both proved to be readily eaten by Gambusia.

At the end of seven days, none of the mosquitofish were given food for 12 hours and all were restricted to one end of the tank. They were released from the restricted area soon after six different food organisms were offered. The six food organisms were larvae and pupae of a chaoborid gnat (*Chaoborus* sp.), mosquito larvae (*Aedes* spp.), fish eggs of brown trout (*Salmo trutta*), young sticklebacks (*Gasterosteus aculeatus*) and young of Corixidae (*Sigara* sp.). Each day, ten of each food organism were given. The number of individuals of each food organisms eaten per 12-hour period was recorded daily. The uneaten food organisms were removed and no food was given for the next half-day. This procedure was repeated for seven days. All six food organisms were previously tested to ascertain that they were of a size that could be ingested by the fish without difficulty.

Experiment III. Selectivity upon different food organisms.

Forty mature mosquitofish were divided into two size groups. The total length of the first group ranged from 30 - 37 mm and that of the second group from 38 - 45 mm. Two 70-litre aquarium tanks were used in this experiment. Three fish were taken from each group and placed separately in two tanks. When a series of week-long experiments was completed, two fish from each tank were removed and replaced by two other fish. The same procedure was followed for succeeding weeks. All the mosquitofish were fed with TetraMin for two weeks and were starved for 12 hours before each experiment. The rest of the procedure was as for Experiment II. During the experiments, the mosquitofish were provided with various combinations of six different food organisms; except for the last series, in which eight food organisms were used. Each day, 10 food organisms were offered. The prey included: (I) larval and pupal stages of Diptera: (1) larvae and pupae of midges including Chaoborinae, *Chaoborus* sp., *Eucorethra* sp.; Chironomids, *Chironomus* sp.; Dixidae, *Dixa* sp.. (2) Mosquito larvae and pupae including *Culiseta* sp. and *Aedes* spp. (II) Young and adults of Hemiptera: (1) water striders (Gerridae, *Gerris* sp.), (2) water-boatmen (Corixidae, *Sigara* sp.) and (3) Backswimmers (Notonectidae, *Notonecta* sp.). (III) Nymphs of Odonata: (1) Dragonfly nymphs (Aeschnidae, *Aeschna* sp.; Libellulidae, *Plathemis* sp.) and (2) Damsefly nymphs (Coenagrionidae, *Ischnura* sp. and *Lestes* sp.). (IV) Mayfly nymphs (Ephemeroptera): Baetidae, *Blasturus* sp.; *Ephemerella* sp. and Heptageniidae, *Stenonema* sp. (V) Caddisfly larvae (Trichoptera): Limnephilidae, *Limnephilus* sp.; *Pycnopsyche* sp.; Psychomyiidae, *Polycentropus* sp. and Phryganeidae, *Ptilostomis* sp. (VI) Larvae and adults of beetles (Coleoptera): Dytiscidae, *Acilius* spp.; *Hygrotus* sp.; *Ilybius* sp.; *Rhantus* sp. and

Hydroporus sp.; Hydrophilidae, Hydrobius sp. (VII) Young of three-spined stickleback (Gasterosteus aculeatus). (VIII) Annelida: Oligochaeta, Tubifex sp. (IX) Arachnida (water mites): Arrenuridae, Arrenurus sp. and Pionidae, Piona sp. and (X) Tadpoles (Rana clamitans).

Experiment IV. Selectivity on microscopic organisms.

A total of 26 mosquitofish (ranging from 18 - 36 mm total length) were used in this experiment. Five glass battery jars (35 cm × 20 cm × 18 cm) were used to accommodate them, with four to six fish in each jar. Nine of the fish were kept in the first two jars containing stream water at room temperature (range 22.5 - 24.0^{0}C). Six were in another jar (range 13 - 14.0^{0}C) and eleven in the remaining two jars (range 5.0 - 5.5^{0}C). They were held in the jars and given artificial fish food for two to three weeks before the experiment started.

The fish were starved for 24 hours. Then, equal samples of thoroughly mixed microscopic organisms, zoo- and phytoplankton freshly obtained from the ponds at Logy Bay, were introduced into the jars. An equal amount of the same sample was preserved in 5% formalin solution for later identification.

On the second day, all the fish were removed from the jars and killed in 10% formalin. No regurgitation by the fish was observed when placed in the formalin.

Individual fish were weighed and measured. The stomach, from the posterior end of oesophagus to the pylorus was cut out of the digestive tract under a dissecting microscope. Then, the stomach was placed on a glass slide. Using two long needles, one holding the oesophagus end, the other was repeatedly stripped over the entire length of the stomach to remove its contents onto the slide. It was again placed on another slide and was carefully cut open with the needle to expose and remove any residue of food. Both slides were examined under a microscope and the food was identified and counted.

Experiment V. Growth and food consumption of mosquitofish.

The experiment was begun with 30 young mosquitofish which were about two and a half months old, having been born and raised in the laboratory as previously described.

Six glass battery jars (35 cm × 20 cm × 18 cm) were used to accommodate them, with five in a jar containing aerated stream water. Two of the jars were placed in the big aquarium tank (Fig. 4) containing tap water at room temperature. Two were in another aquarium tank (Fig. 5) with inlet and outlet holes containing running tap water. Two other jars were placed in an aquarium tank (Fig. 6). The water levels both inside and outside of the jars were maintained constant and were 2 cm below the upper edge of the jars.

Ten fish were kept in the first two jars, with five in each jar. The remaining 20 fish were held at first in four battery jars in the tank with a cooling system at room temperature (21.5^{0}C). Then, the water temperature was lowered at a rate of 1^{0}C daily. At 14^{0}C, ten fish were removed and transferred into the two jars placed in the tank containing running tap water at a water temperature of 14^{0}C. The water temperature of the cooling tank was further lowered at the rate of about 0.5^{0}C daily until 5.5^{0}C and maintained at this temperature throughout the experiment. Two fish were found dead in the water at 5.5^{0}C one week after the experiment had begun and were replaced by two of approximately the same size.

Water temperatures of the jars were recorded twice daily with a stem thermometer accurate to 0.5^{0}C. It varied with changes of water temperature in the outer tank or of room temperature. The temperature throughout the 14-week experiment ranged from 22.8 to 25.7°C in the first two jars; from 14.5 to 17.0°C in the second set and from 5.5 to 6.1°C in the third.

The hydrogen-ion concentration and oxygen content of the water were estimated weekly during the course of the experiment with a Porto-matic pH Meter, Model 175 and YS1 Oxygen Meter, Model 5075 respectively. The pH value of the stream water in the three sets of jars was almost the same and ranged from 5.2 to 5.4. The oxygen content of the first set ranged from 5.7 to 6.0 ppm; 5.7 to 6.1 ppm in the second set and 6.0 to 6.5 ppm in the third.

Since the laboratory fish were kept in the basement of the building, no sunlight or any other external light affected them. Only light of the room and light from a 60-watt light held 30.5 cm over each jar were provided. Fourteen hours light and 10 hours darkness were provided.

The fish were found to survive at different temperatures. They were held in the jars for a week prior to the experiment. During this period, they were fed twice daily with TetraMin and living chaoborine larvae. Once the experiment began, they were given only living chaoborine larvae in excess. At each feeding time, the wet weight of ten chaoborine larvae was measured on a Mettler balance. The number of larvae given each time and the number left over each day were recorded. The reasons for using chaoborine larvae as food were that they were readily devoured by the fish. Also they could be easily obtained in adequate amount from the stagnant ponds at Logy Bay. The left over food, dead or living, together with excreta were removed and siphoned from the jars. Fresh stream water of the same temperature as that in the jars was added back to the original water level. Since the stream water was carefully filtered before use and was changed from time to time, no growth of algae or fungi was detected.

The growth of the fish was recorded as follows. The fish were measured and weighed weekly and were starved for 24 hours before they were weighed. Fish were removed singly from the jar with a hand net onto the measuring board (Fig. 7) which was placed on a towel saturated with water, and covered with the transparent plastic sheet. The fish used to struggle for a moment, but soon became calm. By slightly tilting the measuring board, the fish was slipped down to one end. Its total length was measured to the nearest 0.5 mm. The fish was then dried by rolling gently over a cheese cloth to remove as much surface water as possible and placed in a tube of water of known weight. It was weighed to the nearest 0.5 mg. The water temperature in the tube was the same as that in the jar. The cheese cloth and the measuring board used for the fish were kept at lowered temperature in a picnic chest containing ice before used. As soon as the fish was weighed, it was returned to its original jar. Readings were expressed as the average length or weight of the fish.

The experiment continued for 14 weeks. On the eleventh week, the mortality of fish in the jars at 6.0°C was more than 50%, thus no reading was taken from then on. On the thirteenth week, an accidental blockage of the outlet of the aquarium tank with running tap water, causing an overflow of tap water into the jars and killed 70% of the fish. Thus no reading was recorded on the last week for second group fish.

Field Experiments

Experiment VI. Growth of mosquitofish under stream conditions.

The apparatus used in this experiment was shown in Fig. 8. Two such doubled cages were placed in the stream at Logy Bay. The places where these cages were put were carefully selected so that they would provide a suitable depth, would have a clean stream floor and would be accessible. For most of the time throughout the experiment, water level was about two cm above the inner cage and about five cm below the upper edge of the outer cage. Occasionally, after heavy rain, they were completely covered by water for two to three days. At low water, the level was about the same or even slightly below the upper edge of the inner cage. However, this did not affect the steady and calm cage environment.

Fourteen fish, three and a half months old were transferred from the laboratory and kept in one of the cages. Before the transfer, the fish were held at 14°C in the laboratory for two weeks. The water temperature in the stream was measured to be 13.5°C on the day when they were transferred. There was a slight difference in water temperature in and outside of the cages. It was 0.5°C higher inside the inner cage.

No measurements of length and weight of the fish were made on the first week. At the end of the second week, they were caught in a hand net, and placed in two double-layered plastic bags held in a cooled, foam-insulated picnic chest. Then they were brought back to the laboratory and kept in the aquarium tank with water temperature the same as that in the plastic bags. They were starved overnight. By morning, individual fish were weighed and the total length measured. The method of measuring and weighing was the same as that previously described in Experiment V. Soon after the measurement was done, they were returned to the stream. Great care was taken in handling the fish so that they would not be hurt mechanically, and the differences in water temperature in the stream, the bags and the laboratory tank were kept as small as possible. From then on, the growth of the fish was recorded biweekly.

The fish were fed excessively twice a week on a diet made up of mainly chaoborine larvae, Oligochaeta, Copepods, Ostracods, young Corixids and algae mainly the diatoms Fragilaria and Tabellaria, some other commonly found Diatoms, Microspora and desmids.

The 24-hour water temperature just outside the cages was recorded with a Ryan (weekly recording) thermometer during the course of the experiment. It ranged from 13.5 to 4.4^{0}C. The oxygen content of the water inside the cage was measured periodically with the YS1 Oxygen Meter (Model 5075) and ranged from 7.8 to 10.1 ppm. The hydrogen-ion concentration and dissolved solids of the stream were estimated weekly with a Porto-matic pH Meter (Model 175) and a Myron L Deluxe DS Meter (Automatic Temperature Compensated, Model 532 T1) respectively. The pH value was rather stable, ranging from 4.9 to 5.1 and the dissolved solids ranged from 58 to 70 ppm.

On the day of returning the fish to the stream, the inner and outer cages were thoroughly cleaned. Any fallen decayed leaf debris and sand deposited on the bottom and any algae attached to the corners of the outer cage were completely removed. Debris and dead bodies of food organisms found in the inner cage were also removed.

The experiment lasted for 12 weeks. It was discontinued because more than 50% of the experimental fish were dead at the end of the thirteenth week. Eleven of the fish had survived for 12 weeks.

Experiment VII. Feeding habits of mosquitofish caged in a stream at Logy Bay.

Twenty fish (ranging from 24 - 35 mm in total length) were kept in another doubled cage for the study of stomach contents of the fish. No fully grown or gravid fish were used in this study as it was strictly restricted by the regulations in the permit issued by the Department of Fisheries in Ottawa. As in the study of growth, every precaution was taken in handling the fish to prevent the escape of fish from the cage into the stream.

Ten of the fish were transferred to the cage in the stream in late August and the other ten in early November, at which times, the water temperatures were measured to range from 12.5 to 14.0°C and 3.5 to 5.0°C respectively.

The fish were held in the cage for two weeks prior to the experiment and during this period, they were fed with living chaoborine larvae. Then, the left over larvae were completely removed from the cage 24 hours before the introducing of mixed living food organisms. Samples of food organisms obtained from the nearby ponds were thoroughly mixed and divided into two portions. One portion, together with Brown trout eggs were placed in the cage as food for the fish. The other portion was brought back to laboratory to identify the types of food organisms present. The sizes of the food organisms offered were such that they could be eaten by the fish.

Five fish were removed from the cage by a hand net on each of two successive days and preserved in 10% formalin.

In the laboratory, the stomachs of the fish were cut out and examined as in Experiment IV.

RESULTS

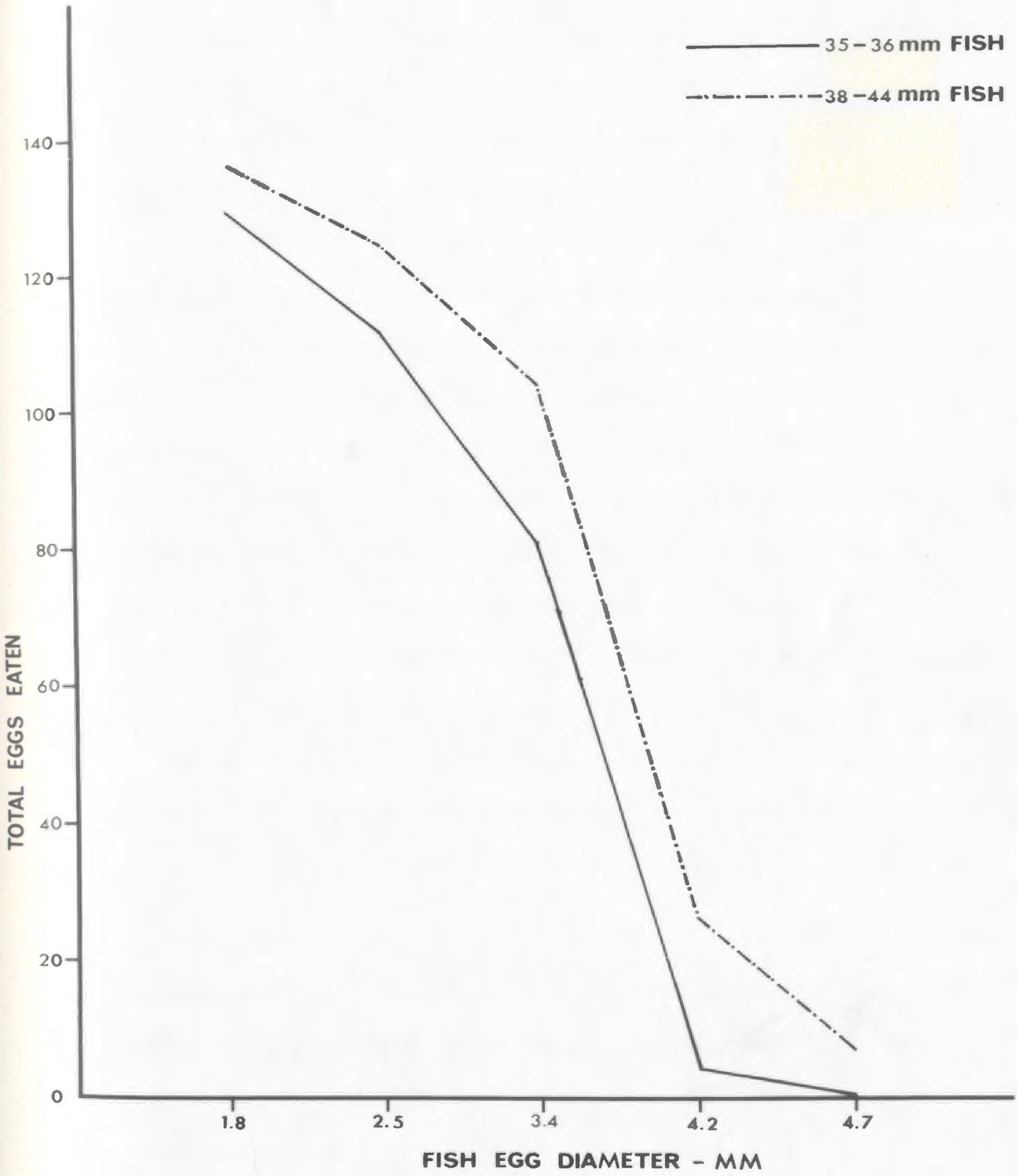
FOOD SIZE AND FOOD SELECTIVITY

Results of experiments based upon selectivity of brown trout eggs and young sticklebacks are summarized in Tables 1 - 4 and expressed graphically in Figs. 9 - 12.

The quantity of fish eggs consumed by mosquitofish, proved to decrease with increasing egg diameter (Table 1). Small mosquitofish (35 - 36 mm) exhibit a gradual decline in their consumption of eggs as the latters' diameter increases from 1.5 to 3.8 mm. There then follows a very rapid decrease of egg consumption as egg diameter exceeds 4.0 mm. No egg exceeding 4.6 mm was ever eaten by fish of this order of size (Fig. 9).

Larger mosquitofish (38 - 44 mm) showed a steadier decline in egg consumption as the diameter increased from 1.5 to 3.8 mm. Once again, there was an accelerated decline after the diameter exceeded 4.0 mm. Nevertheless, 5% of the largest eggs provided (av. 4.7 mm diameter) were consumed by these larger *Gambusia*. Small mosquitofish consumed eggs of less than 3.8 mm diameter without difficulty. Four or five of such eggs could be eaten one after another, without pause. However, eggs of a diameter above 4.0 mm were much less readily broken up and devoured. It was observed on

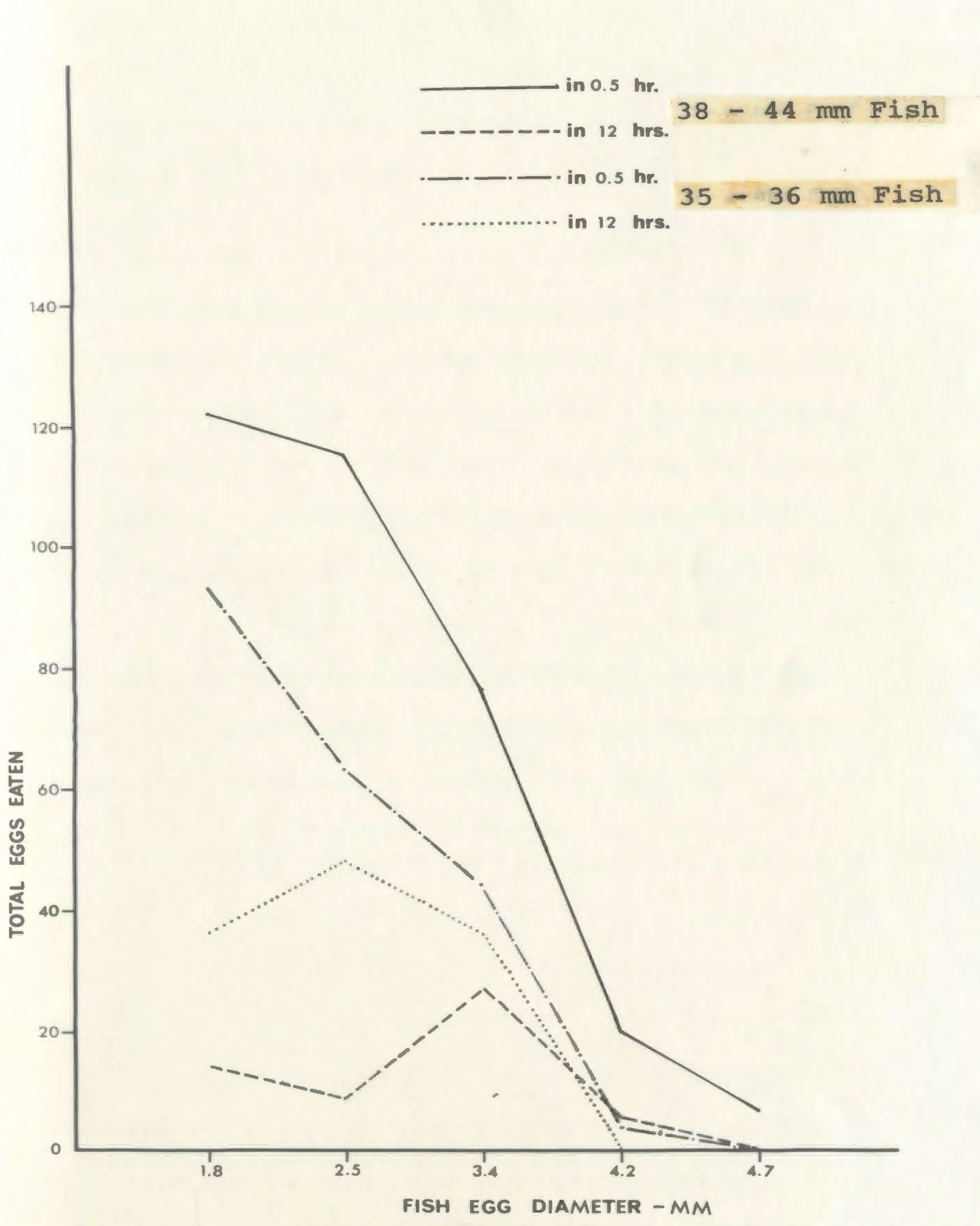
Fig. 9. Total number of brown trout eggs consumed by small (35 - 36 mm) and large (38 - 44 mm) mosquitofish.


