THE USE OF FISH
FOR
MOSQUITO CONTROL

INTERNATIONAL HEALTH BOARD
OF
THE ROCKEFELLER FOUNDATION
61 Broadway, New York, New York, U. S. A.
1924

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PREFATORY NOTE

Most of the material in the following pages was compiled some two years ago for the information of members of the field staff of the International Health Board who did not have access to the literature on the subject. It is now put into printed form for permanent record and for general distribution to those who may be interested. Perhaps the fact should be emphasized that the work does not represent in any sense a first-hand survey of the use that has been made of fish in the control of mosquito breeding; it is merely a brief digest of the information to be found in the literature readily accessible in New York City. It may be assumed that much important work has been done throughout the world which has not been recorded in books and periodicals. The International Health Board will be pleased to have such work brought to its attention and to be informed of important articles not covered by this review or included in the bibliography on pages 109-120.

An attempt has been made to avoid drawing any conclusions independently of those reached by the writers under review or passing judgment upon the facts and opinions they present. This is, in a sense, an uncritical method, but it seems to be one of the inherent defects in any comprehensive digest of the literature on a subject of this kind. While the writers referred to doubtless represent varying degrees of authority, the compilers have not felt at liberty to exclude mention of any material except that which is obviously unscientific and untrustworthy. It has seemed wiser on the whole to leave it to the reader to decide for himself how much weight should be given to the views of each writer.

Although the material presented is primarily a digest of the literature cited in the bibliography, a certain amount of valuable information has been gleaned from correspondence and unpublished reports on file in the Home Office of the Board. The work has also greatly benefited from suggestions and criticisms offered by a number of specialists in this field to whom it was submitted in galley proof. Among those who generously assisted in this way were Dr. H. R. Carter, Dr. M. E. Connor, Dr. Samuel T. Darling, Dr. L. D. Fricks, Dr. T. H. D. Griffitts, Mr. Samuel F. Hildebrand, Dr. H. H. Howard, Mr. W. V. King, Mr. J. A. LePrince, and Dr. Francis M. Root.

The articles from which the material in this report was compiled do not as a rule include pictures of the fish referred to. In order to give the reader some idea of the general appearance of the principal species, illustrations have been incorporated in the text wherever feasible. These have been obtained from a variety of sources, but chiefly from the well-known treatises on ichthyology. One of the most useful of these is David Starr Jordan's "Fishes" (New York, 1908). The cuts have not been used with the idea of giving assistance in the positive identification of the fish; that must be left to the specialists. It is very difficult for the layman to make an accurate identification of many of the small fish found in any locality. In top-minnows, for example, microscopic differences found in certain structures are the chief distinguishing marks. Detailed descriptions of many of the top-minnow genera and species will be found in a technical article by C. Tait Regan in the Proceedings of the Zoological Society of London, 1913, (vol. 2, pages 997-1018). Mr. Samuel F. Hildebrand has given a less technical treatment in his pamphlet "Top Minnows in Relation to Malaria Control," published in 1921 as Bulletin No. 114 of the United States Public Health Service. In the identification of fish sent to the home office of the Board by members of its field staff, valuable service has been rendered by Dr. B. A. Bean of the Division of Fisheries, United States National Museum, Washington, D. C., and by Professor Carl H. Eigenmann of the University of Indiana, Bloomington, Indiana.

December, 1924

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Importance of Mosquito Control

The four diseases known to be carried by mosquitoes are malaria, yellow fever, filariasis, and dengue fever. The science of medical entomology is still young, and the relationship of mosquitoes to these and a number of other diseases has not yet been precisely determined; yet it seems likely that as knowledge of disease transmission increases, the rôle of the mosquito will assume greater rather than less importance.

At present mosquitoes are important chiefly as the transmitters of the two great scourges of tropical countries, malaria and yellow fever. The yellow fever mosquito is often referred to as the *Stegomyia fasciata,* but this name is now being supplanted by the designation *Aëdes aegypti,* the specific designation originally used by Linnaeus. Unlike malaria mosquitoes it never flies far from human habitations. It is a town rather than a swamp mosquito. Its entire life-cycle may take place naturally indoors. Originally it was probably a tree-hole breeder; now it has become an insect that lays its eggs in gutters, in artificial receptacles such as barrels, cans, troughs, pools, and the like. It escapes fish control completely when its larvae occur in such out-of-the-way places as sagging gutters or discarded fruit tins (117).[1]

The malaria mosquitoes belong to the genus Anopheles, of which there are over a hundred species in different parts of the world. It is definitely proved that not all species of Anopheles are carriers of malaria, and that of the three well-defined types of malaria some mosquitoes carry only one (56). Because of the extent and variety of their breeding-places the malaria mosquitoes are more difficult to combat than the yellow fever mosquito. Another important difference which makes the disease produced by the malaria mosquito more difficult to control, is the longer period in which infected persons are capable of transmitting the disease-producing parasite to the mosquito. In the case of yellow fever the patient can infect the Stegomyia only within a brief period of about three days at the beginning of the illness, a period so short that there is a possibility of

[1]A list of sources used in this compilation is appended. Each reference bears a number which corresponds with the numbers given throughout the text. The sources cited are generally those of most importance with respect to the particular point under discussion. Absence of other specific references, however, does not mean that the same subject was not discussed in other literature included in the list.

preventing cases of secondary infection by keeping the patient screened. In malaria, on the other hand, many chronic cases are capable for years of transmitting the malaria germs to mosquitoes (217).

Exact information as to which species of Anopheles do and which do not carry malaria might conceivably save a great deal of trouble and expense in efforts to clean up malaria-infected regions. An important step forward would be made if in any given locality the campaign against malaria mosquitoes could be directed only against the special breeding-places of the particular kinds of mosquitoes that are known to be carriers. However, workers in the Dutch East Indies and elsewhere are now finding that species formerly thought to be harmless are in reality carriers, at least under experimental conditions. As the complicated technique necessary to establish malaria-carrying capacity is perfected, it may be found that more and more Anopheles are capable of transmitting malarial infection. If it should be found that an ever-larger number of species are carriers of sanitary importance, the need for an enemy that will destroy all larvae alike, if only it can obtain access to them, is made more urgent than ever (192).

Biological Method of Combating Insects

The use of larvivorous fish in mosquito control work, to supplement drainage, oiling, and other methods, is of somewhat recent origin, yet cannot be considered an innovation. For hundreds of years similar procedures have been studied and advocated in closely allied fields; for four or more decades they have been successfully practiced. In the insect world the precarious foothold that each species maintains in the face of its enemies makes it quite possible for man to take a hand in their struggle for existence and change the environment in such manner that flourishing and pernicious insects are reduced to harmlessness.

The principle forms the basis of much of the successful work of the Bureau of Entomology of the United States Department of Agriculture. A striking and widely known example was the virtual eradication of the white or cottony cushion scale (icerya), which, accidentally introduced from Australia about 1886, threatened to destroy the entire lemon and orange industry of California. Five years later, after a small beetle *(Novius cardinalis,* also known as vedalia) which feeds exclusively on this scale, had been brought from Australia and released in great numbers in the California orchards, scarcely a scale was to be found. The vedalia was subsequently introduced into other countries with the same complete success. In

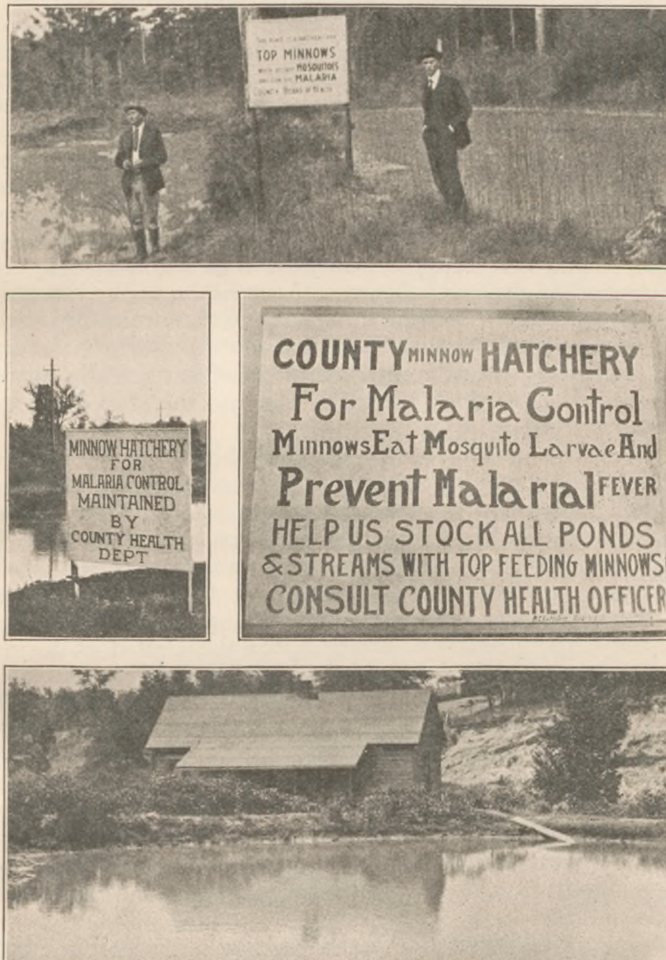

Fig. 1. — Minnow hatcheries maintained by county health departments in Alabama and Mississippi

Hawaii, in 1903, the leaf-hopper damaged the sugar-cane crops to the extent of about $3,000,000, but the introduction of several active parasites resulted in the hopper's being practically eliminated. In Italy the silk industry was saved by the introduction of a minute parasite of the Diaspis insect which threatened to destroy the mulberry trees upon which the silkworms feed. In Spain over 40,000 hectares are planted with orange-trees which were attacked by certain coccids, and the introduction of small beetles known to feed on the eggs of coccids proved most useful in checking their ravages.

The control of the Hessian fly, the cabbage-worm, and the San José scale, are other instances of the application of the biological method. When successful, the method seems almost magical, but unless applied by experts it is not without its dangers. Florida fruit-growers thought that the vedalia, introduced so successfully into California, would also destroy their local variety of scale, but in importing the insect they not only obtained no relief but actually introduced a new kind of scale which had been put into the shipping boxes for the vedalia to feed on.

Moreover, the introduced species may themselves become serious pests. The few rabbits originally introduced into Australia and New Zealand for sport purposes have become a nuisance and caused the abandonment of large areas that had been under cultivation, while attempts to introduce weasels and other animals to prey upon the rabbits have resulted in depredations by the weasels on poultry yards, about the only part of the farm left untouched by the rabbits. Again, the English sparrow, brought into the United States to suppress the snow-white linden moth and held by various entomologists to have succeeded in practically exterminating this shade-tree pest in cities, has developed into such a pest that some states are paying bounties in an effort to reduce its numbers. The introduction of a predacious fish may result also in the elimination of certain smaller fish that are keeping down to some extent the breeding of mosquitoes or are useful for other purposes. Thus, the United States Bureau of Fisheries, because of the danger to native and useful species, sometimes declines to furnish bass and other fish that might do more harm than good (103).

Objection to the attempt to control mosquito production by the use of fish has been made on the ground that nature tends to establish a balance between mosquito larvae and fish, the evidence indicating that in some regions fish and larvae have lived together naturally for a long period of time and that the fish have not succeeded in destroying all the larvae. It is therefore held that under prepared conditions the result would be the same, and that fish and larvae would eventually be found living side by side. In spite of this objection there remains no doubt that through human interference, by such means as destroying aquatic vegetation and affording the fish more favorable opportunities, for instance, this balance can be upset so that the latter may acquire permanent dominance (132; 140). Another objection frequently offered is that there is always a balance between the number of fish that a certain volume of water can support and the amount of food available. If fish are unable to cope with the mosquitoes under natural conditions, it is held that the introduction of additional fish would be useless because the water area is already supporting its full fish capacity and the original balance between food and fish would soon be restored (132; 140; 180; 209).

But objections of this sort are answered by the simple fact that fish have been successfully used not only against the yellow fever but also against malaria mosquitoes. The experience of many independent investigators shows that within certain definite limits excellent results can be obtained by applying the biological method to mosquito control.

The Function of Fish

Mosquitoes of all species pass through four distinct stages: egg, larva, pupa, and imago or adult insect. The first three are aquatic stages during which the mosquito may be most effectively attacked. Then the insect lives in a fixed, accessible, and easily located habitat where it may be destroyed on a large scale. It is, in fact, necessary to rely almost exclusively upon larval destruction in mosquito control measures, as destruction of the winged form bv fumigation and other means, though valuable under certain conditions, counts relatively for very little. During their aquatic stages mosquitoes encounter fish as one of their natural enemies, a great many larvae being destroyed by certain fish that depend on the food they find on or near the surface of the water.

Mosquito eggs are usually laid late at night or in the morning on the surface of a body of water. The eggs of many species are closely joined by a gelatinous substance into a raft-like form. This is not true either of Stegomyia or of Anopheles whose eggs are laid singly or in small groups. Each anopheline egg has air cells or "floaters" on its sides so that it may remain on the surface of the water. Normally the eggs are hatched within two or three days into larvae or "wigglers." Sometimes the separate eggs may resist drying almost indefinitely, so that pools may dry up and the eggs be left in the mud, only to hatch in new pools that may be formed by later rains. Low temperatures prolong the dormant or egg stage, and some species, among them *Aëdes aegypti,* even pass a whole winter in this stage and do not hatch until the following spring.

Fig. 2. — Cleaning the shore of a pond so that even when the water is at its highest point there will be no vegetation to prevent the fish from reaching the mosquito larvae

Anopheles larvae, lacking the long respiratory tube which characterizes various culicids, remain just below the surface of the water and parallel to it—a fact that explains why no fish except top-feeders will be efficient in destroying the larvae of this particular species, which, unlike those of most other species, descend to the bottom only rarely, or when alarmed, and then generally for a short time only. The Stegomyia, provided with a short tube, rests at an acute angle to the surface. During the larval stage, which lasts from about ten days to several weeks or more, varying with the season and temperature of the water, the larva molts three times, growing meanwhile much larger, until with a fourth molt the pupal form emerges. In this last aquatic stage the insect presents the form of a large-headed comma, with curved tail, and swims or tumbles rapidly when disturbed or alarmed. The pupa takes no food, and undergoes several important structural changes. The winged insect or imago is usually ready to emerge in twenty-four hours, though this period may be prolonged in cold weather.

Under the most favorable conditions the aquatic period in the life-cycle of the mosquito lasts about two weeks. If the temperature is low or there are other adverse conditions, however, it may be longer. During this period the immature insect is constantly exposed to attacks from its enemies, for either eggs, larvae, or pupae offer tempting tidbits to ducks, fish, large aquatic insects, and even to larger larvae of the mosquito family, and the active movements of the larvae and pupae are almost certain to attract the attention of enemies if any are nearby. The larvae seem, however, to sense the approach of an enemy — probably from the agitation of the water, which acts upon their sensitive mouth-hairs — and will often sham death to escape detection. They conceal themselves between the leaves of aquatic plants, under bits of bark, dead leaf stems, or among other floatage which hides them very effectively, so that the removal of such natural barricades is necessary in many cases to enable their enemies to have free access to do their work.

Requirements of Fish as Mosquito Destroyers

The natural habits of both fish and mosquito larvae must be taken into consideration in selecting fish to be used for the destruction of larvae. As has been said, the problem of attacking Anopheles of which there are many species is particularly complex, because these mosquitoes breed in quiet as well as running water, and are fond of pools protected by vegetation; moreover, lying horizontally at the surface of the water, they are almost completely hidden by the surroundings. For these reasons the fish used must be of a species that will search for food not only in the shallow water but amid vegetation as well.

Mr. W. P. Seal, formerly of the United States Bureau of Fisheries, lists a number of questions to be considered in choosing fish for mosquito control:

1. Do they live in quiet or open water?
2. Do they swim amid aquatic and semi-aquatic vegetation?
3. Are they solitary or gregarious?
4. Are they sluggish, lethargic, or active?
5. Are they carnivorous, herbivorous, or omnivorous?
6. Are they bottom-feeders, top-feeders, current-feeders, or variable?
7. Are they destructive of other fish?
8. Are they found where there are mosquitoes?

In pools, ponds, lagoons, and other natural bodies of water an adequate supply of food and the breeding habits of the fish become very important points for consideration. The fish must breed rapidly because large numbers of them must be kept in the water. Carnivorous fish are to be preferred to omnivorous (172; 173; 186). Surface feeders are generally best, although sun-perch and goldfish may also be effective. Where game fish eat all kinds not protected by spines, a sunfish may be most practicable.

A distinction to be borne in mind in what follows is that the problems of yellow fever and of malaria control are quite different as far as the use of fish is concerned. The fish required for malaria work must be at home in natural collections of water. Since the aquatic forms of Anopheles are exclusively surface dwellers, the fish should usually be top-feeders. They should be able to work their way into such vegetation and floatage as may harbor the larvae, and in order to escape from destruction by larger fish, they should be small and inclined to frequent very shallow water. The sanitarian's part in controlling malaria by fish, after stocking the breeding areas, consists in removing vegetation and floatage, guarding against destruction by larger fish, and replacing the larvivorous fish in case they are destroyed.

Most of the literature on the control of mosquitoes by means of fish deals with the malaria mosquito, because malaria is much more widespread than yellow fever. The information which follows will therefore apply principally to the malaria problem.

Since the Stegomyia, in the Americas at least, breeds only in artificial containers, there is generally no need of helping the fish to gain access to the larvae. These larvae, although they come to the top for air, spend most of their time at the bottom. Hence either a bottom or a top-feeding fish may be efficient, although the former is given preference. Fish for Stegomyia control must frequently be replaced from a hatchery, for only a few are allowed in each container and they are subject to being dipped or washed out of the water, if indeed they do not jump out, and they may be injured by the dipping utensil, by sudden changes of temperature, or by insufficient light. The sanitarian's problem in protecting fish that insure Stegomyia control is therefore very different. In general a more hardy fish is used, and the chief problems are those of inspection and replacement.

Live fish have not yet been found to carry pathogenic germs. This is of interest in connection with the placing of fish in water for drinking purposes. When larvae and fish remain in the same container it probably means that the fish are too few to consume all the larvae, that they are not of the right kind for the class of receptacle, or that they have not recovered from the shock of removal. Failures are chiefly due to selecting the wrong kind of fish. Gambusia, the topminnow so successful with the malaria mosquito, is not to be recommended for artificial containers.

Earliest Use of Fish for Mosquito Control

Science is much indebted to the laity for calling attention to the usefulness of fish for mosquito control. For a long time it has been known that fish consume the larvae of various kinds of insects, particularly of mosquitoes; and in some sections of the world they have been used for a great many years to rid small tanks, pools, and other water-containers of larvae. The use of fish (generally perch) in open shallow wells to keep down mosquitoes and "purify the water" is said to have been a household custom for generations in the United States. In Georgia in 1854, a certain Dr. Fort freed a tank of all its larvae by placing in it a dozen or more small fish. It was noticed by a Mr. Russell in Bridgeport, in 1891, that all larvae had disappeared from a pool left by a receding tide which had brought in a number of small fish. In a neighboring pool of the same sort, which contained no fish, the larvae were very numerous (22; 115; 117).

Between 1890 to 1899 Ross investigated the use of fish and found minnows in India that could each devour in a few seconds a dozen or more larvae. Large fish, however, disdained such prey. He noticed also that fish and larvae lived together in ditches and in rice-fields. The immunity of Barbados from malaria he thought might be due to a local fish known as "millions." But it was not until 1900, when experiments, all of them disconnected and some of them incomplete, were begun in various parts of the world, that active interest was taken in the subject. However, the results of the early investigations were not altogether satisfactory as some of them were laboratory experiments lacking the needed field tests, while others, though made in the field, were not followed up in a manner to show definitely their results (168).

The United States Fish Commission had begun by that year some investigations into the use of the top-minnow, stimulated, perhaps, by reports that had come from Barbados as to the efficacy of the small fish called millions. Messrs. W. P. Seal and J. P. Moore made observations on the life habits of Gambusia and Fundulus; and the Bureau of Entomology, after conducting a series of laboratory experiments with goldfish in an aquarium, stated that their capacity to eat larvae was limited only by the food-supply and the number of fish in relation to the number of larvae. These experiments may have suggested to Mr. Underwood, of the Massachusetts Institute of Technology, the idea of trying to eliminate mosquito larvae from a pond near his home by stocking the pond with goldfish. The fish throve, the larvae disappeared, and there seemed to be a reduction in the number of mosquitoes. He followed this by some laboratory experiments with goldfish and with fish indigenous to his locality, the results of which showed that all were mosquito exterminators (115; 117).

Fish now began to be tried, in a general and disconnected manner, in various parts of the world. On the Riviera in southern Europe carp were used where mosquitoes were abundant; at Milan in Italy the same species proved effective after sticklebacks and millions had failed. At Larnaca, Cyprus, goldfish were used in the wells; and at Khartum fish from the Blue Nile were put into the undrained ponds and wells, where, however, they were only temporarily effective. In German East Africa, Vosseler concluded that the task of completely ridding a locality of mosquitoes was too large for any variety of fish, though he found certain indigenous species that were a great help (11; 37; 89; 116).

In Antigua in 1905 a consignment of millions that had been sent there in a kerosene can was liberated in swamps and streams, where they flourished and were so successful in suppressing mosquito breeding that they were subsequently introduced into other islands of the West Indies. At about the same time Texas top-minnows were taken to Hawaii, bred in prepared ponds, and placed in the streams, proving so effective that their application has been continued up to the present time. Fish were tried to some extent in Panama as part of the plans for sanitation, but exuberant vegetation and a large amount of floatage, perhaps difficult or impossible to remove, rendered them ineffective (13; 116; 119).

Fish Control in Various Countries

United States

In the United States, in addition to the early work briefly recounted above, various attempts have been made in recent years to try out fish control in definite areas in the hope of obtaining scientific knowledge. About 1914, shortly after interest in fish as mosquito destroyers had been reawakened in India, the United States Bureau of Fisheries participated actively in trials that were being made in the use of fish in the southeastern states. Mr. Lewis Radcliffe classified and briefly described for this Bureau some of the fish that had shown promise for mosquito control; a number of experiments were undertaken in different areas; and much information was obtained concerning the habits of fish and their usefulness in combating mosquitoes under actual field conditions. Many problems still unsolved were discussed at the first annual conference of sanitary engineers of the United States Public Health Service, held in 1919 at Wilmington, North Carolina (209).

Since that time the application of fish in various parts of the United States has spread rapidly playing since 1920 an important rôle in many field operations against malaria. The normal habitat of the top-minnow *(Gambusia affinis)*, the chief fish relied upon to combat mosquitoes in the United States, is in the southern part of the country. Some studies have been made, however, of other fish suitable for northern waters. In 1922, Professor J. P. Moore, of the department of biology at the University of Pennsylvania, and temporary investigator for the United States Bureau of Fisheries, discussed investigations carried on during the summers of 1918, 1919, and 1920, prin-

Fig. 3. — *Enneacanthus gloriosus.* Blue-spotted sunfish

cipally in Philadelphia and Delaware Counties, Pennsylvania, and Palisades Interstate Park, New York. Minor experiments were conducted also at other points in Pennsylvania, New York, Maryland, Delaware, and New Jersey. The plan of procedure consisted in a preliminary examination of many ponds, swamps, and streams, during which collections of the fauna and flora were made and ecological data gathered. Thereafter certain waters, chiefly small ponds, were selected for detailed study. These waters, as far as possible, were visited at weekly or fortnightly intervals, and usually during the visits fish and other organisms were collected. The fish taken were at once dropped into 4 per cent formaldehyde to stop digestion of food in the stomach. The conclusions arrived at concerning the various species studied were based upon their observations and experiments and upon examinations made of stomachs of fish preserved during the inspections of the waters (146).

