

WORLD HEALTH  
ORGANIZATION



Regional Office  
for the Eastern Mediterranean

ORGANISATION MONDIALE  
DE LA SANTÉ

Bureau régional  
pour la Méditerranée orientale

TRAVELLING SEMINAR ON THE USE OF  
LARVIVOROUS FISH FOR MOSQUITO  
CONTROL IN ANTI-MALARIA CAMPAIGNS

EM/TR.SMR.LRV.FSH.MSQ.CTR/7.3 SUDAN

July 1979

Bulgaria/USSR - 27 August - 15 September 1979

Agenda Item 7.3

The Biology of *Gambusia Affinis* and Its History  
As an Exotic Species in Sudan with Respect to  
Other Indigenous Larvivorous Fishes

by

Dr T.T. George\*

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\*) Fisheries Research Centre, Agricultural Research  
Corporation, Khartoum

## INTRODUCTION

The use of fish for mosquito control as biological control agent was recognized in Sudan as early as 1929. But the interest in such larvivorous fish suffered with the advent of HCH, DDT and subsequent fast-acting insecticides. Recently, however, attention is being given to fish as biological control agents, mainly due to the fact that chemical control by insecticides has become less effective, owing to the appearance of resistance in mosquito (Haridi, et al., 1973).

Gambusia affinis, an exotic species, is the only fish used so far in the Sudan for mosquito control. For this reason, a detailed account on its biological characteristics, its history, cons and pros as an exotic species is given in this paper; also, the possibility of using other indigenous fish species as biological control agents is discussed.

## BIOLOGICAL CHARACTERISTICS OF GAMBUSIA

The name Gambusia is derived from the Cuban word, "gambusino", which means "nothing". Gambusia affinis (Baird and Girard), a predator poeciliid, top-minnow commonly known as mosquito fish, is one of at least 30 species of the genus Gambusia, and it is distinguished from all these related species by having the dorsal and anal fins with soft rays only (spines absent), the dorsal fin originating behind the anal fin and a rounded caudal fin. In both sexes, the body is pale grey with a blue metallic sheen. The belly is silver and the back, or dorsum, is brown or olive green. In many cases, there is a dark, transeverse bar across the eye.

Gambusia affinis occurs as two sub-species, Gambusia affinis affinis and Gambusia affinis halbrooki. Both sub-species are almost identical in colour, form, and size, except that Gambusia affinis halbrooki has eight rays in the dorsal fin and not seven, and also its third ray of the ventral fin shows a deep split, when examined under the microscope (Innes, 1956).

The sexes of both sub-species differ in form and structure (fig.1). Females have a deeper body than males and may reach a length of 2.5 inches, while males do not exceed 1.5 inches. Both sexes have, frequently, a faint dark line along the sides, sometimes a dark blotch below the eye, and usually a dark purplish blotch on the side above the vent in the female. The female has a caudal fin with three or four irregular transverse rows of dark spots, and a dark-eyed, small, rounded anal fin with rays connected by a membrane the male has the third, fourth and fifth anal fin rays united and lengthened for form the sexual organ or gonopodium. Gambusia has a closed swim bladder, a short oesophagus and a small intestinal opening; also, they have pseudobranches, which are presumably being used for surface respiration.

*Gambusia* are found in many types of water and tolerate a wide range of temperature and oxygen. They thrive in a wide variety of water types, including fresh or brackish, clear or muddy and shallow or deep; it is seldom found in swift-flowing streams. They show a distinct preference for shallow water, where they are protected from predaceous fish and where food and vegetation are more abundant. *Gambusia* are very hardy (Hildebrand, 1919) and could survive in the harsh microcosm environments at temperature from 25 to 36°C and pH between 7.5 and 10.3. They hibernate in the lower water depths in cold water environments, and are rarely seen until the spring, when water temperature becomes increasingly warmer. They are suited for occupying habitats subject to periodic oxygen depletion because their dorsally-oriented mouths and flattened heads enable them to effectively utilize the oxygen-rich water at the air-water interface without dramatically altering its usual swimming posture. *Gambusia* are secondary consumers which feed primarily on zooplankton and aquatic insect larvae (Maglio and Rosen, 1969). In addition to mosquito larvae, they are voracious feeders, consuming over 50 types of plants and animals, such as cyclops, chironomid larvae, nematodes and other planktonic forms. About 20% of the diet is plant material, primarily blue green algae, diatoms and desmids. They are cannibalistic, consuming their own young as well as the young of other larvivores and game fishes (Meyers, 1965).