35-36 mm FISH
38-44 mm FISH
TOTAL EGGS EATEN
140
120
100
80
60
40
20
0
1.8
2.5
3.4
4.2
4.7
FISH EGG DIAMETER - MM

many occasions that it took the combined efforts of two to three fish to break up an individual egg. One Gambusia would make the first effort to swallow or break the egg. If it failed to do so, another fish, or even two or three fish together would continue the attack. Once the egg was broken and torn, the fish would individually proceed to devour pieces of it. It was quite another story as regards eggs of a diameter beyond 4.6 mm. These proved very difficult to break, although it was occasionally possible for the fish to grasp an egg of even this size - although only momentarily. After several attempts to fragment such eggs, small mosquitofish (35 - 36 mm) would eventually give up. Larger ones (38 - 44 mm), despite the fact that they devoured 5% of the eggs exceeding 4.6 mm diameter, also experienced real difficulty in breaking them up. It is submitted that it would be difficult indeed for even the largest Gambusia affinis to swallow or even break up eggs exceeding 5.0 mm diameter.

In fact, eggs of a diameter of 4.2 mm are close to the maximum size that small mosquitofish can eat; and the largest examples seldom succeed in destroying fish eggs of more than 4.7 mm in diameter. The largest unspawned eggs remaining in Avalon Peninsula brown trout have been reported to be 5 mm in diameter; those of landlocked salmon

Fig. 10. Number of brown trout eggs consumed by mosquitofish both in half an hour and 12 hours.

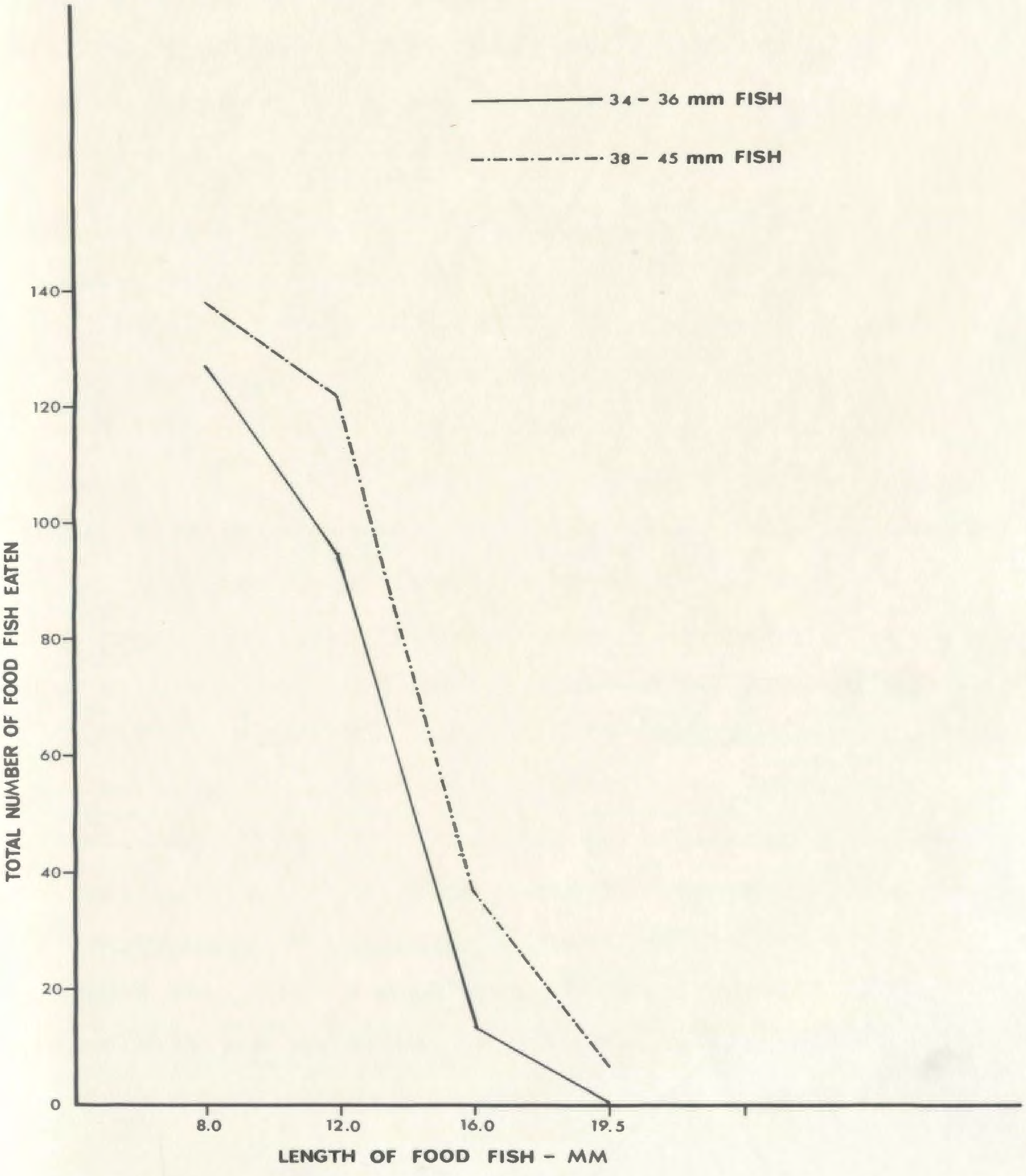

in 0.5 hr.
in 12 hrs.
38 - 44 mm Fish
in 0.5 hr.
in 12 hrs.
35 - 36 mm Fish
TOTAL EGGS EATEN
0
20
40
60
80
100
120
140
1.8
2.5
3.4
4.2
4.7
FISH EGG DIAMETER - MM

6.55 mm; those of rainbow trout 4.80 mm; and those of brook trout 4.55 mm (Lee, 1971). Obviously, the eggs of landlocked salmon, and probably most of those of brown trout too, are far too big to be swallowed by mosquitofish.

Most eggs offered were devoured within 30 minutes (Fig. 10), especially by the larger fish. Beyond this period, more eggs were consumed by the smaller fish than by the larger ones, except for eggs of up to 4.2 mm diameter. No eggs of from 4.2 - 4.7 mm were eaten by the small fish, and none beyond 4.7 mm by the larger ones. Moreover, after 30 minutes had elapsed, many of even the larger eggs had been partly (even half) consumed. Eggs kept in water for extended periods become hardened externally. The hardness is easily detectable after 12 hours, whether by feeling with the fingers or by gently probing with forceps.

More than half of the young of sticklebacks of a total length of less than 13 mm were devoured by both small (34 - 36 mm) and large (38 - 45 mm) mosquitofish (Table 2). There was a rapid decrease in consumption after the length of the prey exceeded 15 mm (Fig. 11). No young of 19 mm and over were eaten by small mosquitofish. Indeed, only 5% were consumed by the larger fish - even after a substantially longer period of time. No sticklebacks over this total length were devoured inside the first half-hour. On several

Fig. 11. Total number of three-spined sticklebacks consumed by small (34 - 36 mm) and large (38 - 45 mm) mosquitofish.

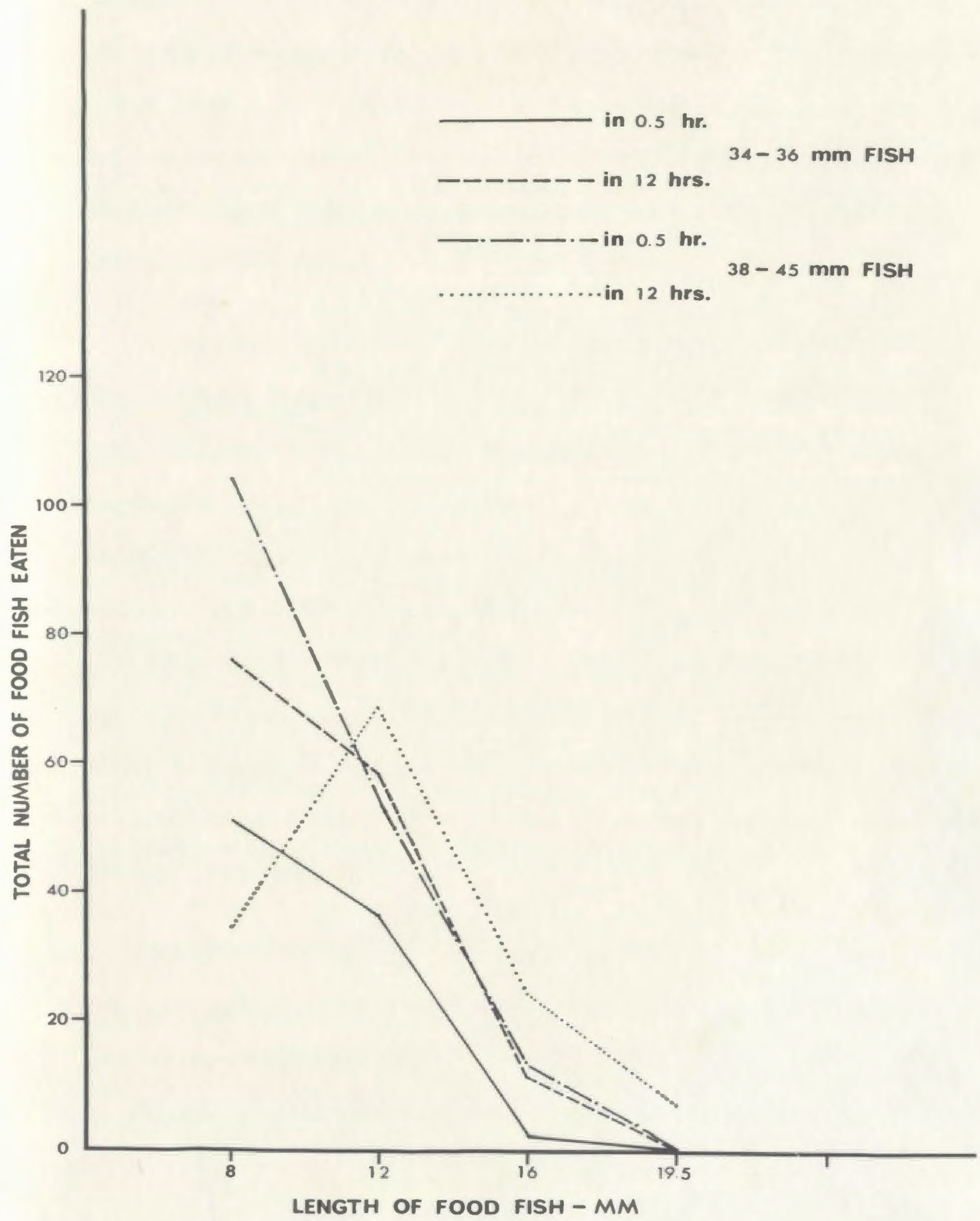

34 - 36 mm FISH
38 - 45 mm FISH
TOTAL NUMBER OF FOOD FISH EATEN
140
120
100
80
60
40
20
0
8.0
12.0
16.0
19.5
LENGTH OF FOOD FISH - MM

occasions, a mosquitofish was observed to seize a stickleback, trying to swallow it; the prey escaping, however, after putting up a vigorous struggle.

One stickleback eaten by one of the larger mosquitofish was at first momentarily held with half of its body length within the predator's mouth. The prey was then disgorged and again attacked by the mosquitofish. At this point, two other predators joined forces with the first one. The victim was then torn to pieces, and shared by the three mosquitofish. Again, some prey above 18 mm long were found dead, although uneaten, in the aquarium tank containing large fish. Prey of this length seem close to the maximum size that small fish are physically able to consume. In the case of the larger fish, 20 mm seems close to this maximum. Comparison of the numbers of brown trout eggs and young sticklebacks eaten within and beyond the first 30 minutes revealed slight differences. Thus fewer sticklebacks (except those of the smallest size) were eaten by the large fish in the first half hour (Fig. 12). It required a substantially longer period for most of such prey to be consumed. This was the opposite situation as regards the number of eggs eaten within the same period of time.

In tests using brown trout eggs of different sizes as food, both small and large Gambusia selected the smaller

Fig. 12. Number of three-spined sticklebacks consumed by mosquitofish both in half an hour and 12 hours.



in 0.5 hr.
34 – 36 mm FISH
in 12 hrs.
in 0.5 hr.
38 – 45 mm FISH
in 12 hrs.
TOTAL NUMBER OF FOOD FISH EATEN
120
100
80
60
40
20
0
8
12
16
19.5
LENGTH OF FOOD FISH – MM

eggs (Table 3). More than 77% of the smallest eggs (av. diameter 2.5 mm), 55.7% of medium eggs (av. diameter 3.8 mm) and only 2.9% of the largest ones (4.5 mm av. diameter) were devoured by the smaller fish. The larger fish consumed 92.9% of the smallest eggs, 74.3% of the medium size and only 17.1% of the largest ones.

Gambusia also selected small sticklebacks when available (Table 4). More than 90% of the smallest sticklebacks (av. length 7 mm), 62.9% and 90% of the half-grown (av. length 12 mm); and none and 12.8% of the largest ones (av. length 17 mm), were devoured by small and large mosquitofish respectively. The results are contrary to the theory (Ivlev 1961) that within their capacity predatory fish usually prefer to devour victims of the largest possible size. They agree, though, with Beyerle and Williams' (1968) observations on northern pike which selected the smallest certrarchids available.

Comparison of the results of conditioning tests (Table 5) and other food selectivity tests (Tables 6 - 8) indicates that conditioning had little effect on selectivity. In these tests, with both small and large Gambusia, mosquito and chaoborine larvae were more heavily utilized than: chaoborine pupae, young sticklebacks, trout eggs and waterboatmen. Chaoborine pupae were more intensively eaten by mosquitofish conditioned to trout eggs than young sticklebacks. These, in turn, were chosen over trout eggs and water-boatmen. When conditioned to young sticklebacks, though, mosquitofish ate chaoborine larvae less intensively. Again, trout eggs and water-boatmen were consumed less readily than sticklebacks and chaoborine pupae.

A number of generalities concerning mosquitofish selectivity towards various food organisms are made possible by the data contained in Tables 6 - 14.

In the test referred to in Table 6, water-boatmen were more heavily utilized than young sticklebacks and trout eggs; whereas in the conditioning tests, the latter were more heavily utilized. The difference might be due to the smaller size of the water-boatmen in the former test. Small water-boatmen are relatively slower in movement and are thus more readily devoured than the speedier larger stages. Also, the smaller water-boatmen are in more constant motion than the larger ones, the immobility of which can keep them from the attention of mosquitofish. However, the results still show that larval mosquitoes and chaoborines, also pupae of the latter, dominated the food organisms consumed. Both dead and living adult chaoborines (live examples with one wing deliberately removed) necessarily remained at the surface of the water. They were less utilized than the larvae and pupae (Table 9). It is interesting to note that the fish preferred live adult chaoborines to dead ones. Twice, when 10 of the adults (five dead and five living) were given to two mature mosquitofish, it was the live ones (struggling and moving around on the water surface) that were first attacked and eaten by the predators. The dead adults were only eaten afterwards, when no more live examples were available.

Small, naked (i.e. with case or cocoon artificially removed) caddis-fly larvae slowly and ceaselessly moving about on the bottom of the tank, also attracted much attention from the fish, being utilized more heavily than young sticklebacks and trout eggs. The distribution of the caddis-fly larvae on the bottom of the tank also contributed in large part to their being heavily consumed, since this provided the fish with greater accessibility to them. Certain caddis-flies (Table 10) were utilized less intensively. This was probably due to their hairiness and longer body length, as well as a larger chitinized head.

Besides mosquito and chaoborine larvae, the relatively inactive chironomid larvae also proved major targets for the fish (Table 7). Indeed, the chironomids were utilized as intensively as larval mosquitoes and chaoborines. Compared with the sticklebacks, water-boatmen or larval beetles, the chironomid larvae were slower in movement and had a softer body covering. This might be the reason why the latter were so heavily utilized. Sticklebacks were eaten more readily than larval beetles which were chosen over water-boatmen and brown trout eggs. The adults of beetles, both small and large (Table 14) were not devoured by the fish. On many occasions, it was observed that mosquitofish did swallow some of the smaller beetles, but spit them out subsequently. Both small and large beetles had tough, chitinized body coverings. Taste may also affect the food preference of the mosquitofish. For example, in the case of water mites, despite their relatively soft body structure, were never eaten either (Table 12).

Compared with other food organisms, the long, slender, and slow creeping oligochaetes (Tubifex sp.) were rather heavily eaten (Tables 9, 12 and 13). It is interesting to note that most of them were devoured soon after they were introduced. Few of them were eaten beyond the first 30 minutes period. Oligochaetae once placed on the bottom of the aquarium, started moving around. Some of them moved to the center and thus were more vulnerable to the fish. However, those that moved towards the corners or sides of the tank, thereby gaining shelter, could hardly be seen by the predators, and were therefore safe from attack. Often, after feeding, when water was pumped through a glass tubing with a rubber pump towards the corners of the tank, hidden oligochaetae would be washed out.

In contrast to oligochaetes, water striders always stayed on the water surface. Mostly they walked and moved rapidly with their legs lightly in touch with the water surface. It was observed that Gambusia did show much interest in catching the water striders. Owing to the speedy movement of the gerrids, the smaller mosquitofish would eventually give up chasing them, after a number of fruitless attempts. This might be the reason why they were less utilized than water-boatmen by the smaller Gambusia. However, the large fish which were more aggressive and swam more rapidly, preferred water striders to water-boatmen (Table 13).

Nymphs of damselfly and dragonfly as well as mayfly larvae were rarely or not eaten at all by both small and large Gambusia (Table 8). Although the nymphs and larvae of these organisms were slow in movement, the fish showed little interest in them. The comparatively larger sizes (both in length and width) and tough body covering of the nymphs might be the main reason that they were less or not eaten. Distaste may have been a contributory factor, too, in which connection it is recollected that the appreciably smaller mayfly larvae were not preyed upon by the mosquitofish either (Table 14).

