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Ecological studies on crater lakes in West Cameroon Lakes Kotto and Mboandong

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(With 6 figures in the text)

Lake Kotto is a shallow crater lake, sometimes weakly stratified, and with a dense phytoplankton dominated by blue-green algae. The ecology of Lake Kotto and the similar, smaller lake Mboandong is described in relation to the feeding biology of their fishes. Of the five species of cichlids in Lake Kotto only one is endemic. Two are phytoplankton-feeders, one takes invertebrates as well as phytoplankton, one feeds mainly on chironomid larvae, and one preys on vertebrates as well as on invertebrates. The three phytoplanktivores are the main species eaten by man. One species of *Clarias* and one of *Barbus* also occur in Lake Kotto; and in the associated streams are four species of cyprinodont fishes. The fish fauna of Mboandong consists of three species of cichlids and two cyprinodonts, all known from the Kotto system. We contrast Lake Kotto with the oligotrophic lake Barombi Mbo, and conclude that Lake Kotto would probably be less sensitive to human interference than would Barombi Mbo.

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Introduction

Lake Kotto and the smaller lake Mboandong lie about 30 km north-north-east of Mount Cameroon at an altitude of about 100 m. Lake Kotto supports large populations of the snails *Bulinus rohlfsii* (Clessin) and *B. camerunensis* Mandahl-Barth and is an important focus of urinary schistosomiasis. In an experimental control programme the transmission of *Schistosoma haematobium* has been reduced by treating infected people with niridazole (Ambilhar-CIBA) and spraying transmission sites around the lake and its island with the molluscicide N-tritylmorpholine (Frescon-Shell) (Duke & Moore, 1971). In this paper we describe Lake Kotto and Mboandong with special reference to the feeding biology of their fishes, contrasting the situation there with that in the nearby oligotrophic lake Barombi Mbo (Trewavas, Green & Corbet, 1972). This study provides the background for another paper dealing with the direct and indirect effects of the molluscicide Frescon on the fishes that provide an important component of the diet of the Barombi people (Corbet, Green & Betney, in press).

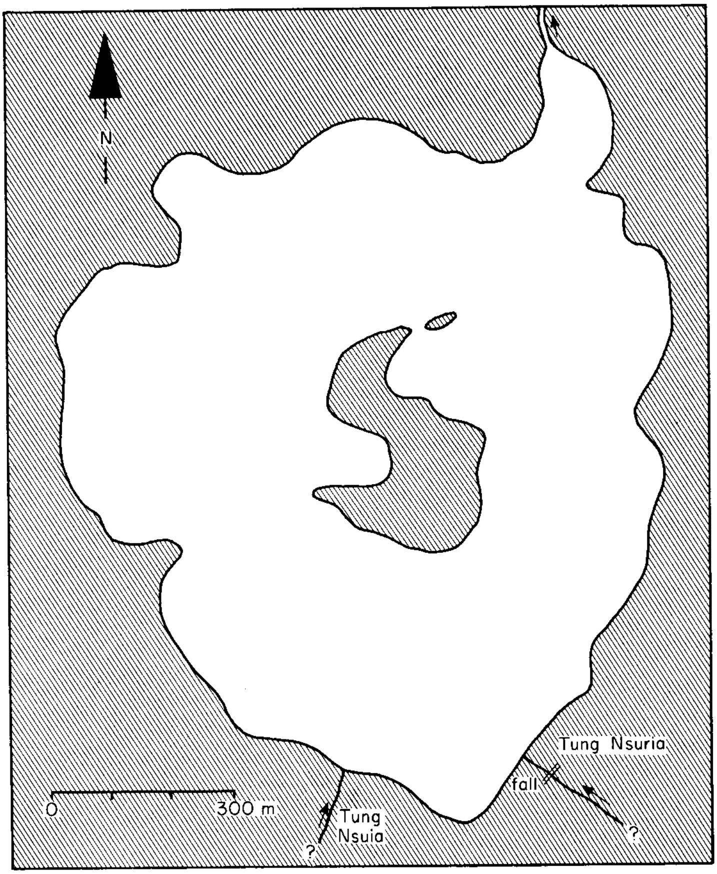

FIG. 1. Sketch map of Lake Kotto.

Lake Kotto

This lake is also known as Barombi Kotto or Lake Barombi Kotto. Lake Kotto is a shallow lake, in most places less than 6 m deep, and about 1200 m across (Fig. 1). The steep walls of the volcanic crater in which it lies rise in places to about 50 m above the water. Part of the crater wall is forested, but most of it is cultivated land where cocoa, cassava and plantains are grown. Around the southern and western shores of the lake are the houses of Nigerian immigrants, and the island is densely populated with Barombis, a fishing tribe. In most places the lake shore is rocky and overhung with dense vegetation. The bottom is sandy in some of the more open, shallow areas, which are used as canoe beaches and, as transmission sites for schistosomiasis, are the main target areas for spraying with Frescon.

The water of Lake Kotto is green-brown with a dense growth of phytoplankton. A secchi disk was no longer visible at a depth of about 80 cm. We found no rooted aquatic plants.

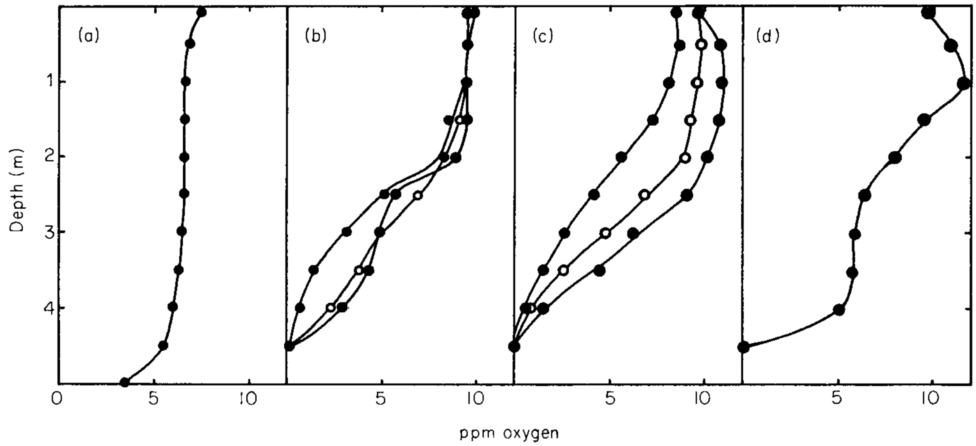

FIG. 2. Oxygen profiles in Lake Kotto, measured on 27 March–2 April 1972. (a) At 10.30 hrs, after a windy night; (b) three profiles taken between 08.00 and 09.30 hrs; (c) three profiles taken between 10.00 and 12.00 hrs; (d) at 17.00 hrs.