Some of the fish discussed were the roach or golden shiner *(Abramis chrysoleucus)*, the goldfish *(Carassius auratus)*, the mud-minnow *(Umbra pygmaea)*, the common killifish *(Fundulus heteroclitus)*, the translucent killifish *(Fundulus diaphanus)*, the common

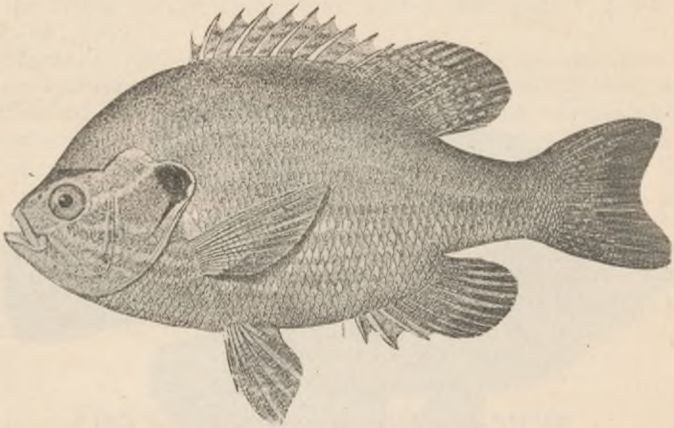

Fig. 4. — *Eupomotis gibbosus.* Common sunfish (6 inches)

top-minnow of the South *(Gambusia affinis)*, the blue-spotted sunfish *(Enneacanthus gloriosus* and *E. obesus)*, the long-eared sunfish *(Lepomis auritus)*, and the common sunfish *(Eupomotis gibbosus)*. In discussing the geographical distribution of these species it was shown that all of them occur not only in the North but also either generally or in some parts of the malarious districts of the South. The results, therefore, are probably in part applicable to the South.

The roach, or golden shiner, does not push its way into the very shallow plant-grown waters, and the investigations, although not conclusive, indicate that this fish has been much overrated as a mosquito destroyer.

The goldfish has a very restricted value and is useful only in containers or small waters where food other than larvae is scarce.

The mud-minnow consumes mosquito larvae, but its chief deficiency appears to be in numbers, i. e., it usually does not seem to become numerous enough to furnish complete control, but since the fish is very hardy, experiments in the direction of artificial propagation are recommended. Of fifty stomachs examined, twenty-two were found to contain mosquito larvae, constituting about 4 per cent of the total contents.

Concerning the common killifish, Professor Moore says, "The value of this species in limiting the numbers of salt-marsh mosquitoes is thoroughly established and attested by scores of antimosquito workers in New Jersey, New York, and Connecticut."

The translucent killifish was found to feed to some extent on mosquito larvae; it may be preferable to the common killifish for muddy ponds and sluggish streams.

Gambusia, although not occurring naturally in the area in which the experiments were conducted, was introduced. It did not survive the winter in ponds in the vicinity of Philadelphia where it was planted, but it was found that this minnow could be used to a limited extent by carrying a brood stock through the winter in a greenhouse or other suitable place for release the following spring. These fish, under favorable conditions, increase with "astounding rapidity," and mosquito breeding may be controlled by this method in small ponds.

"Enough is known of the blue-spotted sunfish to recommend placing them on the list of species for stocking plant-grown ponds and streams," is the conclusion concerning these handsome fish.

Insufficient detailed attention was given to the long-eared sunfish to determine its exact value, but it is probable that the young, at least, may be useful.

The common sunfish was found to be the most valuable of all the sunfish, the young being particularly effective because they visit the extreme margins of the ponds. Stomachs of 224 specimens, the majority under 80 millimeters in length, were examined, and "mosquitoes in all stages" constituted 9 per cent of the food present. Its importance as an antimosquito agent is almost equal to that of Gambusia, except in the South, where it was frequently found necessary to introduce the Gambusia into ponds already populated by this sunfish and by the bream or bluegill sunfish.

As a general conclusion Professor Moore makes the following statement: "The relatively small number of mosquitoes produced by such waters (ponds, lakes, and sluggish streams under natural conditions) results chiefly from this influence. Indeed it may safely be said that were these fish suddenly wiped out, mosquitoes would immediately and generally become an intolerable nuisance." This is in entire accord with the statement made by Hildebrand in a number of public lectures and elsewhere, namely, that several large, prosperous cities in the South never would have been built had it not been for the check on mosquito production provided by fish, chiefly topminnows (146).

Alabama. In 1921 the top-minnow was being extensively and economically used in malaria control work under county health units, particularly in a group of five counties in Alabama, where a sanitary engineer has co-operated with the county health authorities. These counties are Calhoun, Morgan, Sumter, Talladega, and Tuscaloosa. In all 136 ponds were stocked with Gambusia. Practically every farmer has, on his place or in his neighborhood, access to a Gambusia hatchery, which enables him easily, whenever occasion arises, to stock breeding areas with fish. In southeastern Alabama some difficulty has been encountered in connection with aquatic birds as enemies of Gambusia.

Arkansas. During 1918 observations on mosquito breeding in rice-fields near Lonoke, Arkansas, were made by Geiger. Top-minnows occurred naturally along the levees and in the water inlets, but rarely

Fig. 5. — *Fundulus nottii.* Star-headed minnow (1½ inches)

in the middle of the fields. In an attempt to prevent the breeding of mosquitoes, careful experiments were made with various kinds of oil, with intermittent flooding, and with top-minnows.

In one experiment 1,400 top-minnows were placed on a farm at a time when the rice was eighteen to twenty inches high. Although the minnows had been well distributed, subsequent investigation showed that they had migrated to the levees, where the water was deeper, and to the place where the water entered the plot, although ordinarily they do not prefer deep water. There was, however, within one week, a reduction of about 70 per cent in mosquito larvae, and this reduction lasted for the entire eight weeks of the experiment.

On another farm 800 top-minnows were distributed when the rice was three feet high and partly in blossom. Again only an occasional minnow was later found in midfield. There was a reduction in mosquito larvae of 35 per cent within two days but in one subsequent week there was an increase of 85 per cent, which continued without change for nearly five weeks, possibly because most of the larvae

Fig. 6. — *Fundulus notatus* Rafinesque. Star-headed minnow (3.5 inches)

were so small that the fish must have had difficulty in finding them. It was considered fair to measure the success of fish control, not by the abundance of small larvae, but rather by the absence of large larvae and pupae.

The preference of minnows in this case for the deep water where feeding was best, and their avoidance of midfield in rice areas, make them a doubtful control measure in connection with rice culture. However, it was shown that the presence of fish may bring about under some circumstances a considerable reduction in mosquito larvae. The tremendous area of rice-fields and the abundance of obstacles diminish the usefulness of small fish, although in drainage ditches they may be entirely satisfactory (84).[1]

California. Louva Lenert, formerly a staff member of the International Health Board, was detailed to the California State Board of Health in 1922 for an antimalarial survey of the State. The Fish and Game Commission at Sacramento became interested when it learned that Mr. Lenert had received a consignment of top-minnows to use in the mosquito control of California. It is contrary to the California statutes to import into the state any fish except with the authority and permission of the California Fish and Game Commission, owing to the fact that some species of fish introduced into the waters of California have proved harmful to other fish life and a menace to the valuable commercial fishing interests and to the waterfowl of the state. The Fish and Game Commission, pointed out to

[1]Better results were had in rice-fields in Madagascar and Italy. See pages 67 to 71 and 78 to 81.

Mr. Lenert that the young of the striped bass when first emerging from the egg closely resemble mosquito larvae, and should the top-minnow be introduced into the waters of California, it might prove a menace to one of the most important commercial fish. S. F. Hildebrand, whose opinion was sought, stated that he had devoted a considerable portion of his time to the study of Gambusia during the past eight years, and he has "at no time found this fish to be a serious enemy of any of the food and game fish, nor has any one ever to his knowledge raised such a complaint."

Lenert built several hatcheries or rearing ponds in various parts of the state to propagate the top-minnow, but the Fish and Game Commission asked him not to liberate these minnows until it was demonstrated to their entire satisfaction that they are not predatory to the young of striped bass, shad, or other fish. Although the question has not been finally settled, the Commission has decided not to oppose the introduction of Gambusia.

Georgia. Mr. S. F. Hildebrand, of the United States Bureau of Fisheries, who has conducted extensive field experiments since 1916, is convinced that fish can be used successfully if the proper species is found for the conditions it is to meet. His experiments in North Carolina brought him to the conclusion that the hardiness, voracity, and abundance of the *Gambusia affinis* make it a most efficient larva-consumer. When held in captivity it was especially voracious of larvae. The only reasons for their failure he found to be too few fish or too much vegetable matter protecting the larvae. The number of larvae was always greatly reduced no matter under what disadvantage the fish worked. He thinks the sheepshead minnow is less effective than the top-minnow, as it feeds mostly on vegetable matter. Of other fish he considers the star-headed minnow *(Fundulus nottii)* as worthy of trial and he also values highly *Heterandria formosa*, but doubts the value of sunfish, with which mosquito larvae were found to coexist (106; 107).

In 1918, as ichthyologist connected with the United States Bureau of Fisheries, Mr. Hildebrand made some further experiments with Gambusia in Georgia, and was again entirely convinced of their efficacy. The experimental area in Georgia was located in the extra-cantonment zone of Camp Hancock, and covered a territory one mile wide surrounding the camp. The work was carried out from March to November, 1918, and consisted chiefly in distributing and protecting the top-minnow, increasing its numbers when necessary, and making careful observations of results achieved.

Swamps and ponds offered the chief difficulty. Nearly all the former could be drained, but the ponds were so situated that drainage was either impracticable or impossible. Constant vigilance in clearing away edge plants and other obstacles was necessary. Some trouble was encountered with large fish which preyed on the smaller

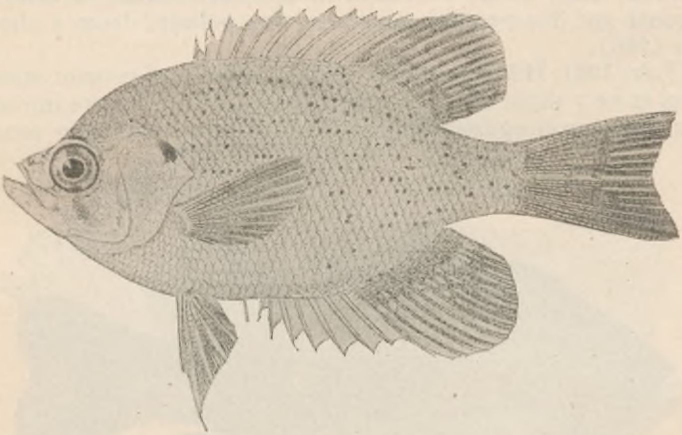

Fig. 7. — *Centrarchus macropterus* Lacépède. Round sunfish (4 to 7 inches)

ones, and with fishermen who used the minnows for bait. The work, which was directed especially toward obtaining a better understanding of the usefulness of the top-minnow, showed that wherever complete elimination of mosquito larvae was not achieved, the failure was due to protection afforded the larvae by vegetation and débris; that the voracity of the top-minnow depended largely upon the amount of food available; that fewer minnows were needed if no obstacles were present; and that to a considerable degree the larvae developed a protective instinct, chiefly consisting in feigning death by maintaining absolute quiet. Fish snap at the larvae only if there is some evidence of motion, but the larvae cannot remain quiet always and are bound to be caught sooner or later if the number of fish is sufficiently large and if the protection afforded by plants and floatage is not too effective.

The chief findings of Mr. Hildebrand relate to the good points of the *Gambusia affinis:* it is a surface-feeder, is prolific, brings forth well-developed young, lives and thrives under a large variety of conditions, and even maintains and propagates itself surprisingly well when surrounded by many predacious fish and floatage. The chief obstacle to its successful use seems to be vegetation. Grossly impure water or water containing acids or other chemicals is also inimical to the fish. Thus, in a test made in Mississippi in 1920 in a two-branched ditch, no larvae could be found in the branch stocked with Gambusia, while larvae flourished in the other branch, in which the fish could not live because the water was polluted from a chemical works (106).

In July, 1921, Hildebrand reported an instance of prompt mosquito control at very slight cost. Two thousand Gambusia were introduced into a pond covering one fourth of an acre and containing countless

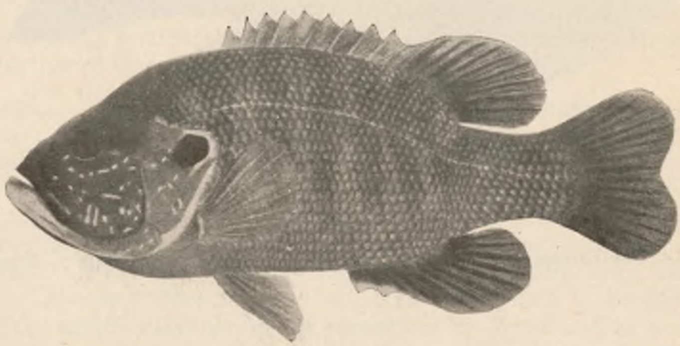

Fig. 8. — *Apomotis (Lepomis) cyanellus* Rafinesque. Red-eyed, blue-spotted sunfish (4 to 7 inches)

mosquito larvae, all of which were promptly suppressed. The fish in this case were brought from another pond only 300 yards away. They were transferred 500 at a time in a wooden tub by a laborer who spent less than half a day. The total cost was one dollar (157).

Louisiana. J. C. Geiger and W. C. Purdy, of the United States Public Health Service, in 1920 studied the rice-fields of Louisiana, Arkansas, and California with a view to determining their effect on malaria. In Arkansas, 1,400 top-feeding minnows, placed in a one-acre field, produced a moderate diminution of mosquito larvae. In Louisiana top-feeding minnows proved fairly satisfactory (85).

An article was published by G. E. Beyer in 1922, discussing the fish available for mosquito control work in Louisiana. In Beyer's opinion various species of perches are as satisfactory as the minnows.

He recommends three species on account of their small size: *Centrarchus macropterus* Lacépède, a round sunfish which is not very common; the *Apomotis (Lepomis) cyanellus* Rafinesque, a little red-eyed, blue-spotted sunfish, very common in all fresh-water bayous throughout the state; and the *Apomotis symmetricus* Forbes, which is the smallest of the family but less abundant (21).

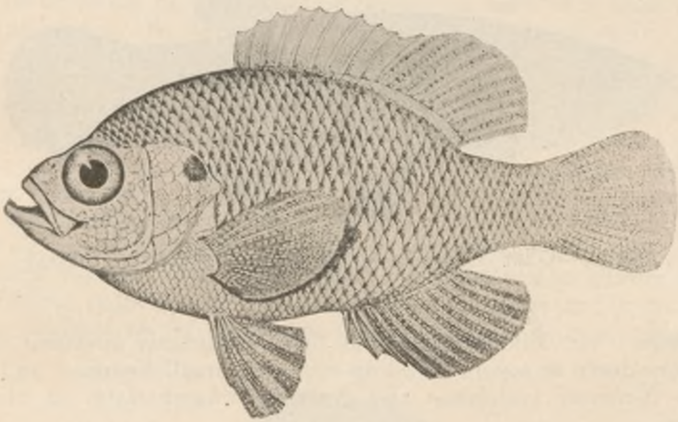

Fig. 9. — *Apomotis symmetricus* Forbes

It is said that at present the fresh-water fish of the state have been exploited only superficially. However, of the Cyprinidae family Beyer mentions the *Notropis chamberlaini* Evermann, which has so far only been recorded in the Atchafalaya River at Melville, Louisiana; the *Notropis roseus* Jordan, in the Natalbany River near Tickfaw, Louisiana, and the *Notropis louisianae* Evermann, in the Atchafalaya River. And of the Poecilidae family he gives the *Fundulus ocellaris* Jordan and Gilbert, which is common in the vicinity of New Orleans, but occurs elsewhere under the name of top-minnow; the *Fundulus chrysotus* Holbrook, a beautiful species sometimes called "shiner," common in Orleans and other parishes; *Fundulus notatus* Rafinesque, called "top-minnow," distributed throughout the state, and common in some places; *Gambusia affinis* Baird and Girard, the true "top-minnow," which is the plainest of all the minnows (the males of the Gambusia are remarkable on account of their curiously modified anal fin); and the *Mollienesia latipinna*, which is abundant in the waters in and about New Orleans, becoming scarcer northward. The *Mollienesia latipinna* is hard to distinguish from the Gambusia. Its feeding habits are different. It has no value as a mosquito eradicator and must not be confused with Gambusia (21). Professor Beyer's observations do not at all points agree with those

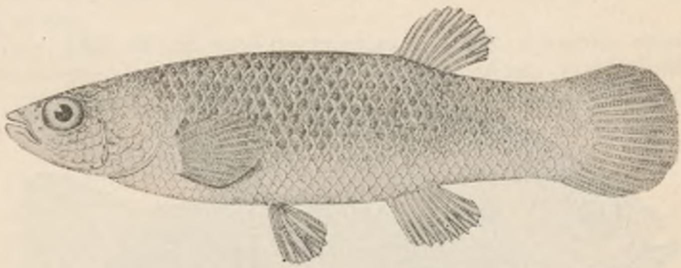

Fig. 10. — *Fundulus chrysotus* Holbrook. "Shiner" (2 inches)

of others. Mr. Hildebrand found that *Mollienesia latipinna* would not keep down mosquito breeding even in a small fountain, and considers *Notropis louisianae* and *Notropis chamberlaini* as obscure species.

Mississippi. The experiment in Hinds County was conducted by Dr. H. H. Howard. It began in June, 1918, and was continued throughout the summer of 1919. The territory covered was an agricultural area in the hills, considered representative of the rural sections of that portion of Mississippi. The usual conditions of climate, soil, rainfall, and drainage existed, and the rate of mosquito production was neither higher nor lower than elsewhere in the neighborhood. During 1918 no control measures were inaugurated, the entire time being devoted to observations and to a study of the habits of top-minnows. The district under observation was about thirty-six square miles in extent, contained 172 homes, and had a population of 830 people. There were, altogether, 228 possible or actual breeding-places in the area. The rate of malaria sickness for 1918, as determined by blood examinations and clinical evidence, was 21.4 per hundred.

The breeding-places included ponds, creeks, springs, pools, potholes, lakes, seepage areas, pits, vats, wells, and cisterns, and the kinds of mosquitoes present were Culex, *A. punctipennis, A. quadrimaculatus,* and a few *A. crucians.* The fish present were *Gambusia* *affinis* and *Fundulus notatus*, as well as sunfish and black bass of the Centrarchidae family. Gambusia predominated. It was noted that in streams and other bodies of water containing top-minnows, the rate of mosquito production was not nearly so high as it was in those without them.

The actual work of stocking breeding-places with fish, and of draining ditches and streams so that the fish could act efficiently, was begun in 1919. The results are set forth in a special report by Dr. Howard in which he records observations on each of a number of breeding-places. By September 30, 1919, 88.7 per cent of the mosquito breeding-places under investigation were being controlled by the top-minnow alone. Care was needed in keeping down vegetation but it was found that this work could be taken care of by two workmen, or, in other words, by one man for each eighteen square miles of territory. It is realized, of course, that the experiment had not been extensive enough in time or area to justify definite conclusions, but it was thought, nevertheless, that the results warranted an optimistic view of the future possibilities of fish control (114).

Control measures were continued in the same area during 1920 with further reduction in the rate of clinical malaria and more conclusive evidence to the effect that the top-minnow is a valuable ally

Fig. 11. — *Mollienesia latipinna* (3 inches)

in mosquito control. During this campaign the practical application of fish in the control of mosquito production by the rural householder was thoroughly demonstrated.

During 1919 several mosquito surveys were made in the town of Canton, Mississippi, and a proposition was made to the town authorities to control malaria within the town limits by antimosquito measures. All water deposits in the town of Canton, such as ponds, creeks, borrow pits, large pools, and large ditches, containing water constantly, were thoroughly cleared of débris and vegetation and stocked with top-minnows, with the result that the top-minnows destroyed the mosquito eggs and larvae and prevented mosquito production in these places throughout the season. A saving of 35 to 40 per cent in the cost of mosquito control was made possible by the use of the top-minnow as an agent of control (111).

New Jersey. A number of years ago the state of New Jersey took up the task of eliminating mosquitoes from its vast areas of tide-lands and salt marshes. First consideration was necessarily given to drainage, but many miles of the land were subject to tidal inundation from

Fig. 12. — *Laucania parva.* Rainwater fish (1.5 to 2 inches)

which it was impossible to drain the water completely, although it has been pointed out that tidal inundation itself may keep down breeding. As an auxiliary measure fish were tried, and at the end of three years were considered successful.

The first trial was with imported Gambusia. The year that minnows were sent to Hawaii (1905), Mr. W. P. Seal was asked by the New Jersey Agricultural Experiment Station to import Gambusia and *Heterandria formosa* for antimosquito measures in New Jersey. The work was carefully planned, and in November of that year 10,000 fish shipped from North Carolina to New Jersey were distributed in various localities. The movements of the fish were watched. By March of the following year some were seen as far as a half-mile above the ponds in which they had been placed, but most of them had disappeared, due perhaps either to their enemies, the black bass, pike, yellow perch, and sunfish which were abundant in these waters or to the northern winter. Early indications suggested that the experiment was doomed to failure.

But in 1907 some *Gambusia affinis* were found in New Jersey in a creek far from the place where they were originally implanted. Mr. Seal thought they had been bred from the fish he introduced, but Mr. Fowler, state ichthyologist, doubted this conclusion, inasmuch as the scene of implantation was ninety miles away, with sunfish and other natural enemies of the Gambusia abundant in the intervening waters. Moreover, other small fish native to New Jersey, such as *Laucania parva* and *Fundulus heteroclitus* were found with the Gambusia. In the case of the Gambusia the males were as numerous as the females — an unusual occurrence (174; 183).

For combating salt-marsh mosquitoes, Mr. John B. Smith, for a number of years in charge of the New Jersey work, was convinced of the necessity of using killifish, as it was found that such mosquitoes could not breed wherever these fish maintained themselves from tide to tide; such breeding-places as existed were on the edges of the upland where only the highest tides occasionally reached and where, under the circumstances, there could be no fish (184).

This suggestion was actively taken up by Chidester, whose experiments, begun in September, 1914, were continued for a little over a year. His work, chiefly a study of the use of fish against salt-water mosquitoes in marshes, consisted of making collections of native fish, with records of tides, the saltiness and temperature of the water, the resistance to salt concentration, and observations on the stomach-contents and rate of growth of young fish. It was found that the *Fundulus heteroclitus*, or barred killifish, was a voracious enemy of larvae, pupae, and adult mosquitoes. On account of its numbers and its migratory habits it was an important natural factor in the extermination of the salt-marsh mosquito.