Tadpoles, the dark grey, soft and oblong creatures, mostly stayed at the bottom or corners of the tank. Occasionally, they rose to the surface or swam along the wall of the tank. They were devoured sparingly in comparison to diptera larvae, sticklebacks and brown trout eggs (Table 11). However, they were consumed in preference to adult beetles and back-swimmers (Notonecta sp.), both of the latter were not eaten at all (Talbe 14). Toughness of body (as in beetles) and larger size and speedier in movement (as in backswimmers) might be the reason that they were rejected by Gambusia. Although the backswimmers spent most of the time swimming around on or beneath the water surface, they were less attacked by mosquitofish which preferred other food organisms available. In comparison to caddisfly larvae and water-boatmen, the tadpoles were also less utilized.

A list of the minimum and maximum lengths of food organisms fed to mosquitofish in determining food preference is given in Table 15. Another list of other insect larvae and adults also found in the pools at Logy Bay is presented in Table 16.

Table 1. Number of eggs consumed by mosquitofish when offered brown trout eggs of one particular size at a time.

Total length of mosquitofish (mm)	Food					% of food eaten
	Mean diameter (mm)	Total no. offered	No. eaten			
			0.5 hr.	12 hrs.	Total	
35 - 36	1.8 (1.5-1.9)	140	93	36	129	92
	2.5 (2.2-2.8)	140	63	48	111	79
	3.4 (3.0-3.8)	140	44	36	80	57
	4.2 (4.0-4.5)	140	4	0	4	3
	4.7 (4.6-5.0)	140	0	0	0	0
38 - 44	1.8 (1.5-1.9)	140	122	14	136	97
	2.5 (2.2-2.8)	140	115	9	124	89
	3.4 (3.0-3.8)	140	76	27	103	74
	4.2 (4.0-4.5)	140	20	6	26	19
	4.7 (4.6-5.0)	140	7	0	7	5

Table 2. Number of young three-spined sticklebacks consumed by mosquitofish when offered one particular size at a time.

Total length of mosquitofish (mm)	Food					% of food eaten
	Mean total length (mm)	Total no. offered	No. eaten			
			0.5 hr.	12 hrs.	Total	
34 - 36	8 (6-9)	140	51	76	127	91
	12 (10-13)	140	36	58	94	67
	16 (15-18)	140	2	11	13	9
	19.5 (19-20)	140	0	0	0	0
38 - 45	8 (6-9)	140	104	34	138	99
	12 (10-13)	140	54	68	122	87
	16 (15-18)	140	13	24	37	26
	19.5 (19-20)	140	0	7	7	5

Table 3. Food size selectivity by mosquitofish when offered equal number of brown trout eggs of various sizes at the same time.

Total length of mosquitofish (mm)	Food					% of food eaten
	Mean diameter (mm)	Total no. offered	No. eaten			
			0.5 hr.	12 hrs.	Total	
34 - 36	2.5 (1.8-2.7)	70	46	8	54	77.1
	3.8 (3.4-3.9)	70	21	18	39	55.7
	4.5 (4.3-4.6)	70	2	0	2	2.9
38 - 46	2.5 (1.8-2.7)	70	45	20	65	92.9
	3.8 (3.4-3.9)	70	31	21	52	74.3
	4.5 (4.3-4.6)	70	11	1	12	17.1

Table 4. Food size selectivity by mosquitofish when offered equal number of young three-spined sticklebacks of various sizes at the same time.

Total length of mosquitofish (mm)	Food					% of food eaten
	Mean total length (mm)	Total no. offered	No. eaten			
			0.5 hr.	12 hrs.	Total	
34 - 36	7 (6-8)	70	40	24	64	91.4
	12 (11-13)	70	19	25	44	62.9
	17 (16-18)	70	0	0	0	0
38 - 46	7 (6-8)	70	48	18	66	92.8
	12 (11-13)	70	26	37	63	90.0
	17 (16-18)	70	3	6	9	12.8

Table 5. Conditioning test. Results of conditioning 12 mosquitofish to brown trout eggs or young three-spined sticklebacks.

Total length of mosquitofish (mm)	Condition to	No. of each food item offered	No. of food items eaten					
			Chaoborus larvae	Chaoborus pupae	Mosquito larvae	Brown trout eggs	Young stickle-backs	Water-boatmen
34 - 36	Brown trout eggs	70	63	54	68	17	48	7
38 - 45		70	70	64	70	26	57	18
35 - 36	Young sticklebacks	70	68	45	70	15	47	12
38 - 44		70	70	56	70	19	63	20

Table 6. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
36 - 37	Chaoborus sp.					
	Larvae	12	80	52	28	80
	Pupae	11	80	11	32	43
	Mosquito larvae Aedes spp.	12	80	77	3	80
	Brown trout eggs S. trutta	4	80	8	2	10
	Young sticklebacks G. aculeatus	13	80	2	14	16
	Water-boatmen Sigara sp.	3	80	6	26	32
38 - 44	Chaoborus sp.					
	Larvae	12	80	18	53	71
	Pupae	11	80	16	40	56
	Mosquito larvae Aedes spp.	12	80	72	8	80
	Brown trout eggs S. trutta	4	80	13	3	16
	Young sticklebacks G. aculeatus	14	80	6	13	19
	Caddisfly larvae Limnephilus sp. Pycnopsyche sp.	11	80	24	41	65

Table 7. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
35 - 36	Chironomid larvae Chironomus sp.	12	80	62	15	77
	Mosquito larvae Aedes spp.	11	80	80	-	80
	Brown trout eggs S. trutta	4	80	7	11	18
	Young sticklebacks G. aculeatus	13	80	29	33	62
	Water-boatmen Sigara sp.	3.5	80	4	15	19
	Larval beetles Acilius sp. Hydroporus sp. Hydrobius sp.	12	80	18	21	39
39 - 40	*Chironomid larvae Chironomus sp.	12	70	70	-	70
	Mosquito larvae Aedes spp.	11	80	80	-	80
	Brown trout eggs S. trutta	4	80	12	1	13
	Young sticklebacks G. aculeatus	13	80	21	54	75
	Water-boatmen Sigara sp.	3.5	80	5	21	26
	Larval beetles Acilius sp. Hydroporus sp. Hydrobius sp.	12	80	18	38	56

* Food organisms given for seven days only.

Table 8. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
33 - 36	Larvae of midge Eucorethra sp.	11	80	49	21	70
	Mosquito larvae Aedes spp.	11	80	56	22	78
	Brown trout eggs S. trutta	3.8	80	18	4	22
	Young sticklebacks G. aculeatus	12	80	14	38	52
	Water-boatmen Sigara sp.	3	80	2	7	9
	Nymphs of damsel-fly Ischnura sp. Lestes sp.	14	80	0	1	1
39 - 43	Larvae of midge Eucorethra sp.	11	80	23	49	72
	Mosquito larvae Aedes spp.	11	80	80	-	80
	Brown trout eggs S. trutta	4	80	12	7	19
	Young sticklebacks G. aculeatus	12	80	31	33	64
	Water-boatmen Sigara sp.	3	80	5	17	22
	*Nymphs of dragonfly Aeschna sp. Plathemis sp.	13	70	0	0	0

Table 9. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food Organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
31 - 35	Chaoborus sp.					
	Larvae	12	80	16	53	69
	Pupae	11	80	9	36	45
	Adults	10	80	0	10	10
	Brown trout eggs	4	80	8	1	9
	S. trutta					
	Oligochaetae	30	80	23	34	57
	Tubifex sp.					
	Water-boatmen	3.5	80	2	10	12
	Sigara sp.					
38 - 41	Chaoborus sp.					
	Larvae	12	80	48	30	78
	Pupae	11	80	27	34	61
	Adults	10	80	0	8	8
	Brown trout eggs	4	80	12	1	13
	S. trutta					
	Oligochaetae	35	80	42	7	49
	Tubifex sp.					
	Water-boatmen	3.5	80	9	14	23
	Sigara sp.					

Table 10. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten 0.5 hr.	12 hrs.	Total
34 - 37	Chaoborus sp.					
	Larvae	13	80	40	31	71
	Pupae	11	80	23	27	50
	Mosquito larvae Aedes spp.	12	80	70	10	80
	Brown trout eggs S. trutta	4	80	4	9	13
	Water-boatmen Sigara sp.	4	80	0	12	12
	Caddisfly larvae Limnephilus sp. Ptilostomis sp. Polycentropus sp.	13	80	0	9	9
39 - 43	Chaoborus sp.					
	Larvae	12	80	58	22	80
	Pupae	11	80	15	25	40
	Mosquito larvae Aedes sp.	12	80	76	4	80
	Brown trout eggs S. trutta	4	80	8	6	14
	Water-boatmen Sigara sp.	4	80	0	11	11
	Caddisfly larvae Limnephilus sp. Ptilostomis sp. Polycentropus sp.	14	80	4	15	19

Table 11. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
33 - 35	Chaoborus larvae Chaoborus sp.	13	80	57	19	76
	Mosquito larvae	11	80	70	8	78
	Pupae Aedes spp. Culiseta sp.	10	80	31	36	67
	Brown trout eggs S. trutta	3.8	80	10	2	12
	Water-boatmen Sigara sp.	3	80	13	9	22
	Tadpoles Rana clamitans	13	80	0	4	4
38 - 45	Chaoborus larvae Chaoborus sp.	13	80	45	35	80
	Mosquito larvae	11	80	80	-	80
	Pupae Aedes spp. Culiseta sp.	10	80	29	23	52
	Brown trout eggs S. trutta	3.8	80	13	4	17
	Water-boatmen Sigara sp.	3.5	80	29	39	68
	Tadpoles R. clamitans	13	80	0	6	6

Table 12. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
32 - 36	Chaoborus larvae	14	80	44	29	73
	pupae	11	80	35	34	69
	Chaoborus sp.					
	Dixa larvae	8	75	75	-	75
	Dixa sp.					
	Brown trout eggs	4	80	10	1	11
	S. trutta					
	Oligochaetae	25	80	69	7	76
	Tubifex sp.					
	*Water-mites	2	70	0	0	0
	Arrenurus sp.					
	Piona sp.					
38 - 40	Chaoborus larvae	14	80	72	8	80
	pupae	11	80	64	12	76
	Chaoborus sp.					
	*Dixa larvae	8	70	70	-	70
	Dixa sp.					
	Borwn trout eggs	4	80	19	2	21
	S. trutta					
	Larval beetles	13	80	12	32	44
	Acilius sp.					
	Hydroporus sp.					
	Adult beetles	2.5	80	0	0	0
	Hygrotus sp.					

Table 13. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
35 - 36	Chaoborus sp.					
	Larvae	14	80	32	46	78
	Pupae	11	80	9	39	48
	Brown trout egg S. trutta	3.8	80	8	6	14
	Oligochaeta Tubifex sp.	25	80	69	3	72
	Water-boatmen Sigara sp.	3	80	2	13	15
	Water striders Gerris buenoi	2.5	80	1	5	6
40 - 43	Chaoborus sp.					
	Larvae	13	80	72	7	79
	Pupae	11	80	26	49	75
	Brown trout eggs S. trutta	3.8	80	22	8	30
	Oligochaeta Tubifex sp.	30	80	76	2	78
	Water-boatmen Sigara sp.	3	80	2	9	11
	Water striders G. buenoi	2.5	80	0	14	14

Table 14. Number of food organisms eaten by mosquitofish when 10 of each food organism were given in combination.

Total length of mosquitofish (mm)	Food organisms	Mean length (mm)	Total no. offered	No. eaten		
				0.5 hr.	12 hrs.	Total
33 - 37	Brown trout eggs S. trutta	4	70	26	8	34
	Young sticklebacks G. aculeatus	13	70	27	19	46
	Caddisfly larvae Limnephilus sp. Ptilostomis sp. Polycentropus sp.	12	70	21	8	29
	Mayfly larvae Blasturus sp. Ephemerella sp. Stenonema sp.	12	70	0	0	0
	Larval beetles Hydroporus sp.	13	70	18	13	31
	Water-boatmen Sigara sp.	4	70	6	5	11
40 - 43	Brown trout eggs S. trutta	4	70	27	26	53
	Young sticklebacks G. aculeatus	13	70	34	5	39
	Caddisfly larvae Limnephilus sp. Ptilostomis sp. Polycentropus sp.	13	70	18	28	46
	Water-boatmen Sigara sp.	4	70	3	20	23
	Larval beetles Hydroporus sp. Acilius sp.	13	70	34	19	53
	Adult beetles Acilius sp.	10	70	0	0	0
	Tadpoles R. clamitans	12	70	1	2	3
	Backswimmers Notonecta sp.	17	70	0	0	0

Table 15. Lengths of food organisms fed to mosquitofish in determining food selectivity.

Food organisms		Range of total length (mm)
Diptera		
Chaoboridae		
Chaoborus nyblaei (Zett.)	Larvae	11 - 14
	Pupae	11
	Adults	10
Eucorethra underwoodi Underw.	Larvae	8 - 13
Chironomidae		
Chironomus (*S.S.*) "Plumosus grp"	Larvae	11 - 14
Dixidae		
Dixa sp.	Larvae	7 - 8
Culicidae (Mosquitoes)		
Aedes spp.		
Culiseta morsitans (Theob.)	Larvae	10 - 12
	Pupae	10
Hemiptera		
Corixidae (water-boatmen)		
Sigara (*Vermicorixa*) *alternata* (Say)		2.5 - 5.0
Gerridae (Water-striders)		
Gerris buenoi Kirkaldy		2 - 4
Notonectidae (Back-swimmers)		16 - 19
Notonecta insulata Kirby		
Notonecta undulata Say		
Coleoptera		
Beetle larvae		11 - 15
adults		2 - 11
Dytiscidae		
Acilius semisulcatus Aube		
Hydroporus spp.		
Hydrobius fuscipes L.		
Hygrotus sp.		

Table 15. Lengths of food organisms fed to mosquitofish in determining food selectivity. (contd.)

Food organisms	Range of total length (mm)
Trichoptera	
Caddis-fly larvae	6 - 15
Limnephilidae	
Limnephilus submonilifer Walker	
Pycnopsyche sp.	
Phryganeidae	
Ptilostomis sp.	
Psychomyiidae	
Polycentropus sp.	
Odonata	
Dragonfly numphs	10 - 15
Libellulidae	
Plathemis lydia Drury?	
Aeshnidae	
Aeshna umbrosa Walker?	
Damselfly numphs	13 - 16
Lestidae	
Lestes disjunctus Selys?	
Coenagriidae	
Ischnura verticalis (Say)?	
Ephemeroptera	
Mayfly larvae	11 - 14
Ephemerellidae	
Ephemerella sp.	
Heptageniidae	
Stenonema sp.	
Baetidae	
Blasturus nebulosus Walker	

Table 15. Lengths of food organisms fed to mosquitofish in determining food selectivity. (contd.)

Food organisms	Range of total length (mm)
Acarina	
Water-mites	2 - 3
Arrenuridae *Arrenurus pseudocylindratus* (Piersig 1904)	
Pionidae *Piona interrupta* Marshall 1929	
Annelida	
Oligochaeta *Tubifex* sp.	20 - 40
Fish eggs	3.6 - 4.1
Salmo trutta L.	
Young sticklebacks	10 - 15
Gasterosteus aculeatus L.	
Tadpoles	11 - 16
Rana clamitans	

Table 16. List of insect larvae and adults found in or near the pools at Logy Bay.

Diptera		
	Chironomidae	
		Chironomus (S. S.) "plumosus grp"
		Psectrocladius cf. simulans
		Ablabesmyia cf. peleensis
		Procladius sp.
		Psectrotanypus sp.
		Monopelopia sp.
		Cricatopus sp.
		Cladotanytarsus sp.
	Chaoboridae	
		Chaoborus nyblaei (Zett.)
		Eucorethra underwoodi Underw.
	Dixidae	
		Dixa sp.
	Culicidae	
		Aedes cinereus Mg.
		Aedes abserratus (F. & Y.)
		Aedes punctor (Kirby)
		Aedes canadensis (Theob.)
		Culiseta morsitans (Theob.)
	Ceratopogonidae	
		Bezzia sp.
	Simuliidae	
		Prosimulium mixtum (S. & D.)

Table 16. List of insect larvae and adults found in or near the pools at Logy Bay. (contd.)

Hemiptera

Corixidae

Sigara (*Vermicorixa*) *alternata* (Say)

Gerridae

Gerris buenoi Kirkaldy

Notonectidae

Notonecta insulata Kirby

Notonecta undulata Say

Copeoptera

Dytiscidae

Acilius semisulcatus Aube

Dytiscus sp.

Ilybius sp.

Hydroporus sp.

Rhantus sp.

Hygrotus sp.

Agabus sp.

Hydrophilidae

Hydrobius fuscipes L.

Carabidae

Agonum mannerheimi Dej.

Amara apricaria Payk.

Harpalus affinis Schrk.

Cantharidae

Cantharis sp.

Helodidae

Table 16. List of insect larvae and adults found in or near the pools at Logy Bay. (contd.)

Trichoptera		
	Limnephilidae	
		Limnephilus submonilifer Walker
		Pycnopsyche sp.
	Phryganeidae	
		Ptilostomis sp.
	Psychomyiidae	
		Polycentropus sp.
Odonata		
	Libellulidae	
		Plathemis lydia Drury?
	Aeshnidae	
		Aeshna umbrosa Walker?
	Lestidae	
		Lestes disjunctus Selys?
	Coenagriidae	
		Ischnura verticalis (Say)?
Ephemeroptera		
	Ephemerellidae	
		Ephemerella sp.
	Heptageniidae	
		Stenonema sp.
	Baetidae	
		Blasturus nebulosus Walker

Table 16. List of insect larvae and adults found in or near the pools at Logy Bay. (contd.)

Acarina		
	Arrenuridae	
		Arrenurus pseudocylindratus (Piersig 1904)
	Pionidae	
		Piona interrupta Marshall 1929
Araneida		
	Phalangidae	
		Odiellus pictus (Wood)
	Lycosidae	
		Pardosa atrata (Thorell)
		Pardosa xerampelina (Keyserling)

Selectivity for Microscopic Organisms.

Data concerning the feeding of *Gambusia affinis* upon microscopic organisms both in the laboratory and under field conditions (the fish being exposed in the escape-proof container described on p.13) are presented in Tables 17 - 22.

Fragilaria spp. diatoms were the most abundant algae in the samples collected from various ponds at Logy Bay, during the summer, 1970. They comprised some 47% of the total algae gathered (Table 17). *Tabellaria* spp. (14%) and *Microspora* spp. (12%) were the next most prevalent algal genera. Other algae of frequent occurrence were *Spirogyra* spp. (6%), *Ulothrix* spp. (3%), *Mougeotia* spp. (3%) and *Desmidium* spp. (2%). The genera *Eunotia*, *Navicula*, *Pinnularia* and *Lyngbya* were present in less than 2% of the samples. Other genera of algae (Table 17) were each recognized in less than 1%.

Analysis of the stomach contents of the mosquitofish held in the laboratory at temperature of from 22.5 - 24.0°C, showed that *Fragilaria* spp. occurred in almost all instances. These diatoms comprised 69% of the total phytoplankton ingested (Table 18). *Microspora* spp. took second place as regards the average number ingested, accounting for 22% of the total microphytes and being present in 70% of the stomachs. Recorded from all of the stomachs examined, *Tabellaria* spp.

comprised some 3% of the algae eaten. Mougeotia spp. and Ulothrix spp. were frequently present, each making up approximately 1% of the total algal mass. Eunotia spp. were identified from 90% of the stomachs dissected, accounting for about 1% of the phytoplankton ingested. Although Lyngbya spp. made up 1% of the average stomach contents where present, this genus was present in only 20% of the mosquitofish sampled. Navicula spp. and Pinnularia spp. were present in 60% of the stomachs, but were low in average number. The remaining algae identified from the container were either of very low incidence or absent altogether from the stomach contents. It is of course conceivable that at least some of the algae found had been ingested within the alimentary tract of Entomostraca, small numbers of which on being supplied as food from time to time, were totally devoured - their remains were identified from 40% (Cladocera) and 70% (Copepoda) of the G. affinis stomachs. Again, microflora could easily be ingested quite adventitiously via water flowing over the gills in respiration.