The lake is usually weakly stratified with respect to oxygen. Oxygen concentrations were measured in 1972 with a Mini-portable dissolved oxygen meter Model 55AT and a Type 30 temperature compensated silver-carbon electrode, both supplied by Protech (now Simac, Sunbury). The electrode was suspended on a cable marked off in metres. The distribution of oxygen in the lake varied with the time of day and with the weather (Fig. 2). The usual situation in mid-lake on calm sunny days was as follows. In the morning (Fig. 2(b)) oxygen was evenly distributed in the top 2 m at a concentration of about 9 to 10 ppm. Below the poorly-marked oxycline at 2–2·5 m the concentration was about 5 ppm, falling off rapidly to zero in the bottom 0·5 m; the black ooze on the bottom did not contain measurable amounts of oxygen. Figure 2(c) and (d) illustrate the development of the oxygen profile on calm sunny days. The concentration of oxygen in the top 1·5 m rose during the day, presumably because of algal photosynthesis, and the water there became supersaturated with oxygen. By late afternoon (Fig. 2(d)) the oxygen profile was markedly heterograde with a bulge at about 1 m, unless there had been enough wind during the day to mix the upper layers of water. The oxygen profile above the oxycline evened up overnight. On one occasion an unusually violent wind during the night removed all traces of the oxycline and brought oxygenated water in contact with the bottom ooze (Fig. 2(a)).

Some other features of the water of Lake Kotto are shown in Fig. 3 which is based on two vertical series of water samples taken with a modified 2-l Patalas sampler. The series of samples represented in the upper part of the figure was taken in the evening when the oxygen profile (Fig. 3(d)) showed the bulge characteristic of a calm sunny day; the lower series was taken next morning. Conductivities were measured with a Dionic conductivity meter (Evershed and Vignoles, Ltd., Chiswick) and pH with a Lovibond comparator using BDH indicators. The oxygen profiles were taken at the same time and place as the water samples, using the method already described. The conductivity of the water ranged from 155 μmho/cm/20°C at the surface to 162 μmho/cm/20°C at the bottom. The decrease in conductivity and the associated high pH in the epilimnion in the evening (Fig. 3(a) and (c)) may be attributable to the photosynthetic activity of the phytoplankton; Ruttner (1963) has shown that both these effects may result from the utilization of bicarbonate by water plants. As is usual in tropical waters the thermocline (Fig. 3(b)) is not well marked and the range of temperature is small.

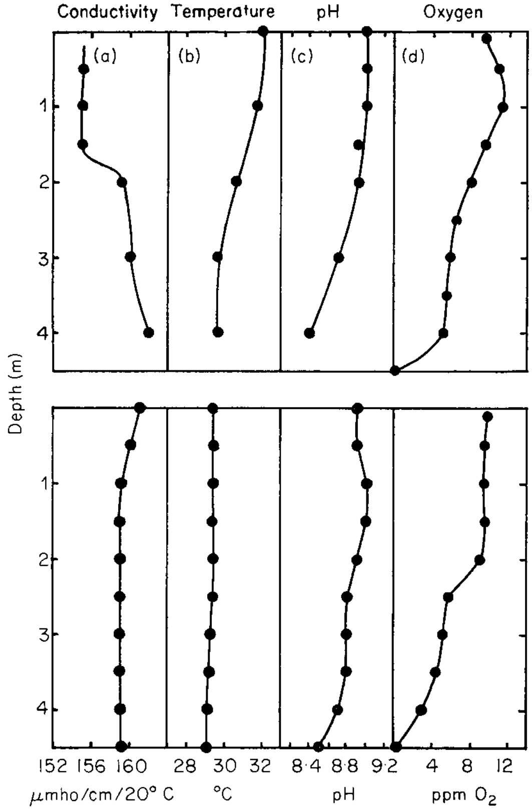

FIG. 3. Profiles of (a) conductivity, (b) temperature, (c) pH and (d) oxygen concentration in Lake Kotto. The upper series were measured at 17.00–18.00 hrs on a calm day (27 March 1972), and the lower series were measured at 08.00–09.00 hrs the next morning.

Plankton

The phytoplankton in Lake Kotto is so dense that the water appears green-brown, and floating masses of *Microcystis* form windrows at the surface. A sample from near the surface was dominated by *Microcystis aeruginosa*. *Synechocystis* sp. was abundant, and *Melosira* sp. and *Microcystis flos-aquae* were common. Other species found in the lake included *Merismopedia ?minima*, *Scenedesmus quadricauda*, *Lyngbya* sp., *Spirulina ?laxissima*, *Ankistrodesmus* sp., *Pediastrum duplex* var. *reticulatum*, *Staurastrum* sp., *Trachelomonas* sp. and *Peridinium* sp.

The zooplankton of Lake Kotto has been described by Green (1972). It includes the copepod *Thermocyclops hyalinus*, larvae of *Chaoborus ceratopogones*, the ostracod *Oncocypris* sp., the rotifers *Hexarthra mira*, *Brachionus falcatus*, *B. caudatus* and *Anuraeopsis fissa*, and hydracarines.