A marsh near Bonhamton, New Jersey, was selected as the chief station for testing the value of *Fundulus heteroclitus*. Collections were made here at intervals, and work was intensified in three prominent pools. Some work was also done at the Marine Biological Station, Woods Hole, Massachusetts. For studying undrained marshland, sites near Beech Haverton, Tuckerton, and Atlantic City were chosen. Laboratory experiments showed that for four days the average daily consumption per fish was slightly over twenty-seven larvae. No preference was shown for the larvae of any particular mosquito. The fish fed by seizing anything that appealed to the eye and ejecting what was not to the taste. They succumbed to cold weather. Specimens in water at a temperature of 43° or 44° F., found trying feebly to burrow into the mud, revived when brought to the laboratory. The fish eggs, which are protected by sinking into the mud, are very hardy and can develop in spite of almost unbelievable maltreatment. The killifish are their own worst enemy, as the adults consume large numbers of the eggs. Of other fish, the striped bass, weakfish, bluefish, and dogfish are enemies of the killifish. Sea birds and domestic ducks also devour them, and, as the killifish are easily caught, fishermen frequently use them for bait.

The results of the experiment led to the conclusion that the vast number of these fish which migrate to shallow, almost even to fresh water, the ease with which they may be artificially fertilized, and the remarkable vigor and resistance of young embryos, rendered the species extremely suitable for stocking pools and streams in which salt-water mosquitoes were found (45).

Other species that are quite common and almost as useful are two other killifish—*Fundulus majalis* and *Fundulus diaphanus*—and the *Cyprinodon variegatus*, or sheepshead minnow. The New Jersey Agricultural Experiment Station has made a special study of these fish in both the field and laboratory (45; 60). A related species, *Poecilia vivipara*, has recently been found by Mr. H. W. Green, in his antimalaria work in Porto Rico, to be an especially good larva-eater.

Tennessee. Mr. W. G. Stromquist, of the United States Public Health Service, who spoke at the Second Annual Anti-Malaria Con-

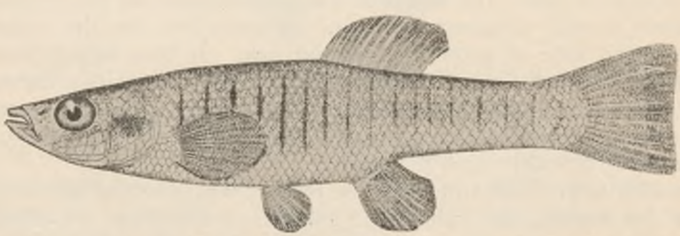

Fig. 13.—*Fundulus diaphanus*. Translucent killifish. Female (4 to 5 inches)

ference, 1920, stated that in a town of about 6,500 population in Tennessee, there was appropriated $5,000 for the season's work, out of which $2,700 was saved. The difference between the actual cost and the estimated cost was entirely due to the presence of Gambusia. Mr. Stromquist differs with the statement made by Dr. T. H. D. Griffitts to the effect that Gambusia was not suitable for lands that are overflowed. The former's problem was river bottoms which were overflowed during the winter. When the water went down, it left a number of sloughs and ponds which were well stocked with Gambusia, and not a foot of ditching had to be done there.

Mr. Stromquist also reported that in a little village located about twenty miles from Memphis there was an artesian well overflowing into a stock pond which in turn overflowed into a pasture. About two or three acres of this pasture were covered with water to the depth of six inches, with such a dense growth of grass that the water

Fig. 14. — *Fundulus diaphanus.* Translucent killifish. Male (4 to 5 inches)

could not be seen. In a great number of dips, he found only three or four Anopheles larvae, but in several dips caught Gambusia, sometimes as many as three in a dip. It is his opinion that the Gambusia provided effective mosquito control at this place (152).

Texas. Gambusia affinis is found in Texas and usually inhabits swamps, ponds, lakes, ditches, and sluggish streams, in either fresh or brackish waters, shallow and stagnant areas, preferably of high temperature. E. G. Eggert, sanitary engineer of the State Board of Health of Texas, states that owing to its extreme prolificity, easy propagation, exceptional devouring capacity, etc., the *Gambusia affinis* becomes the most valuable natural agent known for antimalaria measures in Texas. Gambusia may be employed in such waters as stock ponds, watering troughs, surface reservoirs, and the like, where oiling and draining are impracticable (64).

In one of the counties of eastern Texas, through the efforts of Mr. George Parker, the co-operation of the schools was obtained. Each school district maintained a hatchery supervised by the school children. There were seventy-one school districts in the area involved, which would mean that eventually there will be seventy-one Gambusia hatcheries for this area of about 1,000 square miles and about 37,000 people. The purpose is principally educational, but a marked reduction in malaria fever is looked for as the Gambusia multiply and are distributed. The cost is very low, as it involves merely shipping the fish from the main hatcheries in the larger towns.

The town of Athens, Texas, having a population of 3,704, was selected to demonstrate malaria control through the exclusive use of Gambusia. A total of 14,720 Gambusia were placed in nineteen ponds as a result of which the mosquito nuisance was greatly reduced. In Jacksonville, Texas, a town where a complete program of anti-malaria measures was resorted to, Gambusia were used entirely to control Anopheles breeding in ponds, with the same result as prevailed in Athens. In one lake the star-headed minnow *(Fundulus notatus)* was present in a quantity considered sufficient to control Anopheles breeding. The edges of the lake were cleared of vegetation and the action of the Fundulus observed over a period of six

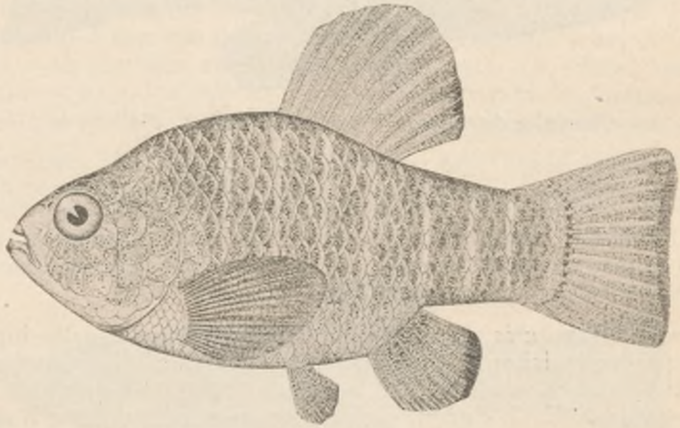

Fig. 15. — *Cyprinodon variegatus.* Sheepshead minnow (3 inches)

weeks. Anopheles breeding continued and increased rather than diminished, though the breeding was not prolific. The lake was then stocked with Gambusia, and in a very short time Anopheles breeding was under control (152).

Virginia. In an article on "malaria control activities, June 15, 1921, to September 30, 1921," Dr. C. E. Harper, formerly director of malaria control for Virginia, states: "With the co-operation of the Richmond City Health Department all fountains, reservoirs, and lakes in the city were stocked with *Gambusia affinis*. The experiment was so successful that a hatchery is being established to furnish minnows to any community in the state that wants them." According to Griffitts most of malarious Virginia is the natural home of Gambusia.

Mexico and Central America

The City of Merida, in Yucatan, Mexico, has long been regarded by sanitarians as an important seed-bed of yellow fever from which the infection has been distributed repeatedly throughout Mexico and the Central American countries. Throughout modern times it has reappeared here and spread, with the result that within the last few years the disease has occurred in sporadic form throughout eastern Mexico, and on the Mexican Pacific coast from Mazatlán to Guatemala.

Attempts to control yellow fever in Mexico before 1920 probably did not include the use of fish. The successful use of Gambusia in other regions led to their being used also for the eradication of yellow fever in Tampico, where there had been several threatened outbreaks of the disease, as for example, in the summer of 1920. The control operations inaugurated here and in Túxpan by the Comisión Especial Contra la Fiebre Amarilla y el Paludismo, an organization formed by the Oil Managers' Association with headquarters at Tampico, in October, 1920, involved the prevention of Stegomyia breeding in barrels, tanks, and other receptacles used for catching and storing rainwater for domestic purposes, in which crude oil could not be used (199).

Mr. J. A. LePrince, in conjunction with the Petroleum Manufacturers' Association, developed a plan for reducing the Stegomyia in sixteen oil-loading terminals on the Pánuco river, near Tampico, and in the oil camps adjacent to the city. This plan consisted of an intensive fish campaign in which every type of water-container was stocked with suitable fish. After experimenting with six or more different varieties, all bottom-feeders were discarded, and a top-feeder about one and one half inches long — a member of the Gambusia family, though not the *Gambusia affinis* — was selected as likely to yield the best results. This species is found in great abundance along the Gulf Coast, in pools of both fresh and brackish water, as well as in inland streams and in flats occasionally covered at high tide.

About December 1, 1920, considerable economy was effected when fish entirely replaced crude oil as a control measure; the inhabitants, moreover, were pleased with the change.

In January, 1921, the International Health Board accepted an invitation extended by the Government of Mexico to co-operate with the National Health Department in a campaign against yellow fever. For this purpose a Special Commission was appointed and Dr. Theodore C. Lyster, of the International Health Board, was appointed Director. For the purposes of organizing the yellow fever work, Mexico has been divided into seven zones. The first has its headquarters in Tampico and includes the state of Tamaulipas and the northern half of the state of Vera Cruz. The second zone comprises the rest of the state of Vera Cruz with its center in the city of Vera Cruz. The other zones of the country were under the direct control of the Mexican health authorities. Each zone was under the charge of a chief. Dr. Joseph H. White succeeded Dr. Lyster as director, working under the Department of Public Health of Mexico. A program was developed having as a basis the reduction of the Stegomyia mosquito by mosquito-proofing all fresh-water containers in or near human habitations in yellow fever centers. The Commission was to practice antilarvae measures only (45).

Fig. 16. — Equipment for transporting fish to be placed in water-containers during yellow fever campaign in Túxpan, Mexico

The Special Commission's field of intensive operations is on the east coast. It took over the first district, where the Oil Managers' Association had previously made efforts toward control, in July, 1921. On January 1, 1922, the Túxpan district came under the direction of Dr. M. E. Connor as part of the first zone, with headquarters at Tampico.

A special difficulty is encountered in Mexico because of the use of lye. The water being very hard, the natives soften it by placing wood ashes in the containers, but though Stegomyia larvae continue to thrive, fish cannot live in lye-water (called *lejía*). Emptying or oiling these tins is an inconvenience to the natives. The use of sheet copper in the *lejía* appears to produce a chemical reaction repellent to the adult mosquito (46). Carter states that soap—a solution of soft soap in alcohol—proved 100 per cent efficacious in Peru (Piura and Paita) and Connor reported the same for Mexico. Soap-powder serves as well as the solution. Laundresses do not object to the soap as they do to placing kerosene in the *lejía* and they forget too often to replace the copper.

In tanks and wells mosquito breeding has been controlled with great success by the use of fish. After a visit to about five hundred homes in the city of Tampico, Dr. Connor estimated that the result obtained was 80 per cent perfect. Dr. Caldwell, of the International Health Board, also comments enthusiastically on the satisfactory results of the use of fish (36; 47). Of the fish used during this period, the best results were obtained with the *Dormitator maculatus*, which is a bottom-feeding fish that reaches a length of three inches. They are most frequently kept as pets, so that with the care they receive, they sometimes remain in the same barrel for six months or a year. Next in importance is the *Gambusia nicaraguensis*, and it is believed that this is the only fish that should be used in the vicinity of Tampico (145). Wherever fish could not be used, as in the case of tanks and other receptacles, recourse was had to covering the surface of containers with oil, or in the case of lye-water, to sheet-copper or soap as stated above.

Replacements have been cared for by maintaining a supply of fish in specially prepared barrels in the *bodegas*, and from this supply the inspectors have each day taken a number sufficient to meet their estimated needs for that day. Work was continued in Tampico until the end of June, when the staff was turned over to the local sanitary delegate for use in malaria control until the recurrence of yellow fever cases made necessary further anti-Stegomyia measures. Most of the containers were large tanks for which covering and sealing was the method required. In other types of containers fish were used and house-to-house inspections were made. Dr. Connor states that galvanized tanks are best for keeping a supply of fish for replacement purposes, and that straining water through cheese-cloth to remove the larvae is the best way of mosquito-proofing jars too small to support fish. Underground cisterns *(aljibes)* and wells have remained stocked even during intensely cold weather when the mortality in barrels and other water-containers was great. In Tampico bottom-feeders were used for wells and underground cisterns and top-feeders for surface containers.

Following the work of Connor in Guayaquil, and of LePrince and others in Tampico, a campaign along similar lines was adopted for Vera Cruz, Dr. Caldwell, the director in charge, first familiarizing himself with the work of LePrince in Tampico. In Vera Cruz a fish related to the Gambusia family, although not a true Gambusia, was found, and a practical study of it was made to determine its value as a mosquito-destroyer. It was thought that upwards of 75 per cent of the breeding in Vera Cruz could be prevented by fish and that the remaining 25 per cent would have to be handled by oiling and other methods. This work has been carried on by a system involving weekly inspection of water-containers and the proper distribution and care of fish. Fish are used in barrels, tanks, and in other large containers kept for water storage, and the small containers are emptied and reduced in number as far as possible. Vigorous effort is made to keep the inspection work from becoming perfunctory.

Late reports indicate that fish have turned out to be a potent factor in the elimination of Stegomyia. Co-operation was readily obtained, especially from the poorer people. The number of containers stocked to date has been 3,129, and the average number of fish used a month is 12,000. About 100 containers have been taken care of daily, in which the average number of fish used has been 496 — about 5 fish to each container (36).

Fully one half of the containers in Vera Cruz were of a kind that held but little water and could be easily emptied. For these, frequent inspection with emptying and cleaning proved to be the most satisfactory method of control. Containers of the large class, including barrels, pozos, and tanks, were covered where practicable. Where this could not be done, the introduction of fish gave highly satisfactory results. For the few containers and other breeding-places that could not be covered and in which fish could not be used, it was necessary to resort to oiling.

In 1921 a campaign against malaria was conducted in San Francisco de Las Peñas, a town of about 4,000 inhabitants, about forty miles north of Vera Cruz. The fish used is known locally as "pullequi," and is probably a species of the Epinepheles family. The two high dorsal fins seem to point to a relation to the basses. It is found in stagnant lagoons close to the shore, but readily becomes acclimatized to fresh water. It is hardy and the death-rate in captivity is very low. However, it is not so active or voracious as the Gambusia, which was not to be found in serviceable quantity in or near Las Peñas. But the pullequi is efficacious, although it takes a few more days to clear a deposit. The main objection to its use is the fact that it grows to a length of eight inches. In the campaign in Campeche, Dr. Perera used no other measure than fish. A small top-feeder known locally as "negrito" gave excellent results, not only in barrels and tanks, but also in cisterns. A special tank was provided for breeding them in plentiful numbers. In wells and other water depositories in Carmen, Campeche, Dr. Campos used small turtles in addition to fish (51).

The preliminary survey made by Dr. Connor strongly indicated that Merida was the seed-bed of yellow fever infection for all Yucatan. When cases did develop in the nearby *haciendas* the source of infection could generally be clearly traced to the city of Merida. In view of these findings a program was developed to reduce the *Aëdes aegypti* population in Merida by antilarvae measures to the critical number or "safety index," the rest of the state being deliberately neglected (48; 50).

The campaign in Merida (fourth zone) was started on February 10, 1921, and the "mojarra," a perch, was found to be the fish *par excellence* for destroying the mosquito larvae in fresh-water containers of all kinds with the exception of galvanized iron tanks and lye tins. It is a hardy bottom-feeding fish and a voracious consumer of mosquito larvae. It thrives as well in a relatively small container as in a large one. In Merida, the top-feeding fish have been discarded in favor of the mojarra. Top-feeders require frequent replacement and do not react promptly, in some instances not at all, from the fatigue sustained in transportation in the inspectors' pails.

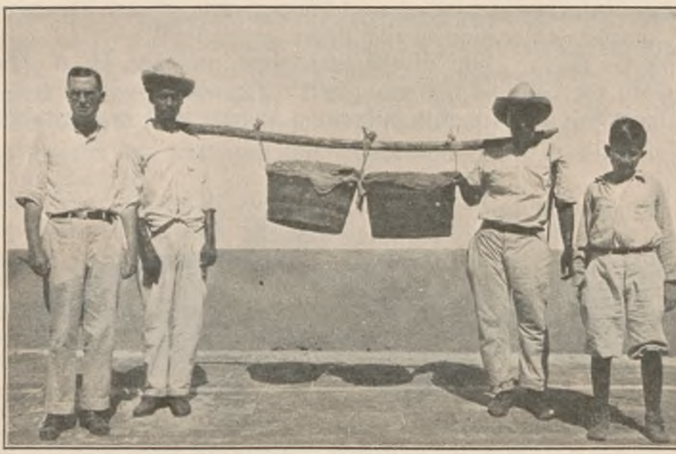

Fig. 17. — Transporting fish for operations against yellow fever in Mexico

With the mojarras, replacements are relatively few, being heaviest at the time the cisterns are being cleaned to receive the new rains. Once this process is over the replacements for the entire city can be easily attended to by one man. Again, top-feeders are sensitive to temperature changes such as occur in Merida during the northern season. The mortality is high when the temperature reaches 69° F., but this sensitiveness is not noticeable in the case of the mojarra.

Barrels, fountains, wells, and *pilas* have been treated with fish in Merida, and the results are very satisfactory. The top-feeder thrives in this class of containers and reproduces rapidly, thereby creating convenient sources of supply of this species of fish. It frequently happens that a well becomes polluted, the fish die, and the well then becomes a Culex breeding-place and must be treated by oiling.

To free the cisterns of mosquito larvae a small top-minnow similar to the Gambusia was tried, but it was not successful. In nearly every instance it died after from three to four days, and during its stay in the *aljibe* the larvae were not materially reduced in numbers. This is accounted for on the grounds that the top-feeder requires a certain amount of sunlight to work to best advantage, and sunlight is practically excluded from the cistern.

The Stegomyia index in Merida at the beginning of the campaign, February 10, 1921, was nearly 50 per cent; by October 28, it had been reduced to 8.5 per cent. Since that time the entire campaign has been under the immediate supervision of Dr. Gil Rojas, who has succeeded in further lowering the index to 1.75 per cent, a rate representing almost complete extinction of the *Aëdes aegypti* (47).

Dr. E. C. Houle, chief of the fifth zone, and Dr. H. A. Harris, assistant to the chief of the zone, in 1922 investigated the possibilities of local fish and for this purpose a special tank was established

Fig. 18. — *Dormitator latifrons.* "Chalaco" (12 inches)

at the railroad emergency hospital in Mazatlan. Observations made in this tank have shown that this area has an ample supply of larvicidal fish, among them being the "chalaco" *(Dormitator latifrons)*. This species was used by Connor at Guayaquil, and is a widely distributed bottom-feeder. A voracious consumer of larvae and eggs and able to withstand change and handling, it was found the most satisfactory for use in small containers. It occurs in all of the rivers and most of the arroyos from the Mocorito to the Santiago River and was used most successfully and economically in Culiacan and Mazatlan.

The "lisa" *(Lebiasina bimaculata)* is fairly well distributed. It is more delicate than the chalaco but hardier than the mojarra or the Robalo. It has been used in cisterns, deep wells, and narrow-necked containers. It has been located in Presidio and Rosario Rivers.

The *Robalo plateado* is a fairly well-distributed top- and bottom-feeder and a voracious consumer of larvae. It was used in Vera Cruz with good results. It has the advantage of being viviparous. One disadvantage is that when frightened it will jump from containers. It can be used in cisterns, wells, and narrow-necked containers but it attains its full growth only in salt water. The Robalo was first used in Culiacan in September, 1922, but all the fish died by the end of the third day. Experience at Mazatlan demonstrates that this fish is very delicate and does not easily accustom itself to new surroundings. It has been identified in the following rivers: Mocorito, Humaya, Presidio, Rosario, Acaponeta, and Santiago (110).

When work was started in Colima in October, 1921, an initial step was the construction of a large storing and breeding tank with a capacity of about 8,000 fish. This tank was built in the home of the special inspector, Mr. Parkes, with the thought that fish breeding, being cheaper and more reliable, would replace altogether fish collecting from the river.

In Colima, Gambusia were used. They are viviparous, the young being born about half an inch long. From birth they are very voracious, a fish two days old consuming larvae until sometimes they have been seen to die literally from overeating. They are mostly surface-feeders, like *Gambusia affinis*, but they differ from the *affinis* in not having the anal fins elongated in the male, and as they are marked with vertical stripes on the sides, one observer has provisionally called this species *Gambusia striata*.

To the end of 1921 the net result of the campaign in Mexico, in which fish had everywhere been the principal and in some places the sole means of control, was that the base ports of the country — Tampico, Túxpan, Vera Cruz, Campeche, and Merida — had, with the exception of one or two cases in Túxpan, remained free of yellow fever for months.

British Honduras. Yellow fever appeared in Belize in August, 1921, among Indian servants in a college near the city. After a preliminary survey of the town gave a 100 per cent mosquito index, ten inspectors and ten laborers were hired to oil or empty containers.

Mr. J. H. Peach in 1923 reported that he had carried out a number of experiments with the different kinds of small fish of British Honduras which were said to be larvivorous, namely, the "billham" (*Tetragonopterus aeneus* Günther), "crana" (*Cichlasoma octofasciatum* Regan), and "poopsey" (*Mollienesia sphenops* Cuv. & Val.) These belong respectively to the families Characidae, Cichlidae, and Cyprinodontidae.

Laboratory experiments carried out with all these fish showed that they are all larva-eaters. They are all fresh-water fish, but not being satisfied as to their ability to live in rainwater in tanks, the Yellow Fever Executive Commission decided to obtain three vats holding 700 gallons each and place fish in them. No sign of larvae or even rafts of eggs could be seen in these vats during the first six months, although they were examined frequently. On account of these experiments, the vats of the different Government institutions were all stocked with fish, and about 200 of the private owners also had fish put into their vats by the Government.

The poopseys are very similar to the millions of Barbados, but are not so hardy and cannot stand much handling. The billham is an extremely voracious fish. It is not necessary to have more than one or two billhams or cranas to a vat of any size and a similar number

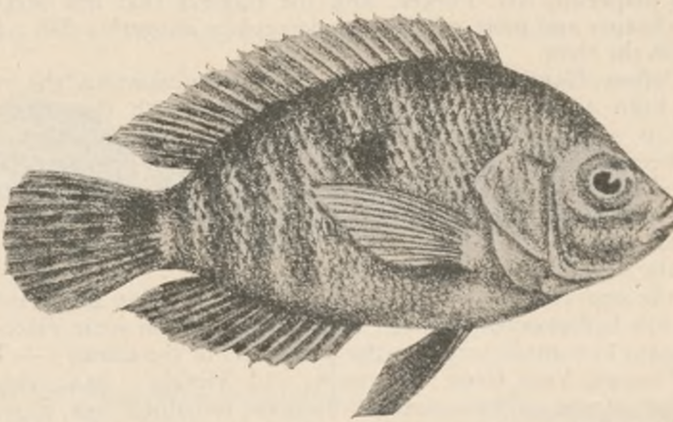

Fig. 19. — *Cichlasoma octofasciatum* Regan. "Crana" (2 inches)

of poopseys to a well. These fish are bought in large numbers at one cent each and are placed in the vats by the Department when requested by the owners.