*Gambusia* are ovoviviparous, giving birth to successive smaller numbers. After the male deposits sperm in the genital tract by using the gonopodium, the eggs get fertilized and the female is then able to produce several broods of young without further contact with a male. The fertilized eggs hatch with 23 to 24 days in the body cavity of the female and the young lie folded with head and tail meeting. They are delivered in this form at birth, either one or two at a time. Immediately, they straighten out and swim. Parturition, or the time required for a single brood to be born, will take 30 to 60 minutes (Kumbloz, 1948). On the average, 3 to 4 broods will be produced and, depending on the size of the female, the number of fry per brood may average from 40 (Hildebrand, 1921) to 104 (Hoy and Reed, 1970), although broods of 300 or more may occasionally be encountered.

The natural range of *Gambusia affinis affinis* extends from the Gulf of Mexico through the Mississippi River Valley and its tributary waters as far north as Central Illinois. *Gambusia affinis halbrooki* ranges from Southern New Jersey along the Atlantic Coast to Florida keys and along the Gulf of Mexico to northwestern Florida (Dees, 1961). This sub-species is unable to survive northern winters (Wascko, 1950).

*Gambusia* have been introduced into many countries, because of its:

- i) larvivorous habit;
- ii) characteristic high density
- iii) small size

- iv) overlapping generations within a season, allowing for rapid geometric increase;
- v) live-bearing habit;
- vi) brood tolerance for temperature, oxygen, pollution and alinity;
- vii) wide range of diet;
- viii) starvation endurance;
- ix) feeding on all immature stages of mosquitoes; and
- x) hardiness and tolerance during transportation.

Thus, their natural range has expanded and it has attained worldwide popularity as an effective larvicidal fish (Krumholz, 1948; James et.al. 1970).

#### HISTORY, PROS AND CONS OF GAMBUSIA AFFINIS HALBROOKI IN SUDAN

In Sudan, the Gezira irrigated area is considered as a big, permanent mosquito-breeding ground producing malaria vectors, An. arabiensis as well as non-vector mosquitoes. This is a vast irrigated scheme, with over a million acres of canalized land situated in the southern part of the Blue Nile Provinces within the Savannah belt. The main transmission season is from July to November, but, owing to year-round irrigation, creating favourable micro-climatic condition, transmission to perneal (Haridi, et al. 1973).

Gambusia affinis halbrooki was introduced into Sudan in 1929, from Italy through Egypt, by Dr Khalil as an anti-mosquito biological measure for the Gezira scheme. Since then, these larvivorous fish have continued to breed in a concrete tank within the Civil Hospital, and, later on, in the ponds maintained at the Medical Engomology Section at Wad Medani. Dr J. Lewis, the then Medical Entomologist, carried out some work on the culture of Gambusia in the ponds, but, with the advent of chlorinated hydrocarbon insecticides, work on Gambusia was abandoned. However, work was revived when it was realized that An. arabiensis had developed complete resistance to these insecticides. New raising ponds were established at the Malaria Office at Wad El Naim, and Hamid Dirdiry (Ministry of Health) started work, for the first time, in four minor canals in 1970. He found that there was reduction in mosquito larvae in the seeded canals. This preliminary work was followed by E.L. Humphrey (WHO Technical Officer) beginning in 1972, and a total of 121 minor canals were seeded up to 1973 with a total of about 120 000 fish (Motabar, 1973; Mahmoud, 1973). However, the work undertaken, in this respect, using Gambusia affinis halbrooki, is accounted for in greater detail by Haridi (1979 Unpubl.). According to him, "the role of Gambusia in the control of the Malaria vector An. arabiensis is not clearly defined yet".