Comparison of the results (Tables 17 and 18) showed correlation between the relative numbers of the different organisms available as food and that of the organisms actually found in the stomach. The higher the incidence of a given food organism in the tank, the higher its incidence in the stomach contents of mosquitofish. The latter showed no special preference for any particular algae over others, and the ingestion of microscopic phytoplankton seemed to be on a completely random basis.

Ulothrix spp. comprised the highest percentage (42%) of the total algae found in the stomachs of Gambusia kept in the laboratory at medium water temperature (13 - 14°C) (Talbe 19). However, this genus occurred in only 30% of the stomach samples. Mougeotia spp. (21%) and Microspora spp. (12%) also featured prominently. Some of the commonest species (Fragilaria spp., Spirogyra spp. and Tabellaria spp.) were also consumed rather frequently. Although of high percentage occurrence, the genera Eunotia, Pinnularia and Navicula were individually represented in quite small numbers; and while Oscillatoria, Lyngbya, Desmidium and Cosmarium were commonly present in the available food, they seldom figured in mosquitofish stomach contents. Some of those found might well have been adventitiously swallowed with other organisms that were deliberately selected.

Again, the small numbers of Entomostraca present were all devoured after artificial feeding had terminated at the end of the experiment. The stomach contents of 30% of the Gambusia yielded still - undigested Entomostraca, 70% of which had not yet lost their appendages. Of course, this did not necessarily mean that the remaining 30% of stomachs showing no trace of Entomostraca, in any way indicated that the fish in question had avoided eating such prey. They might either have digested such food before dissection, or simply have been unsuccessful in the keen competition for the few Entomostraca available.

The feeding habits of the mosquitofish held in the stream (12.5 - 14.0^{0}C) at Logy Bay, showed little difference in algal food consumption from those in the laboratory tanks (Table 20).

The genera Fragilaria and Microspora were those predominantly eaten. The former occurred in all the stomachs examined, and the latter in 70% of them. Tabellaria spp. and Mougeotia spp. were of quite high frequency, but were present in relatively small numbers in individual fish. Although the genera Cosmarium, Pinnularia, Eunotia and Navicula were again frequently noted, they were always few in numbers too. Ulothrix spp. constituted 5% of the total algae, but were nevertheless limited to only 10% of the stomachs. The genera Oedogonium, Spirogyra, Desmidium, Staurastrum, Closterium, Xanthidium, Lyngbya, Euastrum and Tetmemorus seldom occurred, and then only in very small number.

Zooplankton, Cladocera and Copepoda were readily eaten by mosquitofish. They occurred in all the stomachs examined, in relatively high numbers. Among the larger food organisms consumed, young corixids, chaoborine and chironomid larvae were taken in preference either to large and more heavily chitinized insects or to specifically bottom-dwelling or sessile organisms such as larval beetles and caddisflies, brown trout eggs, dragonfly nymphs and tadpoles, none of which were even eaten except under the conditions of starvation described on pp. 44 to 48. Young corixids, chaoborine and chironomid larvae were much more active than any of the last-mentioned group. Though their conspicuousness in moving about in the medium, their presence was presumably more easily detected by the mosquitofish.

Cladocera and Copepoda were the only food found in the stomachs of _Gambusia_ held at low temperatures both in the laboratory (5 - 5.5^{0}C) and in the stream (3.5 - 5.0^{0}C) (Tables 21 and 22). They occurred only sparingly in the stomach contents searched. Their absence from the food recovered from fish from the stream, where there were marked diurnal temperature changes, was especially evident. It is considered that low temperatures definitely inhibited the ingestion of food by these mosquitofish.

Although _Pinnularia_ were recorded from 20% of the laboratory stomach samples of the low-temperature group (Table 20), very few examples were ever present.

Table 17. Checklist of microphytic vegetation collected from ponds at Logy Bay showing the percentage of average number of each item.

Food item	Number of cells per ml of sample	%
Ulothrix spp.	360	3.4
Microspora spp.	1280	12.1
Oedogonium spp.	100	0.9
Closteriopsis spp.	10	0.1
Zygnema spp.	10	0.1
Spirogyra spp.	580	5.5
Mougeotia spp.	300	2.8
Netrium spp.	10	0.1
Desmidium spp.	210	2.0
Bambusia spp.	20	0.2
Staurastrum spp.	20	0.2
Xanthidium spp.	50	0.5
Closterium spp.	80	0.8
Cosmarium spp.	10	0.1
Micrasterias spp.	10	0.1
Euastrum spp.	20	0.2
Arthrodesmus spp.	10	0.1
Pleurotaenium spp.	30	0.3
Tetmemorus spp.	10	0.1
Spondylosium spp.	40	0.4
Chlorococcus spp.	50	0.5
Pediastrum spp.	20	0.2
Oöcystis spp.	20	0.2
Scenedesmaceae spp.	10	0.1
Palmodictyon spp.	20	0.2
Oscillatoria spp.	20	0.2

Table 17. Checklist of microphytic vegetation collected from ponds at Logy Bay showing the percentage of average number of each item. (contd.)

Food item	Number of cells per ml of sample	%
Lyngbya spp.	130	1.2
Anabaena spp.	10	0.1
Merismopedia spp.	10	0.1
Achnanthes spp.	10	0.1
Eunotia spp.	180	1.7
Gyrosigma spp.	20	0.2
Frustulia spp.	50	0.5
Fragilaria spp.	5000	47.2
Navicula spp.	160	1.5
Pinnularia spp.	110	1.0
Stauroneis spp.	30	0.3
Synedra spp.	50	0.5
Tabellaria spp.	1480	14.0
Coscinodiscus spp.	30	0.3
Ceratium spp.	10	0.1
Peridium spp.	10	0.1

Table 18. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish in laboratory at 22.5-24.0^{0}C.

Food item given	Frequency of occurrence (%)	Ave. number of each food item	% of food item eaten
Ulothrix spp.	0.3	130.3	1.0
Microspora spp.	0.7	2793.5	22.1
Oedogonium spp.	0.1	3	0
Zygnema spp.	0		
Spirogyra spp.	0.2	4	0.1
Mougeotia spp.	0.6	163.0	1.3
Netrium spp.	0		
Desmidium spp.	0.1	8	0.1
Bambusia spp.	0		
Staurastrum spp.	0		
Xanthidium spp.	0		
Closterium spp.	0.1	2	0
Cosmarium spp.	0.1	1	0
Micrasterias spp.	0		
Euastrum spp.	0		
Arthrodesmus spp.	0.1	1	0
Pleurotaenium spp.	0.1	3	0
Tetmemorus spp.	0.1	4	0
Spondylosium spp.	0.1	17	0.1
Chlorococcus spp.	0		
Pediastrum spp.	0		
Oöcystis spp.	0		
Scenedesmaceae spp.	0		
Palmodictyon spp.	0		
Oscillatoria spp.	0.2	10	0.1
Lyngbya spp.	0.2	102.5	0.8
Anabaena spp.	0		

Table 18. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish in laboratory at 22.5 - 24.0°C. (contd.)

Food item given	Frequency of occurrence (%)	Ave. number of each food item	% of food item eaten
Merismopedia spp.	0		
Achnanthes spp.	0		
Eunotia spp.	0.9	104.4	0.8
Gyrosigma spp.	0.3	11.3	0.1
Frustulia spp.	0.4	1.5	0
Fragilaria spp.	0.9	8728.5	69.2
Navicula	0.6	26.7	0.2
Pinnularia	0.6	26.5	0.2
Stauroneis	0		
Synedra	0		
Tabellaria	1.0	415.3	3.3
Coscinodiscus	0.2	4	0
Ceratum	0.2	1	0
Peridium	0		
Unidentified	0.6	41.2	0.3
Cladocera	0.4	4.5	
Copepoda	0.7	2.0	
Appendages of Entomostraca	0.3	4.0	

Table 19. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish in laboratory at 13 - 14°C.

Food item given	Frequency of occurrence (%)	Ave. number of each food item	% of food item eaten
**Spirogyra spp.	0.8	19.4	4.2
*Mougeotia spp.	0.8	98.2	21.3
*Microspora spp.	0.2	54.0	11.7
*Ulothrix spp.	0.3	191.0	41.5
Oedogonium spp.	0		
Closteriopsis spp.	0		
*Desmidium spp.	0.2	8.0	1.7
Staurastrum spp.	0		
Xanthidium spp.	0		
Closterium spp.	0		
*Cosmarium spp.	0		
Euastrum spp.	0		
Pleurotaenium spp.	0.2	3.0	0.7
Tetmemorus spp.	0		
Pediastrum spp.	0		
Palmodictyon spp.	0		
*Oscillatoria spp.	0.3	2.0	0.4
*Lyngbya spp.	0		
Merismopedia spp.	0		
*Eunotia spp.	0.8	8.2	1.8
Frustulia spp.	0		
*Navicula spp.	0.5	3.3	0.7
*Pinnularia spp.	0.7	4.5	1.0
**Fragilaria spp.	0.8	34.0	7.4
**Tabellaria spp.	0.7	13.3	2.9
Spondylosium spp.	0.2	17.0	3.7

Table 19. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish in laboratory at 13-14°C. (contd.)

Food item given	Frequency of occurrence (%)	Ave. number of each food item	% of food item eaten
Stauroneis spp.	0		
Synedra spp.	0		
Coscinodiscus spp.	0		
Ceratum spp.	0		
Unidentified spp.	0.7	4.3	0.9
Cladocera	0.3	4.5	
Copepoda	0.3	7.0	
Appendages of Entomostraca	0.7	9.3	

** - Abundantly present in water.

* - Commonly present in water.

Table 20. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish caged in stream at 12.5-14^{0}C.

Food item given	Frequency of occurrence (%)	Ave. number of each food item	% of food item eaten
*Ulothrix spp.	0.1	18.0	4.9
**Microspora spp.	0.7	61.4	16.8
Oedogonium spp.	0.2	4.5	1.2
Closteriopsis spp.	0		
*Spirogyra spp.	0.3	5.7	1.6
*Mougeotia spp.	0.7	13.9	3.8
Netrium spp.	0		
*Desmidium spp.	0.3	10.0	2.7
Staurastrum spp.	0.3	4.3	1.2
Xanthidium spp.	0.1	3.0	0.8
Closterium spp.	0.3	4.0	1.1
*Cosmarium spp.	0.5	2.2	0.6
Micrasterias spp.	0		
Euastrum spp.	0.1	3.0	0.8
Arthrodesmus spp.	0		
Pleurotaenium spp.	0		
Tetmemorus spp.	0.2	1.5	0.4
Pediastrum spp.	0		
Scenedesmaceae spp.	0		
Palmodictyon spp.	0		
Oscillatoria spp.	0		
*Lyngbya spp.	0.3	6.0	1.6
Merismopedia spp.	0		
Achnanthes spp.	0		
*Eunotia spp.	0.4	5.3	1.5

Table 20. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish caged in stream at 12.5-14°C.(contd.)

Food item given	Frequency of occurrence (%)	Ave. number of each food item	% of food item eaten
Gyrosigma spp.	0		
**Fragilaria spp.	1.0	185.6	50.9
*Navicula spp.	0.5	4.2	1.2
*Pinnularia spp.	0.7	3.7	1.0
Stauroneis spp.	0		
Synedra spp.	0		
**Tabellaria spp.	0.8	19.8	5.4
Coscinodiscus spp.	0		
Ceratum spp.	0		
Unidentified spp.	0.3	8.7	2.4
*Cladocera	1.0	10.8	
*Copepoda	1.0	15.0	
Appendages of Entomostraca	1.0	26.6	
Corixids	0.4	1.0	
Appendages of Corixids	0.5	3.4	
Chaoborine larvae	0.4	1.5	
Chironomid larvae	0.3	1.3	
Larval beetles	0		
Caddisfly larvae	0		
Brown trout eggs	0		
Odonata nymphs	0		
Young tadpoles	0		

** - Abundantly present in water.

* - Commonly present in water.

Table 21. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish in laboratory at 5.0-5.5^{0}C.

Food item given	Frequency of occurrence (%)	Ave. number of each food item
*Ulothrix spp.	0	
**Microspora spp.	0	
Oedogonium spp.	0	
Closteriopsis spp.	0	
**Spirogyra spp.	0	
*Mougeotia spp.	0	
Netrium spp.	0	
Desmidium spp.	0	
Bambusia spp.	0	
*Xanthidium spp.	0	
Cosmarium spp.	0	
Euastrum spp.	0	
Arthrodesmus spp.	0	
Spondylosium spp.	0	
Pediastrum spp.	0	
Palmodictyon spp.	0	
*Lyngbya spp.	0	
Merismopedia spp.	0	
Achnanthes spp.	0	
*Eunotia spp.	0	
Gyrosigma spp.	0	
**Fragilaria spp.	0	
Navicula spp.	0	
*Pinnularia spp.	0.2	2.3
**Tabellaria spp.	0	
Coscinodiscus spp.	0	
Cladocera	0.5	2.4
Copepoda	0.6	1.9
Appendages of Entomostraca	0.7	4.1
Corixids	0	
Chaoborine larvae	0	
Larval beetles	0	
Oligochaeta	0	
Debris	0.5	trace

** - Abundantly present in water.
* - Commonly present in water.

Table 22. Percentage frequency of occurrence and average number of various food items in stomachs of mosquitofish caged in stream at 3.5 - 5.0°C.

Food item given	Frequency of occurrence (%)	Ave. number of each food item
*Ulothrix spp.	0	
*Microspora spp.	0	
*Spirogyra spp.	0	
*Mougeotia spp.	0	
Desmidium spp.	0	
Staurastrum spp.	0	
Xanthidium spp.	0	
Cosmarium spp.	0	
Pleurotaenium spp.	0	
Tetmemorus spp.	0	
Palmodictyon spp.	0	
Lyngbya spp.	0	
Merismopedia spp.	0	
Eunotia spp.	0	
Frustulia spp.	0	
**Fragilaria spp.	0	
*Pinnularia spp.	0	
Synedra spp.	0	
**Tabellaria spp.	0	
Coscinodiscus spp.	0	
*Cladocera	0.1	1.0
*Copepoda	0.3	1.3
Appendages of Entomostraca	0.4	1.5
Corixids	0	
Chaoborine larvae	0	
Larvae beetles	0	
Debris	0.6	trace

** - Abundantly present in water.

* - Commonly present in water.

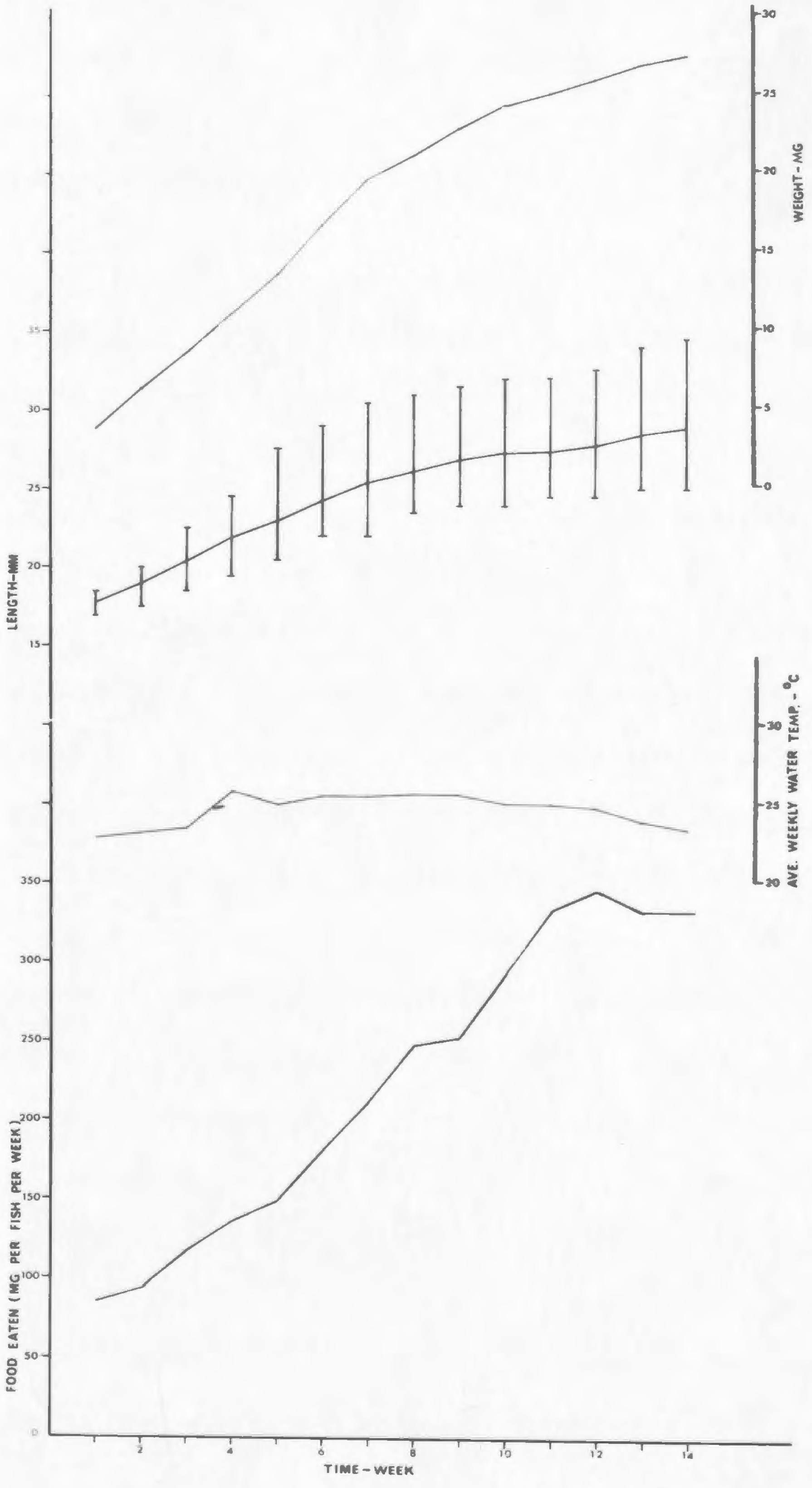
Growth, Food Consumption and Water Temperature

Figs.13-15 show: the average, minimum and maximum lengths; the average weight; and the amount of food eaten by mosquitofish held in the laboratory at various temperatures for 12 - 14 weeks.

Fish from the tank providing the highest range of temperature (22.8 - 25.7^{0}C) grew rapidly from the beginning of the experiment (Fig.13). By the end of 14 weeks, they had attained an average length of 28.8 mm, and a weight of 27.4 mg (Table 23). The largest among them attained a length of 34.5 mm and a weight of 53.0 mg. The smallest reached only 25.0 mm in length, weighing 13.0 mg. Their growth rate was slower after the ninth week. Mortality was negligible. In fact, only one fish died - it suffered accidental injury in the seventh week, dying a week later. All the other Gambusia (five males and four females) were still active and in good condition at the end of the experiment.