Benthos

There is a rich fauna in the oxygenated shallow water around the shores of Lake Kotto, where material from the overhanging vegetation contributes to a thick layer of decomposing leaf trash on the bottom. On fallen logs and branches chironomid larvae live in crevices and larvae of *Povilla adusta* Navas inhabit silk-lined tunnels. Dragonfly larvae are numerous among the decaying leaves, with *Parazyxomma flavicans* (Martin) and *Trithemis annulata* f. *violacea* Sjöstedt among the commonest anisopterans. As well as snails the shore fauna includes baetid larvae, oligochaetes, nematodes, hydracarines, ostracods, the crab *Sudanonautes aubryi* (Milne-Edwards), belostomatid bugs, *Nepa* sp., *Ranatra* sp., hydroptilid caddis larvae and dytiscid and hydrophilid beetles. Sponges are rare. The clawed toad, *Xenopus tropicalis* (Gray) is sometimes caught for food by the Barombis, whose name for it is nteke. One specimen had in its stomach four snails (*Bulinus camerunensis*) and an adult hydrophilid beetle.

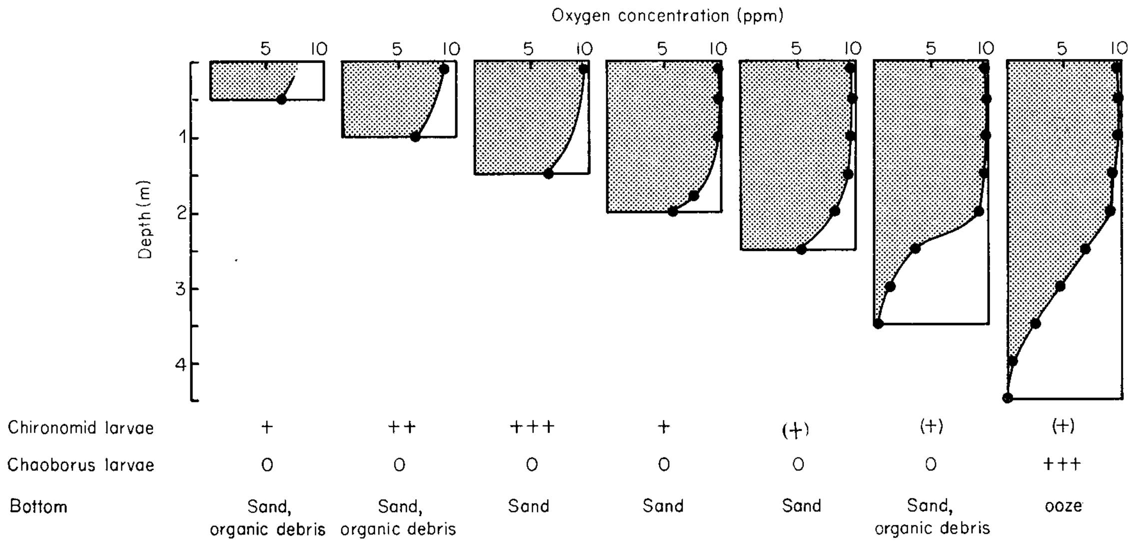

FIG. 4. Oxygen profiles, with the fauna and bottom sediments, in a series of samples taken along a transect out from the shore at Lake Kotto on the morning of 2 April 1972.

The benthic fauna of deeper water was investigated by taking a series of bottom tows at depths of from 0·5 to 4·5 m, using a dredge improvised from a square-framed pond net. The results are shown in Fig. 4, together with an oxygen profile for each sampling site. Down to 2·5 m the bottom was sandy, the proportion of organic matter decreasing with depth. The oxygen concentration at the bottom decreased from 6·2 ppm inshore to 5·2 ppm at 2·5 m. The most conspicuous members of the fauna were chironomid larvae, which were most abundant at 1·5 m, becoming less numerous at greater depths. Most of them were members of the subfamily Chironominae, and had been feeding on organic debris, and there was a single chironomine larva with phytoplankton in its gut; and one tanypodine larva, probably a predator. Ceratopogonid larvae, with the elongate head capsules characteristic of predatory forms (Thomsen, 1934), were found in small numbers down to 2 m. Below 2·5 m the proportion of organic material on the bottom increased and oxygen tensions were very low. At 4·5 m there was a thick layer of fluffy black ooze, which consisted of the remains of phytoplankton, microscopic fragments of higher plant tissue, bits of arthropod cuticle and indeterminate organic particles with a small proportion of inorganic material. Here chironomid larvae were rare and larvae of *Chaoborus ceratopogones* were abundant at the time of sampling (10.00 hours). In this deeper part of the lake any disturbance of the bottom released a flurry of bubbles of gas; and in very calm weather the water surface here was studded with bubbles. No smell of hydrogen sulphide was detectable.

Fish

The fish fauna of Lake Kotto is described by Trewavas (in prep.) and consists of the following species.

Barbus callipterus Boulenger
Clarias walkeri Günther
Hemichromis fasciatus Peters "B"*
Chromidotilapia guntheri loennbergi Trewavas
Tilapia kottae Lönnberg
Tilapia mariae Boulenger
Sarotherodon galilaeus (Linnaeus)

Of these *Tilapia kottae* is an endemic species and *C.g. loennbergi* is an endemic subspecies. The feeding biology of the fishes will be described in another section of this paper.

Inflowing streams

Two small streams, known as Tung Nsuia and Tung Nsuria, flow into Lake Kotto from the south (Fig. 1). Tung Nsuia serves as a source of water for the Barombis living on the island, but the water of Tung Nsuria is said to be tainted. A depression between these two streams may contain flowing water in the wet season.

Both the streams flow for some distance through forest, and both are so much overhung with vegetation that it is difficult to find the places where they enter the lake. In both streams the water is cooler than that of the lake; the midday temperatures about 10 cm below the surface in Tung Nsuria were 25°C in April 1970 and 24°C in April 1972, and in Tung Nsuia 27°C in 1970 and 23·5°C in 1972. The conductivities are higher than that of the lake water, being 275 µmho/cm/20°C in Tung Nsuria in 1970 and 1972, and 310 and 325 µmho/cm/20°C in Tung Nsuia in 1970 and 1972 respectively. The pH, 8·3 in Tung Nsuria and 8·5 in Tung Nsuia (both measured in 1972), is within the range found in the lake.