In September 1974, the author accompanied Dr G. Kovchazov (WHO Expert) and Mr Mahmoud (Ministry of Health) to the Gezira Scheme, and carried out a fishing survey in the minor canals already seeded with Gambusia. It was found that indigenous fishes, such as Lates niloticus, Clarias angularis, Barbus byani and Sarotherodon niloticus (Tilapia) occur in the minor canals and that the number of Gambusia was appreciably far less, when compared

to the initial stocking. According to Mahmoud (1973), "non-survival may be due to inadequate initial seeding or to recent aerial spraying of insecticides or turbidity of the water". According to the author, the reason may also be attributed to the probability that *Gambusia* could not withstand competition with the local fish fauna occurring in the canals, particularly in the presence of the carnivore Lates niloticus and Clarias angularis, or else is affected by the copper sulphate ( $\text{Cu SO}_4$ ) used for killing the snails of schistosomes. James et. al. (1970) stated that copper sulphate, if used above the rates recommended for algal control, can result in high mortality of *Gambusia*.

In many situations, dense vegetation provides adequate protection for larvae and pupae, and hence good control by *Gambusia* may not be obtained. Valle (1929) noted that *Gambusia* was only 20% effective, where heavy aquatic vegetation was the prime factor. However, this problem may be overcome by the fact that the Fisheries Research Centre has recently introduced the grass carp, C. idella and the common carp, C. carpio, which, in a small experimental scale in a minor canal (Souriba 3), proved to be very successful for the thinking it is necessary to modify the environment of such an aquatic situation in order to magnify the effectiveness of *Gambusia* as a larvae predator. This can be accomplished by removing the vegetation, increasing the number of fish by stocking, providing places of refuge or eliminating natural fish predators. In Morocco, mosquito fish in excess of 20 per square yard offered excellent control in warm weather, but allowed extensive breeding when temperature fell below  $5^{\circ}\text{C}$  (James et. al., 1970). In the Sudan, the stocking rate has not yet been determined and, therefore, future experimental work should take this into consideration.

On the other hand, commercial fish farmers look upon *Gambusia affinis* as an undesirable "pest", which may threaten the existence of game fish species by feeding on their young fry (Meyers, 1965). Dr D. Rosen of the American Museum of Natural History and Dr P.H. Greenwood of the British Museum were opposed, as are most ichthyologists, to the further distribution and introduction of the poeciliid top minnow *Gambusia affinis* into habitats where it did not exist. This was because *Gambusia* is so successfully adaptive and so competitive that it often eliminates indigenous small fish populations where it is introduced, and drastically alters the composition of the aquatic community (Bay, 1972). In the Conference on the Safety of Biological Agents for Arthropod Control (WHO/VBC/73.1), it was stated that there are strong indications that *Gambusia*, in particular, is a very real danger to other fish; it may pose a serious danger to the local native fish, both small and large, and until there is more fundamental research, great care should be exercised in its introduction.

Realising these facts, the author introduced, for the first time, in August 1974 a consignment of 500 fish in a pond at the Shagarra Experimental Farm and studied the

compatibility for this fish with the indigenous fish fauna. From this study and other field observations, the author understood the possible impact of *Gambusia* on the local and other exotic fish species, and has already passed a note to the Fisheries Administration Department to restrict further trials for seeding the minor canals and even eliminate this species. This is because *Gambusia* may pose a serious danger to the local fish fauna on chance entry into the natural water systems. However, since *Gambusia* is well established in the Sudan, eradication may not be possible, but it is strongly recommended that care and surveillance be maintained in order that his fish can best perform the function for which it was introduced. Furthermore, it is recommended that local fish species be studied to determine their effectiveness as larvivores, and experimental comparison be made with *Gambusia*.