In dealing with pools, etc., instead of using oil, Peach transferred a few small poopseys from a nearby pond or pool, and until that pond dried up, all his troubles as regards mosquito larvae were over (153).

Guatemala. Distribution of fish as a yellow fever control measure, accompanied by systematic inspection and careful record of containers in which fish have been deposited, was inaugurated in

Guatemala early in 1920 by General Lyster, and has since been continued under Drs. Vaughn and Elmendorf, two varieties of fish, a small perch and a top-feeding minnow, being used most extensively. Varieties known locally as the "zambuco," "mojarra," "pupo," "pepesca," and "sirica," were also used at Retalhuleu, and some use has been made of goldfish, which stand transportation well and have a low rate of mortality but are too scarce and expensive for work on a large scale. Although the rate of mortality of the fish as a whole was high, mainly because the people would not properly care for them when cleaning the containers, it is significant that use of any kind of fish greatly diminished the number of larvae while the fish remained alive (205). In this country some interesting problems were worked out successfully in connection with the transporting of fish from Escuintla to Retalhuleu.

For the Atlantic zone a fish supply was assured through the use of a species of minnow called the "quixque," identical with the type used at Vera Cruz. In some places municipal authority imposed high fines for having larvae on the premises. The problem in Guatemala is much the same as in Guayaquil, being chiefly a question of keeping various water-containers stocked with fish. However, the fact that a large number of the containers were exposed to the sun during the greater part of the day, so that the water got too hot for the fish, complicated the use of fish in this country, especially in the city of Livingston.

The work in Guatemala was performed by means of inspectors divided into two groups, one for inspection of water-containers and breeding-places, and the other for obtaining and distributing fish. The cost was low (204).

In 1921 fish distribution was continued at least once a month in all places with sufficient containers to warrant this work. A definite check was kept on the kinds of fish found satisfactory for the different kinds of containers. Some of the fish used were known by their native names as quixque, zambuco, and pupo.

Records show that the quixques require the lowest percentage of replacements. Replacements were naturally least necessary in wells and *pilas*. Fish do not live so well in tanks and barrels, especially those exposed to the sun and to the exigencies of dipping. Transportation was avoided as much as possible, the fish being transferred from their natural breeding-places to large municipal containers in order to accustom them to different temperatures and then placed in their permanent receptacles. Carrying them in small pails was thus avoided. Transportation in wooden pails as large as could be managed, either in early morning or late afternoon, gave the best results.

Widespread areas are controlled with difficulty by fish alone. Out of 31,000 receptacles in the complete zone, 25,000 were small ones in which fish could not be used, and only 3,250 were of the sort (wells, tanks, and *pilas*) in which fish could be used to advantage. In 1922 the work was continued along the same lines. An inspector was assigned to each district. This system gave excellent results. The larvae continued to be reduced in spite of the high mortality of fish in the limited number of containers where these could be used (165; 166).

Nicaragua. The indigenous tribes of Central American Indians have used fish to a certain extent in water-containers for generations. More than seven years ago, Dr. Molloy found small top-feeding minnows, called locally "ñundos," in water jars, *pilas*, tanks, barrels, tubs, and wells in the Indian village of Subtiaba, adjoining the city of León, Nicaragua, and on questioning the people as to the reason for placing them in these receptacles they almost invariably stated that they had been placed there to "keep the water clean." On getting at the root of the matter they stated that they ate the "clavos" or "gurasapos" (two local names for mosquito larvae and pupae). While they had no idea that mosquitoes hatched out from these gurasapos, their observations were correct as far as they went (144).

Fish were first used in Nicaragua for mosquito control by Molloy in 1915, when wells, pools, and ponds were stocked with them. At that time it was thought that minnows would not live long in water jars, rainwater barrels, tanks, and other artificial water-containers used in and around the houses, with the result that these were not stocked. Intermittent inspections of Corinto, the principal port of the country, were made between that date and early August of 1919, when a severe outbreak of yellow fever caused the authorities to check up again the sanitary conditions of the port. At this time 60 of the 160 wells which had previously been stocked with fish were found well stocked, and also a large number of the water barrels and large earthenware jars, which had not been stocked in 1915. On questioning the people as to how this had happened they stated that they had noted that all gurasapos had disappeared from the wells after stocking them with fish and they saw no reason why they would not do the work in water barrels and jars. This was the first time that an extensive use had been made artificially of fish as agents in mosquito control in Central America.

Late in July, 1919, a yellow fever epidemic reached Nicaragua from Yucatan. Shortly afterward mosquito control by means of fish was put into practice, a Gambusia-like top-feeding minnow being used. These fish were found to be great jumpers, practically all of them leaving the containers in which they were placed within a few hours after stocking. Credit is due to a native sanitary inspector of the fish squad for correcting this defect. He suggested that the fish should be gradually accustomed to their new environment and "tamed" before using them for stocking purposes. On putting this suggestion into practice the fish soon lost their jumping proclivities and they could then be distributed with the assurance that, with reasonable care, they would remain indefinitely in the container in which they were placed and that they would do the work (144).

The minnow used is called locally "olomina," and it is not a Gambusia, but belongs to the same sub-family. Mr. Dorn, president of the Aquarium Society of New York, classified the minnow, and stated that all of the specimens sent to him (taken from the pools along the shore of Lake Managua and from Rio Chiquito, near León, where they exist in teeming millions near some tanneries which are

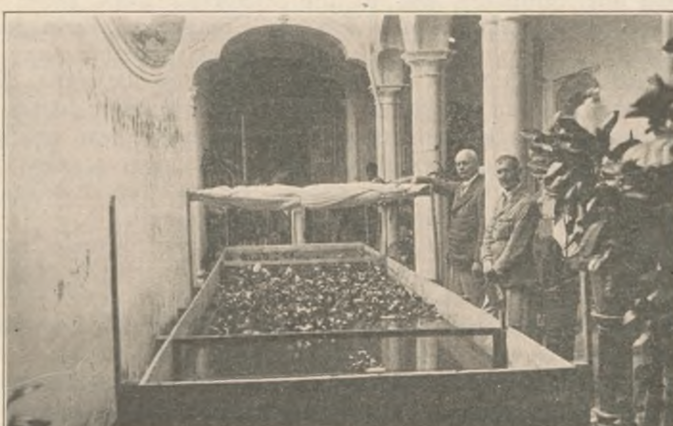

Fig. 20. — Tank at Colima, Mexico, from which were distributed the small fish placed in water-containers at the homes

located on the stream) were *Poecilia sphenops*, and that "these fish are found all through Central America and vary slightly according to location."

Molloy has found them all over Nicaragua. They are hardy, and stand transportation well, particularly after they have been "tamed." With ordinary care at least 75 per cent of the fish reached their destination but it was necessary to allow them to rest for two or three days before distributing them. They are also enormously prolific — much more so than Gambusia. For this reason, it was never found necessary to establish hatcheries.

In Nicaragua a variety of perch was also used. This is similar to the huaija which Connor used in Guayaquil, and was found to give satisfactory results. This perch, called locally the mojarra, is hardier than the olomina, but is much more difficult to secure in sufficient numbers. In fact, it was found that practically any kind of fish, whether top-feeder or bottom-feeder, will eat mosquito larvae if the food supply is limited. The ordinary perch was also found to be efficient in wells and tanks, and in one instance a small catfish kept a shallow well in Corinto free from mosquito larvae for more than three years. The "life" used in Peru is a species of catfish (Eigenmann). The top-feeding minnow, however, has been found to be the most satisfactory and is certainly the most voracious, as well as the hardiest of all the fish which have been used in Nicaragua.

During the campaign and in the follow-up work more than 50,000 containers in the towns of Corinto, Chinandega, León, Managua, Masaya, and Granada, were stocked, using altogether more than 300,000 fish. Yellow fever, which was already on the wane, disappeared promptly as an immediate result of this wholesale distribution of fish, and the partial reduction of the mosquito pest which accompanied the eradication of Aëdes was still evident a year and a half after any fish had been distributed. In the town of Masaya a decided reduction in the malaria rate occurred as well.

An interesting example of the efficacy of fish control under natural conditions is afforded by the lake shore in front of the city of Managua. Molloy is firmly convinced that Managua would rapidly become uninhabitable should these inveterate enemies of mosquitoes disappear from the lake.

Another larvicidal fish, larger and not viviparous, but oviparous, is also found in Nicaragua. This fish resembles the "silversides" of the Southern United States, and bears the name *Tetragonopterus aeneus*. It is not so abundant, nor is it so adaptable to artificial water-containers, although it gives good results in wells.

In malaria control studies which were made in the department of Rivas, fish were relied on exclusively to control Anopheles breeding in natural streams and in ditches which were dug for drainage purposes. By cleaning, brushing, and straightening the banks of streams, in many places a very inexpensive process, fish are enabled to get at every possible breeding-place of mosquitoes and may be relied on to control breeding absolutely. During the dry season all drainage ditches are dry; but when the rains begin and a current is established, fish may be depended on to go to the headwaters in a few hours and penetrate to the extremities of all laterals that empty into the ditch. With a reasonable amount of care in keeping drainage ditches and laterals open, thus allowing fish to migrate upward into the ditches, it is possible to secure a degree of control which is surprising. In fact, no oil or other larvicide has been used in any of the ditches or streams of the area, drainage being relied upon as the chief control measure.

In conclusion Molloy urges that fish be given a trial when conditions offer a semblance of a chance of success. With a little intelligent help they will succeed more frequently than they will fail. It will at least cost little to give them a trial (144).

Panama. In Panama, General Gorgas noted that mosquitoes did not breed wherever small fish could easily gain access. If the water was accessible and clear of grass, the native fish destroyed all larvae (94).

In the Canal Zone, plant life is so exuberant and mosquitoes so abundant that fish normally are not so effective as in more northerly countries. The Gambusia and other minnows abound in brooks and ditches and it is possible that they destroy a great many mosquitoes and that if they were not present, adult mosquitoes might become intolerable and render many places uninhabitable (119; 131). When the larvae are distributed and forced out of the vegetation into the open, the fish snap them up. In the Isthmus, however, swifter methods than fish control were available and were put into effect. Mr. J. A. LePrince states that at Panama as elsewhere in the tropics fish are useful as an auxiliary measure but oftentimes are insufficient alone (131).

Salvador. Dr. Bailey in Salvador also used fish on a large scale in his yellow fever campaign, distributing them to the water-containers in San Salvador city and elsewhere. Here also *Poecilia sphenops* proved a most satisfactory fish. A reduction of from 4.5 to 1.8 per cent of larva-breeding containers was noted in Sonsonate after fish distribution there. During the rainy season (April to October) the container-breeding index was reduced to 0.09 and the house index to 0.6 by the use of fish. Previous to adopting this method, the most careful inspection had not succeeded in bringing the house index below 4.2, from an initial figure of approximately 50 per cent. With the fish patrol at work, it was possible to cut the corps of sanitary inspectors for the city in half, inspect only once in three weeks and still maintain the low index — this during a season which had been marked in 1920 by a yellow fever epidemic in Sonsonate. An interesting test was made in this city after absolute safety was reached, one year after the last case of fever. Fish distribution was discontinued for a time during the rainy season (in August) and the index thereupon rose steadily from 0.4 per cent for containers to 5.3 per cent, and from 1.2 per cent for house breeding to 9 per cent,

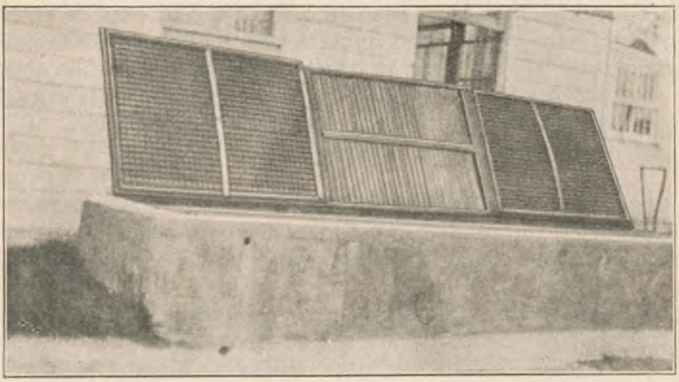

Fig. 21. — Tank in Salvador for storing fish before distribution

the results thus demonstrating conclusively the part fish had played in controlling Stegomyia breeding.

Results in other cities of Salvador were equally successful. The average number of fish used per container in this country was about eight a month, but the replacement percentage was high, due mainly to the householders' lack of care for the fish when clearing the concrete basins or pilas, and to their allowing these and other receptacles to overflow during the rains with consequent destruction of the fish in them (10).

In 1921 fish were widely distributed from hatcheries established at San Salvador, Sonsonate, and Oriente. In the opinion of the director, fish could completely eliminate mosquito breeding if proper care were given to those distributed and if the small containers were regularly emptied or done away with.

Native varieties studied included a number of top-minnows such as *Poecilia sphenops*, *Poecilia salvatoris*, *Poecilia elongata* and *Poeciliopsis*. Locally these are all called "chimbolos" or "uluminas." Another species, the *Heros facetus*, locally known as "chiva" or "burro," is not so good as the *Poecilia sphenops;* it is only partly a top-feeder. It is scarce and sometimes prefers other food to larvae.

The *Poecilia sphenops,* only about an inch long, is a voracious consumer of larvae, but is rather restless and easily injured. Care in distribution somewhat overcomes the high mortality among these fish. Goldfish are also mentioned as excellent larva-destroyers and hardy fish, but they do not multiply rapidly and frequently eat their own young. By careful observations and improved methods of handling, the mortality was reduced about 30 per cent. It was concluded that if fish are properly cared for they are undoubtedly the cheapest, safest, and surest method of preventing mosquito breeding. Experience with them in large bodies of surface water has been limited in Salvador. It was observed that they are not as easily thwarted by vegetation as was supposed. Here, as in Guatemala, about 85 per cent of the breeding was found in small containers in which fish cannot be placed. Fish were satisfactory in wells and tanks.

Dr. Bailey has done special work in evolving acceptable methods of transportation. He states that as the yellow fever campaign progressed, the mortality among fish and the restocking of containers were much reduced by carefully transporting the fish from the streams where they were collected to large concrete receiving tanks. In these tanks they were held one to two weeks to accustom them to the new environment before distributing them to the permanent containers — fountains *(pilas)*, tanks, barrels, etc. In many instances fish were found surviving in wooden barrels six to nine months after being placed in them. The malaria incidence was at the same time materially reduced in San Salvador, Sonsonate, and other towns where yellow fever control measures were conducted.

South America

Brazil. As early as 1905, E. H. Goeldi, of Pará, Brazil, recommended that fish be used in containers of still water where mosquitoes were apt to breed. He favored certain local varieties about three

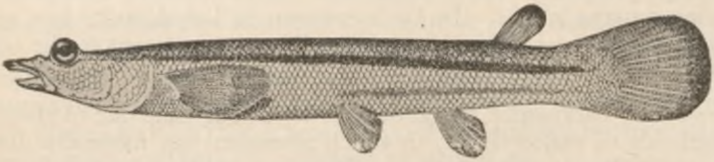

Fig. 22. — *Anableps dovii.* Four-eyed fish
(Courtesy of the American Museum of Natural History)

inches long, which were said to be able to devour an astonishingly large number of larvae (90). Three years later, W. P. Seal, of the United States Bureau of Fisheries, suggested for use in this region, a small fish called the "anableps," which is found in the fresh waters of South America and which is known to be an insectivorous feeder. In addition to the fish recommended by Dr. Goeldi, the "guarúguarú," one of the Poecilidae family of southern Brazil, is said to have all the qualities that should make it useful except that it feeds on decaying organic matter as well as living insects. It is widely distributed (170).

Dr. Hackett made a careful study and classification of native top-feeding minnows and found two excellent varieties.

Colombia. According to Professor C. H. Eigenmann, the life of Peru is not found in Colombia, but other species of the same genus (Pygidium) are found in various places. Altogether there are about sixty-five species of life in South America, and twenty in Colombia. All of them ought to serve the purpose of eliminating mosquito larvae and there should be no difficulty in procuring a supply.

The "capitan" of Bogotá is very like the life, but is confined to the plain of Bogotá. It is a species of Rhamdia (catfish). A name such as capitan may be used for different fish in different places.

The life is found at elevations, and a small fish, *Mollienesia caucana* Steindachner, may serve all purposes in the lowland. They belong to the family of Poecilidae to which the Gambusia belongs.

Dutch Guiana. Dr. P. C. Flu, a Dutch Government health officer, is favorably disposed toward the idea of mosquito control by fish, and although he does not cite any experiments or conclusive proofs, he mentions the following points in support of his recommendation that larva-eating fish be stocked, and that predatory fish be kept down to give them a good chance. The native *Girardinus guppii* Günther, has the same characteristics as the millions of Barbados; this fish is abundant in Dutch Guiana. In places where it can protect itself from the large predatory fish it apparently gives valuable assistance in clearing out the larvae. In his inspection of Lelydorp he has never found larvae in rice-fields where Girardinus was present in the water (73).

Ecuador. Guayaquil, Ecuador, was for a long time one of the final strongholds of yellow fever, to which attention was naturally drawn after the brilliant work in clearing Havana. Although some preliminary work in fighting yellow fever exclusively on antilarvae lines preceded the work done at Guayaquil, it was here that the first large endemic center of yellow fever was cleared by strictly antilarvae measures, depending chiefly upon the systematic use of fish to destroy mosquito larvae in fresh-water containers. Dr. H. R. Carter, in a series of lectures on yellow fever in 1908 suggested that the disease could be controlled by antilarvae measures alone. Dr. Connor states that the first campaign so conducted was carried out by Dr. G. M. Converse at Iquitos (Loreto), Ecuador, in 1913, and that another was undertaken by Beverley at Buenaventura, Colombia, in 1916.

Very satisfactory results were obtained by Dr. Connor in Guayaquil following these methods during 1918 and 1919. In this city the water-supply is delivered during two hours of each day, and a certain amount is stored by each householder in some sort of container, varying from specially constructed overhead tanks in the better households to any sort of receptacle, such as a barrel, an oil tin, or an earthenware jar, in the poorer families. Most of the work consisted of rendering these containers mosquito-proof. For the tanks the method adopted was careful covering and sealing, so that inspections were necessary only when the seal had been broken. Stegomyia breeding went down rapidly as the tanks were covered and sealed, but to control yellow fever completely it was also necessary to prevent breeding in all the other types of containers. For these,

Fig. 23. — *Lebiasina bimaculata* Cuv. and Val. "Huaija," "Lisa," "Chalcoque"

fish were used as the sole agent of control, each container having at least one fish placed in it and strict injunctions being given the householder to allow the fish to remain undisturbed. Fish could not be used in the tanks because the majority of them, to secure pressure, were placed so high that it would have been difficult for the assistants to gain access to them for purposes of inspection.

The fish used for this sort of work are roughly divided into top-feeders and bottom-feeders. The former require plenty of sunlight but are seemingly unable to locate larvae in dark containers. The bottom-feeders therefore seem to give better results for this work. In Guayaquil they were used in all kinds of reasonably large containers such as tanks, barrels, or cisterns, except metal tanks for which no satisfactory fish has as yet been discovered. Local fish were used wherever possible and the system of classifying them, using the kind best adapted to each container, was carefully worked out. The question as to the possibility of fish contaminating water by their excrement or causing disagreeable odors constantly came up. It was said that this might take place if many fish were put in a small amount of water. To avoid this, inspectors were instructed to place one fish, preferably a male, in receptacles holding drinking water (48).

Inasmuch as Gambusia had been introduced into Ecuador several years earlier, this was the first variety of fish with which Dr. Connor experimented. This fish consumed larvae in glass jars in the laboratory but proved unsatisfactory in containers where the water held any other kind of food. Besides, the fish did not seem hardy enough to withstand the frequent dipping of water from the containers. The next fish experimented with was a variety of perch known locally as the "huaija" *(Lebiasina bimaculata* Cuv. and Val.), which was found able to withstand rough treatment. However, this fish proved too restless, often jumping three or four feet to escape from the container. It was abandoned for the "chata," a sardine *(Astyanax bosconamericus)*, which apparently has the good qualities of the huaija with none of its defects. This fish spends a large part of its time on the surface of the water, but sinks to the bottom when the receptacle is approached. The chata is not plentiful and is therefore more expensive than the chalaco, which was finally adopted as the most satisfactory. These fish were placed in water-containers, as indicated above, and in many cases, particularly with hearty co-operation on the part of the householder, the same fish were kept for eighteen months or more. The chata is said to be both a top and a bottom-feeder, like the life (pronounced lefa) used in Peru, while the chalaco is a bottom-feeder.

At the beginning of the campaign, November, 1919, larvae were found in every container examined, so that the "Stegomyia index," the term used to denote the proportion of containers that harbor Stegomyia to the total number of containers examined was 100. In practice the index does not relate exclusively to Stegomyia, as larvae of all kinds of mosquitoes are considered, for convenience, as being Stegomyia larvae. This index of 100 was reduced by the combination of control measures employed to less than 2 by the close of 1919.

It should be remembered, however, that in accomplishing this result fish were only an auxiliary measure, since they were not used in indoor tanks which were among the most important breeding-places in Guayaquil. Nevertheless, the efficacy of fish as egg and larvae destroyers, under controlled conditions, was fully demonstrated. During the wet season of 1920, when the supply of fish for distribution had been exhausted and it was impossible temporarily to secure a new supply, the larvae index in containers other than tanks showed

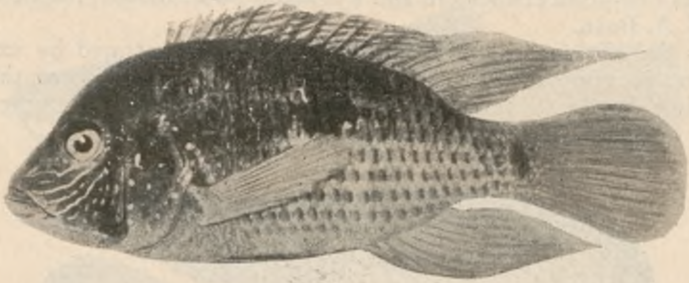

Fig. 24. — *Aequidens rivulatus.* "Mojarra"

an abrupt rise from zero to as high as 10 per cent. Still another strong point in favor of the use of fish is the economy it effects: thus, in Guayaquil the original personnel of 139 was reduced to 20 after fish were introduced (49; 53).

In a recent review of the situation in Guayaquil, Dr. Pareja sums up the advantages of the different kinds of fish used. The millions *(Lebistes reticulatus)* are small but useful in water receptacles where they are left undisturbed. The huaijas *(Lebiasina bimaculata)* are three or four times as large as the millions, very voracious, but on account of their jumping propensities are best used in containers that are closed most of the time or in wells and ditches. The chalacos *(Dormitator latifrons)* are larger than the huaijas and more dependable. They live months or even years and may be used in any sort of a container. Another species used was the "chatito,"[1] a small flat fish which is now dying out.