Weekly food consumption and the average number of chaoborine larvae devoured per fish, are evident from Fig.13 and Table 26. The rapid increase in growth at higher temperature is correlated with a marked increase in the food intake. Individual Gambusia surpassed their average initial weight by 23.6 mg after 14 week. This represented rather

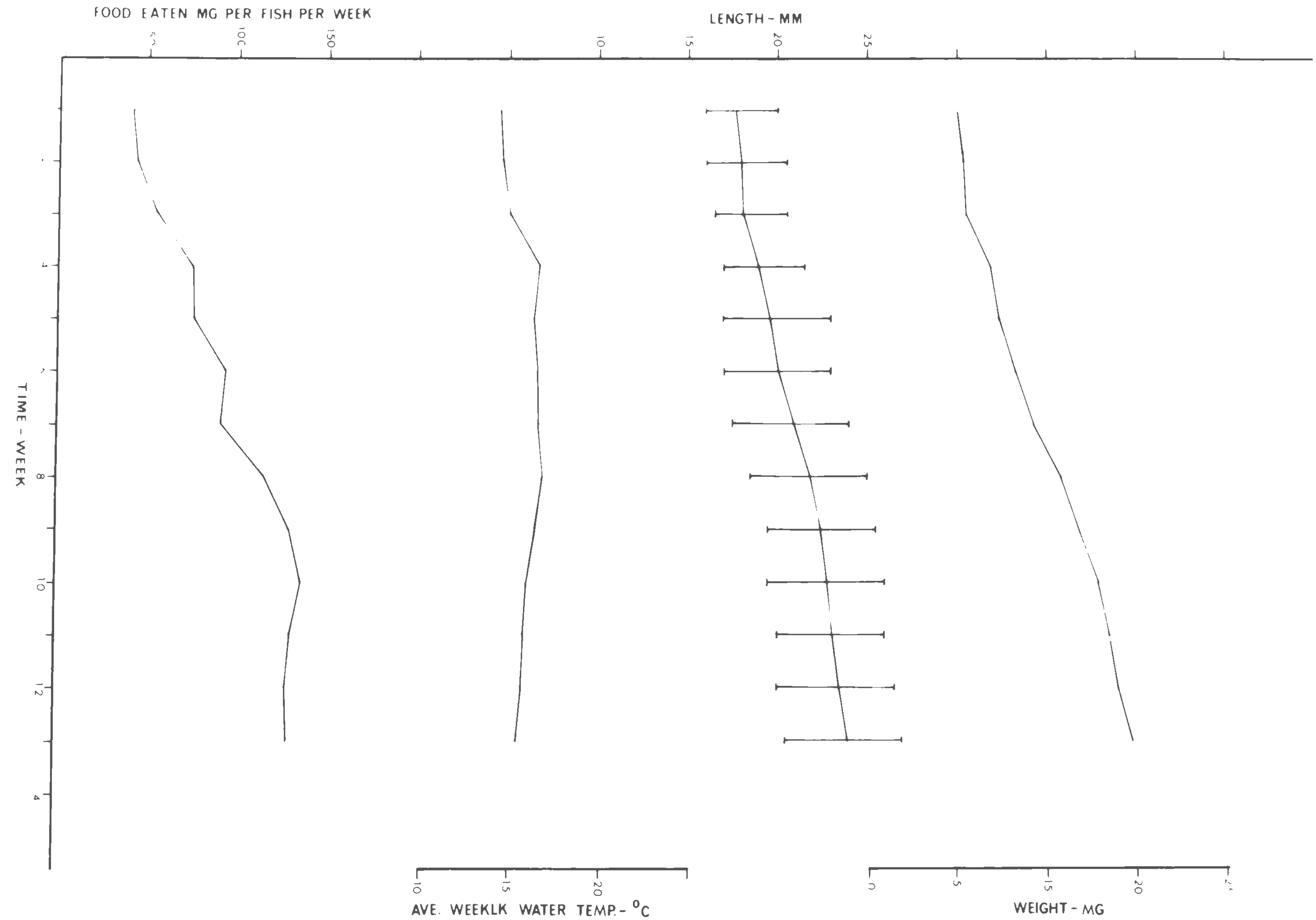
Fig. 13. Average, minimum and maximum length, average weight and food eaten of mosquitofish kept at higher water temperature.


LENGTH-MM
WEIGHT-MG
AVE. WEEKLY WATER TEMP. - °C
FOOD EATEN (MG PER FISH PER WEEK)
TIME-WEEK

more than a sevenfold increase of the original weight. The average number of chaoborine larvae eaten daily by each fish increased from 7.2 at the outset to 18.6 at the end of the experiment (Table 26).

In the 'medium temperature' tanks (14.5 - 17.0°C), after 13 weeks, the difference in growth attained between the largest and the smallest Gambusia was considerable (Fig.14). The largest example reached a length of 27.0 mm and a weight of 19.5 mg (Table 24), while the smallest one was only 20.5 mm long and weighed 10.5 mg. In the first fortnight, growth was slow. A slight increase in water temperature was then followed by a noticeable increase in length and weight between the third and eighth weeks. After that, the rate of growth decreased. One fish died in the third week, and another two in the sixth week. With these exceptions, the remainder (two males and five females) were healthy and active throughout the experiment. Compared with the fish in the warmer tank, those reared in the 'medium temperature' one grew much more slowly. They consumed less than half the amount of food eaten by the former group. Individuals increased their initial weight by 9.9 mg in 13 weeks. This represented an approximately threefold increase. The average number of chaoborine larvae eaten daily by each fish increased from 3.4 to 7.2.

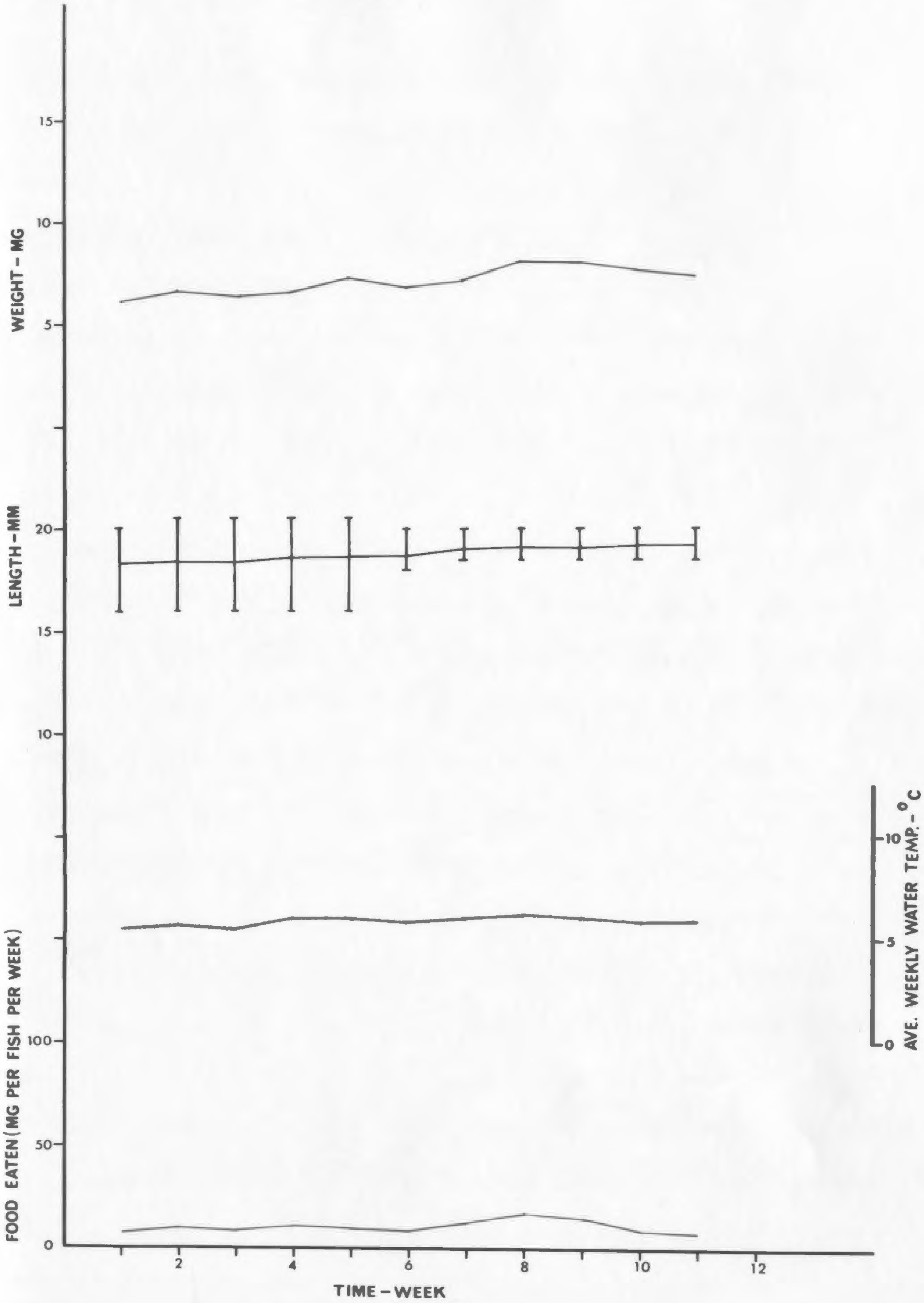
Fig. 14. Average, minimum and maximum length, average weight and food eaten of mosquitofish kept at medium water temperature.


FOOD EATEN MG PER FISH PER WEEK
LENGTH - MM
TIME - WEEK
AVE. WEEKLK WATER TEMP.- °C
WEIGHT - MG

None of the fish kept in the 'cold' tank (5.5 - 6.1^{0}G) reached sexual maturity during the experiment. Their range of length and weight was small (Fig.15 and Table 25). The largest fish reached a length of only 20.0 mm, and a weight of 9.0 mg, while the smallest was 18.5 mm long and weighed 6.0 mg. In this instance, mortality was high. Only nine fish were left by the third week, six by the sixth week and four by the eleventh week. These fish exhibited comparatively poor growth. They showed fluctuations in weight increment, too. At the end of the eleventh week, they attained an average length and weight of only 19.2 mm and 7.3 mg respectively. They were quiet, seldom moving about and being listless when they did. However, no bodily deformation was observed. Slow growth of the fish in the 'cold' tank was associated with correspondingly light food consumption (Fig.15). Also large amounts of surplus food always remained in the tank after feeding. The average weight increased from 6.1 mg to only 8.1 mg in eight weeks. It then decreased to 7.3 mg by the eleventh week. The average number of chaoborine larvae eaten daily per fish was slightly more or less than one. This was the case at the beginning of the experiment, and remained so at the end.

In the experimental cages held in the stream, there was a slight gain in average weight (1.2 mg weekly, for four weeks) though the temperature was dropping throughout the

Fig. 15. Average, minimum and maximum length, average weight and food eaten of mosquitofish kept at lowered water temperature.


WEIGHT - MG
15
10
5
LENGTH - MM
20
15
10
FOOD EATEN (MG PER FISH PER WEEK)
100
50
0
AVE. WEEKLY WATER TEMP. - °C
10
5
0
2
4
6
8
10
12
TIME - WEEK

period in question (Fig.16). These particular fish were older at the outset than those experimented with in the laboratory. Throughout the four weeks during which observations were made, they appeared perfectly healthy and remained active in their plastic container. Entomostraca were observed to be the food they habitually consumed. However, the rapid diurnal changes of water temperature (especially as the temperature continued to fall) had an effect on the growth of the fish. By the fifth week, in fact, mean weight was steadily declining - with a loss of 2.0 mg by the end of the twelfth week (Table 27) - and mortality was as steadily increasing. Becoming sluggish in swimming, the fish were no longer observed to feed, even when fresh food (including the previously well-accepted Entomostraca) was introduced. Six fish survived at the end of twelve weeks. Their stomachs were dissected out and found to be empty (or at best only showing trace of algae). Under truly natural conditions, in which the mosquitofish were free to seek out their prey, the influence of water temperature on growth might well be modified by (a) the available food supply and (b) the marked fluctuations in water temperature within very short periods of time. When the temperature was close to or below a critical point, though, it seemed that little or no growth could occur, however much the food supply was artificially supplemented.

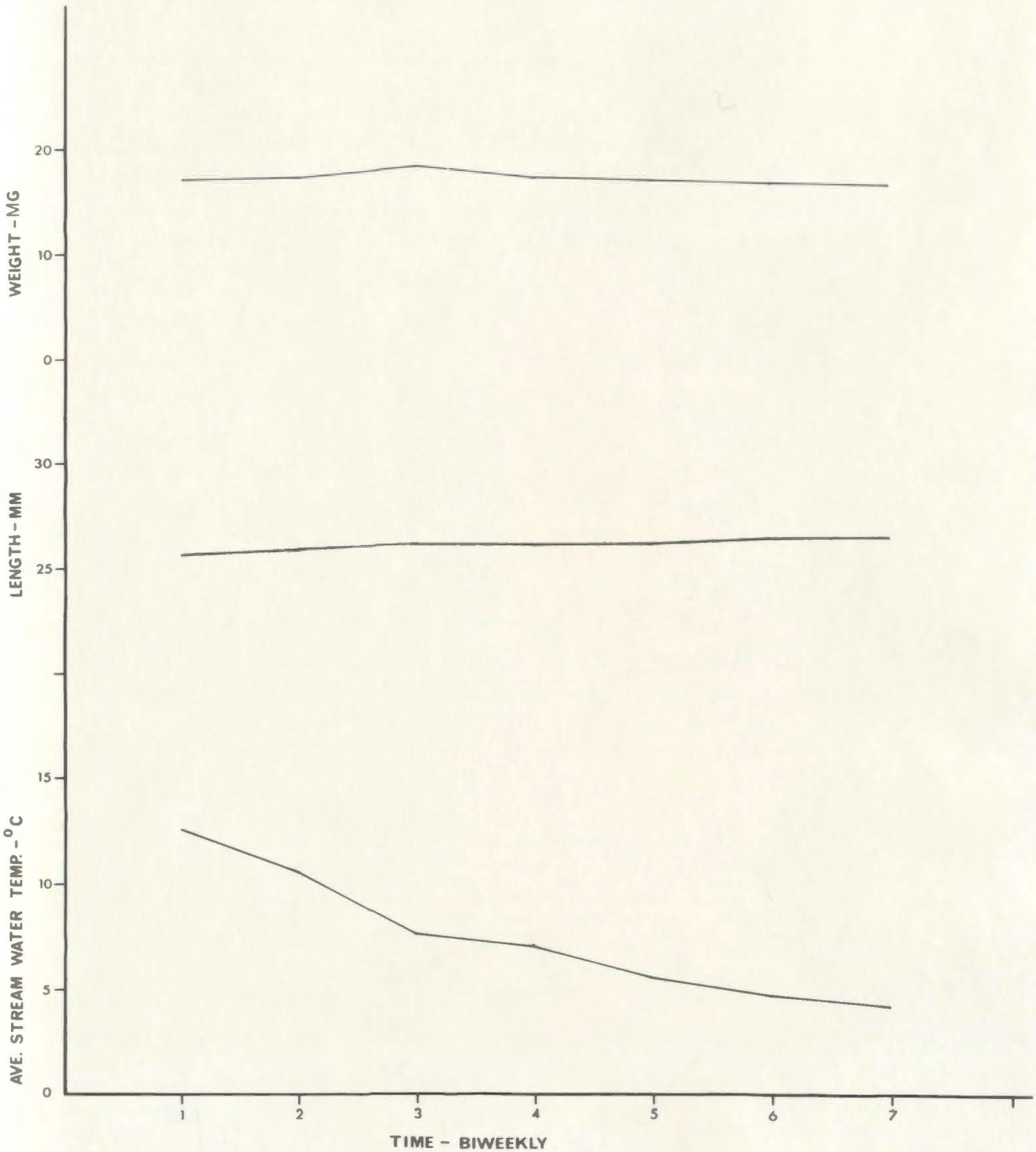

WEIGHT - MG
20
10
0
LENGTH - MM
30
25
AVE. STREAM WATER TEMP. - °C
15
10
5
0
1
2
3
4
5
6
7
TIME - BIWEEKLY

Table 23. Length and weight data for mosquitofish kept at higher water temperature.

Weeks	Total length (mm)			Weight (mg)		
	Min.	Ave.	Max.	Min.	Ave.	Max.
1	17.0	17.8	18.5	2.0	3.8	5.0
2	17.5	18.9	20.0	4.5	6.4	8.0
3	18.5	20.4	22.5	6.0	8.7	12.0
4	19.5	21.9	24.5	7.5	11.2	17.5
5	20.5	23.0	27.5	9.0	13.7	24.0
6	21.5	24.3	29.0	11.5	16.8	33.0
7	22.0	25.4	30.5	12.0	19.8	41.0
8	23.5	26.2	31.0	12.0	21.3	43.0
9	24.0	26.9	31.5	11.5	23.0	40.0
10	24.0	27.3	32.0	12.0	24.4	46.5
11	24.5	27.4	32.0	12.5	25.2	47.0
12	24.5	27.7	32.5	12.5	25.9	48.5
13	25.0	28.5	34.0	12.5	26.9	52.0
14	25.0	28.8	34.5	13.0	27.4	53.0

Table 24. Length and weight data for mosquitofish kept at medium water temperature.

Weeks	Total length (mm)			Weight (mg)		
	Min.	Ave.	Max.	Min.	Ave.	Max.
1	16.0	17.7	20.0	2.5	5.0	7.0
2	16.0	17.9	20.5	3.0	5.3	7.5
3	16.5	18.1	20.5	4.0	5.6	9.0
4	17.5	18.9	21.5	4.5	6.9	11.0
5	17.5	19.6	23.0	4.5	7.4	12.0
6	17.5	20.1	23.0	5.0	8.3	12.0
7	18.0	20.9	24.0	5.0	9.3	13.0
8	18.5	21.9	25.0	6.5	10.9	15.5
9	19.5	22.5	25.5	8.5	11.9	16.5
10	19.5	22.8	26.0	8.5	13.0	17.5
11	20.0	23.1	26.0	9.5	13.6	18.0
12	20.0	23.4	26.5	9.0	14.1	18.5
13	20.5	24.0	27.0	10.5	14.9	19.5

Table 25. Length and weight data for mosquitofish kept at lowered water temperature.

Weeks	Total length (mm)			Weight (mg)		
	Min.	Ave.	Max.	Min.	Ave.	Max.
1	16.0	18.3	20.0	3.0	6.1	9.5
2	16.0	18.4	20.5	3.5	6.6	9.5
3	16.0	18.4	20.5	4.0	6.4	9.5
4	16.0	18.6	20.5	3.5	6.6	9.0
5	16.0	18.7	20.5	4.0	7.3	9.0
6	18.0	18.7	20.0	5.5	6.8	9.0
7	18.5	19.0	20.0	6.0	7.1	9.0
8	18.5	19.1	20.0	7.0	8.1	10.5
9	18.5	19.1	20.0	7.0	8.0	9.5
10	18.5	19.2	20.0	6.5	7.6	10.0
11	18.5	19.2	20.0	6.0	7.3	9.0

Table 26. Food consumption by mosquitofish (1) at higher water temperature, (2) at medium water temperature, (3) at lowered water temperature.

	Week	No. of fish	No. of chaoborus larvae eaten per week	Ave. no. of larvae eaten per fish per day	No. of larvae eaten per fish per week	Ave. wt. of 10 larvae (mg)	Wt. of food eaten per fish per week (mg)
(1)	1	10	432	7.2	43.2	20	86.4
	2	10	474	7.9	47.4	20	94.8
	3	10	594	9.9	59.4	20	118.8
	4	10	616	10.3	61.6	22	135.5
	5	10	672	11.2	67.2	22	147.8
	6	10	726	12.1	72.6	25	181.5
	7	10	852	14.2	85.2	25	213.0
	8	9	894	16.6	99.3	25	248.3
	9	9	912	16.9	101.3	25	253.3
	10	9	882	16.3	98.0	30	294.0
	11	9	1002	18.6	111.3	30	333.9
	12	9	1038	19.2	115.3	30	345.9
	13	9	996	18.4	110.7	30	332.1
	14	9	1002	18.6	111.3	30	333.9

Table 26. Food consumption by mosquitofish (1) at higher water temperature, (2) at medium water temperature, (3) at lowered water temperature. (contd.)

	Week	No. of fish	No. of chaoborus larvae eaten per week	Ave. no. of larvae eaten per fish per day	No. of larvae eaten per fish per week	Ave. wt. of 10 larvae (mg)	Wt. of food eaten per fish per week (mg)
(2)	1	10	204	3.4	20.4	20	40.8
	2	10	222	3.7	22.2	20	44.4
	3	9	246	4.6	27.3	20	54.6
	4	9	306	6.2	34.0	22	74.8
	5	9	312	5.8	34.7	22	76.3
	6	7	300	7.1	42.9	22	94.4
	7	7	294	7.0	42.0	22	92.4
	8	7	324	7.7	46.3	25	115.8
	9	7	366	8.7	52.3	25	130.8
	10	7	384	9.1	54.9	25	137.3
	11	7	330	7.9	47.1	30	131.3
	12	7	300	7.1	42.9	30	128.7
	13	7	303	7.2	43.3	30	129.9

Table 26. Food consumption by mosquitofish (1) at higher water temperature, (2) at medium water temperature, (3) at lowered water temperature. (contd.)