#### POSSIBILITIES OF USING INDIGENOUS FISH SPECIES AS LARVIVORES

In the Conference on the Safety of Biological Agents for Arthropod Control (WHP/VBC/73.1), it was mentioned that "most non-desert regions within the tropics already possess a number of small larvivorous fish species. Often, or usually, each of these is restricted ecologically to certain types of habitat, within which it may be the most effective larvivore. These species should be studied in order to determine their effectiveness, and experimental comparison should be made with the exotics proposed for introduction".

The author is in full agreement with these facts and has already made comparative studies on one of the indigenous species and the exotic *Gambusia affinis halbrooki*. *Sarotherodon niloticus* (*Tilapia nilotica*) is the most common species in Sudan, and occurs in all three rivers, the White Nile, the Blue Nile, and the Main Nile. It has oblique alternating rows of light and dark spots on the dorsal and anal fins, and numerous narrow cross-bars on the caudal fin. Laboratory experiments and field observations indicated that *Sarotherodon niloticus*, when young, are very effective larvivores. Sandon *et. al.* (1953) mentioned that the young of *Sarotherodon niloticus* eat mosquito larvae, and thus can be of value in mosquito control. At a stocking rate of 2 500 to 5 000 per hectare, *Sarotherodon niloticus* controlled filamentous algae, a principal habitat for many species of mosquito larvae (Bardach *et al.*, 1972). As a matter of fact, no mosquito larvae were found in the ponds of the Shagarra Experimental Fish Farm, when stocked with *Sarotherodon niloticus*. The author strongly recommends the use of this species in the Gezira scheme; a hatchery of its propagation to seed the minor canals intensively with its fingerlings every year should be established at Wad Medani.

Research on other indigenous minute-toothed carps, or top minnows species of the family Cyprinodontae, should be initiated to determine whether some species can become an effective mosquito control tool. In Sudan, the species of this family fall into two

genera distinguished as follows:

- A) Epiplatys: Preorbital bone (i.e. bone just in front of the eye) very narrow, less than half diameter of eye; vomerine teeth present; pectoral fin set low down, below middle of side.
- B) Aplocheilichthys: Preorbital bone wider; vomerine teeth absent; upper end of pectoral fin above middle of side.

Genus A is represented by two species:

- i) Epiplatya marnoi (Steindachner 1881) (Fig. 2) is easily recognized by the presence of about 12 bold oblique dark stripes on the sides of the body and on the caudal fin. In some, presumably males, the caudal, anal and pelvic fins are tinged with bright yellow. The caudal fin is slightly longer than the head and is variable in shape, being sometimes rounded and sometimes more pointed. Boulenger (1907) mentioned that the maximum length is about 40 mm., but in the Sudan, they appear to be fully grown at about 30 mm.
- ii) E. bifasciatus (Steindachner 1881) is a very similar fish but its markings consist of two parallel dark horizontal bands running along the sides of the body. The caudal fin is rather longer, slenderer and more pointed than in E. marnoi and it is said to grow up to 45 mm. in length.

Genus B is represented by four species:

- i) Aplocheilichthys loati (Boulenger 1901) is one of the smallest fish known, its maximum length being only about 25 mm. The caudal fin is more rounded than that of either species of Epiplatys, and the snout is very short, its length being equal to only about one half the diameter of the eye. A very fine black line runs from the base of the caudal fin to that of the pectoral fin. Otherwise the colour is very pale, except that the outlines of the scales are delicately indicated by minute black dots.
- ii) A. hutereaui (Boulenger 1913) differs from this, most obviously, in having the pigment aggregated into spots on the hind dorsal and anal rays.
- iii) A. kingii has a few spots, like those of A. hutereaui, in the male and is otherwise distinguished from the other species by the smaller number of its scales and anal fin-rays, and by the slightly more anterior position of the first dorsal fin-ray.