Tung Nsuria is 1–2 m wide near the mouth and up to about 30 cm deep. The bottom is sandy with deposits of mud and fallen leaves. We caught four species of cyprinodont fishes there: *Epiplatys sexfasciatus* Gill, *Procatopus glaucicaudis* Clausen, *Aphyosemion oeseri*

* *See* Burchard, J. & Wickler, W. (1965). Eine neue Form des Cichliden *Hemichromis fasciatus* Peters. *Z. Zool. Syst. Evolutionforsch.* 3: 277–283.

(Ahl) and *A. bivittatum* (Lönnberg) (Trewavas, in prep.). Dragonfly larvae were abundant, including zygopterans, libellulids and a mud-dwelling gomphid in which a much-elongated tenth abdominal segment formed a respiratory siphon. The prosobranch snail *Potadoma freethi* (Gray) was abundant. The decapod crustaceans *Macrobrachium vollenhovenii* (Herklots) and *Caridina africana* Kingsley were also present, with small numbers of chironomids, mayfly larvae, pleid and belostomatid bugs and a hydrophilid beetle. Some specimens of *Caridina* were heavily infested with epibiotic rotifers, and epibiotic peritrichs were abundant on the libellulid and zygopteran larvae and on the hydrophilid beetle. *Stentor* sp. was found living on a libellulid and on a zygopteran.

About 50 m upstream from the mouth Tung Nsuria cascades down a vertical face of black rock about 5 m high. This must be the waterfall mentioned by Comber (1879) who discovered Lake Kotto in 1877. Above the waterfall the stream is heavily shaded and shallow, flowing over and between rocks. We traced it for about 1 km without finding the source; it was fed by springs and by water seeping from soft rock a metre or so above the stream bed. Cyprinodont fishes were seen in this reach of the stream, and the dragonflies *Sapho orichalcea* McLachlan, *Umma* sp. and *Chlorocypha cancellata* (Selys) were on the wing.

Tung Nsuia is similar in width and depth to Tung Nsuria, and the bottom is of soft mud with fallen leaves. The fauna resembles that of Tung Nsuria in the presence of *Epiplatys sexfasciatus*, *Aphyosemion oeseri*, gomphid larvae living in the mud, libellulid and zygopteran larvae, *Caridina africana* Roux and belostomatid bugs. We also found *Barbus callipterus* and a cichlid fish, and the beetles *Aethionectes fulvonotatus* Clark, *Globaria seriata* Regimbert and *Amphiops* sp. We did not find epibionts on any invertebrates in Tung Nsuia, nor did we find any prosobranch snails.

Outflowing stream

The outflowing stream leaves Lake Kotto to the north-east (Fig. 1) to join the Meme river system. A shallow bay about 50 m wide narrows to the outflow stream which, when we visited it towards the end of the dry season in April 1970 (and when Comber visited it in November 1877) was slow-flowing and only about 20 cm deep, with a sandy bottom covered with dead leaves. The conductivity of the water was 145 μmho/cm/20°C. The invertebrate fauna in the origin of the outflow stream was similar to that in the lake. Dragonfly larvae were abundant, and in smaller numbers we found hydrophilid beetle larvae, belostomatid bugs, gerrids, chironomid larvae and mayfly larvae.

Mboandong

We visited Mboandong in April 1970. It is a small, round lake, about 400 m in diameter, lying in a shallow crater about an hour's walk south-east of Lake Kotto. The crater walls are densely clothed in forest which extends right down to the edge of the water except at the canoe beach. Here the forest has been cleared for cocoa trees and in this clearing, the only unshaded region of the lake shore, the dragonflies *Trithemis arteriosa* (Burmeister), *Oxythemis phoenicosceles* Ris and *Orthetrum austeni* (Kirby) were common over the water. We saw no rooted vegetation except small patches of waterlilies not far from the shore.

At the beach, wide enough for the single canoe, the bottom was of firm muddy sand and there were a few boulders of soft volcanic rock with their underwater surfaces tunnelled, like the submerged logs and branches, with the burrows of the mayfly *Povilla adusta*. But most of the shore was heavily shaded and leaves from the overhanging trees formed a thick layer in the shallow water. Raffia palms were common, growing partly in the water, and the skeletons of their dead leaves formed a treacherous platform which, when it gave way, plunged the unwary limnologist into a morass of dead leaves and water.

Within a few centimetres of the edge of the water here the cyprinodont fishes *Aphyosemion oeseri* and *A. bivittatum* were common, and young cichlids about 20–30 mm long were caught in smaller numbers. The most conspicuous invertebrates in this habitat were predatory insects. Dragonfly larvae were numerous; as well as zygopterans and an aeshnid we found several species of libellulid larvae. Three of the libellulids had fragments of mayfly larvae in their guts. Water beetles were common and included the dytiscids *Cybister* (*Melanectes*) *mesomelas* Guignot and *Aethionectes fulvonotatus* Clark and three species of hydrophilids, *Sternolophus angolensis* Erikson, *Globaria* sp. and *Amphiops* sp. The Heteroptera were represented by belostomatids, gerrids, hydrometrids and a species of *Ranatra*. We also found larvae of *Povilla adusta*, chironomid larvae, a leech, a small patch of sponge growing on a dead palm leaf, and a crab *Sudanonautes africanus* (Milne-Edwards). Smaller invertebrates included hydracarines and ostracods. In the stomachs of fishes from the same habitat we found harpacticoid copepods, *Cyclops* sp., the cladocerans *Alona verrucosa* Sars and *Alona karua* King, and the testate rhizopods *Arcella* sp. and *Centropyxis* sp.