	Week	No. of fish	No. of chaoborus larvae eaten per week	Ave. no. of larvae eaten per fish per day	No. of larvae eaten per fish per week	Ave. wt. of 10 larvae (mg)	Wt. of food eaten per fish per week (mg)
(3)	1	10	36	0.6	3.6	20	7.2
	2	10	48	0.8	4.8	20	9.6
	3	9	30	0.6	3.3	20	6.6
	4	9	48	0.9	5.3	20	10.6
	5	9	42	0.7	4.7	20	9.4
	6	6	24	0.7	4.0	22	8.8
	7	6	36	1.0	6.0	22	13.2
	8	6	48	1.3	8.0	22	17.6
	9	6	42	1.2	7.0	22	15.4
	10	6	24	0.7	4.0	22	8.8
	11	6	22	0.6	3.7	22	8.1

Table 27. Biweekly water temperature, average length and weight of mosquitofish caged in stream.

Weeks	Ave. biweekly temp. (°C)	Ave. length of fish (mm)	Ave. weight of fish (mg)
0	12.6	25.7	17.0
2	10.6	25.9	17.3
4	7.7	26.2	18.2
6	7.1	26.2	17.2
8	5.7	26.2	16.9
10	4.8	26.3	16.5
12	4.4	26.3	16.2

Feeding Behaviour of Mosquitofish

Tadpoles (Rana sp.)

When small tadpoles (10 - 12 mm total length) were attacked by three mosquitofish, the former were usually swallowed by individual fish. The prey were often seized by the head and ingested in one gulp. However, when tadpoles proved too large to be swallowed, the predators soon ceased their attacks.

Observations of the feeding behaviour of larger numbers of mosquitofish in individual containers showed that they were in fact able to consume tadpoles of much larger size than those usually attacked and successfully consumed. This was because the fish now combined their efforts. It was observed, for example, that when a tadpole 14 mm long and 3 mm wide at the head was placed in an aquarium containing about 50 mosquitofish (27 - 43 mm in total length) that had been denied all food for a day, it was attacked on all sides - though mostly from the rear and from both sides of its abdomen. None of the fish could individually swallow the prey. However, the tadpoles fragile tail was soon broken and eaten. Then, after intensive attacks by three to four Gambusia at a time,one side of the victim's abdominal wall was pierced, its prolapsed intestine being immediately eaten by the mosquitofish. The now hollow body was further torn apart and devoured by other mosquitofish. The whole sequence of events took place within one minute.

In another experiment, a larger tadpole (25 mm long i.e. more than half the length of the largest mosquitofish) and five mm thick, was completely devoured by the predators within 17 minutes. On introduction into the tank, the tadpole quickly swam down to the bottom. This did not arouse attention from the mosquitofish. However, once the tadpole began to range about, the predators immediately chased and attacked it. Once again the tail and abdomen proved most vulnerable. Frequently, five or six fish would attack together. Owing to the size of such a tadpole, none of the fish could grasp the prey. Nevertheless, the starving *Gambusia* never gave up. They kept attacking from every possible weak point of their prey. Within three minutes (in which more than 70 individual attacks had been made) part of the tadpole's fragile tail had been torn away and eaten. After eight minutes, one *Gambusia* grasped part of the prey's abdominal wall, shaking its victim strongly from side to side. It finally succeeded in piercing the body wall. Extruding through the tear, the intestines were attacked and eaten by the mosquitofish. The eviscerated remains of the tadpole were then pulled apart and finally completely consumed by up to five *Gambusia*.

In one trial, two large tadpoles measuring 29 mm and 30 mm in total length (i.e. some two-thirds the length of the largest mosquitofish), 8 mm in breadth and 6 mm dorso-ventrally were exposed to about 50 Gambusia. None of the latter attacked immediately. The tadpoles stayed at the bottom of the container, swimming from one end to the other at intervals. Five hours later, though both tadpoles had disappeared. No trace of them remaining, it could only be assumed that they had been destroyed like those in the earlier trial. Thus, where a small and isolated body of water contains many starved Gambusia and no other smaller food organisms are available, prey far above the usual maximum size can be utilized by a number of mosquitofish attacking simultaneously.

Larval beetles (Coleoptera)

Water-beetle larvae (Acilius sp. and Hydroporus sp.) proved to be commonly eaten by mosquitofish. Despite their usually slow progression, the larvae took rapid avoiding action when disturbed. Customarily feeding quite close to the surface, these insects are more particularly vulnerable to Gambusia ranging about just beneath the surface film. The smaller larvae (less than 15 mm long) were easily swallowed at a gulp. Larger ones, though, were difficult for individual mosquitofish to grasp. Once, a beetle larva (Acilius sp., 23 mm long and 4 mm wide) was simultaneously attacked by about 30 Gambusia (30 - 46 mm) that had been denied food for 12 hours. While persisting in their attacks, these mosquitofish were unable to grasp or swallow the larva. The latter's large size, heavily chitinized cuticle, and capacity to spring away when attacked, combined to save it; and after 30 minutes during which it had been under constant attack, it showed no signs of harm whatsoever.

Three hours later, though, this larva was found dead. However, its body remained intact. It was left in the aquarium overnight. By morning, parts of the body, including the head and intestine, had been scavenged.

No adult beetles of any species were ever eaten, even when they comprised the only prey available to a group of 40 starved mosquitofish. Five 2 mm (Hygrotus sp.) and three 13 - 15 mm (Acilius sp. and Hydroporus sp.) adult beetles were dropped into an aquarium containing 40 Gambusia. The fish soon began to attack the small beetles, which were swallowed whole but promptly regurgitated alive. The fish concerned made no further effort to devour Hygrotus sp. Dashing up and down through the water, the larger beetles were safe from attack and were not investigated at all by the starving Gambusia.

Water-boatmen (Corixidae)

Observations of the activity of water-boatmen (*Sigara* sp.) revealed a marked difference between their way of movement and that of other organisms offered to mosquito-fish as food. In the aquarium, the dark-coloured water-boatmen mostly either rested at the bottom or in dark corners. Blending into their background, they presumably escaped the predators notice while motionless. Once disturbed, they darted about in the water, with frequent and rapid changes of direction. Their activities, though, were largely confined to intermediate depths, where they often finished up by clinging to the aquarium wall. They seldom came to the water surface.

Gambusia rarely attacked quietly resting water-boatmen. They readily attacked moving ones, though, sometimes after having moved close to the corixids and stimulating them to activity. It was observed that the smaller water-boatmen (2 - 3 mm in length) were easily ingested by mosquitofish, but that the latter usually regurgitated them. This action was sometimes repeated several times before the corixid was finally swallowed. *Gambusia* often encountered difficulty in dealing with large water-boatmen (those more than 5 mm long) which, after being grasped, would struggle to escape and in fact normally succeeded in getting away.

A fish usually had to make many attempts, sometimes for two minutes or more before securing a corixid of this size. Sometimes it finally gave up trying, when there were few mosquitofish present. However, in an aquarium with many Gambusia (40 - 50 mature fish) keenly competing for food, even a large water-boatman (7 mm) would be devoured. A 4 - 5 mm long example could be consumed in less than 15 seconds and larger ones (6 - 7 mm) within a minute and a half. On one occasion, a 7-mm water-boatman was attacked 42 times by a group of seven mosquitofish. The corixid, after being twice swallowed and regurgitated, and held in the mouth of one of the predator for several seconds, still succeeded in escaping. Nevertheless, it was finally incapacitated and eaten.

Another 7-mm water-boatman after being attacked 28 times by eight to nine Gambusia in less than two minutes, made good its escape and took refuge in a dark corner of the tank.

Caddis-fly larvae (Trichoptera)

In nature, a caddis-fly larva protrudes its head and thorax from the case, and crawls slowly over the bottom of the habitat. When touched, it withdraws into the case, remaining motionless and thus being relatively secure from attack. In the aquarium, larvae removed from their cases continued to creep about at the bottom and the smaller ones were readily devoured by mosquitofish.

The larger caddis larvae, even though removed from their cases, posed some difficulties for the mosquitofish. One such larva 22-mm long was dropped into an aquarium containing five Gambusia (38 - 44 mm in length). It was attacked constantly for about a minute, but proved too large for the fish. While two of the predators were able to hold it (by the head) for a few seconds, the larva resisted strenuously and was quickly released. The mosquitofish showed little more interest in it. After half an hour, the larva was still alive, and only slightly injured.

Once again though, matters turned out differently when there was intensive competition for food. Under such circumstances, an even larger (23 mm) caddis-fly larva was completely devoured by one of the 40 starving Gambusia in less than six minutes. As soon as the larva (minus its case) was dropped into the aquarium, its head and abdomen were fiercely attacked by a group of nine to ten mosquitofish. One fish partly ingested the caddis larva's head, and swam about with its captive for a minute. The part of the larva's body protruding from the fish's mouth continued to lash about, and the victim succeeded in freeing itself. Seconds later, though, it was again half swallowed by another fish.

This sequence of events was repeated three times in less than three minutes, different fish being involved on each occasion. Four minutes after the last fish had made its attack, it was being closely followed by other mosquitofish, with about a quarter of the larva's body still protruding from its mouth. It now succeeded in gulping down the whole larva, the large body of which had kept the fish's mouth forced widely open for some time.

Seven normal caddis-fly larvae were now used in an experiment to test the value of their cases in affording protection to the larvae from mosquitofish. Three of five larval Limnephilus sp. were stripped off their rod-shaped cases, free from which they ranged from 12 - 14 mm in length. The other two were removed from their cases for measuring (they proved to be 10 and 12 mm long), and then returned to them. The other two caddis-fly larvae were smaller (Pycnopsyche sp., 6 - 8 mm long). They had spiny, somewhat rounded cases, to which they too were returned.

As soon as the seven larvae were offered to five Gambusia (35 - 43 mm) that had been starved for a day, two of the three naked ones were immediately swallowed. The third naked larva was soon incapacitated, and it too had been devoured in less than 10 minutes. None of the encased larvae were attacked at all. Five hours later, it was found that one of the Limnephilus larvae had disappeared from its case, and had presumably been eaten. The other three larvae were still alive and unhurt.

In another trial, three Pycnopsyche and two Limnephilus larvae were exposed to about 40 mosquitofish (35 - 46 mm). The Gambusia swam around the cases as they were dropped into the water, following them as they sank to the bottom. Soon afterwards, the Limnephilus larvae began to move about with head and thorax protruding from the rod-shaped case. They were immediately attacked by a group of five fish, one of which grasped a larva's head. Trying to drag the larva out of its case, this fish pulled and shook its victim vigorously from side to side. Finally, the larva freed itself and retracted into its case, within which it remained hidden for at least 30 minutes. The Pycnopsyche larvae moved slowly, seldom protruding much of the body from the spiny case. Thus they were less vulnerable to the predators.

Hours later the Limnephilus larvae had all disappeared. The Pycnopsyche larvae, better protected by their spiny cases, were still alive and unharmed.

Dragonfly nymphs (Odonata)

In the first of two trials, five nymphs (Aeschna sp., ranging from 10 - 16 mm in length) were given to five mosquitofish (38 - 44 mm). In the second trial, three nymphs (8 - 15 mm) were offered to about 40 Gambusia (33 - 45 mm). In neither case were any of the nymphs eaten. As soon as the nymphs were dropped into the water, the Gambusia had converged upon them, but soon appeared to lose interest. After 24 hours had elapsed, all the dragonfly nymphs were still alive and unharmed.

Eggs of brown trout (Salmo trutta L.)

When a small egg was swallowed, it was usually ruptured in the mouth of the mosquitofish - this was clearly evident from the dribbling out of egg material from the Gambusia's mouth. If an egg could not be broken at once, the fish would repeatedly reject and eat it again until it was ruptured. Only fresh, soft eggs were consumed without difficulty. Those that had been left in water for some time, or had otherwise become externally hardened were seldom eaten, even if small enough for the fish to ingest.

In one trial, twenty brown trout eggs (3.3 mm in diameter) were offered to five female Gambusia (39 - 42 mm). Nine of them were devoured in 25 minutes, and one three hours later. The remaining ten eggs were not eaten at all. In another trial, twenty 3-mm eggs were given to five mosquitofish, which devoured ten of them in less than 10 minutes. Hours later, the remaining ten eggs were still there, intact and uneaten. However, when ten fresh eggs were individually introduced, eight of them were consumed in six minutes.

Larger eggs were somewhat difficult for individual mosquitofish to swallow or break up, even though very often they could grasp part of an egg and carried it around for a minute or two. It was very commonly observed that three or four *Gambusia* would combine their efforts to attack a large egg, which when broken was shared among them. Individual mosquitofish were unable to ingest most such eggs, though. Some of the latter were found to be partly indented, nevertheless. Presumably, this was caused by the constant nibbling by *Gambusia* at the hard surface of the eggs.

Young of three-spined sticklebacks (*Gasterosteus aculeatus* L.)

The intensity of consumption of young sticklebacks by *Gambusia* was quite different, depending on whether the young were given separately or in combination with other food organisms. When other food were also present, *Gambusia* tended to select tender and relatively vulnerable organisms such as mosquito and chaoborine larvae, rather than the speedy sticklebacks.

At the beginning of an experiment, young sticklebacks were placed from different corners of the aquarium to distribute them as evenly as possible. Nevertheless, they soon grouped together at the corner just beneath the water surface. This behaviouristic characteristic would provide the young Gasterosteus with a distinct advantage when other organisms suitable as Gambusia prey were available. On the other hand, it would render them more vulnerable when unaccompanied by other macroorganisms in the aquarium. Thus, when the roving mosquitofish bumped into the group of young sticklebacks, an immediate, fierce attack followed by remorseless pursuit would occur.

Twenty-four young sticklebacks (ranging from 10 to 19 mm in total length) were offered to three female Gambusia (34 - 38 mm) unfed for 24 hours. As soon as placed in the water, the Gasterosteus were immediately attacked by the mosquitofish. The smaller and weaker sticklebacks were the first to be captured. Within 25 minutes, eight young had been devoured and two more were badly injured. By the end of eight hour, only five young Gasterosteus were still alive, seven had disappeared (presumably they had been eaten) and four were dead, their bodies so flattened and defaced as to be scarcely recognizable. These dead young had probably being eaten and later ejected, or they might have been repeatedly ingested and regurgitated by the mosquitofish. By morning, three of the four survivors left in the aquarium overnight were dead but uneaten.

Ten young sticklebacks (9 - 19 mm) were individually offered at intervals to four mosquitofish (36 - 42 mm). Young prey of a length of less than 14 mm were devoured within seconds. *Gasterosteus* young (16 mm long) was instantly attacked on being dropped into the aquarium. Half ingested from the tail end by a *Gambusia*, it was held for more than two minutes. This *Gambusia* was closely followed by others, attempting to seize its captive. Soon, the victim's unswallowed head was grasped by another mosquitofish. With a shake, the stickleback's body was torn away from its tail and subsequently consumed. Other larger prey (17 - 18 mm) were either killed or badly injured. A *Gasterosteus* 19 mm long was the only survivor.

Young of *Gambusia* as food

Observations were also made by feeding mother *Gambusia* with their own newly born young or other mosquitofish with young of their own species of equivalent size. No young were eaten or attacked by their own mother within an hour of birth - although the latter sometimes seemed to make a close attack in this period. However, when the same young were offered to other mature mosquitofish, or after they had been removed from their mother for a day or two and were reintroduced to her after she had been kept without food, they were eaten quite as readily as the young of sticklebacks.

It was rather unexpected to discover that mature male or female mosquitofish (about 25 mm in length) (mostly the males) were also eaten by larger examples of their own species in an aquarium containing about 50 Gambusia. Although it was not known whether these smaller mosquitofish had died naturally or been killed, it was common to find dismembered bodies of smaller mature mosquitofish, lacking their eyes, intestines and tail fin. It is unlikely that these smaller fish had been dealt with in the same fashion as tadpoles are killed and eaten, by persistent attack upon the abdominal wall until it was pierced and the intestines protruded. Healthy smaller Gambusia were much more active than tadpoles and were able to avoid any sustained attack upon their eyes or abdomen by larger examples of their own kind. These Gambusia were probably accidentally injured by other mosquitofish and afterwards died; their protuberant eyes being readily consumed and evisceration offering no problems under these conditions.

Other food organisms

Fully grown female mosquitofish encountered no difficulty in consuming larval Diptera (mosquitoes, chaoborines, chironomids and dixids). A 40 mm female could swallow eight chaoborine larvae (av. 13 mm in length) in less than 60 seconds, and consume four more within another three minutes.

Unlike females, the physically smaller male mosquitofish could not ingest a chaoborine larva at one gulp. Male *Gambusia* grasped one end of such a larva which was then little by little ingested. Chironomid larvae were similarly consumed. Mosquito and dixid larvae, too, were easily devoured in this fashion by male mosquitofish.

In the first of two trials, three male mosquitofish (26 - 31 mm) were provided with 40 chaoborine larvae. After 30 minutes, only five of the prey had been devoured. In the second trial, 20 of each kind (chaoborine and chironomid larvae) were offered, four chironomids and five chaoborines being swallowed in 30 minutes. Compared with female *Gambusia* (e.g. in one trial, two fish 40 mm in length, consumed 41 chaoborine larvae within half an hour) the males could only eat much smaller prey, much less frequently.

The feeding behaviour of younger *Gambusia* (about 20 mm in length) upon smaller chaoborine larvae (9 - 10 mm) was also observed. Starving young mosquitofish were quite voracious too whenever chironomid and chaoborine larvae were offered - although a longer time was needed before a dipterous larva could be completely devoured. After grasping one end of a larva, some young mosquitofish took 40 - 50 seconds to swallow it. Others took an even longer time - up to two to three minutes. Often a larva would struggle hard, and sometimes succeeded in freeing itself and escaping. It was not uncommon to find that owing to its strength and larger size, a larva when ingested would force the young fish's mouth widely open for minutes at a time.

DISCUSSION (1). ON GROWTH STUDIES

There are many factors, biotic and abiotic, composing and affecting the environment of a species (factors such as food supply, competition, temperature, light, ionic composition and amount of water, gaseous contents and depth of habitats). The efficiency of growth of fish depends greatly on these environmental factors as well as on internal factors, for example, on the age of the fish. Among these factors, temperature and food are considered to be most important and many investigations have been carried out on different fishes related to these two factors (Hathaway, 1927; Markus, 1932; Pentalow, 1939; Allen, 1940; Wingfield, 1940; Baldwin, 1956; Kramer and Smith, 1960; Kinne, 1960; Strawn, 1961; Cridland, 1962; Liu and Walford, 1966; Paloheimo, 1966; Brett etc., 1969; and Keast, 1970).

In the present study on growth of *Gambusia*, the effect of food as a limiting factor was kept to a minimum by excessive supply of food, and other factors were also well under control. Thus, temperature is the basic factor in controlling the growth of mosquitofish in the experiments, of which the results provide interesting insight into the variability of growth caused by different intensities of heat.