Fish continue to be useful, but they require constant watchfulness and an abundant supply must be kept on hand, so that they may be renewed if they die through the carelessness of the householders. In 1922 a vivarium of 400 cubic meters with 20,000 chalacos supplied the barrels of the city during the rainy season.

[1]Possibly the same as the chata already mentioned.

Peru. In Peru, Dr. Henry Hanson adopted a plan similar to that used in Ecuador by Dr. Connor, large numbers of the fish that were successful in Ecuador having been sent to Peru. Several local fish have been found very active as larvivores, the mojarra, "chalcoque" and life being the most suitable. The mojarra has been identified as *Aequidens rivulatus* by C. H. Eigenmann; the chalcoque and life, as *Lebiasina bimaculata* and *Pygidium punctulatum*, respectively, by B. A. Bean.

As the efficiency of the fish control was demonstrated by experiments, in one of which a single mojarra consumed more than a hundred larvae in one night, Dr. Hanson gradually put more and

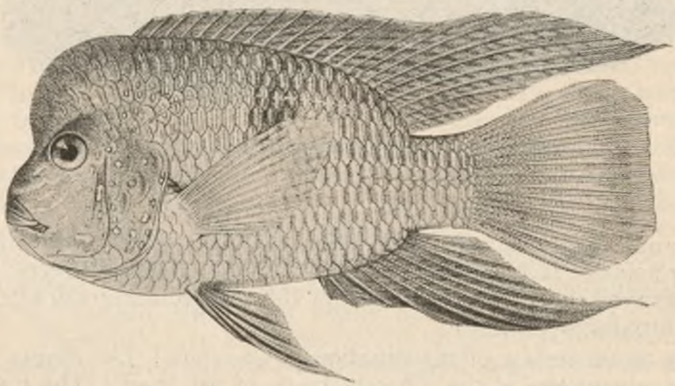

Fig. 25. — *Aequidens rivulatus.* "Mojarra"

more reliance on the use of fish, making it the sole method in some of the departments. He estimated the simplification of the problem of Stegomyia control afforded by the use of fish at 75 per cent. As a concrete instance, he mentions that in one town, in the province of Chiclayo, the Stegomyia breeding index remained obstinately around 10 per cent, in spite of everything that could be done, until distribution of fish was undertaken, when it dropped abruptly to about 2 per cent, with a continued tendency to further decrease. In the north of the country the mosquito index is everywhere down to 1 per cent or less, and the whole problem seems to be reduced to a question of getting enough fish to keep the receptacles supplied. The replacement percentage is rather high, about 35 per cent according to a report made at the end of September, 1921.

Fish were used to patrol a region 500 miles long and from 50-75 miles wide. By the end of 1921, 750,000 had been distributed.

The mojarra *(Aequidens rivulatus)* was perhaps the most satisfactory. Contrary to expectations, the life *(Pygidium punctulatum)*

Fig. 26. — *Pygidium punctulatum piurae* E. "Life"

proved also to be useful. These and the chalcoque *(Lebiasina bimaculata)* known in Guayaquil as huaija, were the chief fish relied upon.

The life, a most hardy and active fish, was used chiefly in the smaller containers. For wells and cisterns the chalcoque served best. By 1922 the situation was well in hand. Some work was done in obtaining a scientific classification of the available fish. In addition to those mentioned above, the "bagre" was classified as *Pygidium vittatum;* the "tripon" as *Curimatus peruanus,* and the "cachuelo" as *Bryconamericus peruanus.*

Asia

India and Ceylon. Next to the work in the United States some of the best experiments in mosquito control by fish have been made in India. The observations are scattered, and they cover a considerable area both in time and in space. Activities are now again being resumed and good results are expected. There are many workers who do not doubt the efficacy of mosquito reduction by the fish method, although the process is considered a slow one. However, in India time has less value than in some other countries (185).

British India is full of pools, ponds, beals, tanks, borrow pits, and swamps, many of which cannot be drained as they are the source of water-supply for various purposes. This led the Government in many localities to investigate the use of small fish. Millions were tried as well as goldfish, and further experiments were made with fish indigenous to India. P. H. Bahr, from 1911 to 1913, made investigations in Bengal both for the use of fish in tanks and in the rice-fields, and succeeded in finding about ten varieties that showed promise of usefulness. The Madras Government, through its piscatorial expert, H. C. Wilson, from 1913 to 1915 made extended experiments on pools and tanks that may prove to be very important in the malarial sanitation work. The names that are connected with the experimental work in India are those of Southwell, Fry, Chaudhuri, Sewell, and Wilson.

The work has been done scientifically and carefully, and had it not been interrupted by the war, definite results might have been reached by now. Fifteen to twenty varieties of larva-eating fish have been discovered and their fitness for tanks, ponds, or rice-fields noted (6; 7; 185; 214).

In 1912 R. B. S. Sewell and B. L. Chaudhuri conducted observations on fish near Calcutta in a stream that became partially dry in summer but was swollen during the rains. It was found that at the

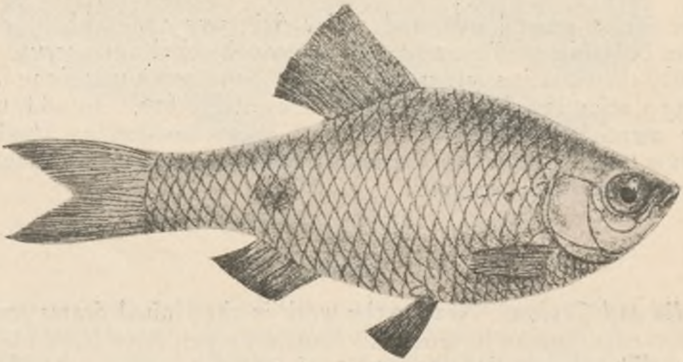

Fig. 27. — *Barbus ticto* (4 inches)

beginning of May there were many larvae which by the middle of the month had practically disappeared, concurrently with the appearance of numerous small fish, chiefly *Barbus stigma.* About thirty of this species were captured and kept in a trough which remained larva-free as long as the fish were in it, although neighboring pools of water were full of larvae. When one of the fish was introduced into the pools the larvae disappeared in a few hours. Observations on a fish bowl in the laboratory showed that the fish devoured 100 larvae in twenty-four hours (180).

A large area of water about two miles in length, shallow at the edge and eight feet deep in the middle, and known as a beal, was next observed. It was free from larvae, owing, it was thought, to the

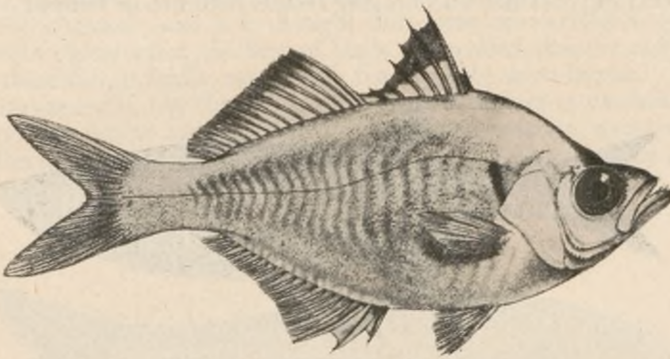

Fig. 28. — *Ambassis nama* (3 to 4 inches)

presence of *Barbus ticto* and *Haplochilus panchax.* There were many other kinds of fish but none of larva-devouring habits.

A series of fresh and brackish water tanks, such as are found all over Bengal for irrigation purposes, was next examined. Some were full of weeds. In most cases they are rectangular in shape and contain about four to six feet of water. A large number of fish were found in the fresh-water tanks, and no larvae. In one large clear tank there were only three kinds of fish, including the *Barbus stigma,* which the author thinks was chiefly responsible for the absence of larvae. Neighboring fishless pools and holes made by the feet of cattle commonly held larvae. Brackish tanks containing fish, mainly *Haplochilus panchax,* and *Gobius alcocki* were larva-free. It is thought that Haplochilus was the leading larva-destroyer and that the presence of weeds in the water does not, on the whole, prevent the complete eradication of larvae (180).

In 1912 Mr. Wilson experimented in India with the *Haplochilus affinis,* the *Ambassis nama,* and the *Chela argentea.* The Chela, especially when small, is effective in tanks, swamps, and village ponds. The Haplochilus, of which Day gives four species, is suitable for stocking wells, channels, stagnant pools, and water at some distance from the breeding-ground. It is a good traveler. The water in which it is kept requires little aeration. The genus Therapon is good for stocking brackish swamps and pools near the coast, as well as fresh-water ponds. The author thinks that more experimental work is necessary (216).

R. K. Ragavendra, a special malaria officer of the Madras City Corporation, obtained encouraging results with fish in wells at Madras

Fig. 29. — *Chela argentea* (6 inches)

during work extending from September, 1913, to January, 1915. At the beginning every well had larvae, but after the introduction of fish, only 72 out of 788, or 9.25 per cent, still contained Anopheles larvae. Sometimes larvae were present in wells where fish were active. Occasionally the wells were filthy and the fish soon died; in 108 wells dead fish were found.

Careful watching is needed to keep the fish alive and in good condition. During the experimental period about 8,000 wells were supplied with fish. It was proposed to devote the full-time services of a number of laboratories to the continuation of this work, and especially to the reintroduction of fish after others had died (160).

In 1913, after an epidemic of malaria in a district north of Madras covering an area of 5.31 square miles and with a population of 76,073, a survey was made and it was found that there were in this area 513 tanks, 2,627 wells, and innumerable pools and cesspits. Fish were present, predominantly the Haplochilus, a voracious surface-feeder, accommodating itself well to the shallow margins of tanks. Other varieties, such as the Chela and Therapon, were efficient, but not widely distributed. Sometimes the fish seemed to make no headway against the larvae. It is thought that stocking these tanks with larvicidal fish cannot replace the more lasting measure of reclamation. However, the use of fish is worthy of consideration (138).

In Ceylon a survey has been made of Kurunegala, a rice-producing district. In the flooded paddy-fields of this region are found various larvivorous fish, locally known as the "pathia," "dandie," "sudaya," and "ahirawa," which have been identified as the *Barbus stigma, Rasbora daniconius, Danio malabaricus,* and *Lepidocephalicthys thermalis,* respectively. They are carried into the fields from tanks by irrigation channels, and it is thought that some are carried as spawn to remote places upon the feet of birds. Provided there is sufficient water these fish multiply, apparently feeding only upon larvae. However, larvae exist together with the fish, which fact is explained as follows: the larvae are generally found in the seepage water which has filtered through the bunds, leaving the fish behind; in the larger

Fig. 30.—*Rasbora daniconius.* "Dandie" (8 inches)

pools which form in the paddy-fields, the larvae are at the edge and the fish in the center. Holes formed by the feet of cattle into which the fish are unable to enter are ideal breeding-places for anopheline larvae. It was noticed that frogs did not appear to touch the larvae (7).

During the last three years, observations have been made on a considerable number of indigenous top-minnows, according to recent advices from Dr. Henry F. Carter. The most valuable species, abundant in swamps and streams in parts of the low-country, has been found to be *Haplochilus lineatus*. Experiments toward the acclimatizing of imported *Gambusia affinis* are being made. Problems of malaria control by fish are not as difficult in the low-country as in the up-country, where the breeding habits of the mosquito carrier are considerably different. Ceylon is one of the few countries in which it is hoped that something can be done with imported Gambusia.

Malay Archipelago. In the Malay Archipelago there are several larva-eating fish, including the *Haplochilus panchax,* which will eat 100 larvae within half an hour, as ascertained by the actual examination of the stomach contents of twenty-six specimens. On the other hand, when placed in a salt-water dish containing definite agglomerations of larvae, the fish swim around without noticing them. They seem to avoid free colonies of larvae, and though they occasionally swim through these colonies, they apparently do not eat them. In the fresh water of rice-fields, conditions are different, but here also *Haplochilus panchax* did not eliminate the larvae (194).

About 800 to 1,000 Barbados millions arrived at Kuala Lumpur on July 30, 1913, in tanks set in packings of shavings. The fish stood the journey of 13,000 miles very well in spite of rusty tins and the

Fig. 31.—*Danio malabaricus.* "Sudaya" (6 inches)

foul-smelling water, which was changed twice a week on the trip. The conditions that seemed to affect them were too much sun and the cold weather experienced in the channel. They were taken to the experimental gardens and deposited in a large tank, fed for a few days, and then put into the natural waters that had been selected for them as most like their native waters in Barbados. These consisted of two reservoirs, a shallow pool of water, an old mining-hole, and a permanent swamp overgrown with rushes. But in all these places the fish seemed to dwindle or disappear entirely. In one reservoir there were some mudfish "ikan aruang" that may have preyed on the millions. This was doubtless true of the shallow pool, where after a short time it was still possible to note a few fish, but there were probably more than appeared on casual observance, as they are not readily visible. There was no accounting for their entire disappearance in the old mining-hole; and the investigator saw them only once in the swamp.

Dr. Strickland thinks that the planting of fish in natural waters is a difficult problem. They are exposed to the attacks of their natural enemies and do not often find conditions for growth so satisfactory as did the rabbit in Australia. In tanks, on the contrary, they proved a great success. Five fish were put into each of three large tanks swarming with larvae, near a deserted house. The millions gorged until they could hold no more, and at the end of ten days no larvae remained in the tanks.

The small fish *Betta pugnax*, known by the Siamese as "pla kat" or "fight fish," also occurs in the Malay Peninsula. Specimens of this fish were identified for Dr. Darling at the Smithsonian Institution in 1916. On the occasion that he collected these fish, anopheline larvae and fish came up in the dipper at the same time.

He advises those who import millions to place them first in a prepared tank with running water and to feed them artificially. Then when they have increased, they can be placed in the waters permanently intended for them. Millions, therefore, can be used at least for stocking tanks and other receptacles to reduce the Stegomyia and Culex that abound in such great numbers in the Malay Peninsula. There is a reasonable hope that they may also establish themselves in the malaria-producing waters (188; 189).

Dutch East Indies. It appears that no attempts have been made to control mosquito-breeding in the Dutch East Indies by the introduction of suitable larvivorous fish. The general opinion held there seems to be unfavorable, to judge from the observations of several recent writers on malaria and mosquitoes. However, in the absence of any serious experiments under controlled conditions, these remarks cannot be given the weight of grave objections, especially as in most cases the apparently unfavorable report on the work of fish may be explained by other attendant circumstances.

The usual breeding-places in most of the regions examined were found to be the fish-ponds, that is, ponds of varying areas and types prepared by the natives for the special purpose of raising fish for the market. Various observers mention that they found larvae exclusively in these ponds. The fish most cultivated, the *chaños chaños,* called "bandeng" by the natives, has an exclusively vegetarian diet, however, and requires aquatic vegetation. This favors the breeding of mosquito larvae in the prepared ponds, where they are undisturbed by the vegetarian bandeng. One writer, who considers that the fish ponds have done greater harm than good, by spreading malaria, urges preliminary drainage and cleaning of the ponds, followed by refilling and restocking with enough bandengs to keep the vegetation down, and with a considerable number of "kepala timah" *(Haplochilus panchax)* to reduce the larvae (28; 29).

Frequently a few hundred, or even as many as 430 Anopheles per square meter of pond surface, were caught in a single night, using nets as recommended by Sir Ronald Ross in his *Prevention of Malaria.* This is vastly different from the experience of Ross himself who states that in Mauritius he once took a "rather large" output — about one half an Anopheles per square yard per diem (29).

The eastern coast of Sumatra is comparatively free from malaria, but the western coast presents conditions more favorable for the increase of Anopheles. A study was made at Sibolga, a small town near a swamp. Originally sea water entered the swamp at high tide, bringing with it fish and other enemies of the larvae. An attempt was made to fill it, with the result that the sea water no longer enters, but larvae continue to breed freely in the remaining holes. This shows the danger of filling up a swamp imperfectly, leaving small ponds in which fish cannot live, but in which the larvae of Anopheles can thrive undisturbed.

In Samarang, Java, de Vogel found the fish-ponds along the coast without larvae; in old half dried-up ponds without fish, larvae were found in abundance, among them Anopheles (191).

N. H. Swellengrebel and J. M. H. Swellengrebel de Graaf, who have made extended studies of the conditions of anopheline breeding in the Dutch East Indies also find mosquitoes breeding almost exclusively in fish-ponds (rice-fields deepened and flooded for the purpose) in the interior of Sumatra, but they mention that the breeding of Ludlowi larvae is confined to ponds overgrown by algae, which include most of the ponds in this region. They consider that the presence of larvae is due to the food-supplying algae, and in discussing this question, they say that they have found both larvae and *Haplochilus panchax* present in large numbers around bunches of algae, where both seemed to have come for food, and that the fish apparently did not bother the larvae. They do not think that this persistence of larvae is due to the protection afforded by the algae, since they have noticed larvae in small clumps of algae which could not have afforded any shelter. They mention that throughout fish-ponds in eastern Samarang that contain no algous vegetation and where Haplochili and other fish are found, there are no larvae, and explain that clearing-out of vegetation alone may account for this. In Tjilatjap no larvae were found where "glodoks" *(Periophthalmus sp.)* were present in open tidal swamps and river estuaries. Larvae and glodoks were found together, however, with algae present, in enclosed fish-ponds. In a rice-field recently inundated only a few larvae were present, owing perhaps to the presence of *Haplochilus panchax,* for in holes made by buffalo hoofs nearby larvae occurred (196).

Dr. C. W. F. Winckel, who studied hygienic conditions throughout North and Central America by order of the Netherlands Ministry for Colonial Affairs, mentions the introduction into Panama of millions for purposes of larvae control, and adds that he has been able to

Fig. 32. — *Haplochilus panchax* "Kepala timah" (nat. size)
(Courtesy of the American Museum of Natural History)

note in Batavia that other kinds of fish are useful as well, since he kept a few goldfish in the water-container of the bathroom, where they lived for a year on mosquito eggs and larvae alone.

In summary, it would seem that this problem has not yet been given sufficient attention in the Dutch East Indies, and that further investigation by local observers might well indicate that the native larva-eating fish mentioned are giving more service than supposed so that reduction of the vegetation in the fish-ponds and restocking as recommended by Van Breemen would be an important step toward malaria control.

Philippine Islands. Mr. Alvin Seale also introduced Gambusia into the Philippine Islands in 1913. Two dozen were placed in an aquarium in Manila, and shortly thereafter 200 were liberated in various surrounding swamps. By 1916 about 10,000 had been distributed to various parts of the islands upon application. Much was hoped of them as aids to mosquito destruction. In 1916 it was reported that there was still plenty of stock for distribution (154; 175).

Later it was reported by Mr. W. D. Tiedeman, on the authority of Dr. Herre of the Bureau of Science, that *Gambusia affinis*, which was introduced, could not maintain itself against the "dalog," a very hardy, widely distributed and carnivorous native fish.

At the time of importing Gambusia, Seale apparently placed a screen across one corner of the pond with a large enough mesh to permit the Gambusia to retreat through it. Some workmen carelessly removed the screen with the result that the Gambusia disappeared, demonstrating that some sort of protection from the dalog is needed as this is a ferocious enemy which can travel across land from one pool to another. It is believed, however, that the Gambusia is faster than the dalog in shallow water and is able in this way to escape.

Dr. Herre revisited the places in which Seale had distributed Gambusia, but did not find any. He believed that the salt water may also have been a factor in their disappearance. The pond in Manila

Fig. 33. — *Dermogenys viviparus* Peters. "Kansusuit" (nat. size)

was restocked with Gambusia from Zamboanga, on the island of Mindanao, and from Jolo, these being the only places in the Philippine Islands where Gambusia have maintained themselves under natural conditions. Those at Jolo have been there for at least ten years.

It was probably due to the failure of Gambusia to thrive under natural conditions that experiments were made with other species of fish. In the summer of 1921 Mr. D. Villadolis, of the Department of Entomology, College of Agriculture, noted that *Dermogenys viviparus* Peters, was a voracious eater of mosquito larvae, an observation confirmed by Tiedeman's early experiments. However, the fact that they were already present at various places and had not increased sufficiently to be effective, makes the success of further stocking with this fish rather doubtful. Tiedeman reported that *Gambusia affinis* still looked very promising. He arranged with the Provincial Government to stock them in Santa Cruz and also in San Pablo as a source of supply for other municipalities.

During 1922 a thorough study was made by R. Reveche of the reproduction and feeding habits of *Dermogenys viviparus* Peters. This fish is found in the province of Laguna in more or less shady places along old streams, ditches, creeks, and rivers. Under laboratory conditions it devoured mosquito larvae. A small "kansusuit," as it is locally known, ate seventy-eight anopheline larvae in five hours and thirty-eight minutes. This fish propagates rapidly. It is a surface-feeder and has been known to maintain itself in places where the dalog and other voracious fish are present. In spite of all this, it has not been demonstrated as yet to be of economic importance in mosquito control, although it may be, under some peculiar conditions. The fact that the fish is so widely distributed and yet is not found anywhere in sufficient numbers to control breeding, shows that there must be many natural enemies to be overcome. It is concluded that further work is necessary to demonstrate the practical possibilities of the use of *Dermogenys viviparus* Peters, in mosquito control. Tiedeman believes, however, that something could be accomplished with this fish if it were aided by Gambusia. Along the coast it is thought that a salt-water minnow might be useful (163).

Palestine. In Palestine, 125 "bulti" *(Tilapia nilotica)* were caught and transported across the desert of Sinai the same night. The eighty that survived the journey were placed in a large reservoir of 900,000 gallons where they at once made themselves at home and multiplied. It is not certain what part they played in the actual disappearance of larvae (5).

In 1922 the shipment of a small lot of fish from Jamaica to Palestine for use in mosquito control in reservoirs there was reported. The fish were selected on advice given by representatives of the Rockefeller Foundation working in South America (162).

The Bureau of Fisheries provided Gambusia for Palestine in 1922, which were taken across by Dr. Kligler and arrived in good condition. Dr. Shapiro also took a small lot, nearly all of which died en route.

In August, 1922, P. A. Buxton reported that owing to the inadequacy of the financial resources of Palestine, the drainage of certain large areas of marsh and swamp could not be attempted. The results of a study of the native fish in this connection were discouraging, though interesting. The contents of the gut of *Mugil sp.*, *Tilapia zillii*, and *Cyprinodon sp.* were examined, but no Culex larvae were found in the dissected fish. Cyprinodon appeared to be almost omnivorous, and this and its variety of methods of taking food are points in its favor, as they probably enable it to exist in spite of changing conditions; it is also apparently resistant to considerable changes in salinity (34).