Mboandong, with a conductivity of 66 μmho/cm/20°C, supported less dense phytoplankton than Lake Kotto and its water looked brown instead of green. Its zooplankton was richer than that of Lake Kotto, Mbo or Soden; it was dominated by *Thermocyclops hyalinus* and included six species of rotifers (*Brachionus falcatus*, *B. caudatus*, *Keratella tropica*, *Anuraeopsis fissa*, *Hexarthra mira* and *Polyarthra dolichoptera*), ostracods, hydracarines and *Chaoborus ceratopogones* (Green, 1972).

A transect across the lake from the beach, plumbed at horizontal intervals of about 10 m, revealed no depths greater than 5 m. A bottom tow made with a phytoplankton net at 4 m produced brown flocculent organic material with the ostracods *Darwinula* sp. and *Oncocypris* sp. and the cladoceran *Ilyocryptus spinifer* Herrick.

The three species of cichlid fishes found in Mboandong are also common in Lake Kotto: *S. galilaeus*, *T. kottae* and *H. fasciatus*. Barombis from Lake Kotto sometimes visit Mboandong and spend a few days there, catching fish with a cast net (*S. galilaeus* and *T. kottae*) or with a hook and line (*H. fasciatus*). One of these fishermen told us that Mboandong had no permanent streams flowing into or out of it, but he showed us a place where a stream would flow out during the wet season.

Food of the fishes

Because of the opacity of the water in Lake Kotto and the presence there of bilharzia we did not make underwater observations on the fishes; our information about their diets is derived from the examination of stomach contents in April 1970, before the treatment of the lake with N-tritylmorpholine began. We obtained our fishes from three sources. Most of them were caught in cast nets by the Barombis, and we were able to preserve or examine them within an hour or two of their capture. Some the Barombis caught on baited hooks and these, too, were brought to us in a very fresh condition. Others we caught in a gill net or in basket traps, made by the Barombis at Barombi Mbo, which we set overnight and emptied each morning.

For each fish we measured the standard length (from the anterior extremity with the mouth closed to the base of the median tail fin rays) and listed the food items found in the stomach. The item occupying the greatest volume in the stomach was recorded as the "main contents" (see Corbet, 1961). The numbers of fishes from Lake Kotto whose stomachs we examined were as follows: *Sarotherodon galilaeus:* 6; *Tilapia mariae:* 31; *T. kottae:* 59; *Chromidotilapia guntheri loennbergi:* 26; *Hemichromis fasciatus:* 53; *Barbus callipterus:* 22. From Mboandong we examined the stomachs of 28 *H. fasciatus*, 21 *T. kottae* and 9 *Aphyosemion* spp.

The results are summarized in Fig. 5.

Sarotherodon galilaeus Barombi names: kurukuma, kibundu, kamabundu

The three Barombi names for this species describe fishes of different sizes: small ones are called kurukuma, middle-sized ones are kibundu and larger specimens are kamabundu. *S. galilaeus* is a widespread species known to feed on phytoplankton (Worthington, 1929).

From Lake Kotto we examined only six specimens, ranging in length from 122 to 200 mm. All had phytoplankton as the main contents. Traces of higher plant tissues, a few rotifers and copepods were also found, but made an insignificant contribution to the diet. A single specimen of length 70 mm from Mboandong also had phytoplankton as the main contents.

Tilapia mariae Barombi name: finjongo

We examined 31 specimens of *T. mariae*, ranging in length from 78 to 155 mm. In about half of these the gonads were ripening, and in four the gonads were ripe. The majority (29) had phytoplankton as the main stomach contents. Items which occurred in small amounts included rotifers, chironomid larvae, ostracods and *Chaoborus* larvae. The presence of chironomid larvae may indicate that this species sometimes feeds nearer to the bottom of the lake than *S. galilaeus*.

Tilapia kottae Barombi names: fikunle, pindu

The name fikunle refers to small individuals; large ones are called pindu.

This species was abundant throughout Lake Kotto, and common in Mboandong. In Lake Kotto it apparently reached a larger size than it did in Mboandong. The largest of 59 specimens from Lake Kotto had a standard length of 178 mm while in Mboandong the largest of the 21 that we saw was only 73 mm in standard length. Specimens caught in the middle of Lake Kotto were less frequently ripe than those caught in traps close inshore. Ripe gonads were found in only three out of 50 caught in a gill net set in mid lake, but in six out of 11 fishes of the same size (60–70 mm standard length) from inshore traps. This may indicate an inshore movement of ripe fishes.

In Lake Kotto we examined the stomachs of 59 fishes ranging in standard length from 70 to 178 mm. The main contents in most of them was phytoplankton, and in others organic debris or dark plant tissues predominated. Evidently the fishes took some of their food very close to the bottom of the lake because many stomachs contained a few chironomid larvae or mayfly larvae. Some had eaten the eggs of other fishes. Items presumably ingested along with the phytoplankton included rotifers, *Chaoborus* larvae and schistosome eggs.