These three fish species are found mainly in the Upper White Nile and can further be distinguished from each other by the following distinctive features:

	<u>A. loati</u>	<u>A. hutereaui</u>	<u>A. kingii</u>
Scales in longitudinal series behind head, excluding any on caudal rays	25 - 27	23 - 25	25 - 27
Dorsal fin-rays	7 - 8	(6) 7 - 8	5 - 6 (7)
Anal fin-rays	12 - 13(14)	13 - 16	11 - 12
Anal ray vertically below first dorsal ray	7th - 9th	7th - 9th	one of last three

iv) Nothobranchius ? (Sandon 1950) mentioned that an unknown species of Nothobranchius ("Fundulus") has appeared in a new hafir near Gebel Migeinis, its natural home being presumably somewhere in the Nuba Mountain.

Also, Electris nanus (Boulenger 1901) the only representative of the family Eleotridae, which was formerly included among the Gobies (Gobiidae), may be a larvivore. It is a slender little fish reaching only some 38 mm. in length. Its length is about 4 times its depth. It is a little, if at all, compressed; has a caudal peduncle about twice as long as it is deep, and a slightly projecting lower jaw. The two dorsal fins are well-separated and very different in shape, the anterior one having only 5 very slender rays, whereas the posterior one has 10. The caudal fin is rounded. The general colour is greyish-olive, changing to pinkish on the under-side, with some irregular darker markings, vertical bars, marblin and dots on the head, body and fins. It is a rare and tiny fish recorded by Boulenger (1907) from the White Nile. Pekkola (1918) states that it was common in Khor, near Tonga, and at Gebelein.

Other tiny riverside fishes which may be tested for their effectiveness as larvivores are Andirsonia leptura, Chelaethiops bibie, Barbus stigmatopygus, Nannaethiops unitaeniatus and Cromeria nilotica.

Andirsonia leptura (Boulenger, 1900) is a tiny fish from the family Mochocidae, easily recognised by its exceptionally slender caudal peduncle. It is regarded as a great rarity, but Pekkola (1918) mentioned that it is not uncommon, in many places, in the Upper White Nile.

Chelaethiops bibie (Joannis 1835) and Barbus stigmatopygus (Boulenger, 1903) are species within the family Cyprinidae:

C. bibie is distinguished by the rather strong compression of the body, and the deep curved ventral surface, which is appropriately compared with the keel of a ship. The first ray of the dorsal fin is well behind the first ray of the anal; the pectoral fins, small, and the caudal fin, lobed. The colour is pale, with a straight horizontal line running forward from the caudal peduncle, and gradually fading out before reaching the operculum. This tripe must not be confused with the lateral line, which, being situated low down on the whitish ventral part of the

body, is very difficult to see, even with a lens. Maximum length is about 55 mm. It has been found at many places along the Nile and White Nile, sometimes in considerable numbers, but its occurrence seems to be very erratic. The long straight dorsal surface, and sharply upturned mouth, mark this fish as one that lives and feeds at the surface of the water.

B. stigmatopygus is distinguished by the absence of the adipose fin, by the fact that the dark horizontal band is reduced to a fine black line and by the presence of three large black spots on this line, and a fourth at the base of the anal fin. Occasionally, additional spots are present. It should be noticed that the dark lateral stripe is not a true lateral line, as it is not formed from sense organs but is merely a line of pigment. The real lateral line is much reduced and is difficult to see. The maximum length of the fish is about 24 mm.

Nannaethiops unitaeniatus (Günther 1871), the only representative of the genus Nannaethiops within the family Citharinidae, is a tiny tropical fish found in Sudan only in the Upper White Nile; it is common at Tonga. It can be readily distinguished from the little Cyprinid and Cyprinodont fish, with which it is commonly associated, by its rather deep and compressed body, very small adipose fin and by the single straight horizontal line running the whole length of its body right up to the snout. The colour is very pale and, in spite of the small size, a slight roughness to the touch indicates that the scales are strongly ctenoid, a fact which can otherwise only be demonstrated with the aid of a microscope. The gill membranes are free at the isthmus. Its length is about 60 mm.