Field observations have been more encouraging. Although *Aëdes caspius* was found breeding in profusion in isolated cattle footprints near a marsh, no larvae were found in the main body of the marsh water, the abundance of *Cyprinodon calaritanus* and *Tilapia zillii* in all shallow places apparently accounting for the absence of the larvae from the shallows of the marsh itself. The larvae of *Culex perexiguus* were also confined to small collections of water to which fish had

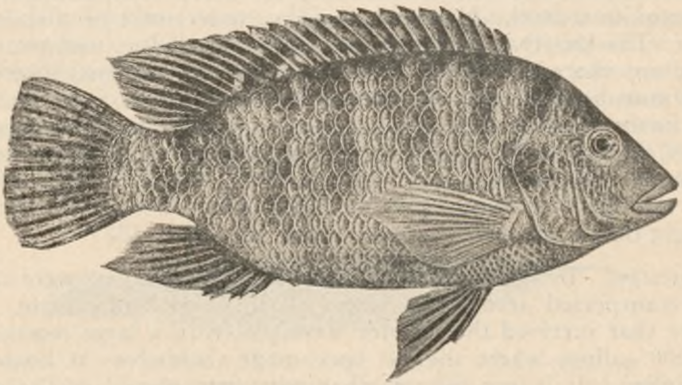

Fig. 34. — *Tilapia zillii* (11½ inches)

no access, but Culex larvae were never found in the large bodies of water, although larvae of *Anopheles hyrcanus* were numerous in patches of green algae that appeared to protect them from Cyprinodon (34).

Europe

England. In 1912 a consignment of millions was taken from the West Indies to London where they throve well in zoölogical gardens, although they did not increase rapidly as was hoped (86).

In the dykes and watercourses in certain parts of England, especially near Kent, fish and larvae apparently live together with no noticeable diminution of the larvae, although Mr. Boyd, through an examination of the stomach content of sticklebacks with which the larvae are supposed to associate, has established the fact that at least a part of the food of these fish consists of mosquito larvae, and that although they may not do away entirely with mosquitoes they aid in diminishing their numbers (26).

France. There has been no actual trial of fish in mosquito control in France. A few individuals, stimulated by an interest in the Barbados story of the utility of millions, have recommended such a measure. G. Vitoux, in 1907, advised that fish be tried, goldfish in particular, where oil was not practical. In 1913, M. Canaud, of the water-works department at Paris, became convinced that fish were more practical and much safer than oil for use in shallow water. He considered them unpractical for large bodies of water. The real solution, in his mind, lay in draining wherever possible, and otherwise using fish of the family of Cyprinidae. In the Grasse region a campaign was carried on to induce owners to keep goldfish in reservoirs used for watering flowers. Where this method was adopted, results were satisfactory. For large ponds neither goldfish nor millions would serve. He recommended the use of some native fish, such as carp, preferably of the family of Cyprinidae. In the central regions of France near Haute-Vienne, Creuse, Corrèze, and Allier where numerous ponds of 5 to 40 hectares exist, mosquitoes are unknown, probably due to the fact that carp are raised on a large scale. There are also tench, pike, and perch. Canaud suggests the planting of carp and tench in the various rivers and canals of the Cannes region. It would take about 1,500 young fish, 15 to 19 centimeters long, to stock all the waters of this region (37).

Dubois in 1922 stated that fish of the ordinary kind sometimes present certain disadvantages. Hence his advocacy of young eels in antimosquito work merits attention. He has experimented with these creatures in Taniaris-sur-Mer, southern France, where he found them to be very resistant to various conditions which might have been thought detrimental to them. They do not eat during the winter, but with the advent of spring they become extremely voracious, and will devour mosquito larvae greedily. They can live for long periods without food, are cheap, can be captured in large numbers, and are easily transported. Hence they appear well suited for use as destroyers of the water stages of mosquitoes. Dr. Carter notes that this method, although extremely interesting, would be confined to Western Europe because elvers (as young eels are called) are rarely seen in the Western Hemisphere in sufficient numbers for use and, obviously, they cannot be bred artificially.

Germany. No important experiments have been made in Germany with the use of fish. This may be the reason for a general consensus of German opinion that fish have a very limited value. Germany uses her inland fresh waters, such as ponds, lakes, sluggish streams, for the production of fish as food, and the fact that there are species of fish in nearly all collections of water may have something to do with the general opinion on the subject.

A few fresh-water fish have been tried and some useful species suggested. The stickleback *(Gasterosteus aculeatus)* and the goldfish *(Carassius auratus)* are generally agreed upon as being the most efficacious. H. Prell states that sticklebacks must not be put into ponds where other fish are to be raised for food (156). He recommends any small, hardy species and adds carp and whitefish. E.

Fig. 35.—*Cyprinus carpio.* "Specularis" (12 to 20 inches)

Breslau recommends the use of fish in place of disinfectants so that the water may be used for the production of fish as food, and emphasizes the fact that fish must be able to reach all parts of the pool including the edges. Adolf Eysell thinks that fish are useful only in water basins that have been cleared of under-water plants and have had the edges sharply cut. He mentions the fish that have already been used and adds some exotic species such as Haplochilus and millions, but does not suggest that such fish might be brought to Germany and tried there (30; 67).

Schilling tells of some good results in the destruction of mosquitoes on the west side of Berlin. The effort consisted of fumigation in winter and the introduction of small fish into ponds and fountains in gardens (148).

Some experimenters in Halle, Prussia, working with the Imperial Board of Health came to the conclusion that the influence of the natural enemies of mosquitoes in a mosquito campaign is of little importance. These enemies are too often found in the same place with Anopheles larvae and pupae. One reason for this is the habit of the Anopheles larvae of hiding among the plants on the surface. Experiments in the laboratory are useless, for existence in a laboratory jar is very different from life under natural conditions, and much more limited. If Anopheles are not found in numbers where their enemies are, the fact may be due not only to the enemies, but to lack of food supply, scarcity of plants or aquatic vegetation, or to too much shade (197).

Mr. Vosseler worked with fish control to somewhat limited extent in German East Africa and then, upon returning to Germany, attempted to introduce there a species of fish which he found widely distributed in Algeria in 1892. The species occurs in thousands of springs of salt or magnesia water, irrigating ditches, polluted pools, in fresh, clean water, in hot springs, and in brackish waters. It even inhabits the subterranean waters of the desert. One of the officers of his garrison called his attention to the fact that there were no mosquitoes in the vicinity and that this fish ate mosquito larvae. His effort to introduce this species into Germany succeeded very well in spite of inadequate preparation. The fish began to lay eggs within a week of their arrival. The species is *Cyprinodon calaritanus*. It is from 5 to 8 centimeters long and prefers larvae and small crustaceans as food (116).

Martini mentions two other fish that have been tried and are worthy of consideration, *Phoxinus laevis* and *Telestes muticellus* (141).

Italy. Most of the experiments with fish in Italy have been unsuccessful and the general opinion is that they are not satisfactory for antimosquito work. The exception to this is the use of carp in

Fig. 36. — *Phoxinus laevis* (4 inches)

the rice-fields. Millions were tried in Italy and failed to become acclimatized. An Italian antimalaria commission concluded that fish could not do the work, one of the fundamental difficulties being that Anopheles mosquitoes very often breed in temporary collections of water and in marshy grounds rather than in permanent pools and ponds. Ascoli thinks that the use of fish may diminish the temporary harmful influence, but that they cannot eradicate the mosquito (4; 37).

Fermi seems to have tried fish a little more carefully than some of the others and concludes that they are inefficient in ponds for the following reasons: (1) ponds contain better and larger quantities of food, than larvae; (2) fish are inactive in marshy water which is a favorable breeding-place for Anopheles; (3) at times the Anopheles larvae rest on the large marshy leaves half submerged and protected against fish and other enemies. They are efficient in laboratory experiments, in tubs and basins containing small amounts of nourishment, and where the larvae cannot be protected by dirt and there is nothing else for fish to feed on (69).

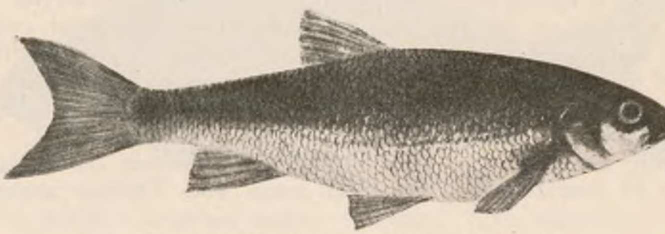

Fig. 37. — *Telestes muticellus* (6 inches)

Carter has noted that in certain parts of the United States the half-dead, floating lotus leaves with water on their upper surface, which ordinarily form a perfect protection for larvae, occasionally hold Gambusia which must have jumped in.

Gioseffi failed to attain any success in some experiments in Brioni and Barbariga where sticklebacks *(Gasterosteus enneaculeatus)* were used in a lake (89). He commented in 1919 on the good effect of the presence of fish in pools in Istria (87). In a later article on malaria in Istria, Gioseffi again referred to the fact that no mosquito larvae were found in ponds which were stocked with fish (88).

The use of carp in the rice-fields has met with a good deal of approval, as a successful economic measure rather than as a scientific achievement. It has not been proved, however, that carp have eradicated mosquitoes to any great extent.

The rice-fields of Lombardy are a veritable paradise for Anopheles, and because, in Italy at least, malaria has always followed in the wake of rice cultivation, this industry has obtained a bad reputation. In recent years medical authorities have pointed out the way toward control, which consists in taking the offensive against mosquitoes. Terni was the first in Italy to use fish for the destruction of mosquito larvae. In 1906 he recommended putting carp, tench, and eels into waters used for irrigating rice-fields. The variety of carp chosen is that known as specularis, the scientific name of which is *Cyprinus carpio*. This species was originally brought from Germany and is better than the common carp because it grows faster. The use of carp began near Milan in 1908; in June of that year, fish were distributed at the rate of two thousand fish per hectare.

A small screen was used to keep the fish from leaving the fields. The only other precaution necessary was the drawing of a furrow a quarter of a meter deep. The carp used were small fry and passed about three months on the rice-fields and were withdrawn at the time of the harvest when the fields were dry. They passed the winter in the reservoir containing the water and the only food they needed was some kitchen refuse occasionally. The following summer they were put into the rice-fields again and by the end of that season had grown to five or ten times their original weight. It is said that fields stocked with fish need less weeding than others. At the end of the second season, incidentally, the fish were of an excellent size for the market. Their value as destroyers of mosquito larvae has not been

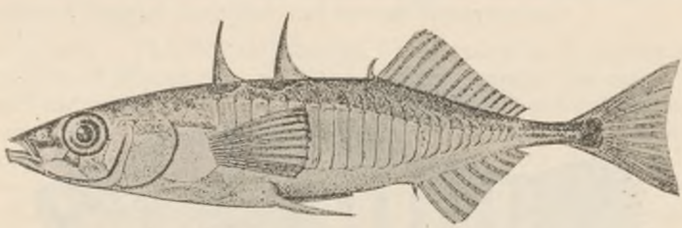

Fig. 38. — *Gasterosteus aculeatus.* Epinoches, Stickleback (4 inches)

scientifically determined. No careful control measures have been instituted. One rice-planter claims that he finds it unnecessary to employ men for destroying mosquitoes since fish have been introduced. The doctor residing on this property also states that malaria has completely disappeared. Terni examined the stomach content of small tenches and in each found from sixty to eighty mosquito larvae. Legendre thinks the same methods could be introduced with great success into the French colonies where rice is grown (130).

Experiments were also tried with tench, Gobiidae, small eels, and other fish, all of which ate various insect larvae. The eels and tench seemed especially voracious. It was noted that Gambusia and tench ate mosquito eggs, although the eel, the native fish, did not seem to care for them (190).

From 1903 to 1908, Galli-Valerio and Rochaz de Jongh made a series of experiments that were disconnected and not very conclusive. They were probably stimulated by the work of Terni and helped to interest a good many other people in the use of fish. These writers confirm the observations of Underwood to the effect that goldfish *(Carassius auratus)* are useful in tubs, casks, and small ponds. They state that *Phoxinus laevis* and *Telestes muticellus* are both excellent eaters of larvae. Their observations upon them seem to have been made in tubs. By some experiments made both in tubs and in two small pools, they conclude that *Cyprinus prasinus* and *Cobitis barbatula* are valuable in the destruction of larvae. They never found mosquitoes in small ditches with green algae and fish (77; 78; 79; 81).

Galli-Valerio and Rochaz de Jongh mention the triton as being useful. Mathieu and Romby have made successful experiments with the eel (142).

In the numerous experiments which have been tried, the goldfish, chub, and stickleback have been found useful. In the districts around Rome *(Campagna Romana)*, Brunelli has found *Cyprinodon calari-*

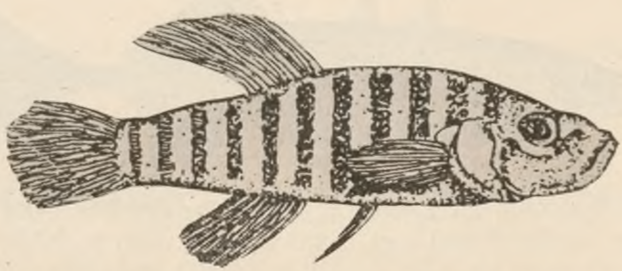

Fig. 39. — *Cyprinodon calaritanus.* "Nonni" (3 inches)

tanus (nonni) and the *Gasterosteus aculeatus* satisfactory (4). The nonni are apparently excellent larva-eaters because they can live in shallow and somewhat warm collections of water (70).

The Italian General Director of Public Health made some experiments in Milan about 1907 with a small fish imported from Australia *(Pseudomugil signifer)* and with Gambusia, but doubted whether the method had any practical value. Without resorting to the importation of exotic fish, he thought that many Italian fish could be used as a subsidiary means in the campaign against malaria, and that it would be well to experiment on a large scale with these native species (190).

In 1919 Sella placed more than 2,000 nonni *(Cyprinodon calaritanus)* in a swamp one meter deep and forty meters wide. Their presence did not prevent the marsh from becoming filled with a large number of larvae and pupae so that petrolization was necessary. In another small marsh about sixty fish (persici) were introduced, also with negative results. The author is skeptical concerning the fish found in the water areas of Italy (178).

In a later article (1922) Sella insists on the use of fish especially *Gambusia affinis* for the control of malaria (179).

Through the efforts of Dr. Sella, the United States Bureau of Fisheries sent two shipments of Gambusia to Italy, but the fish died during the voyage. The Italian Minister of Agriculture has since had Gambusia imported from Spain.

E. Bora in 1921 refers to the mosquito experiments conducted in Fiumicino. A section of canal, about 100 yards, was found in July, 1920, to harbor many larvae of *Anopheles bifurcatus* (claviger) and large numbers of small fish, *Cyprinodon calaritanus*. In the first fortnight of August both fish and larvae disappeared.

Macedonia. The British Malarial Commission in its report on the mosquitoes of Macedonia in 1918 noted that various species of small fish and the fry of larger forms control the larvae to some extent, but that even when fish were present, very little cover was needed to afford protection to the larvae. At Likovan, both fish and larvae were found in the pools. In clear, gravelly, or rocky pools, the fish control appeared effective. In Ardsan Lake, the clear reed pools were patrolled by shoals of fry and there were no larvae. On the other hand, fish were found on the lakeward side of a barrier of broken reeds behind which the larvae of a species of Anopheles abounded. Only one species of the fish found there has been identified, *Gobius rhodopterus* Günther (210).

Spain. In view of the excellent results obtained in many places the Malaria Divison of the League of the Red Cross Societies decided to have Gambusia imported into Europe. In 1921 the United States Bureau of Fisheries sent through the American Red Cross a first shipment of Gambusia to Italy, but unfortunately the fish died before their arrival. Later a second shipment was sent to both Italy and Spain. Those sent to Spain were given to the Spanish Anti-Malaria Commission. They were consigned to the aquarium of the Spanish Oceanographic Institute, where they lived in captivity and flourished for a period of four months (33).

Specimens of *Gambusia affinis* were taken to Talayuela (Cáceres) in July, 1921, shortly after their arrival in Spain. They multiplied enormously, and as early as April, 1922, three generations of the species existed. The program of the Spanish Anti-Malaria Commission included the distribution of Gambusia to numerous water collections and a study of their efficiency as mosquito destroyers (33).

Africa

In 1912 the South African Anti-Malarial Association imported a consignment of millions which throve well in open-air ponds during the summer, but when cold weather came, began to die. It was concluded that these fish could not readily be adapted to conditions in South Africa (86).

It was observed that a small fish known in some districts as "kurper" (Tilapia) had cleared pools of mosquito larvae. It is hardy, stands transportation well, and multiplies quickly in favorable surroundings. Further investigations into its habits may show that

Fig. 40. — *Haplochilus grahami* (2 inches)

it can be utilized. A small species of *Tilapia philander* is abundant near Pretoria, and a glass jar of them was conveyed to the Jonker's Hook hatchery, Cape Town, for trial. They throve well but did not reproduce rapidly, probably because of the cold. Species of Haplochilus from Nyassa, Albert Nyanza, and probably many other regions are deserving of further investigation. A small fish (Galaxia) found in the southwest of the Cape Colony may prove a useful mosquito-destroyer, though its habitat is limited.

The fresh-water fish of South Africa are imperfectly known and still less is known of their habits. That great benefits would result from the discovery of a native fish with habits similar to the millions of Barbados is evident. It is an investigation that should be taken up soon by the combined efforts of all the provinces (86).

At Khartum in the African Sudán, fish from the Blue Nile were put into wells and ponds that could not be drained. In the wells they died because the water was too hard, but in pools containing river water they were a success, except for the fact that sometimes they were carried off, either by natives or by aquatic birds (11).

In 1911 it was noted by W. M. Graham that a swamp a mile and a half from the medical research institute at Yaba near Lagos in

Fig. 41. — *Hemichromis bimaculatus* Bell (6 inches)

Southern Nigeria had no mosquito larvae, although conditions were suitable for them, and egg-laden female mosquitoes frequented the vicinity. As the swamp contained small active surface-feeding fish belonging to the family of Cyprinodontidae including *Haplochilus grahami*, it seemed likely that these fish were keeping the pools free from larvae.

A number of the fish were taken to the laboratory and put in a basin over night. In the morning it was found that some had jumped out and were dead. They jump from pool to pool in their native haunts and their leaping propensities enable them to utilize all the food found in separate pools nearby.

It was also noted that in captivity the fish fed greedily on larvae, either Anopheles or Culex, but did not touch pupae. Perhaps they were unaccustomed to encounter this form of the mosquito. The swamps in which they normally lived consisted of shady pools a few yards long which dotted the whole extent of the marsh.

The water in this swamp contained 0.84 grains of chlorine per gallon. Some fish taken from a hole near the swamp were put into a basin of water having a milky appearance and containing some 0.91 grains of chlorine per gallon. Mosquitoes which were introduced disappeared slowly, but were ultimately all destroyed. The fish were not injured by the water, but it was so milky they could be seen only when near the surface. They flourished also in tap-water.

Mr. Graham thinks that these fish would be effective in eradication work, because of their capacity for covering large areas by leaping from pool to pool. He is not certain that they could be kept in water-holes and pools, as most of these contain catfish which may be a dangerous enemy (97).

The Annual Medical and Sanitary Report of 1915 for Gambia tells of how two comparatively large expanses of water were stocked by dumping in a dozen buckets of small fish. As these increased, the larvae disappeared. A large salt-water lagoon was stocked with equally satisfactory results. The supply of fish must be constantly replenished to counteract the wastage from predatory birds, although

Fig. 42. — *Tilapia mossambica* Peters (14½ inches)

pits at the bottom of the pools afford a certain amount of shelter (61). The report for 1916 states that the number of wells stocked and restocked was 351. Practically all the wells of Bathurst are protected by this means; about two thirds were stocked by the owners and one third by the Board of Health. In 1915, 179 wells were found to contain larvae, but in 1916 the number had dropped to thirty. It is said that there has been a complete absence of the clouds of Culex that used to invade the town from time to time. Fish also proved useful in the lagoons, which are connected by canals through which the fish can pass from one to the other. The species responsible for the improvement are *Hemichromis bimaculatus* Bell, and *Hemichromis macrocephalus* Bleeker.

Very encouraging results were obtained from a mosquito campaign carried on in Dar-es-Salaam in East Africa during the summer seasons of 1918 and 1919. The larvae were destroyed by the use of both fish and oiling measures, and the mosquitoes which had been almost

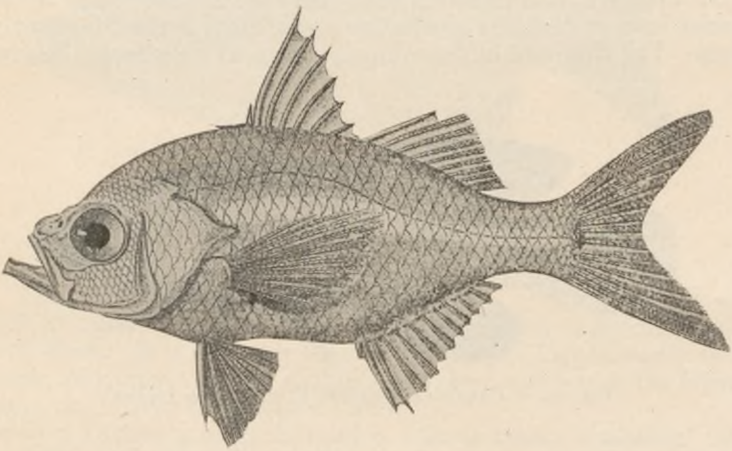

Fig. 43. — *Ambassis commersonii* Cuv. and Val. (5 inches)

unbearable in 1917, causing a great deal of malaria among the troops stationed there, were greatly reduced. The greatest nuisance remaining was the occasional trouble from Stegomyia breeding in the German system of underground drains. Indigenous minnows destroyed enormous numbers of larvae, and when the vegetation was properly cleaned out, allowing access to the entire area of water, very little breeding ensued. An ultimate balance must be attained between the increase of larvae in their natural state and their destruction by fish; but any marked increase of larvae seems to be due to the fact that they can escape among the aquatic vegetation, which prevents the fish from following. When the drains were kept clear, the fish traveled the entire length and completely eliminated the larvae.

In addition to minnows, fish of the genera Gobius and Eleotris readily devoured all larvae that descended to the bottom of the water. Doubtless many other fish besides top-minnows do this.

Various species of small fish were placed in the tanks and house cisterns and kept without food. It was surprising how quickly they destroyed the larvae, six fish being able to cope with a heavily infested tank of 200 cubic feet capacity. The fish were transported in wooden buckets and were carried back to the stock-tanks when they were no longer needed. They were also a success in ornamental ponds.

Dr. Spurrier tried imported fish from the Seychelles, but the local species have proved just as effective and there is a plentiful supply of them. The fish used in the campaign were all indigenous, consisting

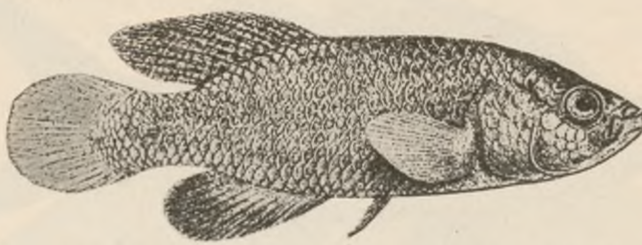

Fig. 44. — *Fundulus güntheri* Pfeffer (2¾ inches)

of four species of Tilapia (*nilotica* L.; *ovata* Stdr.; *natalensis* M. Web.; *mossambica* Peters), a variety of perch, the close relative of the perch (*Ambassis commersonii* C. and V.), one of the Poecilidae family (*Fundulus güntheri* Pfeffer), a variety of mullet (*Mugil macrolepis* A. Smith), a species of Gobiidae (*Gobius giuris* Ham. Buch), and *Eleotris fusca* Bl. Schn. (155).