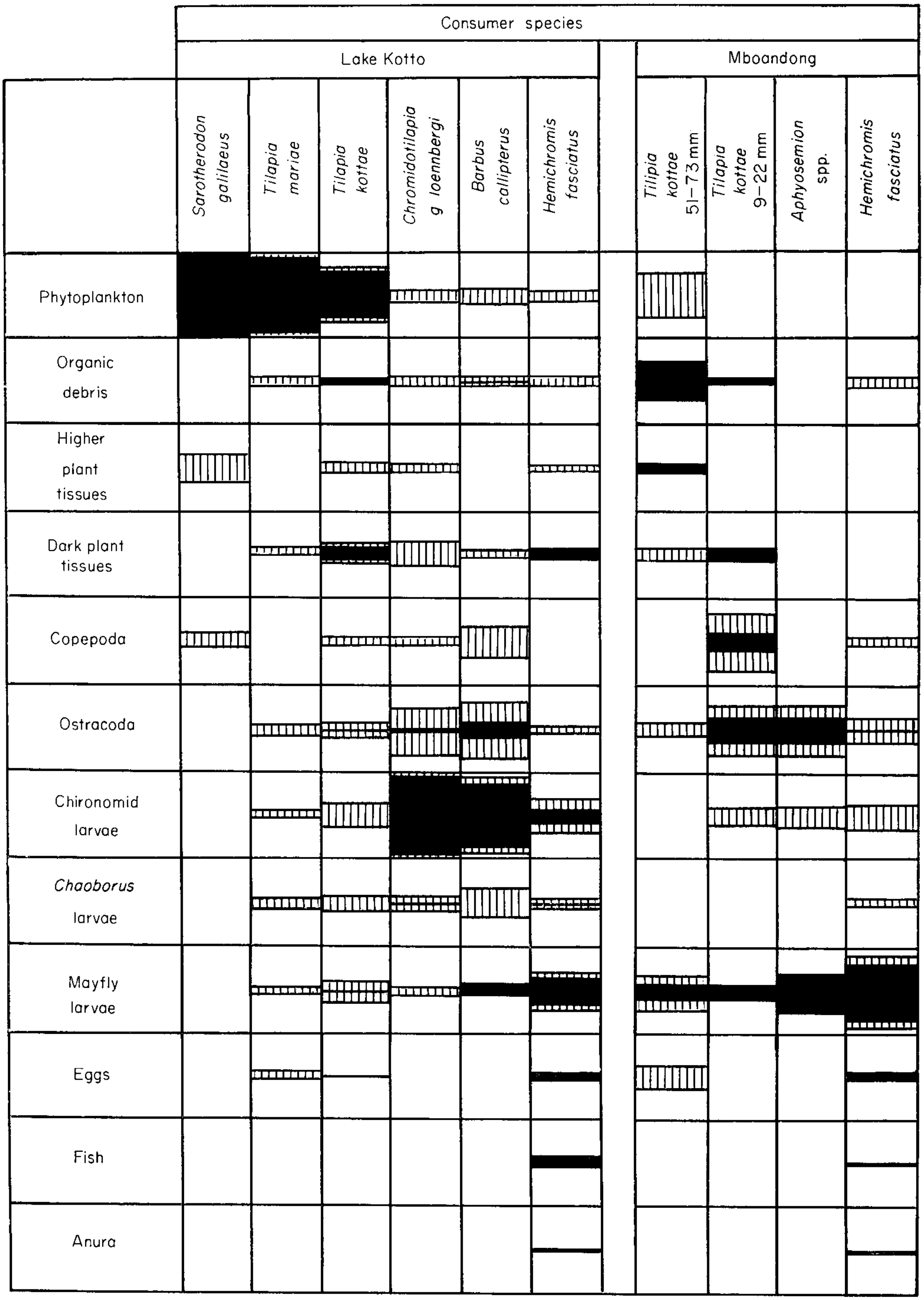

FIG. 5. Trophic spectrum illustrating the results of analyses of stomach contents of fishes of Lake Kotto and Mboandong. The depths of the hatched blocks show the percentages of stomachs in which each food was present, and the depths of the superimposed black blocks show the percentages of stomachs with each food as main contents.

From Mboandong we examined 14 small fishes ranging in length from 9 to 22 mm, and seven larger fishes ranging from 51 to 73 mm in length. The larger fishes had a much larger proportion of organic debris in their stomachs than the fishes from Lake Kotto, but four also contained phytoplankton. The smaller fishes had a different diet, with ostracods and copepods as the most important items, together with hydracarines and mayfly larvae. Some organic debris and dark plant tissues were also taken, but none of the smaller fishes had taken phytoplankton.

Hemichromis fasciatus "B" Barombi name: fibus

This was a very common fish in both Lake Kotto and Mboandong. It was often seen in the very shallow water at the edge of the lake, and it was usually caught with a baited hook near the shore, in water too shallow for cast-netting. This was the commonest species caught in the basket traps we set in about 40 cm of water in a shaded part of the shore.

We examined the gut contents of 53 specimens from Lake Kotto (32–170 mm long) and 28 from Mboandong (26–78 mm long). The diets of those from Lake Kotto were broadly similar to those of the fishes from Mboandong. In both places they had been feeding mainly on invertebrates, particularly the larvae of chironomids and mayflies. Some contained terrestrial insects, probably from the surface. Some of the larger specimens had taken fishes and frogs. Those fishes that were still identifiable in the stomachs were *T. kottae*. Seven of the fishes from Lake Kotto had dark plant tissue as main contents.

Since *H. fasciatus* was normally caught with a baited hook, the stomach contents may be expected to reflect the Barombis' choice of bait as well as the fishes' selection of prey. The usual bait was *Povilla* larvae, which would be taken from a stick conveniently kept on the fisherman's head or from the outer sides of his canoe. Seven of the fishes from Lake Kotto and nine of those from Mboandong contained *Povilla* larvae.

Chromidotilapia guntheri loennbergi Barombi name: ntandt

This species was rarer than the other cichlids in Lake Kotto, and was not found in Mboandong.

All the specimens that we examined, ranging in length from 48 to 90 mm, had eaten chironomid larvae, and over 90 % had these larvae as main contents. The only other items that appeared as main contents in a few specimens were *Chaoborus* larvae and ostracods. The latter were found in over 50 % of the stomachs examined, but formed the main contents in only 4 %. Other items occurring in small amounts included phytoplankton, organic debris, higher plant tissues, sand grains and hydracarines. The last were probably ingested intentionally, but most of the others were probably taken in accidentally with chironomid larvae.

C.g. loennbergi was caught in cast nets in Lake Kotto, and its rarity in the basket traps that we set close inshore indicated that it seldom went into shallow water (less than 1 m deep) where *T. kottae* and *H. fasciatus* were common. From the nature of the gut contents we infer that *C.g. loennbergi* fed on or near the bottom.