Cromeria nilotica (Boulenger 1911), the only representative of the family Cromeriidae, is a little creature no more than about 32 mm in maximum length. The body is elongated, compressed, naked, practically transparent and colourless, apart from a narrow lateral stripe. The head and mouth are small and the latter distinctly inferior and toothless. The dorsal and anal fins are both short and posteriorly situated. It can easily be mistaken for a very young immature specimen of some other type of fish. It is rather rare, being found only in the Upper White Nile.

#### DISCUSSION

In the Sudan, the Gezira minor canals are heavily infested with aquatic weeds, which interfere with water flow, provide breeding and nursery habitat for malaria-carrying mosquitoes and harbour the vector snails Bulinus sp. and Biomphalaria sp. of schistosomiasis, serious major health problems. The network of these canals provide the sole source of water to most of the people for drinking, cooking, bathing and washing clothes, hence, herbicides to eradicate these aquatic weeds is not advisable. Besides, adding chemicals to the water in these canals for eradicating mosquito larvae and Bilharzia snails is

not also much favoured. Because of this situation, and the fact that chemical control by insecticides has become less effective, owing to the evolution of resistant mosquito strains, control by biological means has become inevitable.

Biological control agents are provided by mother nature, and, if perfectly utilized will exhibit no environmental harm, unlike the use of chemicals which have, in some cases, resulted in harmful side effects on the environment and, in other cases, unknown, long-term side effects. However, the use of exotic fish species in biological control measures, if not carefully selected, may pose serious problems for the environment, particularly for the local native fish (George, 1975). This is because once a fish, is introduced, the result be undone, ore repaired, as with a chemical accident; it is a permanent thing, and its impact on the native fish goes on throughout time (WHO/VEC/73.1). Therefore, the following guidelines for introduction of exotic species, as proposed by Lachner et. al.(1970), should be strictly takne into consideration:

- i) It should be objectively determined that there is real need for a proposed introduction, and it should appear likely that the introduction will have desirable ecological, recreational and economic impact.
- ii) The introduction should fill a definite vacant ecological niche, one not filled or suitable for a native species. The probable existance of such a niche should be reasonably well-documented.
- iii) An introduction should not be considered if there is any danger, even apprehension, over the action leading to drastic reduction or regional displacement of indigenous populations
- iv) Studies of the ecology of the animal considered for relaease should precede and guide introductions. Studies should, likewise, be made to determine the suitability of the proposed release area.
- v) Every effort should be made to study disease interrelationships, and to take steps for assuring effective quarantine procedures
- vi) Small trial introductions in suitable areas, using adequate numbers of stock should first be conducted on an experimental basis under controlled conditions. An evaluation of this introduction should serve as a basis for further action.
- vii) Before an exotic is introduced, positive assurance should be obtained that adequate control methods can be instigated to prevent overpopulation or spreading.

In Sudan, the introduction of the exotic Gambusia affinis halbrooki certainly does not comply completely with these guidelines, hence a danger exists for the environment. However, there is still a need for a real body of careful research on the impact of this species on the environment. Meanwhile, it is necessary to conduct research on the effectiveness of the indigenous species already referred to in this paper. This is because species of the African genus, Nothobranchius, for example, are "annual fish" and hence the ability to survive periods of drying in the egg stage, the eggs hatching when

innudated. Bay (1965 and 1967) has reported on research into the possibility of adopting these fish for controlling mosquito larvae in California. Also, Heldman et. al. (1963) called attention to such a group of annual fishes, since a number of species have a potential for controlling mosquitoes and also can pass the dry season as eggs. Vanderblank (1941) pointed the advantage of Nothobranchius as a larvivore over the widely known and extremely distinguished Gambusia. Haas (1965 and 1966) has prepared detailed instructions for rearing the East African N. guentheri in the laboratory and outdoors. Kovchasov et. al. (1967) has conducted laboratory and field studies on annual fish. Also, Welman (1948) has suggested the use of E. marnoi as an agent in mosquito control, and recommended their consideration as larvivore for employment in tropical and sub-tropical regions.