On account of the great physical and chemical differences in the waters inhabited by mosquito larvae in German East Africa, Mr. Vosseler thinks the selection of suitable species of fish is restricted. Shallow shores of rivers or lakes can be excluded, since the young of fish live there and prey upon the larvae and other forms of animal life. Many water-supplies contain salt or other chemicals or are polluted in various ways, while temporary water-holes, such as pools, puddles, irrigating ditches, contain turbulent, muddy water. The level of the water is variable, as well as the temperature, which often rises at midday above the limit that fish can endure. A fish that could survive all these conditions would be very exceptional (116).

In South Oran, in pools fed by the spring of Khreider, there are a great number of a small fish described by P. Gervais under the name of *Tellia apoda.* The Tellia lives on worms and larvae, and when

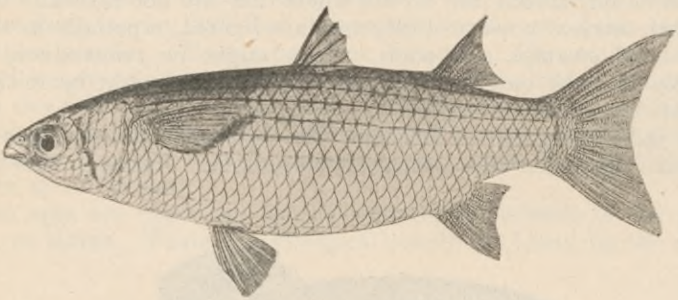

Fig. 45. — *Mugil macrolepis* A. Smith (4 inches)

placed in reservoirs filled with mosquito larvae, will completely destroy them. It is not more than 45 millimeters long, is easily bred in ponds, and since 1889 has multiplied in the reservoirs of the higher schools. It is easily transported (200).

Howard advises putting Epinoches *(Gasterosteus aculeatus)* into water which it is desired to purify, as this fish is voracious and can easily accommodate itself to stagnant water (22).

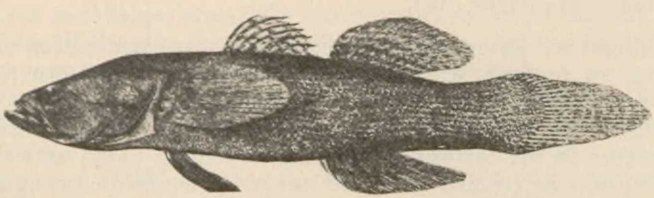

Fig. 46. — *Eleotris fusca* Bl. Schn. (10¼ inches)

C. C. Gowdey, entomologist in Uganda, experimented with two cyprinodonts which he thought were *Fundulus taeniopygus* and *Haplochilus pumilus,* and found that they eat larvae voraciously.

The cyprinodonts in Uganda could never play so important a part in the destruction of mosquito larvae as millions in Barbados, because there are numerous swamps and rivers in Uganda, overgrown with papyrus and reedlike grasses in which the larvae live, but in which fish cannot live and are not found. It is rash to assume that fish cannot be introduced into waters where they are not naturally found, but their normal powers of dispersal are limited, especially in regard to isolated swamps and pools. They might be reintroduced continually in fresh batches, or adverse conditions might be mitigated so that they could survive (95).

An indigenous fish of Berbera, the *Cyprinodon iberus*, has been tried in Algeria for the control of mosquitoes. Although this fish is

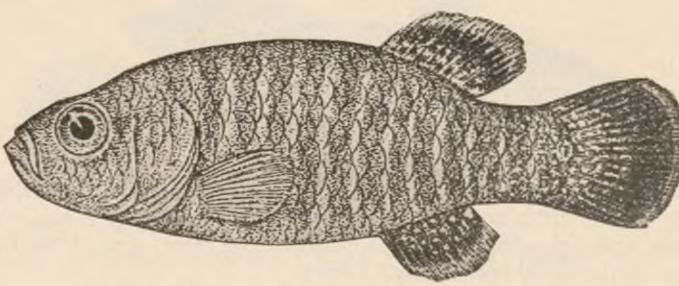

Fig. 47.—*Tellia apoda* (2⅜ inches)

very voracious and an excellent larva-eater, it is not able to destroy the larvae completely (32).

Madagascar. In certain parts of Madagascar examination of school children for malaria brought out the fact that the eastern part was much more heavily infected than any other. In his efforts to discover the cause of this high infection, Legendre came to the conclusion that rice culture in the eastern region had something to do with it. For three months he studied mosquito larvae in rice-fields throughout the country. In certain parts, fish were abundant in the rice-fields, but in other parts they were almost completely lacking. The canals were inhabited by a species of carp, but when the canals extended into the plain, the fish disappeared. Some of the rice-fields had no fish at all, and there mosquitoes bred undisturbed by natural enemies. Legendre recommended extensive stocking with small carp, about four or five centimeters long. In some regions the malaria infection was 100 per cent. Legendre believes this larvicidal measure an urgent necessity. He thinks that some good results and probably success will follow (128).

Legendre also experimented in the rice-fields with the goldfish *(Carassius auratus)* previously introduced into the island by Jean Laborde, and found that not only does this fish devour great numbers of mosquito larvae, but that it increases in the rice-fields in a remarkable manner. To cite only one instance, 1,300 goldfish, having a total weight of about 6 kilograms, placed at the end of January in some rice-fields with a total area of a little more than one hectare, furnished five months later, after the rice harvest, 18,000 goldfish, with a total weight of 120 kilograms, the largest fish reaching the weight of 150 grams.

The eggs are deposited on the submerged portions of the grain, stalk, or leaves. Favorable biological conditions found by the young

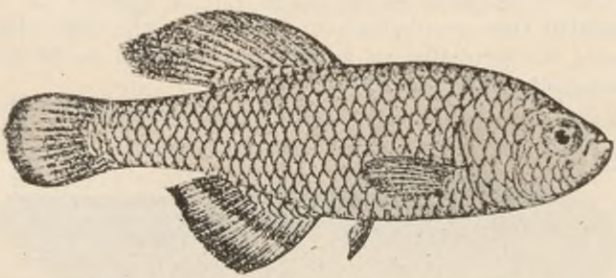

Fig. 48. — *Fundulus taeniopygus* (2 inches)

fish in the rice-fields, especially the presence of small aquatic fauna which develop there in great abundance by reason of the temperature of the water, cause the rapid increase of the goldfish.

The natives in Madagascar are extremely greedy for this fish as a food delicacy. They seek for it eagerly in the rice-fields. Legendre in 1921 reported further observations on fish control in Madagascar, pointing out that the rice-fields in the plains swarm with fish, while those on the hills are free from them, the inference being that the heavier incidence of malaria in the hills is correlated with this fact. He recommends that an antilarval service be instituted, that irrigation be forbidden near towns and that elsewhere the culture of fish should be obligatory (129).

In all these articles Legendre has considered the problem of fish control from the point of view of agricultural economy, but in a malarial country the destruction of mosquito larvae is equally advantageous. In a later article published in August, 1921, Legendre states that the presence of carp in rice-fields brings about a diminution of mosquito larvae. Thorough weeding of the rice-fields is favorable to the antilarval action of fish. The number of fish placed in rice-fields and swamps to control mosquitoes is very important. In rice-fields where the water bed is not more than 30 centimeters, there must be at least ten carp per square meter (126).

Legendre carried out laboratory investigations with the three species found in Madagascar: carp, éléotris, and perche malgache. He has obtained results for each species indicating that the fish attack the larvae as soon as the hot season hastens the development of the entomological aquatic fauna.

Legendre's observations showed that the splenic index of school children from seven to fourteen years of age in the region of Tananarivo varies from 30, 40, or 50 per cent, depending on whether the children live in rice-fields in the plains, on the hillsides, or both. It was concluded that prophylaxis of malaria on the high plateaus of Madagascar is essentially an agricultural problem to be solved by means of drainage and fish culture (126).

Fig. 49. — *Haplochilus pumilus* (2¼ inches)

Contrary to the opinion entertained by Legendre, Fontoynont, director of the school of medicine in Madagascar, described some observations which were communicated to him by Dr. Munier, a physician of Antsirabé, Madagascar. According to Munier, fish are found in large numbers in the large collections of water as well as in the rice-fields. It is noted, however, that the rice-fields are more unhealthy from the malaria point of view than the water collections. According to Munier, therefore, it is necessary to explain this difference by some factor other than fish. He believes that the difference is due to the presence of aquatic insects which are inimical to mosquito larvae. These insects are found in large numbers in the collections of water but are rare in the rice-fields. The article concludes that this matter should be investigated further (74).

Fig. 50. — *Cyprinodon iberus* (2 inches)

Madagascar is the only French colony that has a fish-culture station, and it is thought that the growing of fish in rice-fields has a splendid future. If the right kinds of fish are used, they can first be employed against mosquitoes and later utilized for food (127). Dr. Jean Legendre of the health service in Tananarivó, believes that there is a large future for what he calls "rizipisciculture" in Madagascar. He recommends the same for the French colonies of Indo-China (127; 128; 130).

Australia

In an article by L. E. Cooling, it is stated that the crimson-spotted sunfish, the green perchlet, and the firetail, three native Australian fish, are effective enemies of mosquito larvae in clean natural waters, and that all do well in confinement. Several other native fish, which devour larvae in aquaria, are of little value in streams and ponds. Two Australian fish withstand semi-polluted waters, but are vegetarians, and therefore useless against the mosquito of greatest sanitary importance in Australia, *Culex quinquefasciatus* Say. This species is the vector of filariasis, which is of serious importance in Queensland. It breeds preferably on sewage-polluted water too foul for native fish to tolerate. Therefore, while the native fish may be of value in destroying the anophelines and other "bush" mosquitoes, Australia apparently has no fish of value against its most dangerous disease-carrying mosquito. Possibly the introduction of *Gambusia affinis* might aid in reducing the morbidity from filariasis, as this top-minnow thrives in sewage-charged water, and is effective against non-anopheline as well as anopheline larvae.

Miscellaneous

Bermuda. Dr. Walker, medical officer of health of Bermuda, carried out fish experiments in 1922. Goldfish and mullets were used in water cisterns and tanks. The people often allow goldfish to be put in the drinking-water tanks but refuse to have mullets. The goldfish eat the eggs and larvae of the mosquitoes, but are rather expensive since they are imported from America.

Mullets are caught in the marshes and swamps in brackish water which is very hard from its lime content. If the fish are put at once into fresh water they die. Therefore they are put in large tubs of brackish hard water and rainwater is gradually added until the fish are finally accustomed to the fresh water. They are then distributed, two or three to each water tank. If handled in this way the mullets will breed in the fresh-water tanks.

Hawaii. The first efforts at mosquito control in Hawaii were made at a time when little was known regarding the best fish for this purpose. In July, 1905, Mr. Alvin Seale, formerly of the United States Bureau of Fisheries, was commissioned by the territory of Hawaii to study the problem. He went to Galveston, Texas, and examined several varieties of top-minnows recommended by Dr. Jordan. *Gambusia affinis* was picked out as most suitable, and a considerable number of these were transported to Hawaii. The choice was considered excellent. The fish throve and in two years increased enormously in number.

In 1907 Mr. Van Dine reported that several thousand had been distributed and that the fish had established a record as effective enemies of mosquito larvae and eggs. In 1916 there were millions of Gambusia in the Hawaiian Islands, and two employees of the Health Department were kept busy distributing them to various parts of the islands. Since there are no Anopheles in Hawaii, the fish were used only against Stegomyia and some species of Culex — especially *Quinquefasciatus fatigans*. A decrease was noticeable, especially in *Culex pipiens*, and the governor felt that top-minnows had been a decided success (116; 175).

West Indies. The general though perhaps unfounded belief in millions as the cause of the immunity of Barbados led to their transportation to other islands of the West Indies. The Imperial Department of Agriculture introduced them into Antigua, Jamaica, and St.

Fig. 51. — Goldfish eating mosquito larvae
(Courtesy of the American Museum of Natural History)

Kitts and Nevis. They were found especially serviceable in rainwater tanks and other reservoirs (12).

In Antigua, three years after their importation in 1905, all the more or less permanent streams and ponds were stocked, and it was noted that there was an abatement of the mosquito nuisance in many localities (13).

In Jamaica the use of goldfish has been suggested to supplement the millions, which are, however, said to be successful (86; 208).

Fish were not used in Cuba in the first campaign against Stegomyia (1901), but they were used, tentatively, in the campaign of 1905, and intensively, by MacMillan, in 1908 in Camaguey. Dr. MacMillan also carried out some yellow fever work at Camaguey, Cuba, in January, 1909. The inhabitants caught their rainwater in huge jars which they valued and would not allow to be screened or spigotted. MacMillan developed a method of accustoming the local minnows to live in these jars, and thus solved the question of mosquito breeding. Two cousins of the famous millions, the *Gambusia punctata* Poey, and the *Gambusia punticulata* Poey, are native species, voracious larva-eaters, and perhaps more suitable than the imported Gambusia (99).

According to reports made by the American consul at Trinidad, British West Indies, one of the most serious difficulties in the production of asphalt at the famous Trinidad Lake, and also with petroleum developments in the immediate vicinity, has been the high incidence of malaria. Conditions at the lake are extremely favorable for mosquito breeding. It has been found difficult both to drain off the

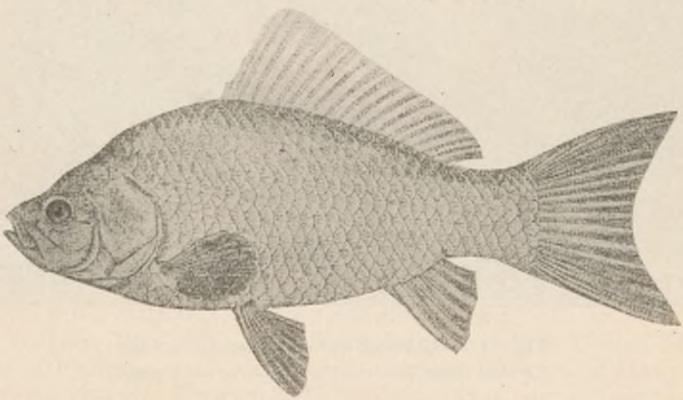

Fig. 52. — *Carassius auratus.* Goldfish

water and to fill up the water holes. Owing to the heretofore ineffectual drainage, about the only check to mosquito propagation has been that resulting from the presence of several varieties of larva-eating fish which are found in large numbers in the water holes (147).

Barbados. According to Mr. Ballou of the British Imperial Department of Agriculture for the West Indies, the malaria-bearing mosquito does not occur in Barbados. It is thought that no case of malaria ever originated in the island. If this is so, the freedom from malaria which it enjoys may be due more to natural conditions and the absence of the mosquito than to the work done by the famous millions indigenous to Barbados. The permanent pools of the island are well stocked with *Lebistes reticulatus.* Goldfish are also used to some extent in mosquito control. There is of course a possibility that the absence of Anopheles has been brought about wholly or in part by these fish, but other mosquitoes, such as the *Culex fatigans* and the *Stegomyia fasciata*, are found in places on the island where there are no millions (12; 13).

Dr. Malcolm Watson, the well-known English authority on malaria, is not inclined to give much credit to millions. During a visit to the island he noticed first of all the absence of jungle due to cultivation of the entire area. The streams indicated on the map are generally dry. In fact, there is a great scarcity of surface water. Although experienced in the search for Anopheles breeding-places in various parts of the world, Watson failed to discover any in Barbados, and he attributes the absence of malaria to this fact. Even possible breeding-places are very few and widely scattered. The coral formation of the land makes it absorb water quickly, and the chance of mosquitoes arriving by sailing vessels is remote, owing to the isolation of the island and the prevailing winds; but even if a boat-load of sturdy Anopheles were landed, it is difficult to see how they would have any chance to propagate. The high cultivation and the geological formation of the island eliminate jungle spots and other conditions favoring mosquito life. However, as Dr. Darling points out, the malaria-bearing anophelines of the West Indies are *A. albimanus* and *A. tarsimaculatus* which do not breed in the jungle.

As a last blow to the millions theory, Dr. Watson quotes the observation of Dr. Low, who found Culex larvae in a swamp swarming with millions (211).

J. A. M. Vipan points out that although in the Barbados, millions, which he calls *Girardinus poeciloides*, are present, and there is no malaria, this is not the case in Trinidad, where there is malaria and the fish *Girardinus guppii* is present, nor in Venezuela where there is a great deal of malaria and the fish *Poecilia reticulata* is present. According to Mr. Arthur Henn, these fish are all of the same species of the Poecilidae family (104; 207). Dr. Carter comments that considering how close Barbados is to Trinidad and the mainland, it would seem perfectly possible that Anopheles imagos might be introduced by vessel, but that this genus, unlike Stegomyia and *C. fatigans*, is not much of a seafarer.

Porto Rico. Efforts to adapt to tropical conditions the antimosquito measures the value of which has been so convincingly demonstrated in the Southern States were continued in Porto Rico and Nicaragua during 1921. In both countries control was sought by the use of top-minnows, supplemented in Nicaragua by drainage and in Porto Rico by drainage and oiling. In the latter Mr. H. W. Green, sanitary engineer, experimented with a local killifish *(Poecilia* *vivipara)* which seems to present most of the good qualities of *Gambusia affinis;* in laboratory experiments it ate an average of about fifty larvae a day (164).

Both the major ditches and even the smaller drainage ditches in the cane-fields were found to contain these native top-feeding minnows. The portions of the ditches which were free from algae and other vegetation and contained these minnows were found to be free from

Fig. 53. — *Poecilia vivipara.* Male (2 inches)

breeding. It was therefore decided to clean the ditches in some of the cane-fields and to stock them thoroughly with native top-feeding minnows obtained from a river which was drying up some four miles from Aguirre. Several thousand feet of ditches were cleaned and between 3,000 and 4,000 fish were placed in them. The results of the subsequent inspections of these fields showed that the fish were active and were eating the larvae as had been expected (98).

It was found, however, that when a field was irrigated many of the fish were lost; some of them swam to the shallow water near the cane stalks and could not return to the ditches when this water dried, others were washed through the field into the drainage ditches, while the remaining fish were redistributed along the length of the ditches. As the small drainage ditch dries, pools are formed in the deeper portions of the ditch. The small fish seem to concentrate in these pools and die if the pools dry completely.

It was calculated that in order to control breeding in the cane-fields by the use of fish, at least 10,000 would be required each month, which made control by this means impracticable since it was not possible to obtain the fish in such large quantities.

Culex larvae were found in artificial containers such as water barrels, tins, flower pots, rainwater cisterns, etc. The top-feeding minnow, *Poecilia vivipara,* was introduced into several barrels, but frequently escaped at night. The *Dormitator maculatus,* a bottom fish native to this country, was used with better success. However, something was constantly happening to remove the fish from the barrels.

The *Poecilia vivipara* has been observed aiding in the control work wherever the body of water was clean, that is, free from algae and an excessive growth of grass. However, with the aid of algae the larvae were able to escape from the minnows for days at a time and even to attain maturity. On several occasions as many as twenty minnows were introduced into a watering trough, but full-grown Anopheles larvae and even pupae were found in the algae mat in the tank some days after the introduction of the fish. In order to keep a tank free from algae it must be cleaned at least every two weeks. It should be allowed to dry completely before refilling. This is impossible in most tanks because the stock needs water frequently and it requires a long time to refill the tanks. It might be stated, however, that the general distribution of *Poecilia vivipara* keeps the number of Anopheles mosquitoes from increasing to enormous proportions.

The *Dormitator maculatus* was the only species of the larger fish that compared favorably in the laboratory with the top-feeding minnow as a larva-eater. The remaining species apparently were herbivorous and slow of movement. Experiments demonstrated that the *Dormitator maculatus* consumed even larger numbers of mosquito larvae under laboratory conditions than did the top-feeding minnows.

Fig. 54. — *Poecilia vivipara*. Female (1⅜ inches)

They seemed to prefer animal food, for under no circumstances would they eat the bread or cracker crumbs thrown to the minnows.

The *Dormitator maculatus* will live in artificial containers, such as water barrels, and keep them free from all larvae. Numbers of these fish were observed in the shallow water covering large reed swamps. They do not seem to require as much water as their size would indicate, for they are quite as satisfied to wriggle and jump in the shallow places as to swim in the deeper water. They are seldom found in water having a swift current, but seem to prefer bodies of standing water. The algae mat does not appear to impede them in their work of eating larvae, for they have been observed when hungry to search diligently for Anopheles and Culex larvae, forcing their way through masses of vegetation and even appearing at the surface of the water. The *Dormitator maculatus* is a great natural aid in the control of

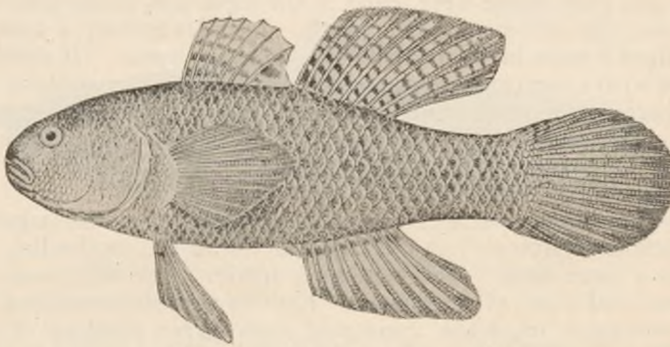

Fig. 55. — *Dormitator maculatus*

mosquito breeding and has been used with success in the control of breeding in artificial containers.

In July, 1921, 143 *Gambusia affinis* were received alive out of 2,000 shipped from the United States Bureau of Fisheries, Edenton, N. C. It is believed, however, that about 1,600 fish were lost during the transportation from the New York Aquarium to the steamship. Soon after their arrival, the minnows were placed in specially prepared reservoirs. The fish multiplied so fast that during the following four months the number increased to approximately 2,500. It was hoped to stock the larger bodies of water in this section of Porto Rico as soon as a sufficient number of pregnant females was observed.

The efficiency of the *Gambusia affinis* in the tropics is limited by vegetation and floatage. It was observed on various occasions that this fish was unable to prevent the development of Anopheles larvae in the mat of algae which grows with such rapidity upon the surface of the water in the tropics. The fish reservoir was constructed in the middle of July, 1921, but so much Anopheles breeding was found in the reservoir itself, that it had to be cleaned during the middle of October and again during the latter part of December (98).

Kinds of Fish Suitable for Use

All experimenters now agree that for mosquito control it is best to use indigenous fish. A special study must be made in each case of the kinds of fish available, their habits, and the conditions under which they are to be used. If an indigenous species is not used, the imported variety must be thoroughly acclimatized and allowed to adjust itself gradually to its new habitat. Smith warns against stocking ponds with fish that have not been thoroughly studied previously. They may prove to be dangerous enemies of useful fish. Larger predatory fish, if present, may destroy the needed larvivorous species, and if there are no fish present, the reason must be ascertained, as the water may be such that fish cannot live in it.

It is not sufficient to note that in the laboratory a certain species will eat mosquito larvae and to conclude from this that it will be useful in mosquito work. The habits of the species in the water into which it is to be introduced must be verified (4; 159). Whether salt-water or fresh-water species should be used must be considered. The United States Bureau of Fisheries offers aid to any one concerning the best kinds available for a given locality (141; 143; 180; 207).