Barbus callipterus Barombi name: ngete

B. callipterus was caught in cast nets in Lake Kotto and we caught one in a basket trap set 1 m deep in 2 m of water. It was not a very common species, and the fact that several individuals were usually caught at one time may indicate that it moves in shoals. Those that we saw were all of about the same standard length, ranging from 64 to 80 mm, and most of them had ripe gonads.

Dissection of 22 stomachs showed that the diet consisted mainly of bottom-living invertebrates, with some sand grains, dark plant tissues, phytoplankton and organic debris that may have been taken in together with prey. Chironomid larvae were present in nearly all the stomachs and formed the main contents in most of them. Ostracods or mayfly larvae predominated in a few, and hydracarines, *Cyclops*, *Chaoborus* larvae and larval, pupal and adult nematoceran flies were present in smaller numbers.

Aphyosemion bivittatum and *A. oeseri* Barombi name: mbonge

We found no *Aphyosemion* in Lake Kotto, although *A. bivattatum* and *A. oeseri* were both present in the inflowing streams and one was found in the outflow. Our observations of lake-dwelling *Aphyosemion* refer to those at Mboandong, where both species were common within a few cm of the water's edge in regions where the bottom was covered by a thick deposit of dead leaves. We did not distinguish between the two species in our dissections.

We examined the stomachs of nine specimens of *Aphyosemion* from Mboandong, 19 to 25 mm long, and found invertebrate prey in all but two, which were empty. The main contents were mayfly larvae, ostracods, or adult beetles; and sponge spicules, chironomid larvae and an adult nematoceran were also present.

The trophic relationships of the fishes are summarized in Figs 5 and 6.

Predators of the fishes

Two of the species of fishes that we examined had eaten other fishes. Large *H. fasciatus* and *Clarias walkeri* both preyed upon *T. kottae*.

The aquatic snake *Grayia smythii* Leach, which is known to eat fishes (Cansdale, 1961), was caught in one of our fish traps. A soft-shelled turtle, *Trionyx triunguis* Forskall, was brought to us from Lake Kotto by one of the Barombi fishermen. This species takes fishes as part of its diet (Worthington, 1929). There are crocodiles in Lake Kotto (P. Moore, pers. comm.) but they are rarely seen.

The birds around the lake include the following species (nomenclature according to Mackworth-Praed & Grant (1970)).

Little grebe	*Podiceps ruficollis* (Pallas)
Long-tailed cormorant	*Phalacrocorax africanus* (Gmelin)
Darter	*Anhinga rufa* (Lacepede & Daudin)
Purple heron	*Pyrrherodia purpurea* (L.)
Great white egret	*Casmerodius albus* (L.)
Hadada	*Hagedashia hagedash* (Latham)
Black kite	*Milvus migrans* (Boddaert)
Palm nut vulture	*Gypohierax angolensis* (Gmelin)
Pied kingfisher	*Ceryle rudis* (L.)
Giant kingfisher	*Megaceryle maxima* (Pallas)
Shining blue kingfisher	*Alcedo quadribrachys* Bonaparte
Malachite kingfisher	*Corythornis cristata* (Pallas)

Of these, cormorants were the most abundant, totalling about 50 individuals. This is a much greater number than we saw on Barombi Mbo, although Kotto is a smaller lake. The darter may sometimes also be abundant; Searle (1965) records that in January 1948 he saw hundreds of darters on "Barombi Koti Lake".

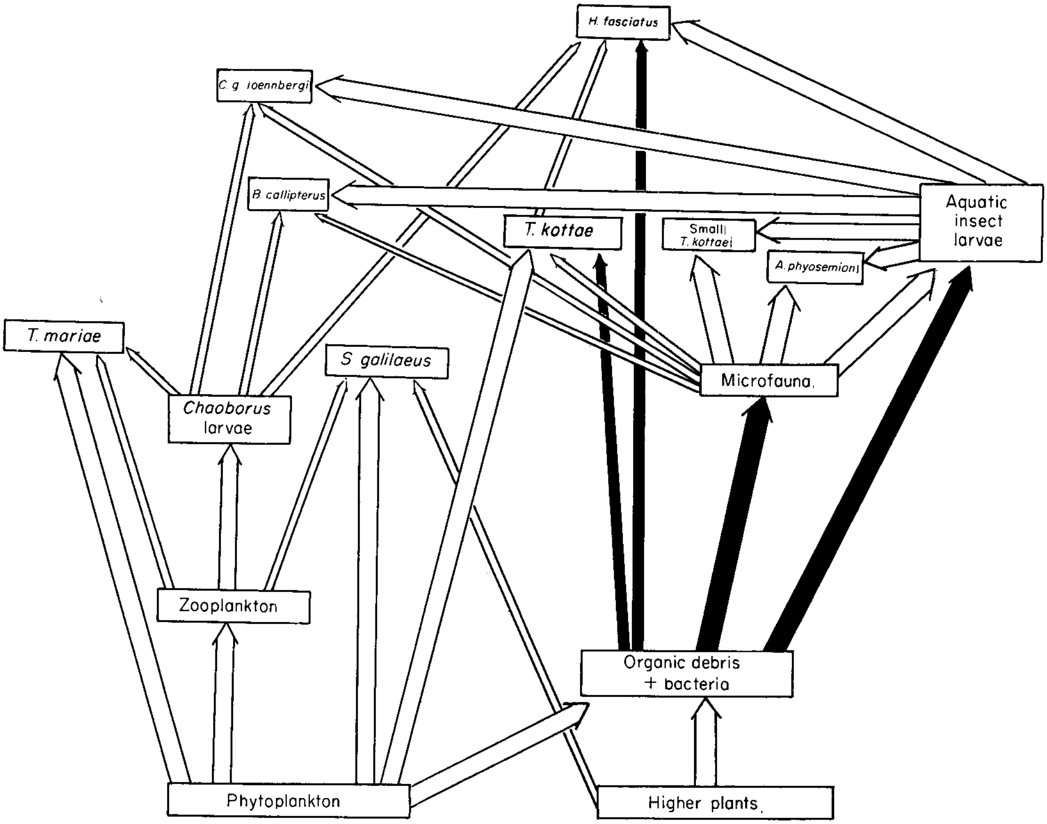

FIG. 6. A food web for the fishes of Lake Kotto and Mboandong, based on the examination of stomach contents. Wide arrows: more than 30% of fishes have the food item as main contents; narrow arrows: fewer than 30% have.