In this paper, all the characteristic features of the indigenous fish species in Sudan that are likely to be effective larvivores are mentioned as they appeared in the book by Sandon (1950). This is because this book is now out of print and research to identify these species for malaria control by enthusiastic scientists should not be handicapped.

#### RECOMMENDATIONS

The complex nature of the malaria problem and other public health hazards in the Gezira Scheme demands the co-operation of scientists from different disciplines at the local, national and international levels. Besides, for effective control of mosquito larvae by biological measures, a four-year project should be started, where laboratory research provides the foundation for field research and support those modifications and improvements which operational parameters may require. In this project, it is necessary to:

- i) undertake ecological surveys for predatory evaluation in the minor canals of the Gezira Scheme;
- ii) undertake studies to evaluate the impact of pesticides and other chemicals on the ecosystems, in particular residues in lethal as well as sub-lethal doses in fish;
- iii) conduct studies on the effect of blood water on the larvivorous fish in the Gezira canals;
- iv) conduct more studies on the ecology, behaviour and stocking rates of Gambusia affinis halbrooki and its impact on the environment; if these studies further confirm that this exotic species is harmful, it should be eradicated immediately;
- v) use Sarotherodon niloticus in mosquito control operations and establish a hatchery for its propagation to seed the minor canals with its young;
- vi) study other local fish species, make experimental comparison to determine their effectiveness as larvivores and combine them together in the same ecosystem;

- vii) observe all the guidelines necessary for introduction of any exotic species and confine all trial introduction sites to closed water systems of manageable size; also facilitate early eradication of the species introduced should it shows signs of becoming a pest.

ACKNOWLEDGEMENTS

The author is deeply indebted to Dr A.H. Taba, Regional Director, WHO Regional Office for the Eastern Mediterranean, for his invitation to participate in, and present this paper to, the Travelling Seminar on the Use of Larvivorous Fish for Mosquito Control in Anti-Malaria Campaigns, and Prof. H.O. Burhan, Director-General, Agricultural Research Corporation, for approving participation in this Seminar.