Temperature has often been cited as one of the most important physical factors affecting the metabolism of poikilotherms. Many studies have shown that the fastest growing fish were also in the best condition (Brown, 1946; Stroud, 1949; Hansen, 1951; Cooper, 1953; and Keast, 1970). The growth of Gambusia both in weight and length was rapid and greater for the fish kept at higher range of temperature (22.8 - 25.7^{0}C). This rapid increase in growth at higher temperature is correlated with a large increase in the food intake. Sokolov and Chvaliova (1936) found that at a temperature of 30^{0}C, the process of digestion of Gambusia is rapid and a temperature of 17 - 23^{0}C caused a slowing-down of digestion. Compared with those fish kept at lowered temperatures (14.5 - 17.0^{0}C and 5.5 - 6.1^{0}C), they had the lowest mortality and highest gain in length and weight. Thus higher temperature is favourable to its rapid growth, and this temperature range is more or less similar to that of other poeciliids. Gibson and Hirst (1955) found the optimum temperature for growth of pre-adult guppies (Lebistes reticulatus), another viviparous poiciliid, to be in the neighbourhood of 23^{0} to 25^{0}C. Keast (1970) found that the optimal temperature for feeding and growth of banded killifish (Fundulus diaphanus)(a cyprinodont fish) in laboratory, between 20^{0} to 30^{0}C. Furthermore, Kinne (1960) in a thorough study of growth, food intake and food conversion in young of Cyprinodon macularius, observed that 25°C and 30°C produced greater growth than did 15°, 20° or 35°C. He further stated that growth rate varies almost directly with increasing temperature until an optimum is reached, after which a further rise in temperature leads to a diminution in growth rate. Strawn (1961) found that the maximum growth of largemouth bass fry (Micropterus salmoides) occurred at 27.5°C and 30°C and slower growth at 20°C and 17.5°C.

Many investigators have shown that Gambusia can grow in a much wider range of temperature. Thus a temperature between 22.8 to 25.7°C might not be the most favourable one for its growth. Hart (1952) found that Gambusia affinis is quite eurythermal and has a high lethal temperature, this species thus being ideally suited to the shallow, warmer marshy area it frequents. Hagen (1964) in a study of thermal tolerance of three species of Gambusia (G. affinis, G. geiseri and G. gaigei) and found G. affinis was more tolerant to a temperature of 39°C and fry of this species were remarkably tolerant to high temperatures. He thus concluded that both G. gaigei and G. geiseri are more stenothermal than G. affinis which is quite eurythermal.

The guppy's normal temperature range, according to Gibson (1954) is 16°C to 32°C; Innes (1966), however extended the upper temperature to 40°C. Krumholz (1948) presented evidence that Gambusia affinis could tolerate decidedly warm water during nine days of transportation in a car trunk (air temperature more than 38°C). Thus, the most favourable temperatures for growth of mosquitofish might be equal to or slightly higher than those presented in this study. This is further supported by the finding of Rees (1934) who stated that Gambusia affinis not only thrives in thermal springs in Utah (normal temperature, 23° - 28°C); but these springs also represent an ideal habitat to keep the fish active and propagating throughout the year.

Cold temperatures have an adverse effect on the growth of mosquitofish. This is clearly shown by the poor growth of fish reared in the laboratory at medium (14.5° - 17.0°C) and cold (5.5° - 6.1°C) temperatures. It is also evident from the field (13.5° - 4.4°C), where food is more abundant and of greater diversity, while there are other favourable factors too (e.g. presence of sunlight, higher oxygen content and less accumulation of waste products). Fish from the medium-temperature tanks did not grow so well as those from higher-temperature tanks. Nevertheless, their growth rate was much better than that of the fish maintained in colder waters. Cold temperatures also delay the maturity of young fish. Thus, gonopodia did not appear in the males, but appeared in other males at higher temperature waters.

Strawn (1961) showed that the growth rate of bass fry is retarded at low temperatures and accelerated at higher temperatures.

The slow growth rate of fish at lowered temperatures is accompanied by a decrease in the amount of food taken; this is especially notable in cold temperature stream where fish's stomach were found empty. Food intake in Cyprinodon macularius decreases with temperature in this order: 30^0, 25^0, 20^0 and 15^0C (Kinne, 1960). The amount of food eaten by fish at medium temperature is about half of that eaten by fish at higher temperature, and that eaten by fish in cold tanks is far less than that amount eaten by medium-temperature fish. This might be due to the fact that fish are cold-blood animals, their metabolic activities are slowed by cold environment and accelerated by warm environment. Thus, more optimal higher temperatures lead to an increased maintenance ration and a greater food intake. The influence of temperature on food requirements of bluegills, sunfish and largemouth black bass has been studied by Hathaway (1927) with results indicating these fish consume only about one third as much food at 10^0C as they do at 20^0C. He further stated that as the exposure to cold was prolonged, the effect of depression of food consumption due to the cold was not counteracted by acclimatization, but rather tended to become more pronounced. Markus (1932) found that largemouth black bass fed voluntarily at temperatures of 16°C and above, but not at 10°C and 4°C; even when force-fed, the bass did not increase in length, on the contrary, they lost weight at lower temperatures.

The rapid diurnal changes of lowered water temperature in the stream apparently had an adverse effect on the growth of mosquitofish kept in cages, just beneath the water surface. Hildebrand (1925) stated that when Gambusia were in confinement, a too sudden chilling of the water would be detrimental to the fish. The prolonged exposure of mosquitofish to cold temperature both in aquarium and in the field leads to a further loss of body weight. Although lowered cold temperature (as low as 4.0°C in the stream) had affected the growth rate of mosquitofish, it seemed that it was not lethal to them. Lewis and Hettler (1968) described the responses of young menhaden (Brevoortia tyrannus) to lethal low temperature as: swim near the surface with heads up, gulp air, are less active and can easily be touched with a probe; prolonged exposure leads to loss of stability, the start of swimming on their sides, settlement to bottom and occasionally swimming in spurts. Besides being less active, no other such responses and no bodily deformation were observed in Gambusia in colder waters. The two obvious reasons for the fluctuation in average weight increment of young fish in cold tanks are (a) the death of larger fish, (b) the retention of varying quantities of water during blotting to obtain wet weight (Davis, 1968).

Kinne (1960) stated that increase in length is an useful measure of growth, that is, of synthesis of tissue or protoplasm, and he had experimentally demonstrated this view in comparative rearing experiments using length, height and weight as criteria. The growth rate and the largest Gambusia attained in length in the present study was much smaller than those found by Sokolov (1936) and Krumholz (1948) in the field. Sokolov (1936) recorded the average growth of offspring of Gambusia in rice fields, proceeded from 7.6 mm at birth to 23.1 mm, an increase of 15.5 mm at an age of 37 days. He also recorded an average growth among adults of Gambusia, an increase of 8 mm (34 to 42 mm) in about 78 days. An even more rapid growth rate of Gambusia affinis was reported by Krumholz (1948) in the ponds located in northeastern and central Illionois, collected during warm summer. He found that in one pond, the length of the new born female would increase 36 mm (9 to 45 mm in length) in 23 days; in a second pond, increase 35 mm (9 - 44 mm) in 75 days; and in third pond, an increase of 23 mm (from 9 - 32 mm) in 60 days. He attributed the difference in growth rate of Gambusia in the three ponds to the marked difference in type of habitat and natural fertility. In pond one, it was high in productivity and plankton flourished throughout the summer; pond two was considered to be less productive and pond three least productive. The growth rate of males found by Krumholz (1948) was not as rapid as for females but still greater than those obtained in this study. He found that in pond two, the males attained an increase in length of 11 - 14 mm (from 10 - 20 mm to 24 - 31 mm) in about 35 days, while in pond three, an increase of about 5 mm in length (16 - 26 mm to 21 - 31 mm) in 60 days.

It is generally agreed that the growth of a given species of fish is variable and is determined by the body of water in which it lives, that is, individuals of a species in one habitat may grow to a much larger size or attain a greater weight than do fish of the same species in another habitat. Besides temperature, food should be another important factor that determines the growth of mosquitofish. Brown (1957) discussed the fundamentals of the growth phenomenon in fish and concluded that food supply is probably the most potent factor affecting the growth in fish. During the summer, provided that water temperature does not rise to a lethal level, the available food supply acts as a limiting factor (Wingfield, 1940). As pointed out before, *Gambusia* grew faster in fertile ponds than in less fertile ones. Although in the laboratory, mosquitofish were given an excessive amount of chaoborine larvae food, it would appear that a greater variety of food, as found in the natural habitat, is much more effective in promoting growth and development. Gambusia were regarded as omnivores (Hiatt, 1947; and Hunt, 1952) and were oppotunistic in its feeding on both animals and algae. Rees (1934) found that stomachs of Gambusia caught in ponds during winter, were free from any animal life, and contained only algal food. Wald (1931) found stomach contents of young contained more algal food than insect larvae and the food of juvenile Gambusia affinis was confined largely to both phyto- and zoo-planktons (Barnickol, 1939; Rice, 1940). Thus, pure animal food might not be a well balanced diet for the growth of mosquitofish. Furthermore, Knauthe (1898) studied the metabolism of fish and found that a balanced ration, consisting of protein, carbohydrate and mineral, was necessary. Reddy and Pandian (1972) in a study of the growth of Gambusia affinis, found that the mortality of juveniles fed on mosquito larvae alone (Culex fatigans or Aedes aegypti) was much higher than those fed on a mixed diet (Tubifex worms and mosquito larvae). They attribute this to the incapability of these larval insects to synthesize the required vitamins, of which a sufficient quantity would promote the normal growth and reproduction of the fish. They, therefore, regard G. affinis as a mixed feeder, and a mixed diet may promote its normal survival, growth and reproduction.

The nutritional value of algae to fish has been studied by a number of investigators whose views were quite different. Gerking (1962) questioned the nutritional value of plants to bluegill sunfish (Lepomis macrochirus) and Davis and Warren (1965) stated that a carnivorous sculpin (Cottus perplexus) derives no food value from algae. However, other authors found that algae do have a nutritional value to fish. Ball (1948) contended that plants serve as a substitute food and has demonstrated that bluegills feed intentionally on plants. Certain largely herbivorous fish use plants more efficiently for growth when a small amount of animal food is added to the diet (Menzel, 1957; and Jancarik, 1964). Puntius sp. (P. sarana and P. sophore) according to Moitra (1956) can utilize a large number of green and blue green algae, and also a number of diatoms which are readily digested in fish stomach (Fish, 1951, 1956). Encouraging results of the effect of feeding selected algae (Scenedesmus obliquus and Microcystis aeruginosa) on the weight, volume and size of freshwater fishes (Puntius tieto, Trichogaster fasciatus and fingerlings of Cirrhina mrigala Ham.) have been found by Ahmad (1966a, 1966b). He also found that S. obliquus is an alga of high nutritional value, containing 43% protein and its beneficial effect is due to this large protein content. More recently, Kitchell and Windell (1970) feeding bluegill sunfish with an alga (chara) found that bluegills do gain some nutritional value. According to the food habits of 16 species of fish which were ranked (Harrington and Harrington, 1961) within different feeding categories, *Gambusia* was ranked first as a diverse feeder, second as a larvivore and average as an herbivore, plankton eater and pisivore. Thus, the absence of plant food in aquarium probably affected the growth rate of *Gambusia*.

The confinement of mosquitofish might also affect its growth since fish in aquaria were isolated and received very few external stimuli. De Buen and De Buen (1922) showed that life in captivity hindered reproduction of *Gambusia affinis* to a considerable extent. Moore (1941) in a study of feeding habits of four species of young fishes found that in aquaria, an excess of available food does not lead to increased consumption by the fish. Hathaway (1927) found that largemouth black bass in running water ate about 50% more food than individuals in captivity. He attributed the difference to the fact that running water stimulates them to greater activity. In addition, Carline (1968), in a series of studies on the relationships between food consumed and growth achieved for juvenile fish held in an aquarium and in an experimental stream, found that fish in the stream had a better growth rate. He attributed this to the greater levels of activity by stream fish or to some possible effect of confinement on the aquarium fish. He further explained that above the maintenance ration the stream fish were more efficient than aquarium fish in utilizing their food; thus the effect of activity diminished as food consumption increased.

The growth of a group of fish in a confined space might encounter interference caused by competition for position as well as food. Comfort (1956) found that female guppies (*Lebistes*) grew faster in large containers than in small containers. Kinne (1960) also found that in aquarium a small amount of water leads to a reduction in growth rate and food intake, and to an increase in activity of *Cyprinodon macularius*, for which there was not enough space to establish a minimum territory and during the day, they were continually chasing each other especially at 30°C. Brown (1946b) found that crowded fish ate less, used the food less efficiently and clearly disturbed each other, and may form such associations as size hierarchy. If the space available is rather small, the fish must inevitably disturb each other when feeding and during their normal activity.

It is not known whether the day-length has any effect on the growth rate of *Gambusia*. There is evidence that certain endocrine organs (for examples, thyroid and pituitary hormones) of fish are affected by the amount of light and it is to be expected that there may also be effects on growth (Brown, 1957). Oasim (1955) showed that fry of Blennius pholis provided with abundant food, grew better with 16 - 17 hours of darkness than in continuous light; he postulated that these fish required a certain amount of "sleep" for optimum growth. However, the absence of sunlight might affect the growth rate of Gambusia under laboratory conditions. Samokhvalova (1941, cit. Krumholz, 1948) stated that, whereas the size of the aquaria, the temperature of water and the number of fish per unit of volume of water have an effect on the growth of that poeciliid as well as all other fish, those factors were not decisive in causing the under-development of aquarium-reared Gambusia. The decisive factor was held to be direct sunlight. He further stated that when the aquaria were placed in the direct sunlight, the mosquitofish grew well and began to spawn; when moved back to laboratory conditions, they relapsed to subnormal growth and reproduction.

Gambusia was reported to have a fairly wide range of tolerance to pH (6.6 to 7.8) and total hardness (12.8 ppm and 320.4 ppm) of water (Krumholz, 1948) and salinity (Petragrani and Castelli, 1927; and Sicault, 1934). It is still an uncertainty about the effect of low pH on growth rate of the fish, nevertheless, a pH between 5.2 to 5.4 (in laboratory) and between 4.9 to 5.1 (in stream) seemed not to affect its survival. Southern (1932, 1935) and

Frost (1939) studied the growth of brown trout in certain acid and alkaline waters and concluded that trout grow larger in alkaline (hard) waters and remain small in acid (soft) waters. However, Brown (1957) found no differences in early growth rate of trout reared in artificial hard and soft waters in laboratory. She explains that differences in ionic composition of natural waters are associated with differences in fauna and hence in food supply. Doudoroff and Katz (1950) after reviewing voluminous pertinent literature concluded that most fully developed freshwater fishes can live indefinitely in waters with pH above 5.0 and up to 9.0 at least. Thus, it is probable that under laboratory conditions with abundant food supply, low pH value, if it has any effect on the growth rate of mosquitofish, would be mild.

In nature, it would appear that the ideal place for Gambusia to live and grow well would be wide and deep pools (with suitable substratum) where they could easily avoid sudden changes in water temperature and where a greater variety of food would be more accessible. Sicault and Roule (1935) found that at lowered temperature, Gambusia left shallow water for deeper water of more stable temperature. Krumholz (1948) suggested that the proper place for Gambusia to overwinter is to introduce them into a muddy, soft-bottomed pond, having a maximum depth of at least five feet and should preferably place them in their new environment early in the summer. Smith (1960) suggested that a pond with fairly heavy growth of water plants and an ample food supply in the form of small aquatic organisms is an ideal breeding site for the mosquitofish. The hardiness of the fish and its ability to grow well in natural cold water has been reported by many authors (Jordan, 1927; Rees, 1934, 1945; and Krumholz, 1944, 1948) and to overwinter in many cold countries. Gambusia affinis was first introduced into Western Canada in the late 1920's (Gibson, 1927 and Hearl, 1928). However, no details of its winter survival were mentioned. Years later, they were proved to survive in outdoor pools in the coldest winters in Alberta (Mail, 1954) and in Manitoba (Smith, 1960). There are no record, until now, of Gambusia affinis being established in a climate as severe as that which prevailed in Manitoba, where the lowest temperature of coldest month in 1960 was - 21^{0}C. Thus, it is highly assumable that with a suitable habitat, abundant food supply and a hardy strain, Gambusia will be able to survive in Newfoundland waters during the cold winter season.

DISCUSSION (2). ON FEEDING HABITS

The food eaten by a fish is controlled by what is present in the water where it lives. The problem of the food selectivity of a fish is to determine which of the animals or plants present are eaten and to what extent. However, both the behaviour of the fish and the nature of the animal under consideration affect the extent to which it is eaten. Among the characteristics of a potential food animal which have this effect are its size, habits, taste, abundance and accessibility.

Confining predator and prey to tanks one can control to a large extent, the components of selectivity related to food items and also the degree of satiation of the predator (Ivlev, 1961). The effect of size of prey on food selection by Gambusia was held to the minimum as far possible in this study by using prey that had been previously proved to be swallowed by the mosquitofish. Prey, small enough to be captured and swallowed by Gambusia, yet not so small as to be unattractive, were offered. Galbraith (1967) reported that fish might be forced to turn to other food organisms if certain food of the proper size are not available. In the tests with young sticklebacks as the only food given, the mosquitofish tended to select smaller sticklebacks. However, Hess and Tarzwell (1942) found that Gambusia preferred consuming mosquito larvae of later instars and no first instar larvae were found in the stomachs of the fish. This might be due to their smallness in size or that they were less satisfactory to the food requirement of the mosquitofish. It has been suggested (Thomas, 1964) that the size of food organisms would probably affect their food value to fish. By capturing not too small organisms a fish would expend less energy to satisfy its food requirements than if it was feeding on organisms that were too small. Lawler (1965) also reported that larger pike eat more small perch than do the smaller pike. He explains that this cannot be strictly a matter of selection for size, but rather must be for the volume of food required to provide for metabolism and growth. However, in the experiment, sizes of prey generally do not affect the selectivity of various organisms by Gambusia, since they were within the edible size range and are not too small to be less conspicuous. Thus, something other than the size of food organisms must affect its selectivity.

Relative abundance is considered as an important factor in determining the incidence of prey consumed (Allee, 1933; Ivlev, 1961; Darnell and Meierotto, 1962; and Lawler, 1965). Parsons (1971) stated that if several forage species are available at preferred lengths, walleyes tended to eat the most abundant species. Nevertheless, relative abundance of prey may have been of minor importance in this study, since it is so controlled that equal numbers of prey species were offered in the experiments. Relative abundance changed during experiments as the food species were eaten, so that the relative abundance of preferred species declined as that of the remainder increased. The mosquitofish did not correspondingly begin rejecting those species that they had eaten first and turn to other species. Obviously, something other than relative abundance determined selection of certain favourable prey by the mosquitofish.

Although conditioning has been observed in other species of fish (Allen, 1940; Ivlev, 1961; and LeBrasseur, 1969), there was little evidence that conditioning influenced the feeding of mosquitofish in this study. Beyerle and Williams (1968) and Mauck and Coble (1971) were unable to condition pike to eat certain food fish. Similarly, Gambusia could not be conditioned to eat readily trout eggs or young sticklebakcs.

To determine food preference of predators, it is necessary to maintain the food items in a condition of nearly equal accessibility. The outcome of these experiments showed that there still exist some difficulties in evaluating all the factors that influence predatory fish to eat certain amounts and kinds of food. Due to the fact that forage organisms used in this study were all alive, capable of moving in any direction, a random distribution of prey was encountered with some difficulties. Crowding of the food organisms near corners of the aquarium and the tendency of the food fish to school just below the surface of the water were observed as reported previously (Allee, 1933; Ivlev, 1961; and Beyerle and Williams, 1968). All these might have affected the vulnerability of prey to the fish. However, in the laboratory, since all prey were restricted to such a limited space in the tank, they could not move far away from the predatory Gambusia which were by far more rapid swimmers than the prey and could capture any prey within sight. Since this equal accessibility was more or less affected by the behavioural patterns of the food organisms, it affected the feeding of mosquitofish to a certain extent. Thus, the majority of tests were measures of selectivity (i.e. preference plus accessibility as mentioned by Ivlev, 1961), but not necessarily of preference because preference could not be isolated from differential accessibility. The appearance of prey also affected to a large extent the relative vulnerability of prey and hence food selectivity of predators (Allen, 1940; Popham, 1942; and Mauck and Coble, 1971). This is the factor which is not possible to control even under laboratory conditions. Animals different in appearance have a considerable effect on the extent to which they are eaten. An animal which closely resembles the background and choses to stay on such background tends to be less frequently seen and therefore less frequently eaten than one which does not. Water-boatmen and Oligochaetae were the food organisms whose appearance and habit affected the extent to which they could be seen and eaten by the mosquitofish. From the evidence that Oligochaetae were readily eaten soon after they were placed in the middle of the tank where they could be seen by the feeding fish, it is concluded that they were favourably preferred. That they were not consumed as intensively as dipterous larvae could only be attributed to its being hidden in corners of the tank and were thus less conspicuous. No Annelida of any kind had been reported by Hildebrand (1923), Barnickol (1939), Rice (1940) and Self (1940) in their studies of the food habits of Gambusia under field conditions. Hess and Tarzwell (1942) found annelids (Family Naididae) had the lowest forage ratio of all organisms consumed by Gambusia taken from the field and they attributed this to its tube-dwelling habit and inaccessibility to the fish. Allen (1940) in his study of the feeding habits of early stages of salmon revealed that in no case were annelids (Oligochaetae) found in the stomachs of salmon although they were consistently common in all streams studied. He also attributed this to the burrowing habits of Oligochaeta and that they would very rarely be visible to the fish.