Fishes are important in the diet of the Barombis at Kotto. The most prized food fish is *S. galilaeus*. This and the other phytoplankton-eaters, *T. mariae* and *T. kottae*, are the main species caught with cast nets, although *C.g. loennbergi* and *B. callipterus* are also eaten when they turn up in the nets. Most of these fishes seem to be eaten by the families of the island fishermen; few were sold on the mainland, where they had to compete in the weekly market with dried marine fish. We never saw more than two or three canoes at a time engaged in fishing on Lake Kotto, although there were cast nets hanging to dry outside many of the houses on the island. Small boys fish for *H. fasciatus* from the shore using rods and lines.

Discussion

In the dense phytoplankton, with the predominance of blue-green algae and *Melosira* sp. (Hutchinson, 1967), Lake Kotto shows biological characteristics of a eutrophic lake. In this respect it contrasts with Barombi Mbo (Trewavas, Green & Corbet, 1972). In temperate regions the occurrence of a stable stratification in summer combined with deoxygenation of the hypolimnion is taken as an indication of eutrophic conditions. But the well-marked stratification and deoxygenated hypolimnion in the deep, oligotrophic lake Barombi Mbo (Green, Corbet & Betney, 1973) contrasts with the unstable situation in shallow, eutrophic Lake Kotto. Here the stability of the stratification seems to be related more clearly to depth than to the trophic status of the lake. Another physical characteristic that has been proposed as an index of trophic status is the conductivity of the water. Olsen (1950), working on a series of Danish lakes, found conductivities below 200 μmho/cm/20°C in his oligotrophic lakes; nearly all his eutrophic lakes had conductivities greater than 200 μmho/cm/20°C. The conductivity of Lake Kotto (155 μmho/cm/20°C) is lower than any of Olsen's eutrophic lakes, although it is considerably higher than those of some oligotrophic lakes in the same area: Barombi Mbo (39 μmho/cm/20°C, Green, 1972); Lake Soden (27 μmho/cm/20°C, Green, 1972); and Debundsha Lake (12 μmho/cm/20°C, Green, Corbet & Betney, in prep.).

It is tempting to attribute the more eutrophic status of Lake Kotto to its higher concentration of ions, as indicated by its higher conductivity, and to relate this to drainage from the densely populated slopes of the island. But the relatively high conductivities of the two inflowing streams (275 and 325 μmho/cm/20°C), draining a considerable area of unpopulated, forested volcanic terrain, indicate that a proportion of the ions contributing to the conductivity of the lake water may derive from that source. By contrast, at Barombi Mbo the conductivity of the only permanent inflowing stream (27 μmho/cm/20°C in April 1972) was lower than that of the lake (39 μmho/cm/20°C), and the conductivity of a small temporary inflow was only 85 μmho/cm/20°C, although a stream of this type might be expected to have a higher conductivity due to ions from the surface of the forest soil (Green, 1970).

Another difference between Lake Kotto and Barombi Mbo is the much greater biological interest of Barombi Mbo, reflected in the large number of species first described from that locality. No doubt the accessibility of Barombi Mbo and the relative ease of collecting there have contributed to this; but our examination of the faunas supports the view that Barombi Mbo is a special habitat with a high species diversity and a high degree of endemism not found at Lake Kotto. This is probably associated with the greater isolation of Barombi Mbo, which is separated from the Mungo river system by a series of waterfalls where its outflow, the Kake River, descends the steep outer wall of the volcanic crater. The land around Lake Kotto is flatter and its slow-flowing outflow stream presents no obvious barriers to immigration by aquatic animals from the Meme river system. The ecological specialization which enable the fishes of Barombi Mbo to make such good use of its slender food resources is less clear in Lake Kotto. *Chromidotilapia g. loennbergi* feeds mainly on chironomid larvae, but there is no parallel in Lake Kotto for the *Chaoborus*-eating *Konia dikume* or the sponge-eating *Pungu maclareni* of Barombi Mbo. The absence of a sponge-feeding fish is obviously related to the rarity of sponges in Lake Kotto, but *Chaoborus* larvae are abundant there (Green, 1972) and the failure of fishes to feed extensively on them may be associated with the opacity of the water, which would preclude hunting by sight at dawn and dusk as *K. dikume* probably does in the clear water of Barombi Mbo. We found no parallel in Lake Kotto for the fishes in Mbo which feed on aufwuchs and organic debris, *Sarotherodon steinbachi* and *S. lohbergeri.*

It is noteworthy that the Barombis both at Lake Kotto and at Barombi Mbo concentrate their fishing effort on primary consumers (*S. galilaeus*, *T. mariae* and *T. kottae* at Lake Kotto, and *Sarotherodon linnelli* and *S. caroli* at Barombi Mbo). The situation at Lake Kotto seems better suited to the exploitation of a fishery than is that at Barombi Mbo. In Lake Kotto the very dense phytoplankton is the food of the adults of the three major food fishes, *S. galilaeus*, *T. mariae* and *T. kottae*. If these species can digest the blue-green and green algae that compose the phytoplankton, the supply of food for the adults is abundant and their numbers are more likely to be limited by the availability of food and feeding habitats for their young stages which live and feed inshore (Corbet, Green & Betney, in press).

Whereas Barombi Mbo shows the diversity and specialization characteristic of a mature ecosystem, Lake Kotto, with its high biomass of algae and its lower diversity, appears to be less mature (Margalef, 1968). According to Margalef's hypothesis a change in the level of exploitation or in the nutrient input at Barombi Mbo may be expected to result in rejuvenation with the loss of the characteristics of a mature ecosystem. Lake Kotto would probably be less sensitive to such disturbance than would Barombi Mbo.

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