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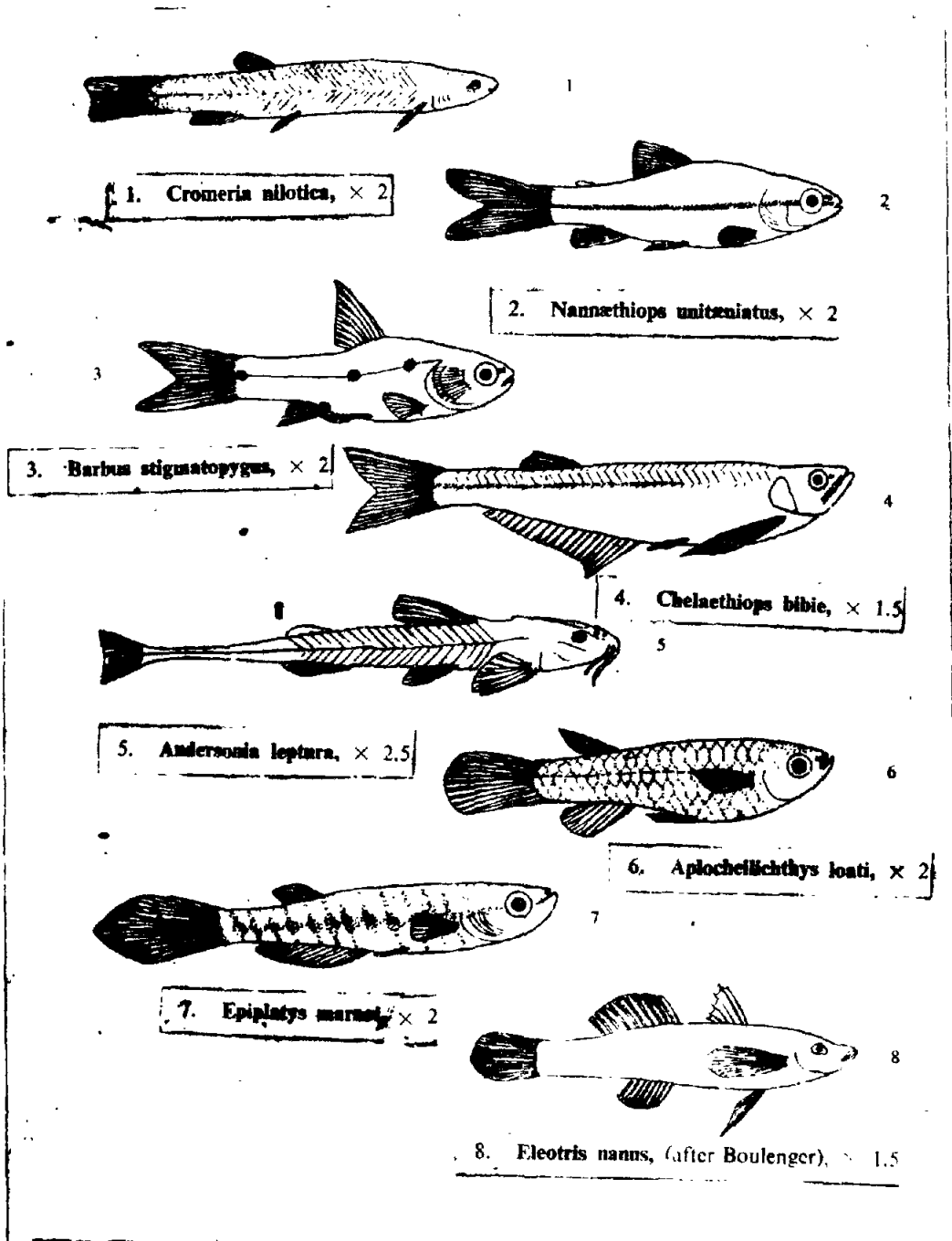


Fig. 2 Tiny Riverside Indigenous Fishes (after Sandon, 1950)

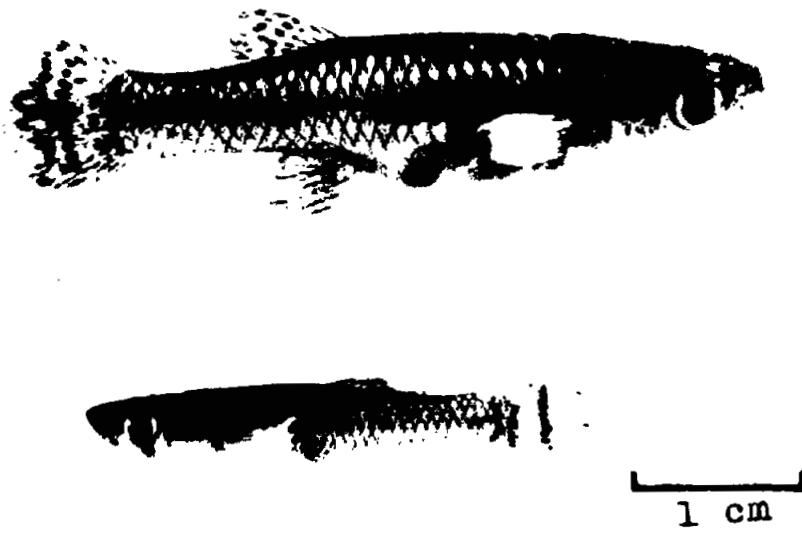


Fig. 1 Male (lower) and female (upper)  
Gambusia affinis halbrooki  
(scale 1 cm)