Compared with some other food organisms, water-boatmen were less readily eaten by _Gambusia_. This might due to several factors namely, the resting habit of water-boatmen in the dark corners, a longer resting period, less preferable to the fish, or adults corixids are less active than their nymphs. These have been indirectly comfirmed by other investigators who found under field conditions that stomachs of _Gambusia_ taken from littoral waters where corixids were in greater abundance, contained large numbers of nymphs of this organisms (Rice, 1940; and Hess and Tarzwell, 1942). They attributed this to lack of heavy protective vegetation in that area, greater abundance in number and the nymphs peculiar activity which made it susceptible to predation. Corixids were also reported by Barnickol (1939) and Hunt (1952) to be consumed by _Gambusia_. Popham (1942, 1943 and 1944) described a series of laboratory experiments in which fish ate Corixidae. He concluded that in an aquarium corixids were eaten by fish and those which did not harmonize with the background tended to be selected more than those which did. However, Frost and Macan (1948) argued that few fishes had taken corixids, and only in exceptional circumstances had any fish devoured a large number of corixids. They further pointed out that in nature, Corixidae were almost restricted to a small fraction of the shallow water region of the lake and only minnows foraged in large numbers in this area, hence consumed large number of corixids. In nature, Gambusia were found to flourish mostly in streams or in shallow waters where corixids were most prevalent. Thus, it is not uncommon to find corixids in the stomach contents of Gambusia. Observation of the habits of corixids in aquarium was in general agreement with those described by Popham (1942) who stated that corixids spent most of the time resting on the bottom of an aquarium and were obvious only when disturbed. Most of the water-boatmen eaten by Gambusia in this study were captured when disturbed by the fish swimming close to them, or during their movement from the hidden site to the water surface to obtain air (Frost and Macan, 1942).

Unlike brown trout which have habit of concentrating on one animal at a time, and it is common to find a trout stomach packed with a single species (Allen, 1938; and Frost, 1939), mosquitofish though with preference to dipterous larvae, consumed a variety of food at a time. Seal (1910) stated that most mosquitofish appeared to gorge themselves with whatever was available. However, there are exceptions because Gambusia do avoid certain food organisms, for examples, water-mites (Arrenurus sp. and Piona sp.), adult beetles (Hygrotus sp. and Acilius sp.), backswimmers (Notonecta sp.) and mayfly larvae (Blasturus sp., Ephemerella sp. and Stenonema sp.); some of these organisms were occasionally given as the only food and have soft body coverings. The rejection of water-mites (Hydracarina) cleared Barnickol's (1939) uncertainty that these organisms were engulfed together with other insect food, since most of them were species parasitic upon insect larvae. Furthermore, they were most abundant in the littoral region of ponds and very often found parasitic upon corixids (Popham, 1942). Taste or a certain odour of these small water-mites might be involved in its being rejected by Gambusia since all water-mites have a large excretory gland on their dorsal area. Elton (1923) found that hungry sticklebacks refused to eat bright scarlet mites and that all water-mites have large skin-glands, and there were very few cases on record of mites being edible. Thus water-mites if not poisonous, must be very distasteful to fish.

Gerald (1966) divided the Order Ephemeroptera into two subgroups: the swimmers (Baetidae, Blasturus sp.) with quick darting movements, clinging to bottom materials whenever they come to rest; the creepers (Ephemerella sp. and Stenonema sp.) which creep about slowly on all types of bottoms. Both types of these nymphs were neither consumed by the present laboratory fish nor found in the stomachs of fish taken from the field by other authors (Barnickol, 1939; Rice, 1940; Self, 1940; Hess and Tarzwell, 1942; and Harrington and Harrington, 1961) except low percentage of Ephemeridae which were reported by Sokolov and Chvaliova (1936). Distaste and less availability might contribute to its being not utilized by *Gambusia*.

My results were generally in agreement with Fermi (1926), Barnickol (1939), Rice (1940) and Hess and Tarzwell (1942) who found no adult beetle food in their specimens, but was in disagreement with Hunt (1952) who reported small beetles as miscellaneous animal food in *Gambusia*'s stomachs. *Gambusia* did not eat any of the adult beetles given and from the observation of repeatedly regurgitation of adult beetles after taken indicated that they were bodily too hard to be consumed, as Fermi (1926) stated that *Gambusia* selected forms with soft cuticula and avoided insects of comparatively large size with hard integument (such as Coleoptera, nymphs of dragonflies, dytiscid beetles and notonectid bugs). However, compared with adults, larval beetles have relatively softer body covering and have also been reported eaten by mosquitofish. Their habits of swimming and staying just below the water surface, moving slowly but darting or springing away when disturbed, might be the reasons why they were rather favourably chosen. As in dipterous larvae, these actions made them very attractive to the fish which usually remained near the water surface and were stimulated to feed by "an object within certain size limits and moving not too slowly" (Baerends, 1957). *Gambusia* prefers insect food which is in motion as reported by other investigators (Hildebrand, 1923; Jackson, 1929; Barnickol, 1939; and Rice, 1940). The ability of some of larvae to lie motionless just under the surface of the water protected them from the mosquitofish (Hildebrand, 1923).

Notonectidae and Gerridae have also been reported to be consumed by Gambusia. Barnickol (1939) and Rice (1940) attributed this to their being much greater abundance and lack of heavy protective vegetation in that area. My findings in the laboratory are that they were either not eaten or less favourably chosen by the fish, probably because of their relatively larger size and harder body. Although both Notonecta sp. and Gerris sp. were rapid swimmers or skaters, under experimental conditions involving unplanted aquaria, hunting was reduced to a minimum and the prey had no chance of escaping unless the predator rejected or avoided them.

Allen (1941) indicated that large fish may better utilize organisms with hard outer coverings or cases than do smaller fish. This holds for Gambusia which is a small fish and even in the aquarium found it difficult to devour a caddisfly larvae hidden in its case. Naked larvae (without case) were successfully ingested by mosquitofish in an aquarium. However, in nature, no caddisfly larvae have been reported in the stomachs of Gambusia examined (Hildebrand, 1919, 1921; Wald, 1931; Rice, 1940; Self, 1940; Hess and Tarzwell, 1942; Hunt, 1952; and Harrington and Harrington, 1961) except those observations made by Sokolov and Chvaliova (1936) who found small percentages. Members of Trichoptera spend much of their time partially emerged from tube-like retreats concealed in crevices or camouflaged by bits of wood, leaves or similar material (Gerald, 1966). This may account for its absence in *Gambusia*'s stomachs taken from the field. In addition, the presence of a case prevents caddisfly larvae from being utilized by the fish. Another instance of prey using a certain defence measure to prevent themselves from larger predators was found by Hoogland, Morris and Tinbergen (1956) in their feeding experiments with Pike (*Esox*) and Perch (*Perca*) as predators and the spined and de-spined sticklebacks (*Gasterosteus*) as prey species. They showed that spined species were much better protected and less vulnerable to the predators. Since sticklebacks used as prey in this study were too young to possess hard spines, they were taken by *Gambusia* without any defence besides struggling when caught or just trying to escape hunting by the fish. If a mosquitofish really dashes towards a young stickleback in a serious attempt to capture it, the latter's chances of escape are small, since in the limited space of a tank and without cover, even single mosquitofish could easily corner and capture any prey.

The hairy or heavily chitinized bodies of some of the food organisms (for examples, some caddisfly larvae, larger dytiscid larvae, adult beetles and nymphs of dragonflies) proved to be an effective means of defending themselves against predation by mosquitofish. Hess and Tarzwell (1942) reported that only small young nymphs of dragonfly, with low forage ratio were in mosquitofish's diet and mature nymphs were too large to be eaten. However, the predatory behaviour of Gambusia in an aquarium showed that they could consume soft-bodied prey of far larger size than they could do in the field and proved that they were a voracious predator on soft-bodied organisms; for example, tadpoles of two-thirds the length of Gambusia were completely torn and devoured by the latter. Any prey of this size would never be found in any mosquitofish's stomach taken from the field because this was too large to be wholly swallowed by a single fish. No evidence of the possible largest sizes of prey ever eaten by Gambusia have been reported by other investigators.

The use of Gambusia for control of mosquitoes in different parts of the world has been extensively studied by many researchers (Hildebrand, 1919, 1921, 1925; Jordan, 1927; Sokolov and Chvaliova, 1936; Hess and Tarzwell, 1942; Craven and Steelman, 1968; Hoy and Reed, 1970; Hoy, O'Berg and Kauffman, 1971; and many others in Bibliography edited by Gerberich and Laird, 1966). Since much has been written and discussed by others regarding the greater preference of mosquito larvae by Gambusia and my findings in the laboratory are in general agreement with theirs, it is unnecessary to repeat detailed discussion here. Nevertheless, one point worthy of mention here is that given equal accessibility, chironomid larvae were fed upon as intensively as mosquito larvae. In natural waters, Gambusia has little effect on chironomids (Rice, 1940; Bay and Anderson, 1966). The reasons for this low percentage of chironomid larvae consumed can be two-fold: most of the Tendipedidae live on the surface of stones in tubes composed of bits of sediment held together by body secretion and partly hidden by algae and sediment which make them less conspicuous to fish (Allen, 1941; and Gerald, 1966). Hess and Tarzwell (1942) found most of the chironomids eaten were in their pupal stage and suggested that these chironomids were taken during night or early morning during periods of pre-emergence activity. Secondly, some degree of adaptation and specialization in feeding of the mosquitofish may exist. The forward and dorsally located mouth of Gambusia could be an adaptation for feeding organisms on water surface or in mid-water. Hildebrand (1919) stated that Gambusia is adapted to procuring its food at the surface of the water. Marshall (1971) also pointed out that the small, upturned jaws of these fish are neatly suited to the picking of food organisms on or near the surface. Thus, in larger bodies of water, surface predation by Gambusia on bottom-living organisms would be less intensive.

Previous investigation by Hildebrand (1921) indicated that a large proportion of the food of Gambusia affinis consists of insect larvae and plant tissue consisting mostly of algae. He regards the presence of plant material in Gambusia as accidental, that is, varying amounts of algae are already in the bodies of insect larvae which are eaten by the fish. On the contrary, many other investigators hold a quite different opinion that Gambusia do feed on plant material. Wald (1931) indicated comparatively large amount of algae found in several specimens and the stomachs of young Gambusia (12 - 27 mm in length) contained more algal food than insect larvae, precluding the possibility that this was taken by accident in the capture of animal prey. Algal food of relatively large amount found in Gambusia's stomachs were also reported by other investigators (Barnickol, 1939; Rice, 1940; Hunt, 1952; and Harrington and Harrington, 1961). My finding in the laboratory is in agreement with these reports and in particular, confirms the uncertainty expressed by Barnickol (1939) in that most of algae eaten by Gambusia are those most available and abundant in the area, that is, no special choice of algal food was made by the fish. Furthermore, examination of the stomachs of 105 Gambusia affinis from Lousiana (Barney and Anson, 1920) led to the conclusion that Gambusia is a plankton feeder. Studies of the food of Gambusia affinis in Hawaiian fish ponds (Hiatt, 1947) showed the diet to consist principally of algae (green algae and diatoms), plant fragments and debris, and rarely animal food such as Entomostraca and insects. Rees (1934) examined the stomach contents of G. affinis taken from pools during winter and found that they were free from any animal life but algae. Thus, Gambusia affinis should be regarded as truly omnivores and apparently opportunistic in its feeding on both plants and animals. Although it may prefer an insect diet when available, it can subsist largely on algae.

In general, in nature, availability as well as suitable size are more important than choice in determining what organisms will be taken as food by Gambusia. The effect is a preference for medium-sized species with more active, soft-bodied, not too distasteful and less secretive habits.

Rapacity should be a term more suitable to describe mosquitofish than combined efforts or co-operation with one another if prey are to be caught and devoured. Often when a prey was held by a Gambusia, the rest would follow closely attempting to grasp its prey. Cannibalism often occurs among starving Gambusia and this cannibalistic habit was also reported by others (Petragnani and Castelli, 1927; and Sergent, 1939, cit. Bibliography by Gerberich and Laird, 1966). Geiser (1921) found that gravid female Gambusia in aquaria frequently attacked and killed the males.

Many authorities were skeptical and had reported that Gambusia were very destructive creatures, not only to fishes of its own small size but also to much larger fishes (Kalanadze and Mchelidze, 1930; Von Ihering, 1933; Legendre, 1937; Rees, 1945; and Myers, 1965). My experimental results in the laboratory that Gambusia readily consumed both young fish and fish eggs especially when there were no other food organisms available, supported the misgivings expressed by these authors. More recently, Wheeler (1971) reported that the introduction of Gambusia into certain parts of Europe had produced striking effect on the native fishes. Gambusia fed on the young of sand smelts, grey mullets and gobies (all were endemic to that region), and numbers of two native relatives of Gambusia, one of which, Valencia hispanica, appeared to have declined considerably since Gambusia was introduced. Furthermore, Gambusia affinis was reported to be predaceous and active, and would reduce the fins of other fishes to shreds (Axelrod and Schultz, 1969).

If Gambusia react to food fish and fish eggs in natural situations the same as they do in aquaria, then predictions can be made of Gambusia-prey relation in nature. Although mature trout eggs in aquarium proved too large to be eaten by individual mosquitofish (largest used was 46 mm in length), larger ones for example, 60 mm or over may have the ability to destroy any mature trout egg. The largest female Gambusia reported by Hildebrand (1917) was 65 mm in length, and 63 mm, 64 mm and 58 mm were reported respectively by Krumholz (1948), Trautman (1957) and Brown (1966). In fact, judged from the feeding behaviour of this surface feeder and the habit of egg laying of trout in stream, the chance for Gambusia to destroy trout eggs in natural waters seems very small. It is not the size of the eggs that would prevent them from being eaten, but the location in the stream in which they are laid, would determine its safety. Gambusia only feed on those organisms that come into view and prefer those that are in motion. Female trout do not lay eggs on top of the spawning area, instead during spawning, the female begins nest-building in gravel beds. With the help of male trout acting as a guard, the female digs a pit in the gravel, into which the eggs are laid. Immediately, it would begin to cover the eggs thoroughly with gravel and pebbles, filling the pit as high as the surrounding bottom levels or higher. Greeley (1932) reported that by the time the female trout deserts the eggs these are so well covered by gravel that disturbance by predators is unlikely. The eggs are further protected by the male which during nest-building, spends his time in fighting other fish, driving them off the nest in a vicious and aggressive manner (Needham, 1969). Although cases of destruction of trout eggs by trout, minnows, suckers and sculpins have been reported, White (1930) and Greeley (1932) pointed out that those are the few eggs being swept away downstream when deposited or those that were exposed to surface by accidental disturbance to trout redds by late-spawning females. It is, therefore, predictable that the chances for Gambusia to destroy large number of trout eggs in nature are slim and only those eggs (e.g. Perch eggs) laid on the surface and exposed to predators will be affected. However, the danger is that the newly hatched fry of trout which later emerge from the redds are likely to be attacked by the mosquitofish. Marshall (1965) reported that the new-born larvae, slightly more than a centimetre in length, after absorption of the yolk sac, may rise out of the nest seeking shallower areas where they could seek their livelihood. It is in these shallower areas of a pond or in stream where Gambusia are most thriving and constantly looking for food. Gambusia, because of its hardiness and its high rate of reproduction, can reach and populate streams in which other fish cannot maintain themselves (Self, 1940). If no other favourable food organisms are present, it is highly probable that young fish in shallow water would find it difficult to survive the perils from *Gambusia*. Furthermore, larger mosquitofish (60 mm or over in length) would be able to consume young fish larger than those maximal size observed in the laboratory.

Owing to its fish-feeding habit and its ability to destroy indigenous varieties in other areas, it will be undesirable to introduce this exotic species into a new environment such as Newfoundland where *Gambusia* does not occur naturally for fear that this imported fish may disturb the existing fish fauna. In its native haunts, smaller fish have learned to hide from destruction by *Gambusia*. But when placed in a new situation, where natural checks do not occur and native species have evolved no defenses, many introduced species of animals will take over and become pests which would crowd out the natural fauna (Myers, 1965). In addition, Hurlbert, Zedler and Fairbanks (1972) stated that lake and pond ecosystems were strongly influenced by the introduction of *Gambusia* which greatly reduced rotifer, crustacean and insect populations and thus permitted extraordinary development of phytoplankton populations. Stephanides (1964) recorded the devastation of the invertebrate fauna of a small, otherwise fishless lake on the Island of Corfu, Greece, after introduction of *Gambusia*. Thus, further careful investigations under field conditions should be carried out before *Gambusia* is to be introduced merely for the purpose of mosquito control.

This is because Gambusia is not only effective in mosquito control, but also able to inhibite the growth of other valuable organisms present as food to local fish species and further leads to the possible extinction faced by hundreds of species of small organisms including small fish.

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Appendix 1. Average weekly temperature, pH and oxygen contents of water (1) at higher temperature, (2) at medium temperature, (3) at lowered temperature, (4) in stream (biweekly).

Week	Ave. weekly temp. (^0C)	pH of water	Oxygen content (ppm)
(1)			
1	22.8	5.3	5.9
2	23.2	5.3	5.9
3	23.5	5.2	6.0
4	25.8	5.2	5.8
5	25.0	5.3	5.9
6	25.5	5.3	5.7
7	25.5	5.4	5.7
8	25.7	5.5	5.8
9	25.7	5.4	5.9
10	25.1	5.4	5.8
11	25.0	5.3	5.7
12	24.8	5.4	5.9
13	23.8	5.2	5.9
14	23.4	5.3	6.0
(2)			
1	14.5	5.3	6.0
2	14.7	5.2	6.1
3	15.0	5.2	6.1
4	16.8	5.3	5.7
5	16.5	5.4	5.9
6	16.7	5.2	5.8
7	16.7	5.2	6.0
8	17.0	5.3	6.1
9	16.6	5.4	6.0
10	16.2	5.3	5.8
11	16.0	5.3	6.1
12	15.9	5.3	6.0
13	15.6	5.3	6.1

Appendix 1. Average weekly temperature, pH and oxygen contents of water (1) at higher temperature, (2) at medium temperature, (3) at lowered temperature, (4) in stream (biweekly). (contd.)

Week	Ave. weekly temp. (^{0}C)	pH of water	Oxygen content (ppm)
(3)			
1	5.5	5.3	6.3
2	5.7	5.2	6.5
3	5.5	5.2	6.3
4	6.0	5.2	6.2
5	6.0	5.3	6.2
6	5.8	5.3	6.3
7	6.0	5.2	6.1
8	6.1	5.2	6.4
9	6.0	5.4	6.1
10	5.8	5.3	6.0
11	5.8	5.3	6.3
(4)			
	12.6	5.0	8.4
2	10.6	4.9	8.2
4	7.7	5.1	7.8
6	7.1	5.1	8.5
8	5.7	5.0	9.3
10	4.8	5.1	9.1
12	4.4	5.0	10.1