The fish used for the destruction of mosquito larvae are ordinarily those found most abundantly in the regions in which the mosquitoes occur, usually tropical or subtropical. Among these are the min-

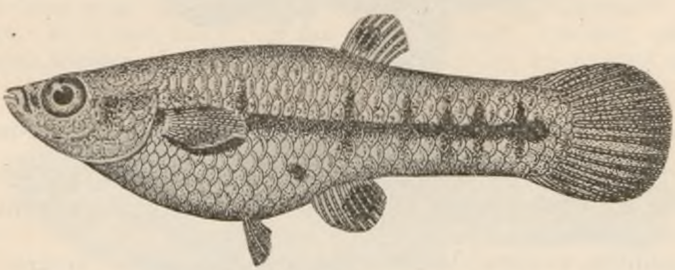

Fig. 56. —*Heterandria formosa* (¾ to 1 inch)

now or carp family (Cyprinidae) distributed throughout Europe, Asia, northern Africa, and North America, constituting the majority of fresh-water fish in those countries. They are all small fish and have been used to a limited extent. More extensively useful are the top-minnows, erroneously associated with the Cyprinidae or minnows.

Top-minnows belong to the order of Cyprinodontes. The important families are the Cyprinodontidae and the Poecilidae. The latter family includes the ordinary viviparous genera such as Gambusia and Lebistes. The former includes the ordinary oviparous killifish, e.g., the genus Fundulus.

There is general agreement that in the United States the most satisfactory fish for Anopheles control is some species of the top-minnow, or cyprinodontids. Seal, Hildebrand, and others recommend *Gambusia affinis* and its close cousin, *Heterandria formosa*. These are found only in the southern warm waters and it is doubtful whether they can become accustomed to northern waters. For the

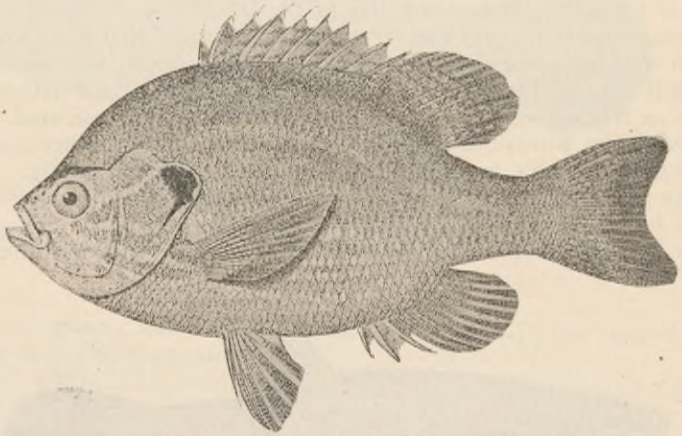

Fig. 57. — *Lepomis gibbosus.* Flat sunfish or "Pumpkinseed" (6 inches)

Atlantic coast there is the killifish or salt-water minnow, a natural mosquito-destroyer.

In addition to these, Mr. Seal mentions the goldfish, several varieties of small sunfish, and the roach or shiner, which is widely distributed. Goldfish are good for small ponds, but are lethargic, likely to grow too large, and, moreover, omnivorous and cannibalistic so that but few of the young survive. For some ponds the possibility of a combination of goldfish, roach, and top-minnow is suggested.

The little flat sunfish, or pumpkinseed *(Lepomis gibbosus)* has been thought of as good for general purposes. It abounds everywhere except in cold mountain streams, and, unlike the top-minnow, is spiny-rayed so that it is not so easy a prey for larger fish. It eventually grows too large, but the young remain small for a considerable time (115; 173).

The large-mouthed black bass has been recommended as of service in lakes and ponds. If it is of any use, it can only be in an indirect way. It is too large and voracious a fish to prey on the mosquito larvae, or even to hold down the numbers of such mosquito-destroyers as Gambusia where these small fish are protected by shallow water to which they can resort. It does hold down the number of fish of intermediate size such as the brook pickerel, which, if abundant, would deplete the Gambusia. A natural balance of this sort is found in some of the waters of the Florida Everglades (103).

The foregoing paragraphs apply to the United States. Each country has its own best native fish, which are mentioned under the name of that country in the account already given. In general the small fish of the families of Cyprinodontidae and Poecilidae, found in low altitudes in nearly all parts of the world, are the most useful. But there are other species that may prove as good. Though the practicability of introducing any species for mosquito control into other parts of the world is very much questioned, the natural fitness of a few species for the task makes them of special interest. Their qualifications at least are of the sort that should be looked for in seeking a suitable species of fish.

Fundulus heteroclitus. This is the barred killifish of the Gulf Coast and the salt marshes on the eastern coast of the United States. It has been used in New Jersey in control of the salt-marsh mosquitoes. It is also called the salt-water minnow, mudfish, cobbler, and mummichog. Most killifish are characterized by banded mark-

Fig. 58. — *Fundulus heteroclitus.* Common or barred killifish; also salt-water minnow, mudfish, cobbler, or mummichog (6 to 7 inches)

ings, rounded fins, a very convex tail fin, short head with obtuse snout, and lower jaws projecting. They reach a length of not more than six or seven inches. The male of *Fundulus heteroclitus* is about four inches long and is distinguished always by a number of transversely arranged bars of silver on the sides and a yellow or orange belly. The dorsal fin of the male bears a dark spot at the base of the last rays, which in the young male is divided into two blotches.

In the vicinity of New Brunswick, New Jersey, the spring migration of killifish toward fresh water begins as early as the latter part of March. Gravid females are found as early as the middle of April. The spawning season for older fish reaches its height late in May,

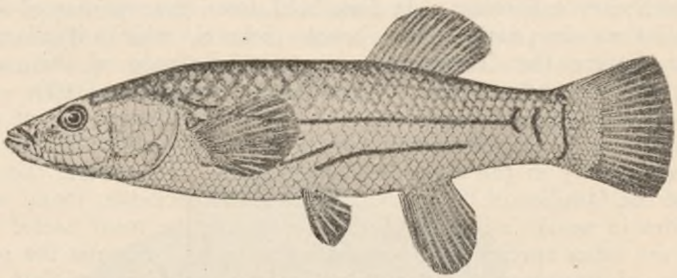

Fig. 59. — *Fundulus majalis.* Mayfish. Female (6 to 8 inches)

during which time the fish do not seem active and migration inland ceases. They react both to temperature and to a lowered salinity of the water. Through all the warmer weather, except two or three weeks in August, they move up into the fresher streams and pools. In September they migrate back to the salt water; large numbers of

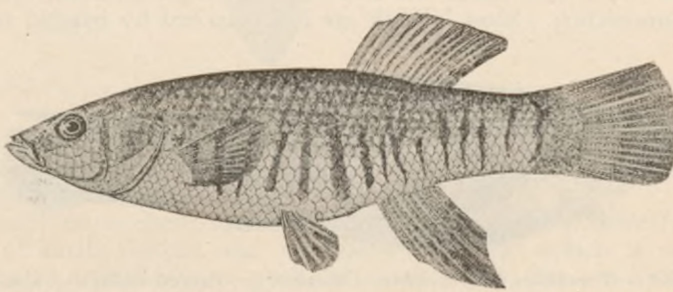

Fig. 60. — *Fundulus majalis.* Mayfish. Male (6 to 8 inches)

them go to the salt marshes and run in and out there with the tide until the colder weather comes. Where fish are retained in the pools and ponds of the marshes during the cold weather, they burrow in the mud to a depth of six or eight inches. Hardenburg in his book *Mos-*

quito Eradication (1922), states that the eggs are very resistant and that they sink into the mud at the bottom, which protects them.

Killifish eat mosquito larvae, pupae, and other water animals, and in the winter small quantities of algous matter and a few small shrimps. They jump out of the water to get food. The fish seizes anything with its mouth that appeals to it and spits out forcibly what is not to its taste. The vast hordes that migrate to the shallows and even into almost fresh water render the species especially formidable. The ease with which the Fundulus may be artificially fertilized and the remarkable vigor and resistance of the young embryos, make the stocking of pools and streams with this species a simple matter.

Its close cousin, *Fundulus majalis*, found in the same environment, moving in and out with the tides, has the ability to convey itself over land in the direction of salt water by flopping along. It does this, keeping its sense of direction, if caught in tide pools during a falling tide.

Gambusia affinis. In the United States there is a general consensus of opinion that various species of the top-minnow are best adapted to mosquito control and that among these *Gambusia affinis* takes first place. This is a hardy fish readily adaptable to many different natural conditions, as well as to life in an aquarium. It thrives in quiet, fresh, or brackish water, which may be very shallow, pro-

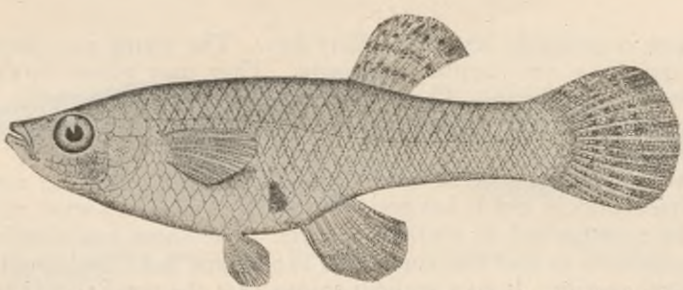

Fig. 61. — *Gambusia affinis*. Top-minnow. Female (2.5 inches)

vided it is not foul. If the proper amount of food is available it withstands a relatively high temperature. The food which it seeks at the surface of the water consists largely of insect larvae, though it sometimes eats its own kind, especially in aquaria. A medium-sized female has been known to destroy 165 large mosquito larvae in a single day. The Gambusia may be changed from fresh to salt water without apparent harm. In moderately cold weather it becomes inactive and ceases to feed. It is not a very active swimmer and becomes an easy prey to large fish when it ventures into deep water (107).

As it is viviparous, the young do not need a special environment. New broods occur every month or six weeks from about the latter part of April until October. Some broods number as high as 100, but the

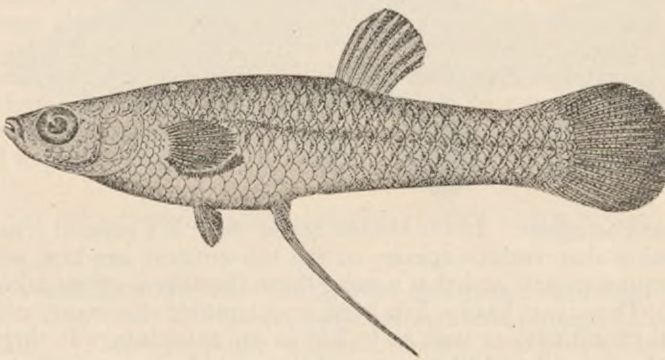

Fig. 62. — *Gambusia affinis.* Top-minnow. Male (1½ inches)

average is probably less than thirty-five. The young are about one half inch long, very active and hardy. They may attack larvae immediately after birth. The proportion of males to females is about one to eight or nine. Sometimes the early broods produce young later in the same season.

This fish is found in the Ohio Valley southward and as far north as southern Illinois, but it has not yet been determined to what extent it can be acclimatized to northern waters. The shore-line should provide shallows so that the young fish can escape from the cannibalism of larger species. It goes without saying that the pond should be free from bass, and other predatory enemies, among which is to be reckoned the water-snake (71; 114; 173).

Haplochilus. In India where fish have been experimented with to a greater extent than in any other place except the United States, one of the cyprinodontids has been found particularly useful. This is a genus Haplochilus, well suited to the peculiar conditions of tanks and reservoirs that supply water during the dry season.

Haplochilus feeds on living organisms near the surface. It has a flattened head and wide mouth, is more agile than millions, a better feeder, and is especially good for wells. Mr. R. B. S. Sewell says that observation of Haplochilus is very convincing as to its usefulness. He has never found it present where larvae were numerous. The Haplochilus is hardy, transferable, acclimatizable to brackish water from fresh water or vice versa. It breeds freely under various conditions. In captivity, three of these fish were sufficient to keep larvae from developing in an aquarium having a surface area of 3.75 square feet.

For other kinds of bodies of water in India, two Cyprinidae and some members of the perch family have been found useful.

Europe has found the goldfish very efficacious, particularly in artificial ponds and pools and more satisfactory than the imported millions. Italy and France recommend the carp in spite of its mud habits, though experiments with it have not gone very far (180).

The above applies chiefly to Anopheles control in the open. Entirely different fish, usually local varieties, are used in containers in yellow fever work. The life belonging to the genus Pygydium, is widely distributed in South America and is very useful.

Millions. Before it was properly classified this fish had several names, the most generally used being *Girardinus poeciloides,* but the proper title is *Lebistes reticulatus.* Because of its voraciousness this fish is a most active enemy of the mosquito. The natural breeding-

Fig. 63. — *Lebistes reticulatus (Girardinus poeciloides).* "Millions." Female (1½ inches)

places of millions are the small shallow pools where mosquitoes live. It is the only fresh-water fish on the island of Barbados.

According to H. A. Ballou the full-grown female is one and one half inches long and the male much smaller. The female is dull in color with no conspicuous markings, while the male has great splashes on the side and a circular black spot. They may also be distinguished by the position and prolongation of the anal fin. Breeding goes on throughout the year. Broods follow each other two weeks apart. The female is pregnant almost continuously, and a single impregnation is sufficient for a fertilization of several broods varying from twenty to twenty-five fish to each brood. They are viviparous. This enables a large proportion of the young to reach maturity, so that the fish increase with astounding rapidity. They also grow very quickly.

Millions live for the most part in water too shallow for the larger fish to enter and are therefore in no danger of attack. They feed on

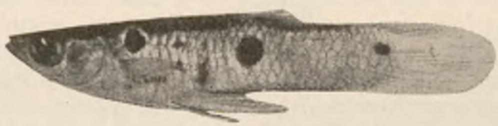

Fig. 64. — *Lebistes reticulatus (Girardinus poeciloides).* "Millions" (1 inch)

all kinds of animal life found in the water, and can swim up-stream and against a strong current. In Barbados they are much used in gardens to eradicate the mosquito nuisance.

Millions vigorously attack any small insect in the water or resting on the surface. It is probable that they prevent mosquitoes from laying eggs in the water. They survive a considerable amount of neglect in changing water and feeding.

In Ecuador it was found that these fish were too small to be used in the tanks, because they failed to attract the attention of careless people who scooped them out when dipping into the tank or barrel. They are more useful in cisterns and reservoirs where they are left undisturbed (12; 13).

Millions have been introduced successfully into several West India islands, and to some extent into the Philippines, but have not taken to temperate climates, such as England, northern Europe, or even Italy. They also refuse to live in certain tropical places such as Africa and India (12; 86).

Limitations of Fish for Mosquito Control

It is evident that fish are of no use where mosquitoes breed in tiny receptacles about dwelling-places, or in moist spots where the water is not permanent. Likewise there are wide areas aloof from human abode, where mosquitoes abound and where the problem of their control undoubtedly will tax human ingenuity. Fish are useful, however, on the margins of very large bodies of water. Le Prince cites an example of a lake twenty miles long and with several hundreds of miles of shoreline, and Carter mentions bodies of impounded water up to 10,000 acres, where fish have proved efficient.

If the body of water is neither too minute nor too enormously vast there are still other conditions to be met. It must be unpolluted and it must have shallow edges. This applies especially to pollution by chemicals, for certain mosquito larvae will live in water where fish will die in a few minutes. The water must be shallow because the only fish that will eat mosquito larvae are necessarily small and themselves the prey of larger fish; shallow edges enable them to escape their large carnivorous brethren. In small pools of water found in tropical climates the temperature is an added difficulty. At different hours of the day and night this varies to such an extent that most fish are unable to endure the changes. There is besides always the possibility that quantities of organic matter provide sufficient food for the fish so that they do not have to eat the larvae (116; 140; 209).

The chief obstacles to the successful use of fish mentioned by almost every writer on the subject are aquatic vegetation and floatage. A partly submerged lily leaf, when used as a raft by larvae, is enough to place them out of reach of the fish. Swamp areas choked with grass cannot be cleared of larvae by fish, and the same applies to waters covered with algae or floatage.

Mr. W. P. Seal thinks that aquatic gardens are a special source of danger. These beautiful plant clusters carefully tended for esthetic effect breed thousands of mosquitoes that under given conditions no fish can successfully combat (173; 181).

In general, anything that hurts the fish or hinders them from eating larvae reduces the efficacy of fish control. Success varies with the adaptability of fish to the area in which they are used and with the skill and patience by which man is able to protect and aid them. The fish can be protected from predatory species either by providing shallows or by removing the enemy. It is also sometimes necessary to put up a sign or otherwise protect them from fishermen who would use them as bait. Wherever larvivorous fish and larvae are found living together under natural conditions the reason generally is simply that the fish cannot gain access to the larvae. In certain parts of the United States an alliance between fish and cattle has been suggested, the latter being placed in a field containing ponds to keep the vegetation cleared around the edges. With regard to this use of cattle it seems probable that the hoofprints made in the soft ground would soon be breeding larvae in quantities, which no fish could reach.

With regard to the difficulty of vegetation and floatage, Dr. Carter remarks that some fish (as Gambusia and Fundulus) will work into a fairly dense growth and give a good percentage of control. Much

Fig. 65. — Seining top-minnows for use in stocking other waters to control mosquito breeding

depends on the nature of the vegetation. Plants with single, stiff stems at the water's surface offer little obstruction to fish control — unless they are extremely close together (like a bunch of bulrushes). Plants with flexible stems much longer than the depth of the water, the tops of which float on or just under, the surface as a dense mat, may give *absolute* protection. Some of the worst are the wild celery *(Vallisneria spiralis)* as it occurs in bights of the Potomac, and *Naialis flexibilis* in ponds in north Alabama. The silver leaf grass *(Hydrochloa carolinengis)* in ponds in Georgia and South Carolina though bad, is less of an obstruction. The ordinary water-lily rarely gives much protection, while the dying pads of the American lotus hold water in the cavity of their upper surface like boats and thus protect larvae. The burr reed *(Sparganium americanum)* found near Birmingham, Alabama, and in the southwest part of Virginia (east of the Blue Ridge) is very bad for a short time in spite of its stiff straight stems. The seeds — much like those of the wild garlic — fall into the water in September and October, and spread out as a floating mucilaginous mass, catching all kinds of small floatage and specks of alga, which grows well on it, and furnish a perfect protection for larvae against fish.

He also adds that his experience has been that the breeding in the tracks of cattle about the edges of ponds much overbalances the good they do in keeping vegetation down about the edges of the water. And naturally cattle have no effect on the trash on the pond, which also protects the larvae. In the Canal Zone they were (and are now) regarded as doing only harm.

Advantages of Fish Control

According to Dr. H. H. Howard, among the several measures most frequently employed for mosquito control, drainage unquestionably occupies first place as regards efficiency and permanency of results. It is likely that figures could be adduced to show that ultimately in the majority of instances it would be the most economical measure. It is not often possible, however, at the present stage of mosquito eradication work to secure funds to meet the initial cost of a comprehensive drainage program in areas of large extent, and it is not practicable to elaborate an effective plan of drainage for small areas, because of the fact that streams and natural drainage channels, which must be handled as a whole, generally extend far beyond the limits of a small area.

It is the impossibility of attaining the ideal which has led to other methods, of which oiling, probably the most temporary of all in its results, has been considered the most effective under favorable conditions, and has consequently been the most widely used. The value of this method should not be underestimated, yet with the price of oil high, and with very high labor costs for its distribution and the preparation and maintenance of field conditions necessary for its successful use, due consideration should be given to less expensive and possibly more permanent measures of control, especially when operations in large areas are contemplated.

Moreover, oiling is transient in its results, and its effectiveness is subject to definite limitations which are often lost sight of. Mr. J. A. LePrince, for example, notes that it is inadvisable to oil just before rain-storms or during rainy periods and that a film will not penetrate a barrier of grass or move around similar obstacles. Wind will break up the oil film and transport it to or near the shore of the body of water. These limitations can be overcome only by constant inspection and supervision. Oiling, though by some considered secondary to drainage, is insufficient.

Compared with it the use of fish is less expensive. Top-minnows, where native, cost nothing except the labor of capture and transportation. The petroleum mixture used in Hinds County, Mississippi, consisted of three parts kerosene and one part crude oil, at a maximum cost of 18 cents per gallon, f. o. b. Oil must be applied every seven to ten days in dry weather, and oftener when there is wind or rain, whereas one stocking with minnows in a permanent body of water will suffice for an indefinite period. The second season finds the fish more firmly installed and doing better work than during the first season.

For both oil and fish, vegetation must be removed. Dr. Howard thinks that the preparation of bodies of water for oil and fish cost about the same, but that fish can sometimes maintain an effective control in the presence of débris and vegetation which would render oil useless.

Fish control is less liable to accident such as destruction by winds, rain, or waves — natural phenomena that frequently interfere with the use of oil, but have no harmful effect whatever on the use of minnows.

Fish control is more enduring in its results. If oiling is discontinued, no lasting benefits accrue from its previous use, whereas fish, unless disease, natural enemies, or other unforeseen causes should lead to their extermination, operate indefinitely (114).

Summary

Fish as an agent for the control of mosquitoes have been tried in a desultory way on every continent and in a large number of countries, but only in the United States and South America has definite scientific progress been made, although in India important investigations were interrupted by the war and are now being continued.

If a body of water in which mosquitoes breed is permanent, not chemically polluted, nor obstructed by vegetation, there seems to be no reason why the right kind of fish may not be extremely useful for mosquito control.

The use of fish in South America against the yellow fever mosquito was a complete success because the water-containers to be dealt with were obvious and at all times subject to human control. Under these conditions fish proved themselves savage and efficient enemies of mosquito larvae.

Similar conditions exist in limited natural areas not too large to be successfully patrolled by men. In Mississippi it was shown that in bodies of water cleared of vegetation, properly edged, and amply stocked with the right fish, no mosquito larvae survived. As a consequence the malaria index went down.

However, it is stressed by all that floatage and vegetation must be restricted or the fish cannot reach the larvae. In this connection the suggestion is of interest that Anopheles are perhaps averse to breeding in exposed water with open edges and no vegetation (116; 196).

There is general agreement among workers in all quarters that indigenous fish are best. The importation of fish from other regions has frequently been a failure, and in each case not so much because of transportation difficulties as because of difficulties in acclimatization. As a rule fish are carefully adjusted to their home environment and unlikely to thrive outside of their established habitat. There is also general agreement as to the best kind of fish to choose. Experience has shown that small fish belonging to certain widely distributed families, prominent among which is the top-minnow, are likely to give best results for Anopheles control. For the Stegomyia, bottom-feeders of various kinds are preferred.

Fish control is not a new method. But certain carefully controlled experiments capable of demonstrating its limitations and its advantages have only recently been made. There is ample controversial literature, more extensive than important, for most of it rests on slender scientific footing. This period of groping and of desultory opinions based on speculation rather than facts is now practically over. Within limits, "perhaps not so narrow as may be supposed," the method is ready to take its place as a recognized auxiliary means of both yellow fever and malaria mosquito control.

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